Archaeological and Anthropological Sciences _####################_
https://doi.org/10.1007/s12520-025-02177-8

RESEARCH

Finding your strong points: exploring the design and resilience of barbed composite weapons

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Received: 19 September 2024 / Accepted: 27 January 2025

Abstract

Laterally hafted projectiles have long been of interest in archaeology. While evidence of composite tools with organic shafts and stone barbs appears in Europe as early as the Gravettian, some scholars trace their origins to the early Upper Paleolithic, particularly with Protoaurignacian bladelets. However, the identification of lateral stone elements remains methodologically challenging, and a comprehensive interpretative framework is still under development. Experiments on lateral projectiles focus on diverse research objectives and protocols vary, complicating consensus on the identification of lateral insets, especially in the absence of their organic counterparts. In most experiments, the fragility of lateral hafting systems often leads to detachment of insets upon impact, preventing the formation of characteristic wear and complicating diagnostic analysis. This paper seeks to advance the understanding of lateral hafting systems by investigating their resilience and damage patterns through experimental studies, testing different adhesives, evaluating the role of grooves, and documenting the resulting impact-related wear. The results will help ensure the success of future experimental programs tailored to specific archaeological examples and serve as an additional step in developing a robust reference framework for identifying barbs based on wear traces and macrofractures.

Keywords Projectiles · Experimental archaeology · Hafting · Composite weaponry · Use-wear · Tool design

Introduction

Hafted stone projectile points are known to exist from about 250.000 years ago, with the oldest examples identified for the early Middle Palaeolithic period in Europe (Rots 2013). All these early systems systematically concern apically hafted stone points. Archaeological evidence for the appearance of weapon systems with lateral insets is much younger with the oldest preserved bone point associated with a series of lateral insets discovered at the site of Les Prés-de-Laure (France) and dated to 23.500 years ago (Tomasso et al. 2018). While this find is remarkable, use-wear traces and macrofracture evidence suggest that laterally hafted weapon systems may have appeared before this Gravettian example.

The appearance of lateral weapon systems is an important innovation that has often been linked with trends towards microlithisation. Microliths are indeed unlikely to have been used without a haft. Laterally armed composite weapon systems may vary significantly given the broad range of possible choices in the number, size, and morphology of lateral insets, the nature and morphology of the point on which the insets are mounted, and the orientation of the insets with regard to the shaft, to name just a few. Lateral insets hafted parallel to the shaft create wider wounds inducing heavier bleeding (Wood and Fitzhugh 2018), may enhance penetration performance (Pétillon et al. 2011), and could have additional functions in cutting and scraping, depending on the chosen designs. Lateral insets hafted under an angle not only inflict potentially more lethal wounds but are also more difficult to retrieve from the target's body. From a production and maintenance point of view, the use of multiple smaller stone implements on a lateral composite tool allows to create a longer, straight, cutting edge without the difficulties of producing a long straight blade. They can also be mounted individually, making it a very adaptable system with parts that can be removed and/or replaced without changing the entire set of insets when needed (Bleed 2002). Uniting these advantages in one object is a novelty and laterally hafted

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composite weapons are excellent examples of curated, reliable and maintainable tools in the Palaeolithic (Bleed 1986; Lombard et al. 2020; Pétillon et al. 2011). They require specific skills in their production and are crucial to understanding the evolution of hafting and hunting technology.

While armatures can be identified based on wear traces and macrofractures (Fischer et al. 1984; Rots 2016; Rots and Plisson 2014), there is fewer reference data available to identify their hafting position, particularly for lateral insets. Some criteria have been suggested to differentiate between tips and barbs, based on experimental programs (Chesnaux 2014; Rots 2016), although a comprehensive framework that encompasses a range of morphologies and raw materials is still under development. Researchers have faced common challenges in experiments involving lateral armatures, such as the frequent detachment of insets before or upon impact into the target or their difficulty in piercing the hide. On average, more than half of the armatures detach upon impact or during penetration, and in some cases, fewer than a third of recovered elements show traces of use (Moss 1983; Moss and Newcomer 1982; Philibert 2002; Chesnaux 2008, 2014; Pétillon et al. 2011; Yaroshevich et al. 2010). This is largely because the energy from the impact is mostly, if not entirely, absorbed by the detachment of the armature, rather than through its fracturing. This detachment also complicates the reuse of the same laterally armed composite weapon for multiple shots, which is often necessary for diagnostic wear traces to form, as demonstrated by experiments with apical points. Furthermore, there is a variability in data availability, as not all published experiments on lateral armatures disclose their precise hafting choices, such as the presence or absence of grooves or bindings, or the adhesives used. Similarly, the experimental setups are sometimes not sufficiently detailed to fully understand the role of each variable. Consequently, the current experimental reference framework would benefit from further refinement to support broader archaeological interpretations.

To create a robust set of distinctive criteria that permit recognising lateral armatures in archaeological assemblages, the reinforcement of their hafting is a key issue to address in experimental programs. A lot of research has already been performed on glue performance, mostly based on mechanical testing (Kozowyk et al. 2016, 2017a; Pargeter et al. 2022; Schmidt et al. 2021; Tydgadt and Rots 2022), but such studies, while informative, seldom explore the interaction between the glues and their contact materials. Realistic hafting arrangements are generally avoided to limit the number of variables and permit their control. A more appropriate understanding of how lateral armatures can be hafted successfully is thus needed. In a previous study (Tydgadt and Rots 2022), an exploratory step in this process was taken: the resilience of different glues was tested to mount flint blanks on either osseous or wooden points in a composite system. As such, the performance of the glue could be evaluated in direct relation to tool use and the exact conditions of use, which permits evaluations with archaeological relevance in terms of glue choice and composition. For instance, certain glues do not combine well with a particular raw material, while their performance varies depending on whether use conditions are warm or cold, moist or dry, which may be compensated for by adjusting the glue composition.

To improve our understanding of the appearance and evolution of barbed composite systems and to permit the proposition of strict identification criteria, we need to understand the factors that influence the successful hafting and use of composite weapons involving lateral armatures. Therefore, we examine the potential impact of two variables on the robustness of the hafting system: the presence of a groove on the organic point and the choice of glue mixture. These variables are key to insights into the functioning and design of laterally armed composite weapons. This study builds onto previous work in which the performance of glues was tested in single-lap joints and intends to provide new data to improve future experiments and to serve as a reliable experimental reference for archaeological applications. Finally, we explore the influence of these variables on the formation of impact damage and its nature by presenting preliminary experimental use-wear results.

Research context

Terminology

Many terms have been used to describe organic points fitted with laterally hafted stone elements: *barbed points*, *composite points*, *lateral points* or *cutting edges* can all be found in literature, next to *inset*, *barb* or *armature* for the stone tool itself. To avoid confusion, we review existing terms and propose the terms and definitions we will use in this article.

The term *composite* may be used to refer to hafted tools (Barham 2013) or a hafting arrangement with multiple lithic components. Similarly, the term *composite weapon* may also refer to shafts with a single hafted element (apical point or lateral inset) (Wadley et al. 2015) or to systems involving multiple components, such as lithic insets on a wooden shaft or lithic insets on an organic point that is mounted on a wooden shaft (Tomasso et al. 2018). To avoid confusion, we use the term ***barbed composite weapon****and****lateral composite weapon*** (Fig. 1C) to specifically refer to weapon systems involving at least one stone component that is hafted laterally to the shaft independent of whether a lithic is mounted on the distal tip.

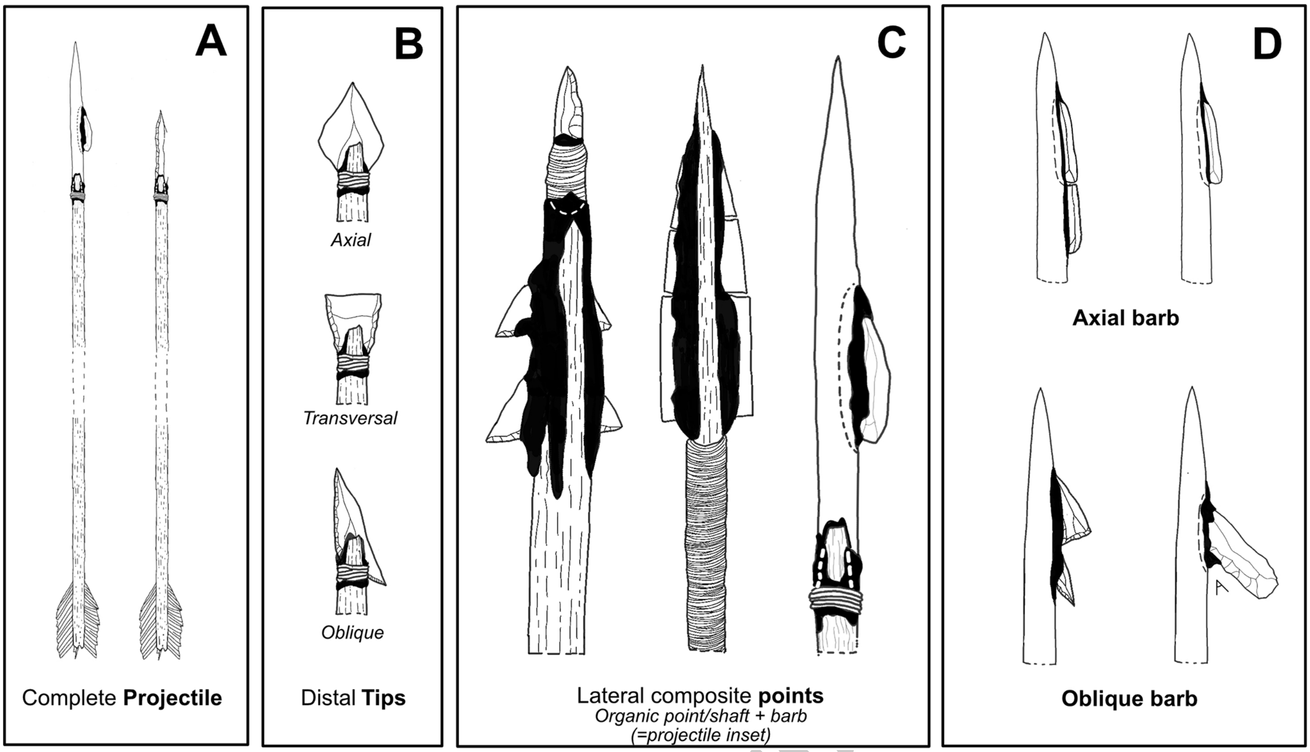

Fig. 1 Terminology. (**A**) Examples of complete projectile with a shaft and a composite point. (**B**) Distal tips are stone armatures that are hafted at the distal end of a projectile They can take many forms, including that of an axial point, a transversal edge or an obliquely hafted point. (**C**) Barbed composite points combine an organic element (point, shaft or foreshaft) with at least one laterally hafted inset, which is called a barb. (**D**) Lateral insets are hafted on the side of the organic component. Axial barbs take the form of a cutting edge and are hafted parallel to the axis of the projectile. Oblique barbs have a protruding hafting position and create a secant angle with the axis of the projectile (**D**) (Drawings: L.T.)

Any lithic implement mounted as part of a projectile, independent of its orientation and position (axial, transverse or lateral) is considered an armature (Fig. 1). We distinguish ***tips*** (Fig. 1B) (distally hafted) and lateral elements (mounted on the sides of a projectile's organic point or shaft). Laterally hafted lithic elements have been called insets, both for projectiles and other tool uses (e.g., sickles, *tribulum* (threshing sledge), composite knives). This is a general term to be used when the lateral hafting is evident but the function uncertain or not yet identified. A ***barb*** (Fig. 1D) is a lateral inset that is specific for projectiles; it does not serve a piercing purpose but contributes to increasing the wound. A barb can be mounted with two possible orientations: an ***oblique barb*** is mounted under a secant angle to the shaft or organic point, an ***axial barb*** is mounted parallel to the shaft/organic point and functions like a cutting edge. One projectile can combine different types of barbs and tips (see the Tlokowo barbed composite point for an example - (Osipowicz et al. 2020). Pétillon defines a barb as a "more or less pointed lateral prominence intended to hinder or forbid extraction of the weapon from the wound" (Pétillon 2008), which corresponds to what we term an oblique barb, and he proposes to restrict the term to organic points because lithic implements do not always function to hold the weapon in place (cf. axial barbs). We consider the term relevant for lithic armatures as well but we propose the addition of the hafting orientation.

Archaeological evidence of lateral composite points

Composite systems with lateral insets are best known from the Mesolithic, with several very well-preserved partial and complete specimens from European contexts (Nuzhnyi 1990; Osipowicz et al. 2020) including projectile points and a range of grooved tools with multiple uses (Chesnaux 2014). This widespread direct evidence is preceded by several more isolated older finds, including a preserved Magdalenian organic point with a cutting edge found in Pincevent (Leroi-Gourhan 1983) or the flint bladelet encased in a lump of adhesive with the negative imprint of an organic point or shaft found in Lascaux (Leroi-Gourhan and Allain 1979). The earliest example of a barbed composite weapon was found in the Gravettian (23.500 years ago) layers of Les Prés-de-Laure (France) and consists of lateral elements with use-wear associated with the remnants of an organic point (Tomasso et al. 2018). Older stone tools have been interpreted as lateral insets in composite systems based on either the results of functional analysis, the presence of residues or solely their morphology. For Europe, the oldest possible evidence for barbed composite weapons appears to date to the Protoaurignacian for which the numerous retouched bladelets have often been identified as projectile elements based on functional analysis and interpreted as lateral insets for composite tools (Broglio et al. 2005; Normand et al. 2008; Pasquini 2013). In Africa, there is no record of complete, preserved composite tools with lateral insets before the Holocene. However, backed microliths from the Howiesons Poort (MSA) and Nasampolai Industry (Kenya, LSA) have been interpreted as barbs based on the location of possible glue or ochre residues (Ambrose 1998; Gibson et al. 2004). Multiple records of microlithic, backed bladelet technologies exist in Asian contexts from 45.000 years ago (Wedage et al. 2019), but despite being interpreted as lateral elements of projectiles or composite tools, no evidence was presented and it is only justified by the comparison with recent, complete composite finds (Bleed 2002; Elston and Brantingham 2002; Wedage et al. 2019).

Identification of barbs based on wear traces

Similar to apical points, barbs have been identified based on what has been termed “diagnostic impact fractures” (DIFs) (Fischer et al. 1984), in addition to other wear evidence. While the fractures used vary between authors (see Coppe and Rots 2017 for a review), identifications typically rely on bending breaks at the tip and/or base with spin-offs and oriented microscopic linear features associated with edge damage (MLITs) (Moss and Newcomer 1982; Rots 2016), and/or obliquely oriented lateral edge damage, edge crushing, and “burinations” (Albarello 1986; Chesnaux 2014; Philibert 2002; Rots 2016; Rots and Plisson 2014).

Studies have primarily focused on flint tools, but similar damage has also been observed on quartz (Lombard 2011; Pignat and Plisson 2000; Taipale et al. 2023; Taipale and Rots 2019). For the specific distinction between lateral armatures and apical points, a few authors have offered useful frameworks (Yaroshevich et al. 2010; Chesnaux 2014; Rots 2016). Identifications are also hindered by the impact of taphonomic processes, as these may lead to the formation of lateral damage, crushing, and certain types of bending breaks, which needs to be considered when examining wear patterns (Mcbrearty et al. 1998; Pargeter 2011; Prost 1988; Tringham et al. 1974). The development of strict criteria for reliably identifying a barb and distinguishing it from an apical point at an individual level is still on-going, and further refinement is needed (Odell and Cowan 1986; Rots and Plisson 2014). More than in the case of apical points, wear formation on insets proves variable and includes breaks, oriented lateral damage, MLITs, “meat polish” resulting from contact with the prey, and compressional damage such as basal crushing or bending breaks caused by movement within the shaft or point (Normand et al. 2008; Rots 2016). In cases involving multiple insets or combinations of tips and lateral elements, also wear from contact between these components has been observed (Rots 2016). For backed bladelets, most interpretations that rely on damage propose a hafting position that considers the retouched back as the “hafted part”, and the unretouched edge as the exposed cutting or lacerating edge. While this may be a logical conclusion, it needs to be independently demonstrated, as these elements could also have been hafted apically or with their dorsal surface against the shaft (proposition by Nuzhnyi 1990). In reality, composite weapon designs may vary significantly in the number of armatures, their position and distance to each other, the absence or presence of a groove, the nature of the adhesive or bindings, etc. and each of these variables may contribute to wear formation. A range of hafting solutions and designs therefore needs to be integrated into experimental set-ups to capture the complexity in wear formation on lateral insets and develop a robust identification system.

Experimental reference: state of the art and shortcomings

Relatively few experimental studies have specifically focused on barbs, and it has been frequently reported that a considerable number of barbs detach from their hafting positions upon impact, often before fully penetrating into the target (Chesnaux 2008; Moss and Newcomer 1982; Pétillon et al. 2011; Tomasso et al. 2018). When barbed composite projectiles do not systematically enter the target, little wear can form and it may be challenging to identify distinctive traces or recurring wear patterns. Consequently, the experimental reference framework that currently founds identifications of barbs is still rather constrained (Borgia 2008; Chesnaux 2008, 2014; Fischer et al. 1984; Moss and Newcomer 1982; Rots 2016; Yaroshevich et al. 2010). For instance, Moss (1983) is often cited for her work on barbs, but her experimental reference consisted of four lateral composite projectiles only, incorporating a total of fourteen barbs. Some studies have attempted to use larger sample sizes, but such efforts are still relatively uncommon (Chesnaux 2014; Pétillon, 2004; Rots 2016). Consequently, some insight into observable wear patterns has been acquired, but the understanding of lateral composite projectiles would significantly benefit from further development, verification and completion with more elaborate experimental programs.

Great variety in hafting designs exists for barbed composite projectiles, which constitutes a challenge when experimenting. How a particular hafting design may impact

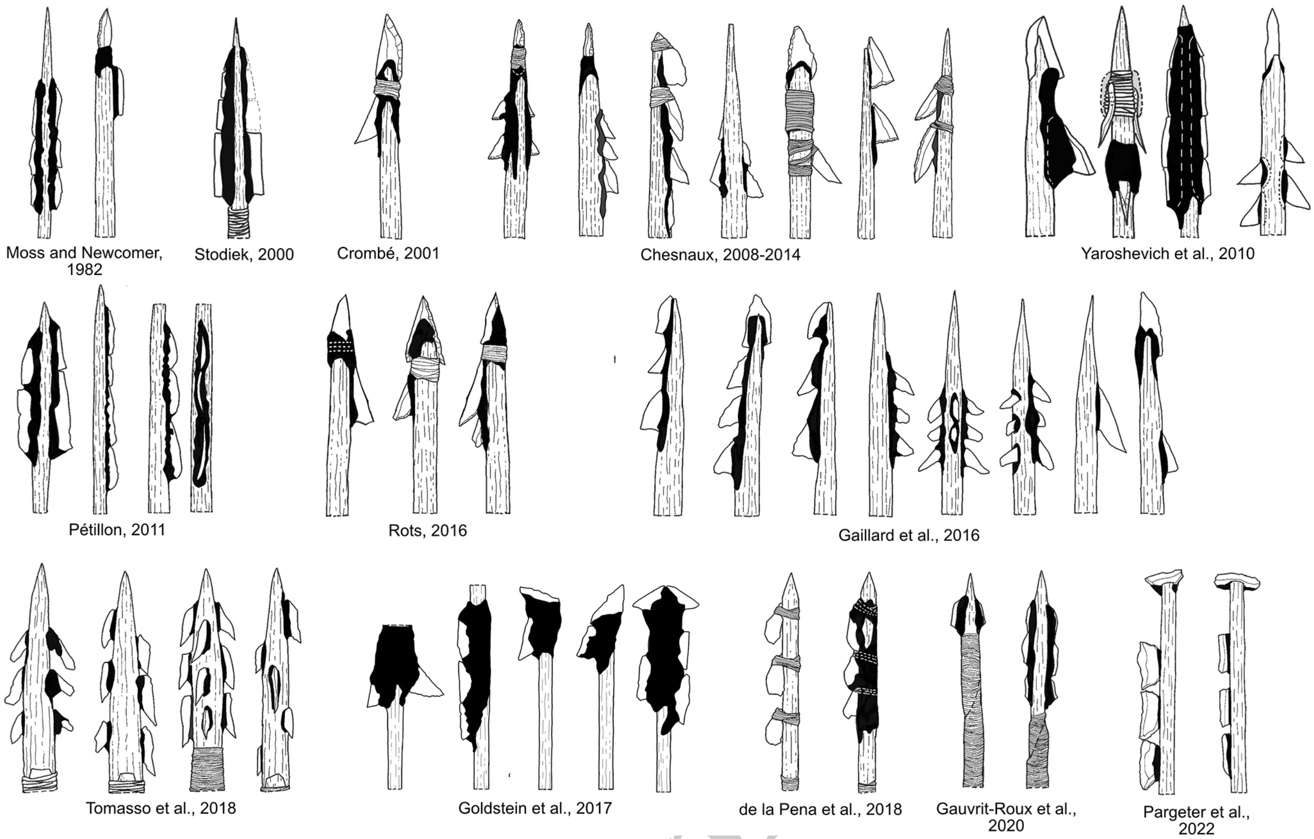

Fig. 2 Representation of published experimental designs for laterally armed composite projectiles (drawings: L. T.)

wear formation still needs to be investigated. While a range of hafting designs has been reported in published experiments (Fig. 2), the number of examples per design remains very small (Table 1). The materials used, the presence, type and composition of an adhesive, the presence/absence of a groove, the number of barbs and their orientation, alignment, separation (i.e., the distance between each element) and position (close to the apex of the weapon or away from it), all potentially affect wear formation and require systematic testing with representative sample sizes. This adds to an already large number of variables that need to be taken into account for all projectiles, such as the lithic raw material, the armature morphology, the conditions upon impact, the target, the propulsion mode, etc. (Rots and Plisson 2014; Coppe et al. 2022).

Moreover, when reviewing published experiments related to barbs, significant variation in tested lithic morphologies and in archaeological or ethnographical context can be noted (from the African MSA to the European Mesolithic) (Table 1). Backed pieces have been tested most frequently (Barton and Bergman 1982; Gauvrit Roux et al. 2020; Lombard and Pargeter 2008; Moss 1983; Moss and Newcomer 1982; Pargeter et al. 2022; Pétillon et al. 2011; Stodiek 2000; Tomasso et al. 2018), next to bladelets and geometric microliths (Chesnaux 2008, 2014; Crombé et al. 2001; Gaillard et al. 2016; Rots 2016), while unretouched products (de la Peña et al. 2018) are less frequent. Most projectiles have been mounted on arrows and shot with a bow, or more rarely a spear-thrower (Gauvrit Roux et al. 2020; Pétillon et al. 2011; Tomasso et al. 2018) or a mechanical device (Lombard and Pargeter 2008; Pargeter et al. 2022; Stodiek 2000). Sample sizes vary greatly, and clear descriptions are often lacking with barbs and tips not always being separated in discussions on protocols and results. Some studies have launched less than five projectiles (Moss 1983; Moss and Newcomer 1982; Stodiek 2000), while others record more than a hundred weapons (Chesnaux 2014). Some of the larger samples integrate many different hafting designs, (Yaroshevich et al. 2010). Tested designs range from single barbs glued to a wooden shaft, up to half a dozen elements of varying morphologies, secured in or on a shaft under varying angles and with differing fixing systems (Fig. 2), which offers a glimpse of the many possibilities, but makes it challenging to identify wear patterns. and reach a consensus on how to reliably identify and characterize barbs.

Research questions and the experimental protocols also vary significantly. Several studies dealing with laterally hafted projectiles aim to investigate their performance and durability instead of also aiming for a reliable reference set to identify criteria that permit their archaeological

Table 1 Review of published projectile experiments involving barbs. Significant variation exists in tested arrangements and use-wear results. Use-wear descriptions have been quoted and sometimes edited for length and style

Author(s)	Year	Title	No Exp	Function	Action (if not shot)	Propulsion mode	*Hafting system*	*Haft/point morphology*	*Haft/point material*	*Grooved haft/point*	*Inset material*	*Inset morphology*	*Archaeological model*	*Fixation/glue type*	*Sample size*	*Target*	*Aim of experiments*	*Traces*	*Penetration*	*Detachment*
Moss and Newcomer	1982	Reconstruction of tool use at pincevent: microwear an experiments	Yes	Projectiles		Bow and arrow	Axial barbs row	Arrow	Wood	No	Seine flint	Backed bladelets	Magdalenian backed bladelets from Pincevent	Pine resin	3 arrows − 13 insets	Meat	Building a use-wear reference collection to analyse an archaeological lithic collection	Basal crushing when hafted in rows, occasional presence of linear meat polish along the exposed edge when hafted singly	NA	Nearly all insets detached
Barton and C. A. Bergman	1982	Hunters at Hengistbury: Some evidence from experimental archaeology	Yes	Projectiles		Bow and arrow	Tips and barbs in slots	NA	Wood - Port Orford cedar and ordinary Ramin dowel	Yes	Chalk flint from East Anglia	Backed bladelets	Mesolithic microlithic points from Powell site	Pine resin mixed with beeswax and animal sinew	NA − 17 flint tools including insets	Juvenile fallow deer	Experimental reproduction of breakage patterns	Several points developed burin-like breaks along their unretouched sides. Some of the points passed right through the target undamaged whilst others developed only transverse breaks	NA	Documented for one arrow and three insets
Moss	1983	The Functional analysis of Flint Implements	Yes	Projectiles		Bow and arrow	Axial barbs row	Arrow	Wood	No	Seine flint	Backed bladelets	Magdalenian backed bladelets from Pincevent	Pine resin	4 arows − 14 insets	Meat and sandbag	Building a use-wear reference collection to analyse an archaeological lithic collection	Insets show distinct meat polish, and MLITs along the unhafted edge, on either surface	NA	Nearly all insets detached
Albarello	1986	Sur l'usage des microlithes comme armatures de projectiles / The use of microliths to frame projectile	Yes	Projectiles		Bow and arrow	Tips and barbs in slots and without slots	NA	Wood	Both	NA	Asymetrical trapeze - Martinet Trapeze-point - transverse arrowhead	Mesolithic microliths	Pine resin mixed with beeswax and additives such as charcoal, crushed bone and wood residues	NA − 33 flint tools including insets	Hide-meat-bone forming a 15cm deep target	Create a reference of use-wear traces related to projectile use	Striations and microlinear polish developped in the *functional* direction	NA	Inset failure observed in 13 lateral composite weapons
Stodiek	2000	Preliminary Results of an Experimental Investigation of Magdalenian Antler Points	Yes	Projectiles		*Firing mechanism similar to. a crossbow*	Two axial barbs row	Simple bevelled and double bevelled conical points	Osseous - antler points	NA	NA	Backed bladelet (n=?) Hamburgian type (n=5) and Upper Solutrean type (n=3)	Hamburgian type (n : 5) and Upper Solutrean type (n : 3)	Pine resin and beeswax	5 projectiles − 30 insets (?)	Fallow deer (gutted)	Investigate the suitability and durability of various methods of hafting, secondly to examine patterns of impact damage on projectile points and bones and, thirdly, to document possible differences in the depth of penetration by projectiles.	NA	NA	"Very easily detached upon contact with hard material"
Crombé et al.	2001	Wear analysis on early mesolithic microliths from the verrebroek site, east flanders, belgium	Yes	Projectiles		Bow and arrow	Tip and barb combination	Pine shaft	Wood	Yes	Fine grained flint from the Meuse region (Belgium)	25 crescents, 24 triangles, and 47 obliquely truncated points	Mesolithic microliths from the Verrebroek Site	Pine resin	87 arrows (?) − 96 insets	Sheep	Proving that low fracturation levels can be associated with lateral hafting	All but three specimens were undamaged. Fractures appeared to be more or less perpendicular to the long axis of the arrow shaft, together with the creation of a languette -i.e., a fracture zone running parallel with the flake surface that displayed hinge termination running parallel to the back of the experimental piece. Fracturing always initiated along the unmodified edge. On two specimens the surface of these fractures exhibits a diffuse bulb adjacent to the same edge. On two of our total of ninety-six experimental barbs, we observed that lateral cones were created on the unretouched edge. There was not any evidence of MLITs or any appeareance of linear meat polish found upon the unmodified edge	NA	"A large number of barbs detached"

Table 1 (Continued)

Author(s)	Year	Title	No Exp	Function	Action (if not shot)	Propulsion mode	*Hafting system*	*Haft/point morphology*	*Haft/point material*	*Grooved haft/point*	*Inset material*	*Inset morphology*	*Archaeological model*	*Fixation/glue type*	*Sample size*	*Target*	*Aim of experiments*	*Traces*	*Penetration*	*Detachment*
Borgia	2008					Bow and arrow	Two axial barbs row		Wood - viburnam	NA	NA	Bipoints with a retouched back	Gravettian backed bladelets from Paglicci	Commercial glue, sinew	70 armatures (approx.) - ? Insets	Pile of animal parts - wall - soil	Creating a reference collection of impact traces	Absence of macroscopic wear, but the presence of a linear microscopic polish is seen both perpendicularly to the axis of the inset on the proximal and distal extremities and longitudinally on the unretouched edges	NA	NA
Chesnaux	2008	Sauveterrian Microliths: Evidence of the Hunting Weapons of the Last Hunter-Gatherers of the Northern Alps	Yes	Projectiles		Bow and arrow	Tip and barbs	NA	Wood - cedarwood	Yes	Val de Lans and Vaucluse flint	Scalene triangles (n = 80) and segments (n = 80)	Sauveterrian microliths	Vegetal resin and beeswax	40 arrows − 160 insets	Wild boar	Reconstruct a hafting system based on the functional hypotheses for each weapon element type and compare the ballistic functioning of triangles and segments	Near absence of traces on the barbs. Two insets show impact damage on the proximal point, one with a smooth, snap fracture, and the other with a fracture with a hinge termination. Two insets show edge damage. No impact traces such as hafting polish or striations were found on a microscopic level.	0–115 mm	Approximately 66% of inset failure
Yarhosevich et al.	2010	Design and performance of microlith implemented projectiles during the Middle and the Late Epipaleolithic of the Levant: experimental and archaeological evidence	Yes	Projectiles		Bow and arrow	Oblique point with oblique barb- Straight point with four oblique barbs-Self-pointed with twisted barbs-Self-pointed with lateral blades	Shafts and simple conical osseous points	Wood	Both	NA	Arch-backed bladelets (N = 4), Kebara points (N = 9), trapeze/rectangles (N = 7), Helwan lunates (N = 6) and lunates with abrupt retouch (N = 6)	Levantine microliths	Mixture of beeswax and resin with the addition of either gypsum powder or ochre powder as a filling. Fiber binding in some cases	40 arrows − 160 insets	Goat and skinned sheep thorax encased in cardboard	Analyzing performance abilities of the arrows, identifying projectile damage types characteristic of particular hafting modes, detecting factors influencing the frequency of projectile damage and estimating the frequency of projectile damage expected to be found in archaeological samples.	Few traces are found, mostly consisting of transversal bending fractures initiated from the unretouched edge and oriented obliquely and perpendicularly in the mesial part. Several bending tip fractures have been found, both longitudinally and obliquely to the long axis. Only a few oriented lateral scars have been recorded on the unretouched edges.	56–430 mm	Approximately 50% of inset failure
Pétillon et al.	2011	Hard core and cutting edge: Experimental manufacture and use of Magdalenian composite projectile tips	Yes	Projectiles		Spear-thrower	Axial barbs row	Dowels made of tropical light hardwood (meranti)	Osseous - antler points	Both	Cher Valley Flint	Backed bladelets with inverse retouch	Lower Magdalenian microliths	Mixture of beeswax, resin and ochre - birch-bark pitch	24 spears − 58 insets	Deer	Test the role and efficiency of the lithic inserts	NA	NA	More than 80% of inset failure
Chesnaux	2014					See Chesnaux, 2008														
Chesnaux	2014	Réflexion sur le microlithisme en France au cours du Premier Mésolithique Xè-VIIIè millénaire avant J .-C . : approche technologique, expérimentale et fonctionnelle	Yes	Projectiles		Bow and arrow	Tip and barbs (see Chesnaux 2008)	NA	Wood - pinewood	Yes	Val de Lans and Vaucluse flint	Scalene triangles and segments	Sauveterrian microliths	Vegetal resin and beeswax	20 arrows − 80 insets	Wild boar	Reconstruct a hafting system based on the functional hypotheses for each weapon element type and compare the ballistic functioning of triangles and segments	Few traces are found, and burination are found more often on lateral insets than on tips	NA	Partial detachment in each shot
Chesnaux	2014	Réflexion sur le microlithisme en France au cours du Premier Mésolithique Xè-VIIIè millénaire avant J .-C . : approche technologique, expérimentale et fonctionnelle	Yes	Projectiles		Bow and arrow	Tip and barbs, sometimes oblique barbs only	NA	Wood - pinewood	Yes	Val de Lans and Vaucluse flint	Scalene and isocele triangles, segments, sauveterrian points, truncated points, retouched base points	Sauveterrian and Beuronian microliths	Araldite - pine resin and beeswax with ochre and commercial resin addition	55 arrows − 109 insets	Sheep (shaven)	Evaluate the resilience of different glues in a projectile hafting system and evaluate the influence of a thinner-skinned target on barb failure upon impact. Producing wear.	25% of the insets show impact damage, most often lateral scars, sometimes sliced scarring. Seven insets show a burin-like fracture and two are transversely fractured.	NA	More than 50% of inset failure

Table 1 (Continued)

Author(s)	Year	Title	No Exp	Function	Action (if not shot)	Propulsion mode	*Hafting system*	*Haft/point morphology*	*Haft/point material*	*Grooved haft/point*	*Inset material*	*Inset morphology*	*Archaeological model*	*Fixation/glue type*	*Sample size*	*Target*	*Aim of experiments*	*Traces*	*Penetration*	*Detachment*
Rots	2016	Projectiles and hafting technology	Yes	Projectiles	/	Bow and arrow	Tip and barbs combination	Arrow	Wood	No	Flint	Geometric microlith	NA	Resin	100 arrows − 104 insets (+ 100 tips. Four arrows were eqipped with 2 insets	Sheep	Examine whether a reliable distinction between tips and barbs was possible based on a microscopic analysis. In addition, the efficiency of using bindings instead of resin for hafting the pieces was tested.	Overall, barbs showed less diagnostic damage types than tips. Tip fractures occur on 57% of the barbs, but were rarely diagnostic. Spin-offs and burination occured on barbs. Lateral scarring was frequent on both tips and barbs, but sliced scarring – typical of the cutting motion upon impact – were clearly more frequent on barbs. MLITs are present on barbs (less than on tips) associated with lateral damage. Resin striations were visible. One type of fracture that could be typical of barbs: a specific type of compression fracture occurs on the tips of barbs located inside the haft.	0–250 mm	50% of inset failure
Gaillard et al.	2016	Assessing Hafting Adhesive Efficiency in the Experimental Shooting of Projectile Points: A new Device for Instrumented and Ballistic Experiments	Yes	Projectiles		Bow and arrow *used with a mechanical arm*	Multiple oblique barbs in rows or random positions around the shaft	NA	Wood - pinewood	Yes	Flint	Triangles, segments and points	Sauveterrian microliths	Different blends of rosin and beeswax	NA	Balistic gelatin block and boar shoulder	Provide better control of shooting experiments performed with replicas of prehistoric projectiles	NA	250–300 mm	NA
Tomasso et al.	2018	Gravettian weaponry: 23,500-year-old evidence of a composite barbed point from Les Prés de Laure (France)	Yes	Projectiles		Spear-thrower + bow and arrow	Multiple barbs in rows or random positions around the shaft	Gravettian conical point	Osseous	No	Flint	Backed bladelet with a curved back and appointed extremeties	Gravettian backed bladelets from Les Prés de Laure site	Resin mixture and protein glue	12 projectiles ; 83 recovered insets	Artificial - balistic gel/horse bones/ fresh hide	Produce reference material that further supports typical damage patterns for barbs	The barbs of the “design (a)” (in this paper, see Fig. 2, first composite point of Tomasso et al. 2018) point have very specific impact traces. Scars along the cutting edge occur frequently. The distal point (i.e. the truncation) shows damage related with an axial force, while the proximal part often shows scars related to a counter-pressure. A single fracture identified in the proximal part of one backed point indicates a twisted force. The three other point designs show comparable damage patterns. The proximal point frequently has damage caused by an axial force, consisting of large scars and/or transverse fractures asso- ciated with a spin-off. Scars occur frequently on both faces of the cutting edges. The distal point (i.e. the truncation) frequently shows a twisted fracture that is initiated from the cutting edge.	148–165mm	Partial detachment in each shot

Table 1 (Continued)

Author(s)	Year	Title	No Exp	Function	Action (if not shot)	Propulsion mode	*Hafting system*	*Haft/point morphology*	*Haft/point material*	*Grooved haft/point*	*Inset material*	*Inset morphology*	*Archaeological model*	*Fixation/glue type*	*Sample size*	*Target*	*Aim of experiments*	*Traces*	*Penetration*	*Detachment*
Goldstein et al.	2017					Bow and arrow	Tips and barbs		Wood -cedarwood	No	Obsidian	Backed microliths - crescents	Pastoral Neolithic microlithic crescents (Kenya)	Mixture of pine resin, animal glue and ochre	83 arrows −24 insets (12 oblique barbs, 12 axial barbs) + 104 tips	Pig ribcage, fresh cowhide and balistic gel	Provide an experimental use-wear reference for different hafting designs and functions for obsidian microlithic crescents in view of functional analysis	Barbs were very rarely damaged, oblique barbs even less than axial barbs. Several step-terminating bending fractures were observed, but only one with associated secondary damage. Bending breaks terminated on an edge (burinations) were also recorded. Lateral scarring was observed on only one inset.	NA	NA
de La Pena et al.	2018	A techno-functional perspective on quartz micro-notches in Sibudu's Howiesons Poort indicates the use of barbs in hunting technology	Yes	Projectiles		Bow and arrow	Oblique barbs row	Pine shaft	Wood	Both (grooved = 2)	Crystal quartz (n = 18) and vein quartz (27)	Retouched (n = 17) and unretouched (n = 28) notched microliths	Quartz micro-notches from Sibudhu Howieson's Poort	70% natural spruce resin and 30% bees-wax + sinew bindings	13 arrows −45 insets	Artificial - balistic gel/horse bones/fresh hide	Evaluate different hypotheses for notch formation	Elongated bending-initiated fractures starting on one edge and terminating on the opposite edge (Burinations), and spin-offs, defined here as cone- initiated scars starting from an earlier fracture surface and termi- nating on a ventral or dorsal surface or a lateral edge are found. Distinct micro-notches were observed on four pieces, in two cases in association with a fracture. They consist of a series of bending-initiated scars that most often have a strongly curved profile ("sliced scars") and an abrupt termination. MLITs could be observed, either in direct association with the notch, or elsewhere along the cutting edge. At least three of the micro-notches were clearly caused by bindings that were used to attach the barbs on the shafts. Clear zones of edge damage were observed on 23 barbs, in three cases in association with a fracture. In most cases the damage is located near the distal or the proximal extremity. Breaks were observed on an additional eight barbs. Only six barbs show no clear damage.		More than 50% of inset failure

Table 1 (Continued)

Author(s)	Year	Title	No Exp	Function	Action (if not shot)	Propulsion mode	*Hafting system*	*Haft/point morphology*	*Haft/point material*	*Grooved haft/point*	*Inset material*	*Inset morphology*	*Archaeological model*	*Fixation/glue type*	*Sample size*	*Target*	*Aim of experiments*	*Traces*	*Penetration*	*Detachment*
Gauvrit Roux et al.	2020	Reconstructing Magdalenian hunting equipment through experimentation and functional analysis of backed bladelets	Yes	Projectiles		Spear-thrower	Single axial barbs r in rows	Single-bevelled points	Osseous -reindeer antler	Yes	Bergeracois flint, Upper Turonian flint, Campanian flint and Kimmeridgian flint from Switzerland.	Early Middle Magdalenian backed bladelets, come with convergent retouch and appointed, some with parallel retouch	Early Middle Magdalenian backed bladelets	Hafting adhesive composed of colophony (30–40%), Beeswax (60–70%) and Villecroze bauxite powder (5–10%)	24 spears −84 insets	Sheep	Investigate microliths function and address the question of projectile design, and developing a methodological frame for the functional analysis of damages on the lithic projectile inserts with a specific focus on lateral scars	Impact damages affect 38% of the bladelets. Most frequent damages are scars (37% of the microliths). Fractures (6%) and MLIT (2%) are scarcer. The head bladelet is as often scarred as tail bladelets. Four categories of scars can be found. The first one gathers large isolated scars, oblique to the edge, they can be quite large and invasive and are grazing. They have varied morphologies and terminations. The second and third groups gather scars that are overlapped or aligned and may show crushing. They have varied morphologies and terminations and are generally large. Differences between the second and third categories are their inclination and orientation: scars from the second group are oblique and grazing and those from the third group are slightly oblique or perpendicular to the edge and generally semi-abrupt. The fourth category brings together crescent break scars with a snap section and a half-moon morphology; they are found isolated or aligned.	15–320mm	Minimal detachment
Pargeter et al.	2022	Stone tool backing and adhesion in hunting weaponry: First results of an experimental program	Yes	Projectiles		*Spot Hogg Hooter-Shooter*	Transversal tip and axial barb rows	Poplar dowels	Wood	NA	Texas Georgetown chert	Backed segments (n = 75) and standardized unretouched bladelets (n = 75)	NA	Ferr-L-Tite and Sterno™ gel	50 projectiles −150 insets	Oak board	Determine the influence of a back retouch and hafting position on adherence with a haft, and the influence on haft splitting.	NA	85–260mm	Approximately 80% of inset failure

identification (Borgia 2008; Chesnaux 2008; Pétillon et al. 2011; Stodiek 2000). When weapon performance is investigated, variables are not always fully communicated, in part due to the nature of a realistic shooting experiment.

Experimental details are variably disclosed, for instance with regard to the exact hafting materials used, and only few studies discuss the impact of their choice of hafting materials (i.e., particularly adhesives) in their shooting experiments (Gaillard et al. 2016; Wilson et al. 2021). Adhesives are mostly tested in isolation from a hafting system and weapon design. Resinous mixtures and tars are most frequently used, while protein glues are rarely used (see Goldstein and Shaffer 2017 and Tomasso et al. 2018 for exceptions) and remain largely under-studied. Adhesive studies have focused on the manufacture of vegetal-based glues (Kozowyk et al. 2017b; Kozowyk and Poulis 2019; Osipowicz 2005; Schmidt et al. 2021; Wadley 2005) and mechanical tests of their resilience (Kozowyk et al. 2016, 2017a; Wadley 2005; Zipkin et al. 2014). In preparation of the present study, we have followed this approach as well, focussing on the resilience of a broad range of adhesives in a mechanical set-up but in this case incorporating a realistic hafting situation (Tydgadt and Rots 2022). We observed that resinous mixtures show less resilience in mechanical lap shear tests than protein glues, and we suggested that this low resilience was because this type of glue is less suitable for applications in a single lap joint and works better as a mastic.

Two key variables for the resilience of lateral composite projectiles have remained untested up to now, being the influence of the use of a groove and the glue. Archaeological evidence demonstrates that grooves are not present on all organic points, with the split-based points of the Proto-Aurignacian and Aurignacian as notable exceptions, and some authors have argued that it is therefore unlikely that lateral insets were mounted on them (Tartar 2015a) while others propose that lateral elements could have been secured to an organic shaft or point with sinew or hemp thread without the need for a groove (Nuzhnyi 2000). For Europe, grooves on organic points only occur archaeologically from the Gravettian and the Solutrean onwards (Ducasse et al. 2017; Goutas 2016), but still, their numbers are low compared to points without a groove in these early contexts. By contrast, grooved points occur regularly in the Magdalenian (Langley et al. 2016; Langley and Delage 2018), side-by-side with ungrooved points, some of which at least have carried lateral insets as demonstrated by the find of Lascaux of a bladelet preserved within its mastic showing the imprint of the organic point or shaft (Leroi-Gourhan and Allain 1979, p.101, Fig. 80, n°16). To understand this variability, we first need to understand whether these grooves influence the resilience of the hafting arrangement compared to a system that does not utilise a groove. Moreover, when a resilient hafting system can be identified, this will significantly facilitate experiments as it will permit to ensure that barbs will be exposed to sufficient stress to break before their hafting does and, as a result, accumulate relevant wear traces that can be registered and studied.

Materials and methods

Based on the results of previous mechanical tests (Tydgadt and Rots 2022), a selection of glues, including protein glues (see 3.1.4. Glues), was tested in a realistic shooting experiment to isolate different influential factors determining the behaviour of a laterally hafted system upon impact. By using a realistic shooting experiment and different hafting designs with grooved and ungrooved organic points and different kinds of glue or glue mixtures, we aim to understand the behaviour of barbed composite weapons, evaluate the resilience of different hafting designs, and identify successful hafting components for barbs. The advantages and constraints of each hafting design were evaluated, from their manufacture to their use as a projectile. The results provide a first building block of a robust reference framework for the identification of barbs based on wear traces and guarantee more successful future experimental programs oriented towards archaeological case scenarios.

Materials

Forty-eight projectiles were produced, each consisting of an organic point (wood or antler) with a single stone barb, attached to an arrow shaft. The choices in hafting materials benefitted from the results of a preceding experiment (Tydgadt and Rots 2022) that aimed to identify the most resilient combination between a glue type and an organic material. Bone glue, fish glue and resinous mixtures provided the most promising results, with the note that resinous mixtures underperformed because they should not be used as an adhesive, but rather as a mastic. The current study continues this investigation and adds the design variable, with grooved and ungrooved organic points and backed bladelets. Some combinations failed (i.e. ungrooved points used with bone glue) during the production phase and these points could not be used in the shooting experiment. In total, 39 projectiles could be used in the shooting experiment and were successfully shot into the target.

Shafts

All arrow shafts used in this experiment were made of pine wood, with a diameter of 11/32 inches (8.7 mm), a length of 80 cm and a spine of 13 mm. Each arrow shaft was fletched with three natural five-inch feathers (see Lepers and Rots 2020 for details).

Stone insets

The general morphology, dimensions and variability of the insets were inspired by Protoaurignacian bladelets from Fumane Cave (Falcucci et al. 2018; Falcucci and Peresani 2018), but our observations permit extrapolations to backed bladelets in general. Insets were made of fine-grained flint from Harmignies (Belgium) by C. Lepers (TraceoLab) who has 30 years of experience in stone knapping. Bladelets were knapped from a core with opposed platforms by direct percussion with a sandstone hammer. The maximum length of the bladelets ranges from 27 to 48 mm, the maximum width ranges from 5.5 to 10 mm, and the thickness (taken both at the centre and thickest points of the stone tools) ranges from 1.5 to 5 mm. Each inset was shaped by lateral direct retouch with a sandstone hammer (Fig. 3). Only one edge was retouched while the unretouched edge was exposed to increase the chances of visible damage. The morphological variation is representative of what was observed archaeologically, in order to face similar challenges in terms of hafting. We believe that the precise morphological characteristics of the inset influences what choice can be made in hafting materials. However, extrapolations towards geometric microliths are not possible and require a separate experimental program. All insets were photographed before hafting to record any production wear that could interfere with use-wear analysis.

Organic arrow points

Both wooden and osseous points have been found archaeologically, and both were included in our sample. Wood was in use for weapon production from early on, with the earliest examples being (fragments of) wooden spears found at Clacton-on-Sea (UK) and Schöningen (Germany) dating back to the early Middle Palaeolithic, but also at Lehringen (Germany) (Movius 1950; Oakley et al. 1977; Thieme 1997). Despite wooden points and shafts being rarely preserved in archaeological contexts, it seems reasonable to assume they were manufactured and used as well (Wagues-pack et al. 2009). Osseous points have been frequently documented for the European Upper Palaeolithic. Bone was used in the manufacture of a range of tools, but antler is more commonly used for crafting projectile points during this period (Tartar 2015b). Bone and antler have very similar properties in terms of resilience to compression, but antler is more resilient to bending stress (Albrecht 1977) and therefore better suited for impacts experienced in hunting. To avoid redundancy and to align with the archaeological evidence, we chose to only test antler in our experiment.

Two sets of organic points were made, a series made of oakwood ($n=24$) and another out of antler ($n=24$). Half of the points out of each material were grooved ($n=12$ made out of oak, $n=12$ made out of antler). Points with an oval cross-section, a double-bevelled proximal end and an appointed distal end were chosen on two grounds: the possibility of carving a groove when needed without risking a split and the possibility of ensuring a solid hafting joint with

Fig. 3 Experimental stone insets

the shaft. The length of the organic points ranged from 94 to 208 mm, their width from 8 to 15 mm and their weight from 4,9 to 16,3 g.

The use of two raw materials had the additional advantage that we could also test the robustness of the different hafting systems with regard to the type of glue that was used given that previous experiments (Tydgadt and Rots 2022) had shown that not every glue is equally suitable for each organic material. Furthermore, differing wear patterns may also result from the counter-pressure of the bladelets against either a wooden or antler point. Another reason to integrate both wooden and osseous points is their structural difference, which could again influence the formation of wear traces.

Glues

The insets were secured on the points using three types of glue, selected based on results from the mechanical bench test experiment (see Tydgadt and Rots 2022), which showed that the resilience of a bond in a single lap joint situation depends on the interaction between both the contact material and the type of glue. The glues resulting in the strongest bond with both wood and antler were selected here as a strong hafting bond increases the chances the inset would accumulate damage rather than detach. Fish glue, bone glue and a mixture of resin, beeswax and ochre (7.5%) were used with wooden points. Fish glue, bone glue and a mixture of resin and beeswax were used on antler points. Each glue type was used to secure stone implements on 4 grooved and 4 ungrooved points per organic material (i.e. wood or antler) (Table 2).

Assembling procedure

Each point was equipped with a single inset (Fig. 4) hafted parallel to the point's axis, as an axial barb. We experienced several problems during the hafting process related to the choice of the glues. While all glues had proven effective in the mechanical experiment, their application in a more actualist setting was variably effective. Particularly bone glue proved to be problematic, and we frequently failed to glue insets on the organic points because the glue was too liquid to hold the inset in place long enough on the rounded surface of the organic points for the glue to set. As a result, no barbs could be attached to the ungrooved wooden points with bone glue, while on the ungrooved antler points, only one tool could be properly hafted to allow its use. We also failed to haft barbs with fish glue to two of the wooden points (one grooved, one ungrooved), again because this glue proved too liquid. Stone insets detached from the points before the glue dried, either falling out completely or lying flat on the points, rendering them unusable. In some cases, the morphology of the axial barb proved incompatible with the absence of a groove because the irregular transition between both could not be smoothened with the highly liquid fish glue. From a total of 48 prepared organic points, only 39 composite projectiles could be effectively hafted and used in the experiment.

Target

The target (Fig. 5) was manufactured at TraceoLab, University of Liège, according to existing protocols described in Coppe and Rots (2017). The target consisted of a dismantled ribcage of a horse encased in a ballistic gel and covered by a fresh deer hide. The ribs were dismantled from the thoracic cage and attached individually on a wooden frame. The frame was then placed in a rectangular mould and a ballistic gel was poured over the ribs up until full immersion. Once the gel had set, the mould and the wooden frame were removed, the gel was sculpted into shape, and the target was secured to a stand and covered with a stretched fresh deer hide. The lateral sides of the target were left uncovered to permit filming the behaviour of the projectile when entering the target (Fig. 5, *center*).

Experimental protocol

All the experimental projectiles were shot with a bow from a distance of 10 m by J. Coppe (TraceoLab; 10 years of experience). Using a bow was a purposeful choice, as its kinetic energy is one of the lowest in the range of prehistoric projectile weapons (Coppe et al. 2019) and if our hafting

Table 2 Combinations of materials and adhesives used to assemble the experimental projectiles. RB = Resin and beeswax (70 − 30%); RBO1 = Resin, beeswax and ochre (64.75-27.75-7.5%). Four barbed composite points of each combination were planned for, but some of the combinations failed during the hafting process (0/4 indicates complete failure and the production of no points, ¼ indicates the production of only one barbed composite point out of four, etc.)

Wooden points							18
Grooved	RBO1	4	Fish Glue	3	Bone Glue	4	11
Ungrooved	RBO1	4	Fish Glue	3	Bone Glue	/	7
Antler points							21
Grooved	RB	4	Fish Glue	4	Bone Glue	4	12
Ungrooved	RB	4	Fish Glue	4	Bone Glue	1	9
TOTAL							39

Fig. 4 Hafted points. EXP114/230- Grooved antler point with a resin and beeswax mixture. EXP114/283- Ungrooved antler point with fish glue. EXP114/245- Ungrooved wooden point with a resin, beeswax and ochre mixture. EXP114/235- Grooved wooden point with bone glue

Fig. 5 A realistic target made of a sequence of horse ribs that are encased in ballistic gel and covered with fresh deer hide. The wooden frame (left) was removed before the experiment and the hide was maintained under tension by turnbuckles attached at the sides and the back

systems would fail, they would not be successful with any other propulsion method either. Testing with a bow is thus a necessary first step and has the added advantage that results can be compared with a greater number of published experiments that featured barbs (cf. Table 1). The bow is made from yew wood and has a draw weight of 48 pounds for a draw length of 80 cm (31 inches). All shots were filmed. To guarantee uniform lighting, an intense LED light was placed on one side of the uncovered target. A high-speed FASTCAM Nova camera with a recording capacity of 16,000 frames per second (TOKINA ATX-I macro 100 mm F2.8FF lens) was placed at the other side of the target to permit the filming of the projectile impacts. To ensure the best possible film quality, we targeted the 20 × 20 cm window that corresponds to the camera's point of focus but despite the use of a slow-motion camera, not every shot could be filmed in detail (when it did not arrive in the small target window). As a result, penetration depths could not be recorded for all barbs.

The experiment took place over two summer days with no rain and an average temperature of 25 °C. To reach bones, our shots were taken perpendicularly to the target's ribcage, even if it has been theorised that prehistoric hunters might have preferred to shoot their prey from a narrower angle (30–40°) (Friis-Hansen 1990). Each point was to be shot until dysfunction (dismantling of the point, detachment of the inset, shaft damage,.) and up to a maximum of ten shots. Lithic insets were checked for damage after each shot. When damage could be observed with the naked eye, their use was discontinued. The pictures of the insets taken before hafting aided in easily distinguishing macroscopic manufacture-related damage and use-related damage. If a point or inset moved in its shaft but did not bear visible damage, it was secured back in place and used again. If the point or insets dehafted, the use was discontinued.

Analytical protocol

All recovered insets were removed from the shaft, cleaned with water and an ultra-sonic cleaning tank and examined for wear evidence. During the analysis, a Zeiss V12 stereoscopic microscope (magnification between×8 to×100 – PlanApo S1.0x FWD 60 mm) and a Zeiss Axio Zoom V16 motorized microscope (magnification between ×6.5 to ×180 – PlanApo Z0.5x/0.125 FWD 114 mm) were used. The exact location of all damage was recorded and damage was described in detail according to the terminology proposed by Coppe and Rots (2017). No statistical processing of the data took place given that the sample sizes are insufficient to produce relevant and reliable results. Robust statistical testing should be part of future research when sample sizes are increased following subsequent experiments.

Results

Shooting experiment

A total of 39 projectiles were shot at the target, accumulating a total of 70 shots. The number of shots for each projectile, the penetration depth and the impacted materials (hide, gelatine, bone) are documented in Table 3. Most projectiles succeeded to pierce through the skin and reach the gelatine ($n=50$), some also hit bone ($n=8$). Upon the first impact with the target, only 14 barbs remained in position, while 18 detached from the organic point with no damage and two organic points were too damaged to be shot again. Visible damage on the barbs potentially caused by contact with a bone led to four more projectiles being put to rest. In comparison to other published experiments, this success rate does not stand out, but differences in design and material choices have to be taken into account. Particularly, the set-up of this experiment aimed to reflect on the relationship between design and performance.

Resilience index

To evaluate the resilience and durability of the different hafting components, we converted our results into an index of durability, illustrating the mean number of shots a projectile successfully achieved before breakage. To calculate this index, we divided the total number of shots taken per group of projectiles (for each design) by the number of projectiles (excluding the six points that missed the target (cf. Table 4).

We first compare the potential effect of a groove, independent of the points' raw material or the glue that was used. A total of 20 grooved points amounted to a total of 43 successful shots where the projectile entered the target, which resulted in an index of 2.15 shots per arrow. The ungrooved points (13) amounted to 19 successful shots and an index of 1.46 shots per projectile.

With regard to the raw material of the point, we observe that wooden barbed composite projectiles an index of 2.43, while the ones with antler points have an index of only 1.41. This important difference should however be nuanced. One of the barbed composite projectiles with a wooden point (EXP114/235, wood-grooved-bone glue) proved very successful and it could be shot a total of ten times. None of the other projectiles were equally successful. If this piece is excluded from the index calculation, a value of 1.93 is reached, which is more comparable to antler points, even if it remains higher.

We also evaluated glue performance. Bone glue was applied on seven projectiles resulting in 16 shots, resulting in an index of 2.28, but this score is largely due to the exceptional projectile EXP114/235. When this projectile is excluded, we count six shots for six projectiles which results in an index score of 1. Fish glue was used on a total of 11 projectiles, for a total of 11 shots, which also resulted in an index of 1. Resin mixtures amount to 15 arrows and 33 shots for an index of 2.2 (all mixtures are considered together because their performance is similar to their respective organic points, see (Tydgadt and Rots 2022). When the glue type is considered per organic point material, bone glue has an index of 1 for both wood and antler points. Fish glue combined with antler points also yields an index of 1, while an index of 1.2 is obtained when used with wood. Resinous mixtures lead to an index of 1.85 with antler and 2.5 with wood. If the presence or absence of a groove is incorporated, the sample becomes very small, often due to difficulties encountered when assembling the points, which is a result in itself. Overall, grooved points have better results than ungrooved ones. Bone glue used on an ungrooved antler point resulted in only one successful shot and no flint insets could be successfully glued to any of the ungrooved wooden points. With both wood and antler grooved points, we reach an index of only 1 when ignoring EXP114/235,

Table 3 Experimental details, including impacted material and penetration depth. An ID number is attributed to every projectile (114/XX) and a sequence number is added for each shot taken by each projectile (the first shot taken by projectile 114/XX is 114/XX/01, and the second is 114/XX/02)

Tool ID	Shot ID	Point material	Groove	Glue type	Contact material	Hafting state after shot	Penetration (cm)
114/213	114/213/01	antler	yes	fish glue	skin; gel	detached	18
114/214	114/214/01	antler	yes	fish glue	missed shot	point breakage	0
114/215	114/215/01	antler	yes	fish glue	skin; gel	point breakage	12
114/216	114/216/01	antler	no	fish glue	skin; gel	unchanged	13
114/216	114/216/02	antler	no	fish glue	missed shot	detached	0
114/217	114/217/01	antler	yes	fish glue	skin; gel	detached	12
114/218	114/218/01	antler	yes	bone glue	skin; gel	detached	1
114/222	114/222/01	antler	yes	bone glue	skin	detached	0
114/223	114/223/01	antler	yes	bone glue	skin; gel	detached	1
114/225	114/225/01	antler	yes	RB	skin; gel	unchanged	5
114/225	114/225/02	antler	yes	RB	skin	unchanged	6
114/225	114/225/03	antler	yes	RB	skin	unchanged	0
114/226	114/226/01	antler	yes	bone glue	missed shot	point breakage	0
114/228	114/228/01	antler	yes	RB	skin; gel	unchanged	17
114/228	114/228/02	antler	yes	RB	skin; gel	detached	13
114/230	114/230/01	antler	yes	RB	skin; gel	unchanged	14
114/230	114/230/02	antler	yes	RB	skin; gel	detached; point breakage	12
114/231	114/231/01	antler	yes	RB	skin	detached	0
114/233	114/233/01	wood	yes	RBO1	skin; gel	unchanged	?
114/233	114/233/02	wood	yes	RBO1	skin; gel	unchanged	11
114/233	114/233/03	wood	yes	RBO1	skin; gel	unchanged	?
114/233	114/233/04	wood	yes	RBO1	missed shot	point breakage	0
114/235	114/235/01	wood	yes	bone glue	skin; gel	unchanged	19
114/235	114/235/02	wood	yes	bone glue	skin	unchanged	?
114/235	114/235/03	wood	yes	bone glue	skin; gel	unchanged	19
114/235	114/235/04	wood	yes	bone glue	skin; gel	unchanged	19
114/235	114/235/05	wood	yes	bone glue	skin ; gel ; bone	unchanged	20
114/235	114/235/06	wood	yes	bone glue	skin; gel	unchanged	19
114/235	114/235/07	wood	yes	bone glue	skin; gel	unchanged	19
114/235	114/235/08	wood	yes	bone glue	skin; gel	moved but still usable	19
114/235	114/235/09	wood	yes	bone glue	skin; gel	moved but still usable	?
114/235	114/235/10	wood	yes	bone glue	skin; gel	moved but still usable; point breakage	?
114/236	114/236/01	wood	yes	bone glue	skin	detached	0
114/237	114/237/01	wood	yes	bone glue	skin; gel	detached	11
114/238	114/238/01	wood	yes	RBO1	skin; gel	detached	5
114/240	114/240/01	wood	yes	bone glue	missed shot	point breakage	0
114/241	114/241/01	wood	yes	RBO1	skin ; gel ; bone	unchanged	17
114/241	114/241/02	wood	yes	RBO1	skin; gel	unchanged	18
114/241	114/241/03	wood	yes	RBO1	skin ; gel ; bone	moved but still usable	18
114/241	114/241/04	wood	yes	RBO1	skin; gel	unchanged	?
114/241	114/241/05	wood	yes	RBO1	skin; gel	unchanged	?
114/241	114/241/06	wood	yes	RBO1	skin; gel ; bone	detached	0
114/244	114/244/01	wood	yes	RBO1	skin; gel	unchanged	13
114/244	114/244/02	wood	yes	RBO1	skin ; gel ; bone	unchanged	?
114/244	114/244/03	wood	yes	RBO1	skin ; gel ; bone	point breakage	0
114/245	114/245/01	wood	no	RBO1	skin ; gel ; bone	unchanged	17
114/246	114/246/01	wood	yes	fish glue	skin; gel	unchanged	?
114/246	114/246/02	wood	yes	fish glue	skin; gel	detached	18
114/247	114/247/01	wood	no	fish glue	missed shot	point breakage	0
114/248	114/248/01	wood	no	RBO1	skin; gel	unchanged	?
114/248	114/248/02	wood	no	RBO1	skin; gel	detached	0
114/249	114/249/01	wood	no	RBO1	skin; gel	unchanged	11
114/249	114/249/02	wood	no	RBO1	skin; gel	detached	1

Table 3 (continued)

Tool ID	Shot ID	Point material	Groove	Glue type	Contact material	Hafting state after shot	Penetration (cm)
114/251	114/251/01	wood	yes	fish glue	skin; gel	detached	10
114/253	114/253/01	wood	no	RBO1	skin	unchanged	5
114/253	114/253/02	wood	no	RBO1	skin	detached	0
114/255	114/255/01	wood	no	fish glue	skin; gel	detached	14
114/256	114/256/01	antler	no	fish glue	other	point breakage	0
114/261	114/261/01	wood	no	fish glue	skin	detached	0
114/269	114/269/01	antler	no	bone glue	skin; gel	detached	12
114/274	114/274/01	antler	no	RB	skin; gel	detached	9
114/275	114/275/01	wood	yes	fish glue	skin; gel	detached; point breakage	1
114/277	114/277/01	antler	no	RB	skin; gel	unchanged	17
114/277	114/277/02	antler	no	RB	skin; gel	unchanged	12
114/277	114/277/03	antler	no	RB	skin; gel	unchanged	13
114/277	114/277/04	antler	no	RB	skin ; gel ; bone	detached	13
114/280	114/280/01	antler	no	RB	missed shot	point breakage	0
114/281	114/281/01	antler	no	RB	skin	detached	0
114/282	114/282/01	antler	no	fish glue	skin	detached	8
114/283	114/283/01	antler	no	fish glue	skin	detached	9

Table 4 Number of projectiles and respective number of successful shots for each hafting design

	UNGROOVED				GROOVED			
	Wood points		Antler points		Wood points		Antler points	
Resin mixtures	4	7	3	6	4	13	2	8
Fish glue	2	2	3	3	3	4	3	3
Bone glue	0	0	1	1	3	12	3	3
	Nr of projectiles	*Nr of successful shots*	*NP*	*NSS*	*NP*	*NSS*	*NP*	*NSS*

and 3.25 when including it for wooden points. Fish glue reaches an index of 1 with both ungrooved and grooved antler, but also with ungrooved wood. It reached an index of 1.3 with grooved wood. Resinous mixtures again yielded the best results as they reached a 1.6 index with ungrooved antler, 2 with grooved antler, 1.75 with ungrooved wood and 3.25 with grooved wood.

Penetration

Varying penetration depths have been recorded (see Fig. 7), depending on whether the projectile fails upon impact or hits bone and has its trajectory interrupted. However, our results show that contact with bone did not automatically lead to reduced penetration, as the five barbed composite points that hit bone reached a depth between 13 and 20 cm (Table 3).

We first discuss the results (see Figs. 6 and 7) of the projectiles that penetrated the target by excluding penetration values of 0 (see the values including 0 in Fig. 6). Grooved points have a slightly higher mean penetration depth (13.5 cm) than ungrooved points (12.5 cm). Their maximal penetration is 20 and 17 cm, respectively. We observed that penetration was the deepest with barbed composite points that showed a seamless transition from the inset to the shaft, both thanks to the point morphology (i.e. 114/235) and/or the use of a resinous mastic to hide imperfections of the transition.

Use-wear analysis

Nine barbs missed the target and/or were lost, so 30 out of a total of 39 barbs were studied for use-wear traces. Use damage remains very light in most cases. Fourteen barbs (out of 30; 46.6%) showed no macroscopic wear from projectile use. A total of eight pieces show one break or scar only, while the remaining eight pieces show between two and seven scars or breaks each. In the first case, most barbs did not impact bone directly, while it was more frequent in the second group. Some of the barbs without wear evidence were shot multiple times before they finally detached, indicating that even multiple shots do not always lead to damage formation. None of the undamaged barbs proved to have impacted bone and many of these even did not make it through the hide. We mainly observed wear on the exposed unretouched edges of the barbs that encountered the target. The retouched hafted edge was more durable and little to no wear from counter-pressure or detachment could be observed. A total of 35 wear occurrences were registered (Table 5), 6 of which were multiple scars considered as one event. Lateral scars are most frequent (21 occurrences – 60%) and mainly occur in the mesial (11/21-52.3%) and the

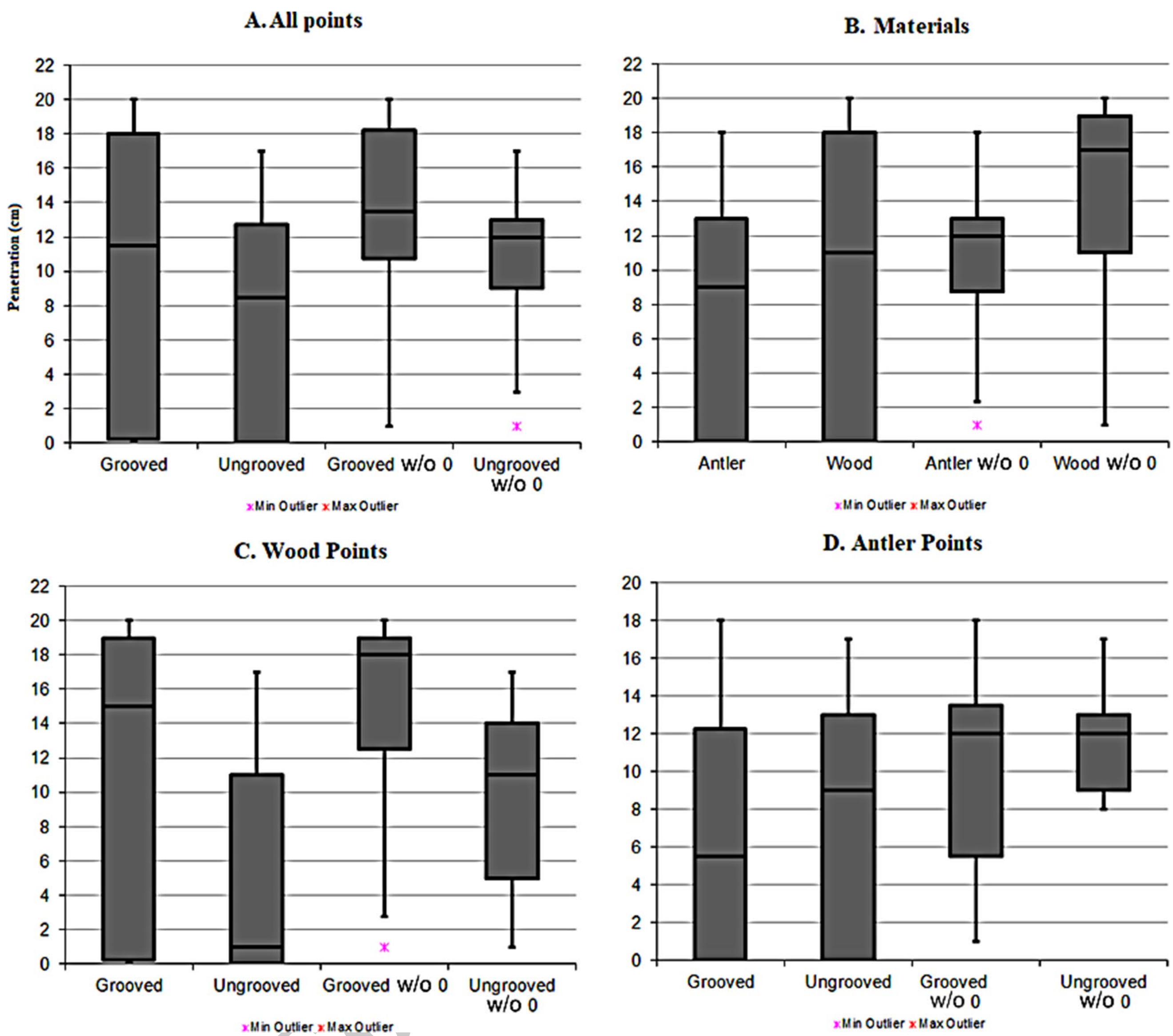

Fig. 6 Boxplots documenting the penetration depth of the projectiles according to morphology and material, with null results included (left section of each graph) or excluded (right section of each graph). **A.** Penetration depths grouped by the presence/absence of a groove. **B.** Penetration depths per material of the organic points. **C**. Penetration depths of all wooden composite projectiles grouped by the presence/absence of a groove. **D**. Penetration depths of all antler composite projectiles grouped by the presence/absence of a groove

distal area (7/21-33.3%) with similar frequencies on both surfaces. They are mainly oriented obliquely towards the base of the inset, which is oriented towards the proximal end of the projectile. Most lateral scars originate from a surface and show a bending initiation (15/21 -71.4%) and an oblique orientation, while only a few scars were cone-initiated with a perpendicular propagation to the long axis of the inset (5/21–23.8%). Five (23.8%) of these lateral scar occurrences are multiple scars, but they are not associated with bending or cone initiations in particular. These lateral scars are most often feather-terminating (13/21–57.1%) while step-terminating scars are always associated with a bending initiation (6/21–28.5%).

Breaks initiate in bending (9/35– 25.7%) and propagate from the apex to the base, in all cases except one that initiated from the proximal end and ran towards the apex. They are short in their propagation, which can be partially explained by their very thin section (Coppe, *in prep)*. Most breaks terminate in a step or hinge (7/8-87.5%). Two of the breaks terminated on an edge. Only one bending break was initiated from the retouched edge (see EXP114/241, Fig. 11).

Five secondary scars, initiated from an earlier scar or break surface, have been recorded, and two were multiple scars. The first multiple scar patch is found on the edge of the propagation of a large bending-initiated lateral scar (Fig. 12.

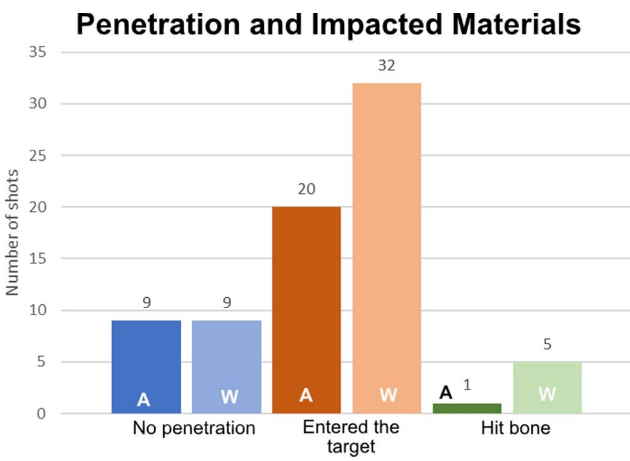

Fig. 7 Impacted materials for each organic point material (A=Antler points; W=Wooden points). Shots registered as not having penetrated the target are considered as such when the inset detached before breaching the skin. Shots that have successfully entered the target include contact of the inset with skin, gel, and sometimes bone

C and D - EXP114/245), and the other one is found initiated from another secondary scar (Fig. 9. *A4*- EXP114/215). Two of the secondary scars terminated along an edge.

No specific link between the nature of the damage and the hafting parameters or the penetration depth could be observed in this experiment, as several pieces that did enter the target successfully were not damaged at all. In one case, even contact with bone did not produce damage (Table 3. EXP114/217), and in another case, a projectile was shot three times into the target and the inset was still unscathed (Table 3. EXP114/225).

If we want to evaluate how many of the barbs would have been recognisable as armatures in the archaeological record, we can test this with the scoring system that was developed for apical points (Coppe & Rots, *submitted*) as part of an attribute-based recording system of fractures and damage (see Coppe and Rots 2017). It relies on the importance of the degree of compression that the lithic element was subjected to during breakage and evaluates the probability of use as an apically hafted projectile. While its relevance for lateral armatures has not yet been demonstrated, a test was nevertheless judged relevant to evaluate our results. According to this scoring system, only five out of 16 damaged barbs prove to show enough damage to be interpreted as definite projectile elements if it were an archaeological sample (Figs. 8, 9, 10, 11 and 12), which corresponds to 16% of the insets. Such a result sharply contrasts with the 40% that is put forward for apical point identification (Coppe & Rots, in prep). It emphasises the low rate of damage formation on laterally hafted elements in comparison to apically hafted ones, as has been reported by others (Chesnaux 2008, 2014; Moss and Newcomer 1982; Rots 2016; Yaroshevich et al. 2010).

Of course, identification criteria used for apical points should not be directly transferred to barbs and reliable wear patterns should be identified on the barbs themselves. In this light, the importance of obliquely oriented lateral scars in our experimental dataset is highly relevant: 9 out of 16 damaged insets show this type of damage in some form. Moreover, these oriented scars are frequently associated with other typical fractures (e.g. bending-initiated step-terminating breaks with secondary damage) (Fig. 8). Also, two patches of multiple scars were found that initiate from the termination of preceding scars, but did not follow the same axis, which indicates stress from another direction than the one of impact (Fig. 9.*A4* and Fig. 12C *and D*). Such "secondary" scars have not been documented for apical points to the best of our knowledge and their formation should be investigated further.

Discussion

Laterally hafted composite weapons represent an important innovation in weapon technology that is often linked with trends towards microlithisation and changing hunting strategies (Attenbrow et al. 2009; Broglio et al. 2005; de la Peña et al. 2018; Elston and Kuhn 2002; Robertson 2011). Stone implements of varying morphology that may have been used as barbs in such systems have been identified on every continent, but such identifications rely on diverging criteria and analytical approaches. Moreover, hafting designs are rarely known, including whether the role of the barbs is to lacerate, enhance penetration, increase the wound, hinder retrieval, or a combination of these. Several experiments have been performed to aid in the understanding of specific stone morphologies recovered at archaeological sites, and to document the performance of barbed composite weapon systems and the wear that may result on stone insets(Chesnaux 2008; Moss and Newcomer 1982; Stodiek 2000; Tomasso et al. 2018; Yaroshevich et al. 2010). Researchers who perform these experiments face recurrent challenges that are inherent to this specific hafting design: stone insets are generally glued to the shaft or point they adorn, and frequently detach upon impact. When stone insets detach too quickly, even before proper insertion into the target, the production of adequate sample sizes is difficult, which significantly hinders understanding of the wear pattern that is specific to barbs, their orientation, and the composite weapon design. Studying issues of weapon performance is also complicated when key elements of the design detach before or immediately upon insertion. It is thus essential to examine more closely how the effectiveness of such weapon designs can be improved, by better understanding the variables that are essential in their functioning. Is it just the strength

Table 5 Description of the wear features observed on the barbs during analysis. Each fracture is individually identified, located and described by isolating the nature of the initiation, propagation and termination

Fracture	Initation	Locus	Location of initiation	General direction	Termination	Location of termination	Composition	Fracture type	Category
EXP114/213/01	Cone	Distal	Left lateral edge	diagonal towards the base	Feather	Dorsal surface	multiple	Scar	Lateral scar
EXP114/213/02	Bending	Distal	Left lateral edge	diagonal towards the base	Feather	Left lateral edge	multiple	Scar	Lateral scar
EXP114/215/01	Bending	Distal	Apex	apex to base	Snap	Right lateral edge; ventral surface	single	Break	Bending break
EXP114/215/02	Cone	Distal	Earlier fracture surface	apex to base	Step	Dorsal surface	single	Scar	Secondary damage
EXP114/215/03	Bending	Mesial	Right lateral edge	diagonal towards the base	Feather	Dorsal surface	multiple	Scar	Lateral scar
EXP114/215/04	Bending	Mesial	Right lateral edge	diagonal towards the base	Feather	Dorsal surface	single	Scar	Lateral scar
EXP114/215/05	Cone	Distal	Earlier Fracture surface	perpendicular to the long axis	Feather	Dorsal surface	multiple	Scar	Secondary damage
EXP114/215/06	Bending	Distal	Earlier fracture surface	apex to base	Step to step	Dorsal surface	single	Scar	Secondary damage
EXP114/223/01	Bending	Distal	Apex	apex to base	Step	Ventral surface	single	Break	Bending break
EXP114/230/01	Bending	Distal	Apex	apex to base	Step	Ventral surface	single	Break	Bending break
EXP114/230/02	Bending	Distal	Right lateral edge	diagonal towards the base	Feather	Dorsal surface	multiple	Scar	Lateral scar
EXP114/235/01	Bending	Distal	Apex; ventral surface	apex to base	Snap	Dorsal surface; left lateral edge	single	Scar	Scar
EXP114/236/01	Cone	Mesial	Right lateral edge	perpendicular to the long axis	Feather	Dorsal surface; right lateral edge	multiple	Scar	Lateral scar
EXP114/237/01	Cone	Proximal	Right lateral edge	perpendicular to the long axis	Feather	Dorsal surface	single	Scar	Lateral scar
EXP114/237/02	Cone	Proximal	Right lateral edge	perpendicular to the long axis	Feather	Dorsal surface	single	Scar	Lateral scar
EXP114/238/01	Bending	Mesial	Right lateral edge	diagonal towards the base	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/238/02	Bending	Mesial	Right lateral edge	diagonal towards the base	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/238/03	Bending	Mesial	Right lateral edge	diagonal towards the base	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/241/01	Bending	Distal	Apex	apex to base	Step to step	Left lateral edge	single	Break	Bending break
EXP114/241/02	Bending	Distal	Right lateral edge	diagonal towards the apex	Step	Dorsal surface	single	Scar	Lateral scar
EXP114/241/03	Bending	Distal	Right lateral edge	diagonal towards the apex	Step	Dorsal surface	single	Scar	Lateral scar
EXP114/241/04	Bending	Mesial	Right lateral edge	diagonal towards the apex	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/244/01	Bending	Distal	Apex	apex to base	Step	Left lateral edge	single	Break	Bending break
EXP114/245/01	Bending	Mesial	Right lateral edge	diagonal towards the base	Hinge to feather	Right lateral edge; ventral surface	single	Scar	Lateral scar
EXP114/245/02	Bending	Distal	Apex	apex to base	Step	Ventral surface	single	Break	Bending break

Table 5 (continued)

Fracture	Initation	Locus	Location of initiation	General direction	Termination	Location of termination	Composition	Fracture type	Category
EXP114/245/03	Bending	Mesial	Right lateral edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/245/04	Bending	Mesial	Right lateral edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/245/05	Bending	Proximal	Right lateral edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/245/06	Cone	Mesial	Earlier fracture surface	diagonal towards the base	Feather	Ventral surface	multiple	Scar	Secondary damage
EXP114/249/01	Bending	Distal	Right lateral edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/253/01	Bending	Distal	Apex	apex to base	Hinge to step	Ventral surface	single	Break	Bending break
EXP114/274/01	Cone	Mesial	Right lateral edge	perpendicular to the long axis	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/275/01	Bending	Proximal	Dorsal surface	base to apex	Step	Ventral surface	single	Break	Bending break
EXP114/275/02	Bending	Proximal	Ealier Fracture surface	base to apex	Step	Right lateral edge	single	Scar	Secondary damage
EXP114/277/01	Bending	Distal	Apex	apex to base	Feather	Ventral surface	single	Break	Bending break

and quality of the glue that is key or can other factors be identified, such as the raw materials used for the organic point or the presence of a groove? We need to know how the weapon design can be improved to increase the success rates in experiments and permit an adequate understanding of the wear patterns on barbs. It is a condition to understand the morphological variability of possible stone insets on an archaeological level as well as the appearance and evolution of barbed composite weapon designs and how this influenced lithic technological strategies.

We have presented the results of a first experiment that aimed to evaluate several hafting variables and components and improve their understanding leading to a resilient barbed composite weapon system. It provides the first crucial building block in the study of barbed composite weapon systems. We discuss the influence of each variable separately, and reflect on what weapon designs would function best in an experimental context. Rather than producing a resilient standard design for experimental laterally hafted armatures, we aim to provide insight into how design and hafting materials can influence the behaviour of barbed composite weapons so that appropriate designs adapted to specific research questions can be chosen in further research.

The glue used for hafting the barbs proved to have an important influence, as attested during the assembling process. Protein glues, such as bone and fish glues, tend to have a higher viscosity and slower drying than resinous mixtures, making them less easy to handle for hafting, particularly for the purposes described here. Especially in the case of ungrooved organic points, these glues failed to hold the barbs in the right position during drying. Some barbs could be successfully hafted to the organic points, but the whole process proved to be very difficult and inefficient despite a lab context, so it appears unpractical for outdoor. Despite the strength of these glues, in practice they prove less appropriate for lateral hafting systems. Nevertheless, we could note the relevance of a groove as a receptacle for both the glue (especially less viscous ones such as protein glues) and the barbs.

With regard to glue strength, the properties of different glues have been recently tested in single-lap joint situations (Kozowyk et al. 2016; Tydgadt and Rots 2022), but few studies have evaluated the resilience of glues in combination with different hafting designs, which requires separate demonstration. Resinous mixtures have shown little resilience in our mechanical lap shear tests (Tydgadt and Rots 2022) but we suggested that this low resilience was because these glues are meant to be used as mastic or sealant. In this experiment, we observe that the nature of the glue and its viscosity are key to a successful assembling process and a resilient hafting system. Resinous mixtures are more prone to keep a barb in place long enough for the glue to set. Moreover, these glues permit moulding, implying that one can easily smoothen the transition between the stone inset and the organic point so that intrusion into the target is not hindered abruptly. When sufficient additives are mixed in the resin to avoid brittleness, resinous glues prove more successful in keeping the inset in place upon impact than

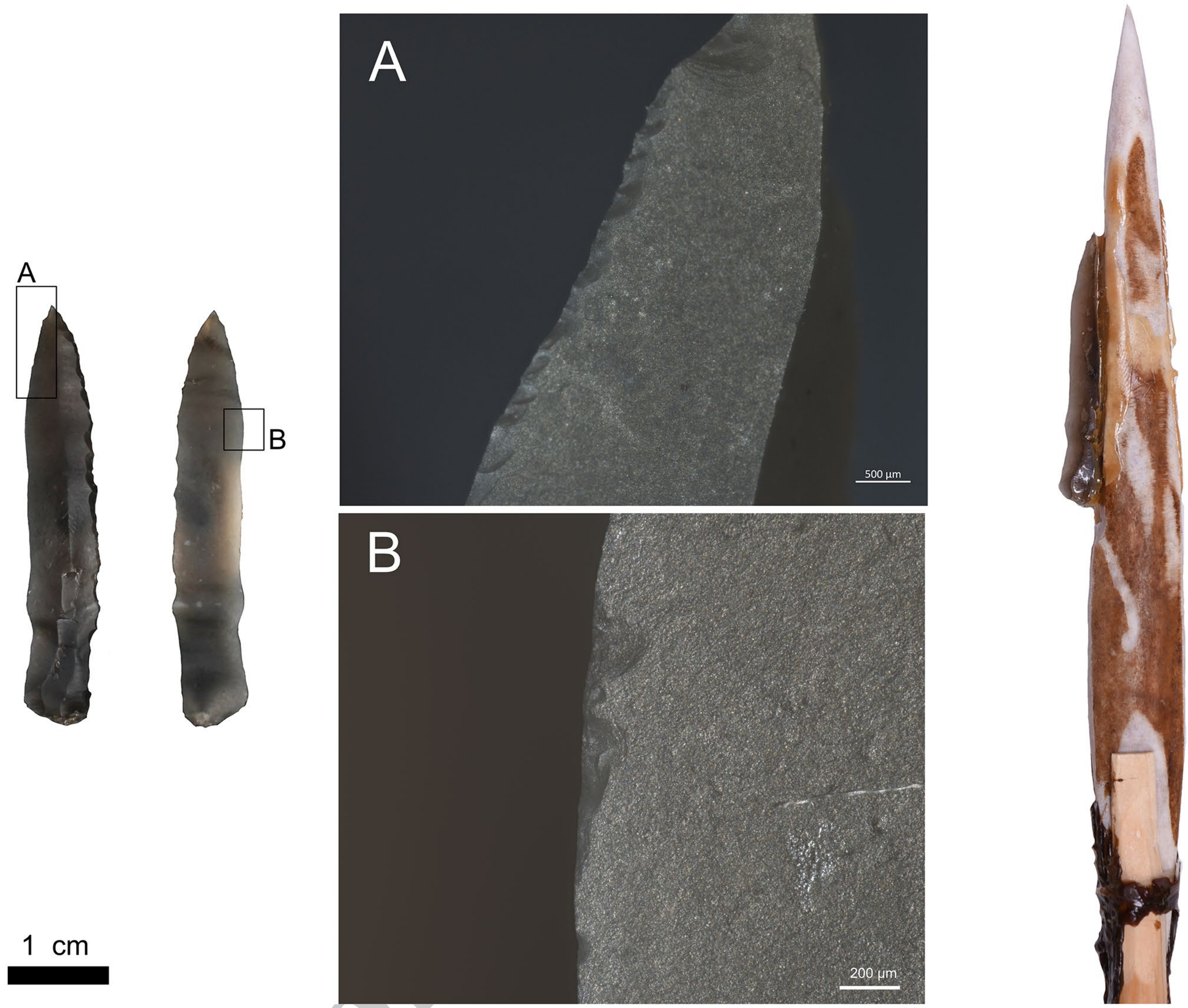

Fig. 8 Use-wear evidence on experimental lateral inset **EXP114-213**: (**A**) multiple obliquely oriented lateral scars on the left edge, cone-initiated and with a feather termination on the dorsal surface; (**B**) multiple obliquely oriented lateral scars on the left edge, bending-initiated, and with feather terminations on the ventral surface

a protein glue, especially when used in combination with a groove. We observed that resinous mixtures with ochre applied to antler points were less successful than resin and beeswax mixtures applied to wooden points even though these combinations showed nearly identical results in a previous mechanical bench test (Tydgadt and Rots 2022). This lack of correspondence shows that these mechanical tests focusing on one variable do not provide results that can be directly transferred to situations in which multiple variables intervene (see Oberholzer and Rots, *submitted*, for a more detailed argument). We can conclude that glue resilience is not the main variable that influences the success of a barbed composite weapon, but that attention needs to be devoted to the viscosity of the glue, the combination with other hafting materials, and the hafting design itself.

Both grooved and ungrooved organic points have been recovered archaeologically, raising the question about the role and importance of these grooves for the success and performance of the hafting design. In a previous study (Pétillon et al. 2011), researchers have argued that grooves function more as a gutter for glue than as an actual slot for barbs and that it only slightly helped assembling their experimental points. Here we observed that the presence of a groove is one of the most influential variables, independent of glue type and organic point material. We found that a groove greatly facilitates the hafting process and that grooved composite points led to more successful shots than ungrooved examples. As mentioned earlier, organic evidence indicates that grooves on points in hard animal material have been in use at least since the Gravettian, and it is assumed that

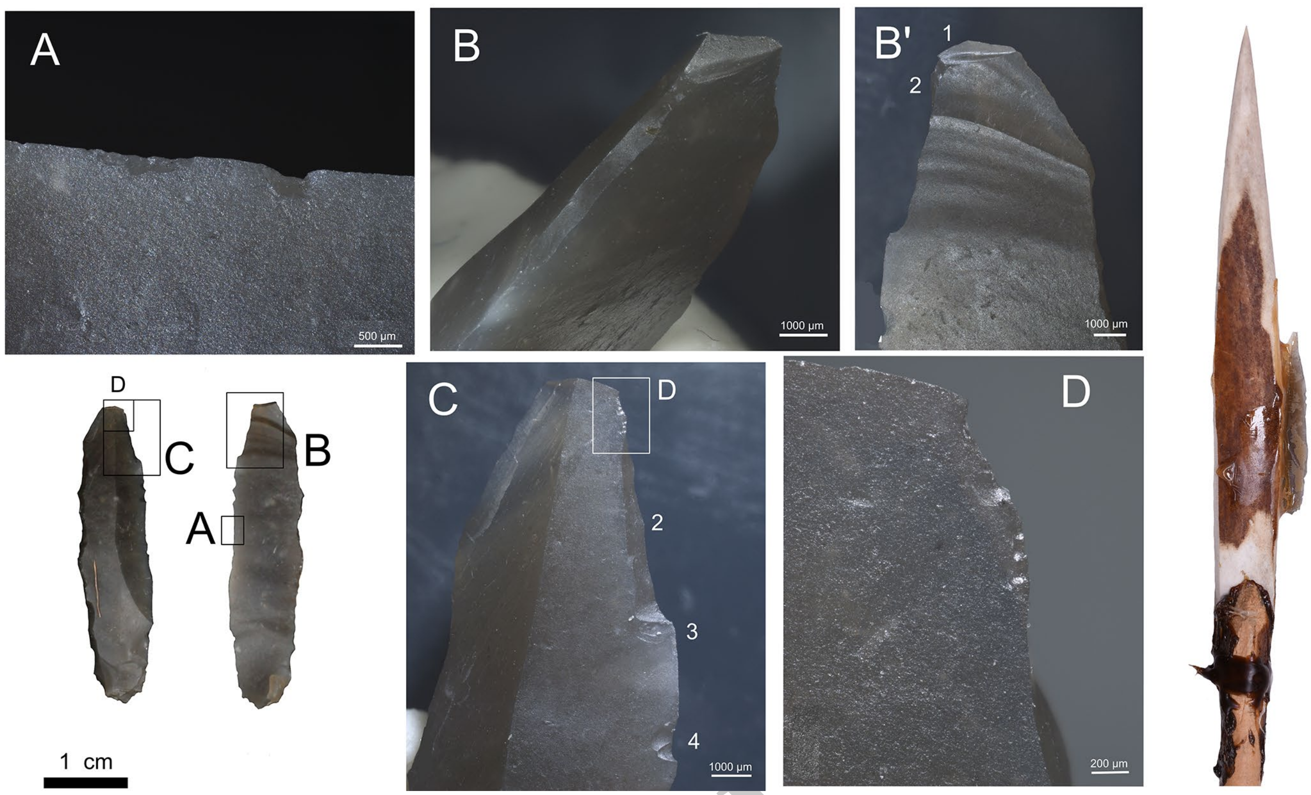

Fig. 9 Use-wear evidence on experimental barb **EXP114-215**: (**A**) Multiple obliquely oriented scars, bending-initiated and feather-terminating (**B** and **B'**) wear pattern with different damage locations with (B-1) bending-initiated break of the apex that propagates on the ventral surface towards the base (see also detail in **C**); (B'-2) bending-initiated secondary scar; it is initiated from the preceding bending break on the ventral surface, and terminates in step on the dorsal surface ("burination"); (-2) Secondary scar initiated in bending from the preceding secondary scar, and terminating in a step to step (C-3). Patch of bending initiated multiple scars with an oblique orientation and feather termination (C-4). (**D**) Multiple obliquely oriented secondary scars, cone-initiated from the edge of the propagation of the first secondary scar

grooves were carved to facilitate the mounting of insets even though a sufficiently well-preserved complete barbed composite point was not yet found to prove it (Goutas 2016; Tomasso et al. 2018). Grooved points are more frequent in the Magdalenian, but archaeological evidence also indicates that bladelets were laterally hafted to ungrooved antler points (Langley et al. 2016; Leroi-Gourhan and Allain 1979). We found that grooves are not essential to a successful shot, but they improve the resilience of laterally armed projectiles over repeated uses. As a result, the absence of a groove in organic points in certain archaeological contexts cannot be used to assume an absence of barbs, especially considering that also other fixing systems could be imagined, involving for instance the use of bindings (Nuzhnyi 2000; Yaroshevich et al. 2010). Grooved organic points may however represent a technical improvement in weapon design, depending on the use context, or reduce the pressure on how carefully the barbs are prepared (i.e., morphology). Such factors (in addition to cultural choice or preference) need to be considered when studying the evolution of lateral weapon systems.

The raw material the organic point is made from does not prove to have an indisputable influence on success rates. Wood has higher success rates, but this is because of the excellent performance of EXP114/235. The above-average success of this particular point is attributed more to its overall design than to the materials used (see below). Therefore, the choice of either wood or osseous materials to manufacture points does not appear to be an essential factor in weapon design and performance. One may assume that this choice relates more to procurement issues, production preferences and challenges, issues of maintainability, or cultural choice. Future experimental and/or ethnographic studies could perhaps contribute more comparative data on the performance of these organic materials.

By contrast, our experiments indicate that weapon design and barb morphology are crucial factors for the successful penetration and reuse of a barbed composite weapon. EXP114/235 played a key role in these insights as it outperformed all other projectiles regarding resilience and penetration. The projectile had a grooved wooden point in which the barb was secured with bone glue, which did not perform well otherwise. The excellent performance of point

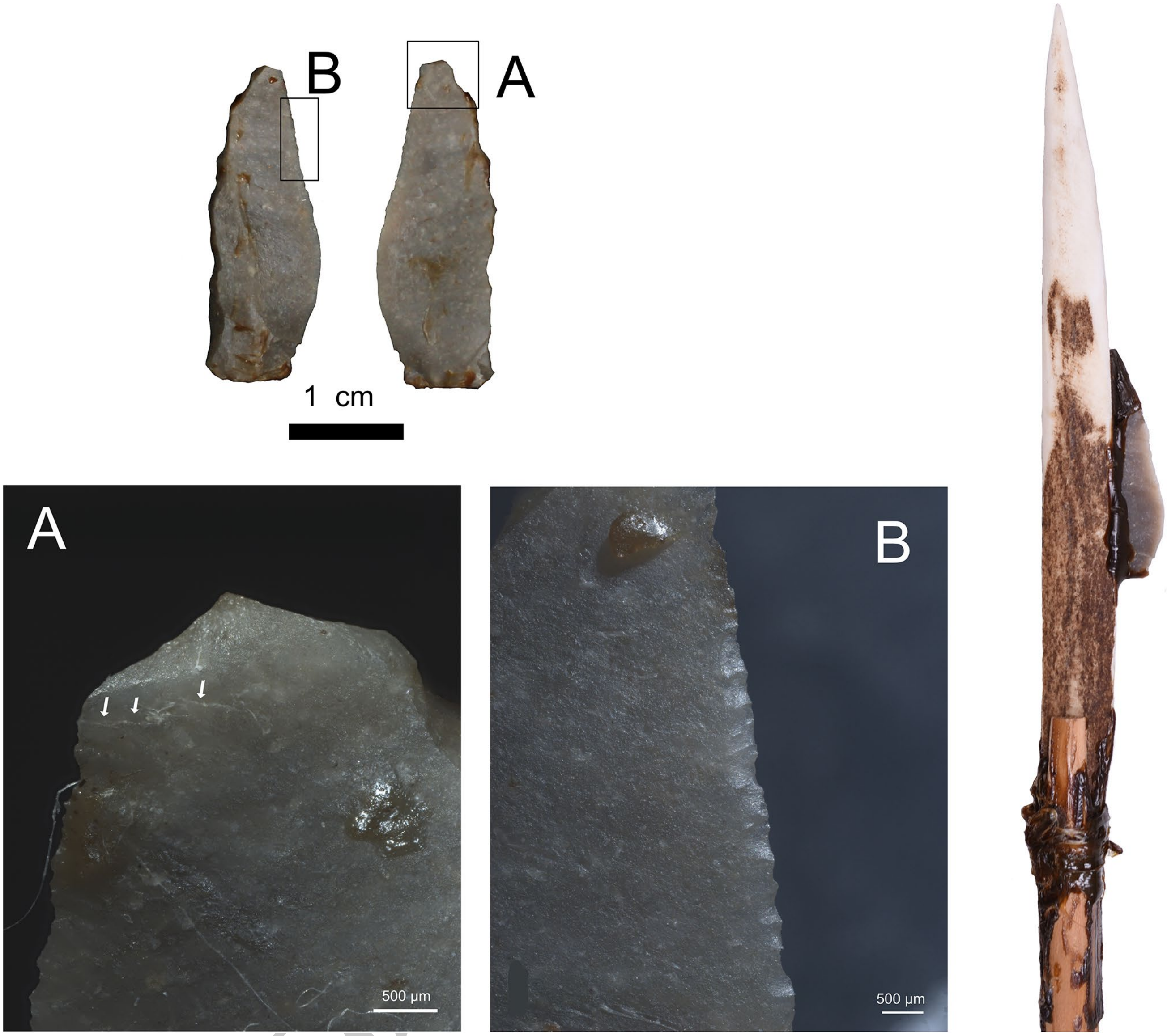

Fig. 10 Use-wear evidence on experimental lateral inset **EXP114-230**: (**A**) bending-initiated step-terminating axial break of the apex; (**B**) multiple obliquely oriented bending-initiated scars

EXP114/235 can be explained by the hafting design and the morphological details of the barb. The slightly curved retouched back of the barbs did not always allow a seamless fit in the groove and a small space sometimes remained between the tip of the inset and the organic point which created the risk of it getting stuck on the hide upon impact and being torn away from the organic point. A similar problem may arise if the base of the stone inset faces the tip of the point. The solution is to shape the glue as such that it fills these spaces and creates a seamless transition between the barb and the organic point. Resinous mixtures have proven to lend themselves best to such an application. In the case of EXP114/235, a smooth transition could be created with bone glue, despite its liquid nature, which is unusual. A perfect design combined with the very resilient bone glue resulted in the maximum number of successful shots and no detachments. Also other points presenting a smooth transition (most often with resin mixtures) regularly penetrated more than 10 cm and were shot multiple times. In a few rare cases, points with an abrupt transition did penetrate well, but those could only be shot once as they detached inside the target.

We may thus conclude that the interaction between the organic point design (with or without groove), the careful shaping of the barbs, and the glue used – particularly its quality to permit creating smooth transitions, are the key components of successful barbed composite weapon designs (Fig. 13). The materials used are secondary to how carefully

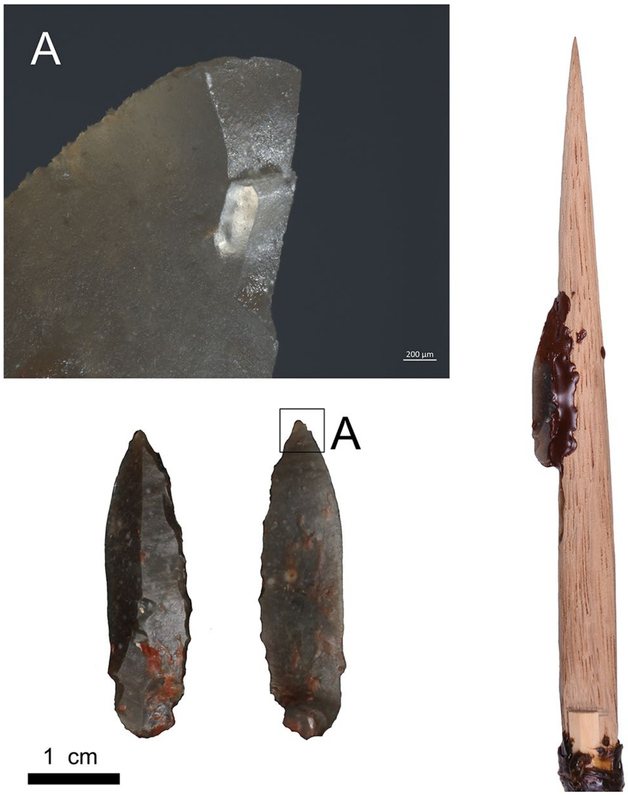

Fig. 11 Use-wear evidence on experimental barb **EXP114-241**: (**A**) Bending-initiated break starting from the retouched apex to the sharp edge with a step-to-step termination

these materials are combined within a design, which requires experience and know-how. Significant investment in the careful preparation of barbs has been documented archaeologically with a lot of attention often devoted to the preparation of the back (Tomasso et al. 2018). Our experiment shows why this investment is so important and conditions the weapon's success. Within this perspective, backing has multiple advantages: it facilitates hafting, it reinforces the bond when the morphology is adapted to the design of the organic point, it may create standardised morphologies, and it increases the surface area that is in contact with the glue and the shaft or point. Viewed in this light, an improvement of the success rate of barbed composite weapon designs starts by carefully backing the barbs. This result sharply contrasts with the significant attention that has lately been devoted to how glue compositions can be made more resilient, this proving to be a secondary variable to the weapon's success, after variables related to morphology and design.

Several morphological aspects of barbed composite weapon designs were not yet explored in this experiment, and not all variables could already be isolated and tested with large samples, because the general lateral weapon design had to be obtained first. Among the variables that need to be explored in future experiments are the distance between the barb and the tip of the organic point or the use of multiple barbs on a single point. Only one barb morphology was tested here and the overall shape of a stone inset, beyond its retouched back, can influence its most suitable position on the organic point, orientation (apex towards the projectile's point, or the contrary) and hafting angle, both when hafted as a single inset or in a row (including its position therein). These factors will also determine what role the barbs play in the weapon's behaviour upon impact (detachment, enhanced penetration, creation of a larger but shallow wound, etc.).

There are ethnographic examples of composite weapons where this careful preparation of all components, particularly the barbs, seems less important, such as for the death spears from aboriginal people in Australia. In the latter, several irregular pieces (stone or glass) are mounted with gum on a grooved or ungrooved shaft and little attention appears to be given to their morphology (Davidson 1934; Smyth, 1878; Worsnop 1897). Such barbs have a high chance of detaching upon impact, but their high number on one shaft or point counterbalances this loss, especially when also considering the damage that the detached barbs may cause within the animal. Barb quantity thus compensates for the limited investment in barb manufacture, making death spears attractive in a different way. A similar case was made for the Howiesons Poort of Sibhudu Cave, where both retouched and unretouched quartz pieces of varying morphologies were interpreted as barbs (de la Peña et al. 2018). It has been hypothesised for this weapon design that the detachment of barbs within the target may have been an anticipated characteristic, which allows for more variation in barb shape.

To further explore the importance of weapon design, also the depth of penetration needs to be considered, as it is often used as proof of efficiency in shooting experiments (rather than resilience) (Gaillard et al. 2016; Pétillon et al. 2011; Stodiek 2000). The argument is based on the theorised lethal depth that is needed to reach vital organs and to cause critical damage to the hunted prey. A 15 cm deep wound would be sufficient to incapacitate the hunted game quickly (Friis-Hansen 1990; Wood and Fitzhugh 2018), but this depends on the nature of the target, the shooter's angle, the position of the hunted animal, amongst other variables. In our experiments, we observed that for a given point with multiple successful shots, the penetration depths remained similar between shots. This reaffirms the crucial nature of the weapon design. We observed no causality between contact with bone and a more limited penetration depth. Several shots were shallow while they did not involve contact with bone. On the other hand, some deeper penetrations occurred despite bone contact: instead of being stopped due to contact with bone, the projectiles tended to deviate and continue

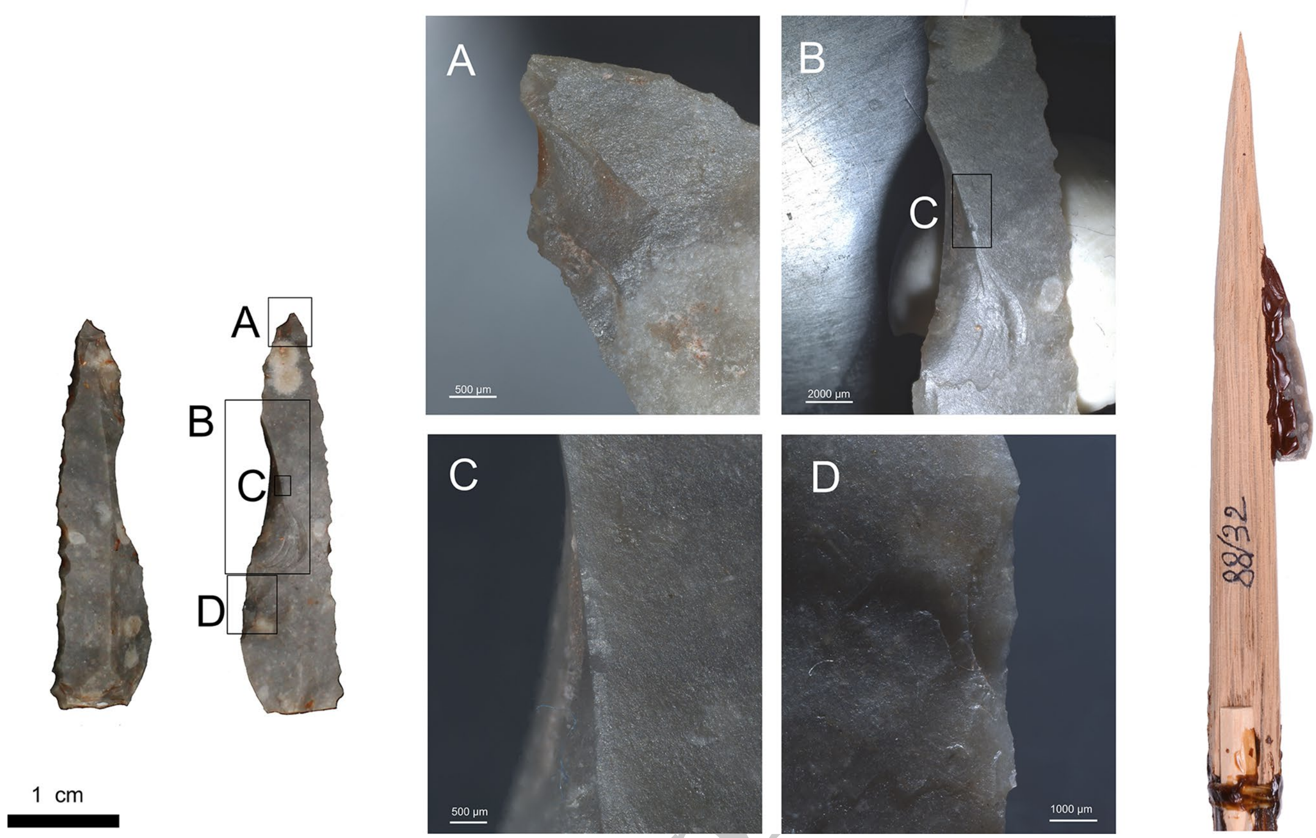

Fig. 12 Use-wear evidence on experimental barb **EXP114-245**: (**A**) Axial break initiated in bending from the apex with a long propagation and a step termination; (**B**) Very large, twisted scar initiated in bending on the dorsal surface and terminating in step on the ventral surface; (**C**) Multiple oriented secondary scars with cone initiations on the propagation of the preceding scar; (**D**) Obliquely oriented bending-initiated scar with a step termination

further inside the target, for as far as the energy permitted. Only when points hit a bone head-on, they could get stuck in the bone matter and have their penetration interrupted.

Pétillon et al. (2011) suggested that the presence of barbs determined the penetration depth and not the shooter, the point's mass or point type. Points that had kept the most barbs on their shafts obtained the deepest penetration. We found that deeper penetrations correspond with the more resilient hafting designs. In our experiments, resinous mixtures were associated with the deepest penetrations, followed by systems secured with fish glue. EXP114/235 showed similar results (c.20 cm), which can again be attributed to the sturdiness of its morphology. As mentioned previously, we also found that penetration depth is favoured when the transition between the point and the barb is smooth and does not include step-like features that may get caught in the hide. Careful hafting design with seamless transitions prove to be key to the success of the projectile and resin mixtures prove to facilitate this.

Wear traces on our experimental pieces are numerically limited, and the experiment therefore does not yet provide a sufficiently complete and representative reference base for concluding on the diagnostic trace patterns on barbs. Also the possible influence of taphonomic processes or overlap with other uses still need to be studied in-depth. Yet, an intriguing feature concerns the secondary scars found on a large, obliquely oriented, twisted lateral scar (EXP114/245, Fig. 4) that was not yet reported in any other instance and that appears very diagnostic for barbs. Other wear evidence was already considered relevant previously for the identification of apically hafted projectile elements, such as the important proportion of oriented lateral and secondary scars, and bending-initiated breaks, often terminating in a step, sometimes on an edge. Variation in wear phenomena may of course occur for other barb morphologies following differences in contact. Also the use of multiple barbs may influence, for instance, analysts have documented traces on the retouched hafted backs of barbs when hafted in a row (Moss and Newcomer 1982). Borgia (2008) observed linear microscopic polish that developed perpendicularly to the axis of her experimental barbs, which she interpreted as being the result of the hafting procedure. No such traces were observed in our experiment.

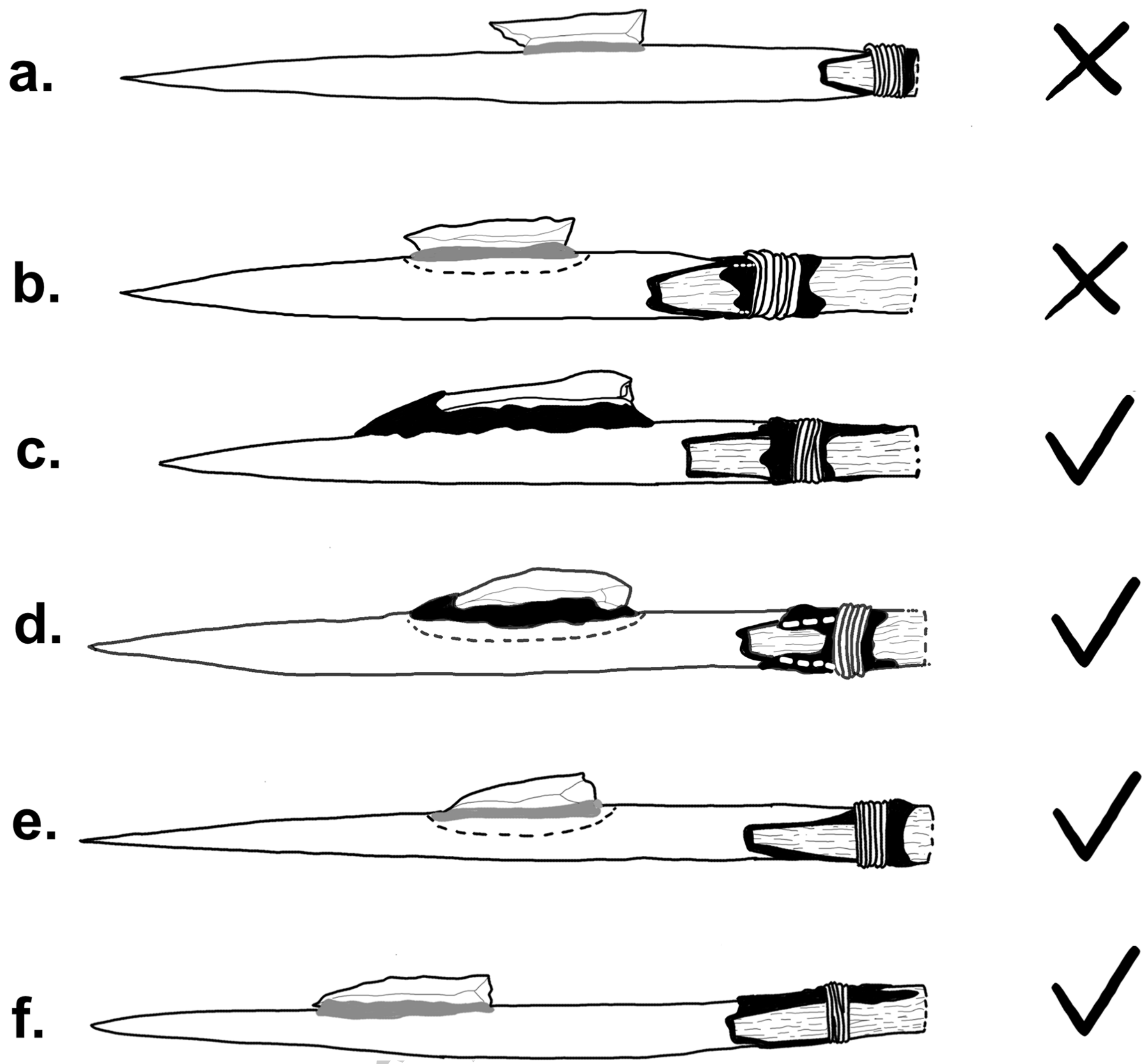

Fig. 13 Examples of different hafting designs for barbed composite weapons. (**a**) Inset secured to the ungrooved point with a protein glue, showing an abrupt transition. (**b**) Inset secured to the grooved point with protein glue, showing an abrupt transition. (**c**) Inset secured to the ungrooved point with a resin mixture, molded to create a smooth transition. (**d**) Inset secured to the grooved point with a resin mixture molded to create a smooth transition. (**e**) Inset secured to the grooved point with protein glue. The morphology of the inset fit into the groove to create a seamless transition. (**f**) Inset secured to the grooved point with protein glue. The backing and morphology of the inset allowed a seamless transition. Designs that show a smooth transition between the inset and the point, with the help of resinous mastics or not, prove to be more successful than designs with more abrupt transitions. The presence of a groove facilitates the assembling process and improves the resilience of the inset, but it is not essential to the success of the weapon (Drawings: L.T.)

A detailed understanding of the trace patterning on barbs requires continued experiments and microscopic analyses so that larger sample sizes can be obtained. In experiments, the resilience of hafting designs has to be improved upon so that detachments can be minimalised and multiple shots become more frequent. In microscopic analysis, recording systems must be further adapted to barbs and diagnostic patterns must be further identified. Given the important variation in possible hafting designs (and propulsion modes), a robust and large-scale experimental program is a prerequisite to understanding the wear patterns and contributing to the broader study of the appearance and evolution of barbed composite weapon systems.

Conclusion

Laterally hafted composite weapon designs that combine an organic point with a laterally hafted lithic inset are still poorly understood. We aimed to explore the influence of different choices of hafting materials and arrangements on the behaviour, penetration and resilience of barbed composite weapons. Previous experiments with barbs have highlighted the difficulty of securely hafting them to guarantee successful penetration of the target, which is a precondition for understanding the damage patterning. To improve our understanding of barbed composite weapon designs and their archaeological recognition, we thus need to improve the resilience of experimental barbed composite weapons that serve as a reference for archaeological interpretations. More resilient weapons will increase the chances of damage formation on the barbs and will permit to definition of what wear pattern is diagnostic for barbs so that these can also be reliably recognised archaeologically. We highlighted that the choice of hafting materials is important, but that the shaping and careful hafting of the barbs is all the more vital for the successful penetration of a weapon into a target. Our results re-attribute importance to the whole hafted tool concept instead of a focus that lies too much on the qualities of its constituents. Weapons are designed to effectively enter an animal target and the resilience of an individual component, such as a glue, is important, but not the most fundamental element in the design. Both protein glues and resinous sealants prove to be effective and resilient if used in combination with carefully prepared and hafted lithic barbs and a grooved organic point. On non-grooved organic points, resinous mixtures have the upper hand because they can be moulded and shaped and therefore offer a more plastic and adaptable hafting. The smooth transitions between the organic point and the barb indeed proves a crucial element in the weapon's success. While further, more extensive experiments are still needed, we postulate that the presence of a groove or a particularly strong adhesive is an advantage to the resilience of the system, but not a necessity, as long as the morphological requirements of the weapon design are respected and permit the projectile to enter a target without resistance from the projectile itself. The wear traces are limited in number but some diagnostic features could be proposed, while an in-depth understanding of the wear patterning on barbs requires further experimenting and analysis. Our results indicate that carefully hafted weapon designs are the key to successful experiments with barbs and continued investigations will permit to lay a solid foundation for understanding the appearance and evolution of composite weapon designs in the Palaeolithic.

Acknowledgements This research was funded by the University of Liège and by the Fund for Scientific Research (FRS-FNRS; PDR). We thank members of TraceoLab for their help and advice during the experiments, in particular, Christian Lepers who produced all the experimental samples and Justin Coppe who shot the projectiles and helped with manufacturing the target.

Author contributions L.T. conducted the experiments under the supervision of V.R. and proceeded to the analysis of the experimental material. L.T. wrote the main manuscript text and prepared all the figures. V.R. contributed to and reviewed the manuscript and the figures.

Data availability Data is provided within the manuscript.

Declarations

Competing interests The authors declare no competing interests.

References

Albarello B (1986) Sur l'usage des microlithes comme armatures de projectiles / the use of microliths to frame projectile. Revue archéologique du Cent re 25:127–143. https://doi.org/10.3406/racf.1986.2491

Albrecht G (1977) Testing of materials as used for bone points of the Upper Palaeolithic, in: Méthodologie Appliquée à l'industrie de l'os Préhistorique: Deuxième Colloque International Sur l'industrie de l'os Dans La Préhistoire, Abbaye de Sénanque (Vaucluse) 9–12 Juin 1976. Paris, pp. 119–124

Ambrose SH (1998) Chronology of the later stone age and food production in East Africa. J Archaeol Sci 25:377–392. https://doi.org/10.1006/jasc.1997.0277

Attenbrow V, Robertson G, Hiscock P (2009) The changing abundance of backed artefacts in south-eastern Australia: a response to Holocene climate change? J Archaeol Sci 36:2765–2770. https://doi.org/10.1016/j.jas.2009.08.018

Barham L (2013) From Hand to handle: the First Industrial Revolution. Oxf Uni ed Choice Reviews Online. https://doi.org/10.5860/choice.51-6829. Oxford

Barton RNE, Bergman CA (1982) Hunters at Hengistbury: some evidence from experimental archaeology. World Archaeol 14:237–248. https://doi.org/10.1080/00438243.1982.9979864

Bleed P (1986) The Optimal Design of Hunting weapons: maintainability or reliability. Am Antiq 51:737–747

Bleed P (2002) Cheap, regular, and Reliable: implications of design variation in late pleistocene Japanese Microblade Technology. Archaeol Pap Am Anthropol Assoc 12:95–102. https://doi.org/10.1525/ap3a.2002.12.1.95

Borgia V (2008) Le Gravettien Ancien dans le sud de l'Italie: Analyse fonctionnelle de pointe à dos de Grotta Paglicci (Foggia) et de Grotta della Cala (Salerno). Rev. Francoph. en Préhistoire 1–22

Broglio A, Bertola S, De Stefani M, Marini D, Lemorini C, Rossetti P (2005) La production lamellaire et les armatures lamellaires de l'Aurignacien ancien de la Grotte de Fumane (Monts Lessini, Vénétie). Prod. lamellaires Attrib. à l'Aurignacien chaînes opératoires Perspect. technoculturelles, XIVe Congrès l'UISPP, Liège 2–8 Sept. 2001 415–436

Chesnaux L (2008) Sauveterrian Microliths: evidence of the Hunting weapons of the last Hunter-gatherers of the Northern Alps. Paleoethnologie 1:133–146

Chesnaux L (2014) Réflexion sur le microlithisme en France au cours du Premier Mésolithique Xè-VIIIè millénaire avant J. -C.: approche technologique, expérimentale et fonctionnelle. Université Paris 1 Panthéon-Sorbonne

Coppe J, Lepers C, Clarenne V, Delaunois E, Pirlot M, Rots V (2019) Ballistic Study Tackles Kinetic Energy Values of Palaeolithic Weaponry. Archaeometry 61:933–956. https://doi.org/10.1111/arcm.12452

Coppe J, Lepers C, Rots V (2022) Projectiles under a New Angle: a ballistic analysis provides an important building block to Grasp Paleolithic Weapon Technology. J Archaeol Method Theory 29:1131–1157. https://doi.org/10.1007/s10816-022-09551-z

Coppe J, Rots V (2017) Focus on the target. The importance of a transparent fracture terminology for understanding projectile points

and projecting modes. J Archaeol Sci Rep 12:109–123. https://doi.org/10.1016/j.jasrep.2017.01.010
Crombé P, Perdaen Y, Sergant J, Caspar JP (2001) Wear analysis on early mesolithic microliths from the verrebroek site, east flanders, Belgium. Int J Phytorem 21:253–269. https://doi.org/10.1179/jfa.2001.28.3-4.253
Davidson DS (1934) Australian Spear-traits and their derivations. J Polyn Soc 43:143–162
de la Peña P, Taipale N, Wadley L, Rots V (2018) A techno-functional perspective on quartz micro-notches in Sibudu's Howiesons Poort indicates the use of barbs in hunting technology. J Archaeol Sci 93:166–195. https://doi.org/10.1016/j.jas.2018.03.001
Ducasse S, Renard C, Pétillon J-M, Costamagno S, Foucher P, San Juan C, Caux S (2017) Les Pyrénées Au cours Du Dernier Maximum Glaciaire. Un no man's land badegoulien? Nouvelles données sur l'occupation du piémont pyrénéen à Partir Du réexamen Des industries solutréennes de l'abri des harpons (Lespugue, Haute-Garonne). Bull De La Société préhistorique française. https://doi.org/10.3406/bspf.2017.14773
Elston RG, Brantingham PJ (2002) Microlithic Technology in Northern Asia: a risk-minimizing strategy of the late paleolithic and early holocene. Archaeol Pap Am Anthropol Assoc 12:103–116. https://doi.org/10.1525/ap3a.2002.12.1.103
Elston RG, Kuhn SL (2002) Thinking Small: Global Perspectives on Microlithization, Archaeolog. ed. Arlignton
Falcucci A, Peresani M (2018) Protoaurignacian Core reduction procedures: Blade and Bladelet Technologies at Fumane Cave. Lithic Technol 43:125–140. https://doi.org/10.1080/01977261.2018.1439681
Falcucci A, Peresani M, Roussel M, Normand C, Soressi M (2018) What's the point? Retouched bladelet variability in the Protoaurignacian. Results from Fumane, Isturitz, and Les Cottés. Archaeol Anthropol Sci 10:539–554. https://doi.org/10.1007/s12520-016-0365-5
Fischer A, Hansen PV, Rasmussen P (1984) Macro and Micro wear traces on lithic Projectile points. J Dan Archaeol 3:19–46. https://doi.org/10.1080/0108464x.1984.10589910
Friis-Hansen J (1990) Mesolithic cutting arrows: functional analysis of arrows used in the hunting of large game. Antiquity 64:494–504
Gaillard Y, Chesnaux L, Girard M, Burr A, Darque-Ceretti E, Felder E, Mazuy A, Regert M (2016) Assessing Hafting Adhesive Efficiency in the experimental shooting of Projectile points: a new device for instrumented and ballistic experiments. Archaeometry 58:465–483. https://doi.org/10.1111/arcm.12175
Gauvrit Roux E, Cattin MI, Yahemdi I, Beyries S (2020) Reconstructing Magdalenian hunting equipment through experimentation and functional analysis of backed bladelets. Quat Int 554:107–127. https://doi.org/10.1016/j.quaint.2020.06.038
Gibson NE, Wadley L, Williamson BS (2004) Microscopic residues as evidence of hafting on backed tools from the 60 000 to 68 000 Howeisons Poort layers of Rose Cottage Cave, South Africa. South Afr Humanit 16:1–11
Goldstein ST, Shaffer CM (2017) Experimental and archaeological investigations of backed microlith function among Mid-to-late Holocene herders in southwestern Kenya. Archaeol Anthropol Sci 9:1767–1788. https://doi.org/10.1007/s12520-016-0329-9
Goutas N (2016) Gravettian Projectile points: considerations about the evolution of Osseous Hunting weapons in France. In: Langley M (ed) Osseous Projectile Weaponry: towards an understanding of Pleistocene Cultural Variability. Springer, pp 89–107. https://doi.org/10.1007/978-94-024-0899-7
Kozowyk P, Langejans GHJ, Poulis JA (2016) Lap shear and impact testing of ochre and beeswax in experimental Middle Stone Age compound adhesives. PLoS ONE 11. https://doi.org/10.1371/journal.pone.0150436
Kozowyk P, Poulis JA (2019) Reconstructing adhesives: an experimental approach to organic palaeolithic technology issue. J Hum Evol 20:i1–i1. https://doi.org/10.1093/envhis/emv038
Kozowyk P, Poulis JA, Langejans G (2017a) Laboratory strength testing of pine wood and birch bark adhesives: a first study of the material properties of pitch. J Archaeol Sci Rep 13:49–59. https://doi.org/10.1016/j.jasrep.2017.03.006
Kozowyk P, Soressi M, Pomstra D, Langejans G (2017b) Experimental methods for the palaeolithic dry distillation of birch bark: implications for the origin and development of neandertal adhesive technology. Sci Rep 7:1–9. https://doi.org/10.1038/s41598-017-08106-7
Langley MC, Delage C (2018) New antler, shell, and tooth technology from La Grotte Du Placard (commune de Vilhonneur, Charente). Grotte Du Placard 150 New considerations an except. Prehist Site 112–123. https://doi.org/10.2307/j.ctv1nzfwcf.16
Langley MC, Pétillon JM, Christensen M (2016) Diversity and evolution of osseous hunting equipment during the Magdalenian (21,000–14,000 cal BP). Vertebr Paleobiol Paleoanthropology 143–159. https://doi.org/10.1007/978-94-024-0899-7_10
Lepers C, Rots V (2020) The important role of bow choice and arrow fletching in projectile experimentation. A ballistic approach. J Archaeol Sci Rep 34:102613. https://doi.org/10.1016/j.jasrep.2020.102613
Leroi-Gourhan A (1983) Une tête De Sagaie à armature de lamelles de silex à Pincevent (Seine-et-Marne). Bull La Société préhistorique française 80:154–156. https://doi.org/10.3406/bspf.1983.5435
Leroi-Gourhan A, Allain J (1979) Lascaux Inconnu, editions D. ed. Editions du Centre National de la Recherche Scientifique, Paris
Lombard M (2011) Quartz-tipped arrows older than 60 ka: further use-trace evidence from Sibudu, KwaZulu-Natal, South Africa. J Archaeol Sci 38(8):1918–1930. https://doi.org/10.1016/j.jas.2011.04.001
Lombard M, Pargeter J (2008) Hunting with Howiesons Poort segments: pilot experimental study and the functional interpretation of archaeological tools. J Archaeol Sci 35:2523–2531. https://doi.org/10.1016/j.jas.2008.04.004
Lombard M, Parsons I, Lombard M, Parsons I (2020) South African Archaeological Society Blade and Bladelet function and variability in Risk Management during the last 2000 years in the Northern Cape Linked references are available on JSTOR for this article: BLADE AND BLADELET FUNCTION AN MANAGEMENT DURIN. South African Archaeol. Bull 63:18–27
Mcbrearty S, Bishop L, Plummer T, Dewar R, Conard NJ (1998) Tools underfoot: human trampling as an agent of lithic artifact edge modification. Am Archaeol 63(1):108–129
Moss EH (1983) The functional analysis of Flint implements: Pincevent and Pont d'Ambon - two case studies from the French Final Palaeolithic. BAR Publishing, Oxford
Moss EH, Newcomer MH (1982) Reconstruction of Tool Use at Pincevent: Microwear and Experiments, in: Cahen, D. (Ed.), Tailler! Pour Quoi Faire: Préhistoire et Technologie Lithique II. Recent Progress in Microwear Studies. Tervuren, pp. 289–312
Movius HL, A Wooden Spear of Third Interglacial Age from Lower Saxony Author (s):, Movius HL Jr (1950). Source: Southwestern Journal of Anthropology, Vol. 6, No. 2 (Summer, 1950), pp. 139–142 Published by: University of New Mexico Stable URL: http://.Southwest.J.Anthropol. 6, 139–142
Normand C, O'Farell M, Garaizar JR (2008) Quelle(s) utilisation(s) pour les productions lamellaires de l'aurignacien archaïque? Quelques données et réflexions à partir des exemplaires de la grotte d'Isturitz (Pyrénées-Atlantiques; France), in: Recherches Sur Les Armatures de Prokectiles Du Paléolithique Supérieur Au Néolothique (Actes Du Colloque C83, XVe Congrès de l'UISPP, Lisbonne, 4–9 Septembre 2006). pp. 4–9

Nuzhnyi D (1990) Projectile damage on upper paleolithic microliths and the use of bow and arrow among pleistocene hunters in the Ukraine, in: The Interpretative Possibilities of Microwear Studies. Proceedings of the International Conference on Lithic Use-Wear Analys 15-17th February 1989 in Uppsala, Sweden

Nuzhnyi D (2000) Development of Microlithic Projectile Weapons in the Stone Age. La Chass. dans la Préhistoire 95–101

Oakley K.P., Andrews P, Keeley LH, Desmond JC (1977) A reappraisal of the Clacton Spearpoint. Proc Prehist Soc 43:13–30. https://doi.org/10.1017/S0079497X00010343

Odell GH, Cowan F (1986) Experiments with spears and arrows on animal targets. J Field Archaeol 13(2):195–212

Osipowicz G (2005) A method of Wood Tar Production, without the use of ceramics. EuroREA 2:11–17

Osipowicz G, Orłowska J, Bosiak M, Manninen MA, Targowski P, Sobieraj J (2020) Slotted bone point from Tłokowo– rewritten story of a unique artefact from Mesolithic Poland. Prahistorische Z 95:334–349. https://doi.org/10.1515/pz-2020-0023

Pargeter J (2011) Assessing the macrofracture method for identifying Stone Age hunting weaponry. J Archaeol Sci 38(11):2882–2888. https://doi.org/10.1016/j.jas.2011.04.018

Pargeter J, Chen C, Buchanan B, Fisch M, Bebber M, Eren MI (2022) Stone tool backing and adhesion in hunting weaponry: first results of an experimental program. J Archaeol Sci Rep 45:103639. https://doi.org/10.1016/j.jasrep.2022.103639

Pasquini A (2013) Les traces de notre passé européen. Le Protoaurignacien Au début Du Paléolithique supérieur. l'éclairage de la tracéologie

Pétillon J-M (2008) What are these barbs for? Preliminary study on the function of the Upper Magdalenian Barbed Weapon Tips. Paleoethnologie 1:66–97

Pétillon JM, Bignon O, Bodu P, Cattelain P, Debout G, Langlais M, Laroulandie V, Plisson H, Valentin B (2011) Hard core and cutting edge: experimental manufacture and use of Magdalenian composite projectile tips. J Archaeol Sci 38:1266–1283. https://doi.org/10.1016/j.jas.2011.01.002

Philibert S (2002) Les Derniers Sauvages. Territoires économiques et systèmes techno-fonctionnels mésolithiques

Pignat G, Plisson H (2000) Le quartz, pour quel usage? L'outillage mésolithique de Vionnaz (CH) et l'apport de la tracéologie. In: Crotti P (ed) Actes de la table ronde "Epipaléolithique et Mésolithique" Lausanne 21–23 novembre 1997. Cahiers d'archéologie Romande, pp 65–78

Prost D (1988) Essai d'étude sur les mécanismes d'enlèvement produits pas les façons agricoles et le piétinement humain sur des silex expérimentaux. In: Beyries S (ed) Industries lithiques, Tracéologie et Technologie, volume 2: aspects méthodologiques. BAR Publishing, pp 40–63

Robertson G (2011) Aboriginal use of backed artefacts at Lapstone Creek rock-shelter, New South Wales: an integrated residue and use-wear analysis. Tech Rep Aust Museum Online 23:83–101. https://doi.org/10.3853/j.1835-4211.23.2011.1572

Rots V (2013) Insights into early middle palaeolithic tool use and hafting in Western Europe. The functional analysis of level IIa of the early Middle Palaeolithic site of Biache-Saint-Vaast (France). J Archaeol Sci 40:497–506

Rots V (2016) Projectiles and hafting technology. In: Iovita R, Sano K (eds) Multidisciplinary approaches to the study of Stone Age Weaponry. Springer, pp 167–185. https://doi.org/10.1007/978-94-017-7602-8_12

Rots V, Plisson H (2014) Projectiles and the abuse of the use-wear method in a search for impact. J Archaeol Sci 48:154–165

Schmidt P, Blessing MA, Koch TJ, Nickel KG (2021) On the performance of birch tar made with different techniques. Herit Sci 9:1–9. https://doi.org/10.1186/s40494-021-00621-1

Smyth RB 1878. The aborigines of Victoria. Trübner and Co. and George Robertson, London

Stodiek U (2000) Preliminary results of an experimental investigation of Magdalenian Antler points. Anthropol Praehist 111:70–78

Taipale N, Rots V (2019) Breakage, scarring, scratches and explosions: understanding impact trace formation on quartz. Archaeol Anthropol Sci 11(6):3013–3039. https://doi.org/10.1007/s12520-018-0738-z

Taipale N, Lepers C, Rots V (2023) Blind-testing the quartz microwear method. In: Apel J, Sundström L (eds) Stones. Current stone-age research in northern europe, pp 116–130

Tartar É (2015a) Origin and development of Aurignacian Osseous Technology in Western Europe: a review of current knowledge. Palethnologie 35–55. https://doi.org/10.4000/palethnologie.706

Tartar É (2015b) Origine et développement de la technologie osseuse aurignacienne en Europe occidentale: bilan des connaissances actuelles, in: White, R., Bourrillon, R., Bon, F. (Eds.), Aurignacian Genius: Art, Technologie et Société Des Premiers Hommes Modernes En Europe, Actes Du Symposium International, 8–10 Avril 2013. pp. 34–56. https://doi.org/10.4000/palethnologie.696

Thieme H (1997) Lower palaeolithic hunting spears from Germany. Nature. https://doi.org/10.1038/385807a0

Tomasso A, Rots V, Purdue L, Beyries S, Buckley M, Cheval C, Cnuts D, Coppe J, Julien MA, Grenet M, Lepers C, M'hamdi M, Simon P, Sorin S, Porraz G (2018) Gravettian weaponry: 23,500-year-old evidence of a composite barbed point from Les Prés De Laure (France). J Archaeol Sci 100:158–175. https://doi.org/10.1016/j.jas.2018.05.003

Tringham R, Cooper G, Odell GH, Voytek B, Whitman A (1974) Experimentation in the formation of edge damage: a new approach to lithic analysis. J Field Archaeol 1(1/2):171–196

Tydgadt L, Rots V (2022) Stick to it! Mechanical performance tests to explore the resilience of prehistoric glues in hafting. Archaeometry 1–18. https://doi.org/10.1111/arcm.12779

Wadley L (2005) Putting ochre to the test: replication studies of adhesives that may have been used for hafting tools in the Middle Stone Age. J Hum Evol 49:587–601. https://doi.org/10.1016/j.jhevol.2005.06.007

Wadley L, Trower G, Backwell L, D'Errico F (2015) Traditional glue, adhesive and poison used for composite weapons by ju/'hoan san in nyae nyae, Namibia. Implications for the evolution of hunting equipment in prehistory. PLoS ONE 10:1–27. https://doi.org/10.1371/journal.pone.0140269

Waguespack NM, Surovell TA, Denoyer A, Dallow A, Savage A, Hyneman J, Tapster D (2009) Making a point: Wood-versus stone-tipped projectiles. Antiquity 83:786–800. https://doi.org/10.1017/S0003598X00098999

Wedage O, Picin A, Blinkhorn J, Douka K, Deraniyagala S, Kourampas N, Perera N, Simpson I, Boivin N, Petraglia M, Roberts P (2019) Microliths in the south Asian rainforest~45–4 ka: new insights from Fa-Hien Lena Cave, Sri Lanka. PLoS ONE. https://doi.org/10.1371/journal.pone.0222606

Wilson M, Perrone A, Smith H, Norris D, Pargeter J, Eren MI (2021) Modern thermoplastic (hot glue) versus organic-based adhesives and haft bond failure rate in experimental prehistoric ballistics. Int J Adhes Adhes 104:102717. https://doi.org/10.1016/j.ijadhadh.2020.102717

Wood J, Fitzhugh B (2018) Wound ballistics: the prey specific implications of penetrating trauma injuries from osseous, flaked stone, and composite inset microblade projectiles during the Pleistocene/Holocene transition, Alaska U.S.A. J Archaeol Sci 91:104–117. https://doi.org/10.1016/j.jas.2017.10.006

Worsnop T (1897) The Prehistoric Arts, manufactures, works, weapons, etc., of the aborigines of Australia, C.E. Brist. ed. C.E. Bristow, Adelaide

Yaroshevich A, Kaufman D, Nuzhnyi D, Bar-Yosef O, Weinstein-Evron M (2010) Design and performance of microlith implemented projectiles during the Middle and the late Epipaleolithic of the Levant: experimental and archaeological evidence. J Archaeol Sci 37:368–388. https://doi.org/10.1016/j.jas.2009.09.050

Zipkin AM, Wagner M, Mcgrath K, Brooks AS, Lucas PW (2014) An experimental study of Hafting Adhesives and the implications for compound. https://doi.org/10.1371/journal.pone.0112560. Tool Technology 9