The Effects of Use and Resharpening on Morphometric Variability of Aurignacian Antler Projectile Points

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Abstract: *Despite their morphological similarities, Aurignacian antler projectile points show a wide range of dimensions that remains to be explained. In this paper we focus on the contribution of use and resharpening to this morphometric variability. Our results show that these two converging processes primarily affect the distal tip of the armature. This analysis and discussion set forth an unexplored research perspective, i.e., how curation behaviors produced some of the observed morphometric variation among Aurignacian antler projectile points. We argue that artifacts must be approached in terms of functional constraints, and both structural and mechanical properties of the raw material should be considered within a broader theoretical framework that highlights how the dynamics between social transmission mechanisms and individual practices can introduce morphometric variability into material culture. Finally, we propose a new metric, the proximal-distal ratio, that can serve as a proxy measure of the range of relative dimensions of antler projectile points that Aurignacian hunters considered fit for dispatching prey.*
Keywords: *Aurignacian, antler projectile points, resharpening, morphometry, typology, proximal-distal ratio*

Die Auswirkungen von Gebrauch und Nachschärfung auf die Variabilität in der Größe und Form von Geweihspitzen aus dem Aurignacien

Zusammenfassung: Trotz ihrer morphologischen Ähnlichkeiten weisen die Geweihspitzen aus dem Aurignacien hinsichtlich ihrer Abmessungen eine weite Spanne auf, die es nach wie vor zu erklären gilt. Das Augenmerk der Autoren liegt auf dem Beitrag, den die Benutzung und die Nachschärfung der Geschossspitzen zu dieser morphometrischen Variabilität leisten. Die Ergebnisse zeigen, dass diese beiden Hand in Hand verlaufenden Prozesse vor allem die distale Spitzenpartie der Waffen beeinflussen. Mit den Analysen und der Diskussion öffnet sich eine bisher unberücksichtigte Perspektive, nämlich die Frage, in welchem Umfang der allgemeine Umgang mit Geweih-Geschossspitzen aus dem Aurignacien und die Nachbearbeitung solcher Stücke für einige der beobachteten morphometrischen Unterschiede verantwortlich sind. Die Autoren sprechen sich dafür aus, dass eine Interpretation auch solcher Artefakte funktionale Grenzen einbeziehen muss. Sowohl die strukturellen als auch die mechanischen Eigenschaften des Rohmaterials sollten in einem breiteren theoretischen Rahmen betrachtet werden, der deutlich werden lässt, wie die Dynamik zwischen gesellschaftlicher Übermittlung und individuellen Verhaltensweisen morphometrische Variabilität in der materiellen Kultur hervorrufen kann. Schließlich wird ein neuer Messwert vorgeschlagen, das proximal-distale Verhältnis, das als Maß (*proxy measure*) für die Spannweite der relativen Abmessungen von Geweihspitzen dienen kann, die die Aurignacien-Jäger als geeignet für die Beutejagd angesehen haben.
Schlagwörter: Aurignacien, Geweihspitzen, Nachschärfung, Morphometrie, Typologie, proximal-distales Verhältnis

Introduction

The European early Upper Paleolithic is a theater of major changes in material culture. The widespread adoption of laminar debitage, the ever-increasing production of objects with symbolic function, and the manufacture of osseous technologies appear simultaneously for the first time in the Aurignacian technocomplex. While these aspects of material culture are present in the Middle Paleolithic technocomplexes (Boëda 1988; Chase 1990; Delagnes and Ropars 1996; Gaudzinski 1999; Gaudzinski et al. 2005; Burke and d'Errico 2008; Zilhão et al. 2010; Peresani et al. 2011; Rosell et al. 2011; Soressi et al. 2013), they are sporadically distributed both spatially and temporally. Moreover, the earliest evidence of a clear functional distinction in the choice of raw material for the manufacture of both lithic (Bon 2002, 2005, 2006; Teyssandier et al. 2010) and osseous (Liolios 1999, 2006; Tartar et al. 2006) tools appears during the Aurignacian. In addition to the production "in series" of hunting armatures (Tartar and White 2013) and symbolic elements such as beads and other forms of ornamentation (White 1989), the production of osseous objects is characterized by a standardization of technical behavior quite distinct from Middle Paleolithic production sequences (Mellars 1996). This apparent standardization needs to be considered in the context of the observed morphometric variability of Aurignacian material culture. This research focuses on an important source of morphometric variability of osseous tools, specifically use and resharpening of Aurignacian projectile points made of antler.

Research background

From the earliest research concerning prehistoric material culture, archaeologists have analyzed the formal variability and shared features of objects in order to group them into types. Designated types were subsequently interpreted as reflecting either different cultural entities (Bordes 1953) or assemblages dedicated to specific activities (Binford 1973). Adapting the anthropological concept of *chaînes opératoires* (Lemonnier 1976, 2010) or operational sequences to archaeological contexts and analyses (Pelegrin et al. 1988) helped account for the fact that use of different combinations of techniques, or technical sequences, can result in the production of identical tools (Boëda 1995). Instead of being limited to typological analyses, this theoretical perspective integrates analysis of contextual elements, such as raw material properties and the employed technical sequences, in order to identify the technical repertoire of prehistoric populations, as well as the choices they favored in the face of the constraints (technical, mechanical, environmental, etc.) that were imposed on them. Moreover, techno-typological analyses of variability that integrate ecological considerations examine the ways in which technological choices vary according to environmental constraints, activities performed at a given site, and mobility strategies over a given territory (Kuhn 1995; Delagnes and Meignen 2006; Wallace and Shea 2006; Shott 2009).

The typological classification of Aurignacian projectile points made of antler has not been revised since the late 1980s. Indeed, three types are recognized and grouped into two super-types: the simple-base super-type includes both lozenge-shaped and spindle-shaped points, while the split-base super-type is restricted to a single type (i.e., split-base points). This categorization conflates two different sorts of classification criteria into a single typology: (1) the presence or absence of a proximal split and (2) the general

contour of the point (Hahn 1988a, b). In other words, the criterion used to designate an antler point as a split-base point is inherently different from the criterion used to designate antler points as lozenge-shaped or spindle-shaped; the definition of a split-base point relies solely on a proximal feature as opposed to the point's general shape. Furthermore, if the presence of a split is disregarded and only form is considered, the objects classified as split-base points could be designated as either lozenge-shaped or spindle-shaped points.

Although the proximal attribute of a split clearly distinguishes split-base points from simple (i.e., non-split) base points, the criterion used to subdivide simple-base points into two formal typological categories remains somewhat subjective. One extreme of the range of morphological variation of points classified as lozenge-shaped overlaps the morphological variability encompassed by points classified as spindle-shaped (Fig. 1). Because these are purely formal typological designations, they do not account for the manufacturing or use strategies implemented by the prehistoric artisans. This classification system also ignores the transformations through which a tool can be subjected

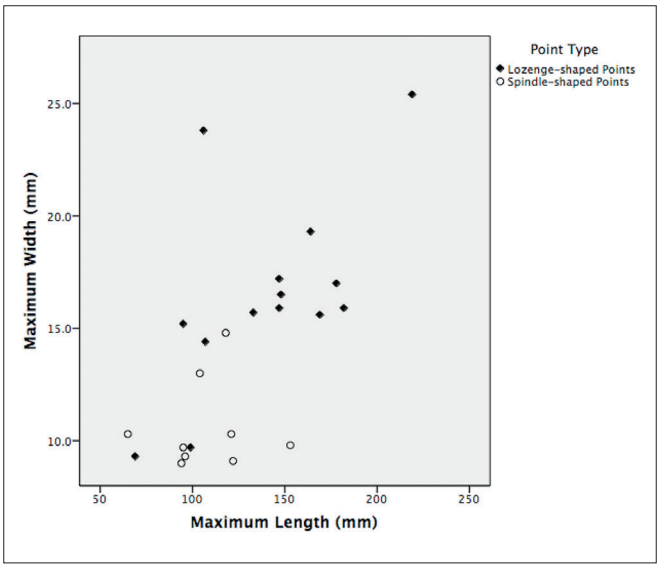

Fig. 1: *Maximum width compared to maximum length of lozenge-shaped and spindle-shaped points (n = 23) from La Ferrassie (Dordogne, France).*

during its use life (Rolland and Dibble 1990), which in turn can bias cultural-behavioral and functional interpretations. The techno-typological approach aims to mitigate these problems.

Several authors have attempted to explain the typological and morphological variability of Aurignacian armatures. The most frequently suggested interpretations include (1) designation of types that change through time and can be used as index fossils (Peyrony 1933; subsequently revised by Albrecht et al. 1972; Leroy-Prost 1975, 1979; Delporte and Mons 1988; Hahn 1988a, b); (2) functional differences related to either modes of throwing (Tartar and White, 2013) or the size of targeted prey (Leroy-Prost 1975; Cattelain

2010); (3) differences in manufacturing techniques (Liolios 1999); and (4) distinct degree of use and resharpening (Hahn 1988a; Knecht 1991, 1997). Although the first interpretation is more a description of variability as a function of time rather than an explanation of the selective pressure that led to morphometric variation, these hypotheses pose some problems.

The first proposal – typological and morphological variability represent a succession of index fossils – implies a uniform and linear evolution of technological adaptations over a vast territory, but does not explicitly state why or how these forms might have changed. Historically, these chronological successions were defined based on observation of a restricted number of assemblages from sites in southwest France (Didon 1911; Peyrony 1933, 1934). Archaeological sites being the result of various palimpsests of occupation, this chronological model cannot explain the occurrence of different types or morphotypes within a single cultural stratum (Leroy-Prost 1974; Hahn 1988a). In a series of publications, Davies proposed to proceed with direct dating of the points themselves to reliably resolve the issue of the chronological relationships between types or morphotypes (Davies 2001, 2007). This costly procedure would indeed provide novel information about the chronological succession of types on the Eurasian landscape during the Early Upper Paleolithic (as also suggested by Banks et al. 2013) but, in and of itself, would fail to explain what led to the appearance of such innovations in the archaeological record. It would also evade explanation of how or why morphological variability was introduced in the production sequence and/or throughout the use life of the points.

The proposal that the types represent functionally different armatures can be separated into two hypotheses: (1) a point's form is determined by its mode of projection and (2) the projectile size, expressed by the size of its armature, is determined by the size of the targeted prey. Concerning the mode of projection, recent research on ballistic proxies led Shea and his collaborators to propose metrics that could help derive the mode of propulsion of a lithic projectile from its armature's dimensions, namely the tip cross-section area and perimeter (Shea et al. 2001; Shea 2006; Sisk and Shea 2011). Tests of this hypothesis with data from the Australian ethnoarchaeological record demonstrate the importance of careful interpretation of morphometric variability as an armature's dimensions do not necessarily correlate with the type of projectile (arrow or spear, for example) that it armed (Newman and Moore 2013). This example reinforces the proposition that some armatures could have been used with multiple types of hunting equipment (Cattelain 1997), emphasizing the complex interplay between notions of form, efficiency, and choices embodied by the prehistoric artisans when reproducing elements of material culture, especially when these are directly linked to subsistence (Nelson 1997).

The second functional hypothesis – that projectile size is determined by the size of the targeted prey – can be tested by detailed analysis of associated faunal assemblages. The hypothesis would be refuted if associated faunal assemblages failed to show a statistically significant correlation with the types or morphotypes. If a statistically significant correlation were observed, the interpretation of a direct link between fauna and hunting devices would warrant considerable caution for several reasons: (1) The only direct evidence of a link between a particular hunting weapon and the acquisition of an individual animal is clear impact traces on skeletal elements. However, these are extremely limited in the archaeological record because they are unintentional (Morel 1993); (2) Assuming that such stigmata are available, although it may be possible to observe differences

in the amplitude of the damage, different types of weapons do not necessarily generate identifiably different impact marks (Morel 1993; Letourneux and Pétillon 2008); (3) Finally, unless a point is recovered while still embedded in the skeletal element, making a link between the hunting technology and the faunal remains recovered in a single layer would be a simplistic interpretation of site use and formation in the larger paleoanthropological context. A solid experimental program designed to compare the stigmata produced by the use of different types of projectile (e.g., spear versus arrow) on prey of various sizes could begin to move us toward a more secure understanding of the contribution of these factors to morphometric variability.

The third hypothesis, which posits that antler projectile point morphological variability represents differences in manufacturing techniques, can easily be tested experimentally. Efforts have already been made to understand the effects of manufacturing techniques on the morphometric attributes of Aurignacian projectile points (Knecht 1991, 1997; Liolios 1999; Tartar 2009; Tejero Cáceres 2010; Tejero et al. 2012; Baumann and Maury 2013; Tartar and White 2013). However, experiments conducted to date have used small to medium size antler. Some sites, such as La Quina (Henri-Martin 1925, 1930, 1936; Leroy-Prost 1979), La Ferrassie (Capitan and Peyrony 1912; Peyrony 1934; Delporte 1984), and Les Rois (Mouton and Joffroy 1958), have yielded antler points with dimensions that attest to the use of large antlers in the manufacture of armatures. Of considerable interest is that the range of shapes of these large points does not differ from that of the global sample of smaller points. Although experimentation is still necessary to understand the relationship between antler size and the manufacturing techniques employed for producing tools from antler of various sizes, some general statements are warranted: first, obviously, a large point cannot be made of small antler; second, it seems the Aurignacian artisans were maximizing the size of the manufactured points relative to the size of the antler cortex (compact tissue), as evidenced by the presence of spongeous tissue on nearly all specimens. Further experiments must be conducted to determine if any distinction in manufacturing strategies could explain variation in size and form among Aurignacian antler projectile points.

The present article discusses tests of the fourth hypothesis by beginning to quantify the contribution of use and resharpening to morphometric variability of Aurignacian antler projectile points. The concept of curation was introduced into the archaeological literature to describe a practice whereby items "are produced with the clear anticipation of long-term use […] and are transported to and from locations in direct relationship to the anticipated performance of different activities" (Binford 1973, 242-243). Originally, the concept served to support a functional interpretation of the variability in Middle Paleolithic lithic assemblages. Over the years, the term "curation" has carried many meanings, such as the planned production of armatures; the design of implements for multiple uses; the transport of implements from location to location; and maintenance, recycling, and resharpening (for a critical review of the concept's history, see Bamforth 1986; Odell 1996; Shott 1996).

If resharpening aims to maximize the use life of a tool, it is best expressed as a function of use episodes (Shott 1989a). For instance, an expedient tool produced to satisfy an immediate need is less likely to be resharpened than would a carefully manufactured tool designed for a long use life or a tool for which the raw material used in its manufacture is available only sporadically (Kuhn 1995; Shott and Sillitoe 2005). Resharpening

intensity is determined not only by considerations of form and efficiency (Nelson 1997), but may also vary according to mobility strategies (Binford 1973; Kuhn 1995; Delagnes and Meignen 2006), which in turn depend on social and environmental contexts (Rondeau 1996).

Study sample

In 1995 one of the authors (HKK) performed a series of experiments in collaboration with the TFPPP (Technologie Fonctionnelle des Pointes de Projectile Préhistorique) to begin to test the durability, efficiency, and maintainability of Early Upper Paleolithic osseous projectile technology, mainly Aurignacian points made of antler and Gravettian points made of bone. Our current analysis of a sample of 79 experimental points (using traditional typological designations: 29 split-base points, 24 lozenge-shaped points, and 26 spindle-shaped points) from the 1995 experiments was undertaken to quantify the contribution of both use and resharpening to morphometric variability of Aurignacian antler points.

Manufacture and projectile experiment

For the 1995 projectile experiments, (reindeer) antler projectile points, identical in size and form to particular Paleolithic specimens, were attached to wood handles. These spears were launched with a calibrated crossbow into a fresh cow cadaver suspended in anatomical position. Since it was necessary to manufacture large numbers of points, the points used in the projectile experiments were manufactured with machine tools (an electric band saw and a sander) and then finished with stone tools (retouched and unretouched blades) to remove the surface stigmata generated by the machine tools. The distal ends of the experimental points were shaped with stone tools. The points' dimensions were recorded before use (Knecht 1997).

During experimentation, each spear was used repeatedly until it (1) was unusable due to wear, damage, or breakage of the projectile point, haft, foreshaft, or shaft; (2) became embedded in bone and could not be removed without breakage; or (3) repeated attempts to cause breakage failed. For each shot, information was collected on the force of projection, anatomical point of impact, depth of penetration, and state of the projectile.

Methodology

The morphological analysis was designed to address questions concerning the morphometric change of individual projectile points throughout their use life, that is, over successive episodes of use, breakage, and resharpening. The morphological analysis was conducted in two steps. First, the transformations caused by the use of the projectiles needed to be understood. The state of the distal tips of the 79 specimens after use was classified into five categories (i.e., intact and four damage types). Relations were sought between the tip state and (1) the nature of the impacted target, which was categorized into two classes: hard tissue (bones) and soft tissue (hide, muscle, and cartilage); (2) point type (split-base, lozenge shaped or spindle shaped); as well as (3) force of projection – 25 kg, 29 kg or 32 kg.

To quantify the metric changes that resulted from use, used points were removed from their hafts, cleaned, and measured. The length reduction, calculated as a percentage of the point's original maximum length, was recorded for each specimen. Correlations were then explored between this percentage and three morphometric variables: original maximum length, flatness, and elongation. While the first parameter (maximum length) refers to the point's absolute size, the latter two parameters (flatness and elongation) are proxy measures of the point's shape. Flatness describes the relationship between maximum width and maximum thickness at the point of maximum width, while elongation expresses the relationship between maximum length and maximum thickness at the point of maximum width.

Analysis of the relationships between these variables should allow us to determine if the point's response to impact depends on either the nature of the target and the projecting force or the point type. It should also be possible to determine if tip damage types vary based on point morphology. If this is not the case, it can be argued that tip damage is dependent on mechanical properties of the raw material.

The second step of our experimental analysis aimed to explore the transformations caused by resharpening the projectile points. A sample of 40 points was randomly selected from the specimens presenting any of the three tip damage types. Following soaking in hot water for 15 minutes, the specimens were resharpened by scraping using Aurignacian unretouched blade replicates. The length reduction caused by resharpening was measured and calculated as a percentage of the point's maximum length after use. Finally, the morphology of each point was compared before use, after use, and after resharpening.

The analysis of the relationships between the morphometric changes due to breakage and resharpening should allow us to determine the contribution of these events to the morphological variability of an individual antler projectile point throughout its use life. It should also be possible to determine if the changes vary based on either tip damage types or point types.

Results

First, we will explore the causes underlying specific tip damage types. Two testable hypotheses are proposed: (1) Antler points of different types show statistically significant differences in the type of tip damage generated when used in the same way; (2) Antler points of different types show similar types of tip damage when impacting a similar target.

Experimental data show that damage related to the use of projectile points made of antler is principally localized either at the tip of the armature or at the haft (Knecht 1997). In the sample from the 1995 projectile experiments, the proximal ends of most points remained intact during and after use. Only three spindle-shaped points showed proximal damage, which was characterized by a step-fracture. It is relevant to note that these specimens were all projected at the maximum force used during the experiments, i.e., 32 kg; the relationship between proximal morphology and proximal breakage, both as independent of and related to hafting technique will be explored separately. On the other hand, distal ends were damaged on 62 of the 79 experimentally-used specimens.

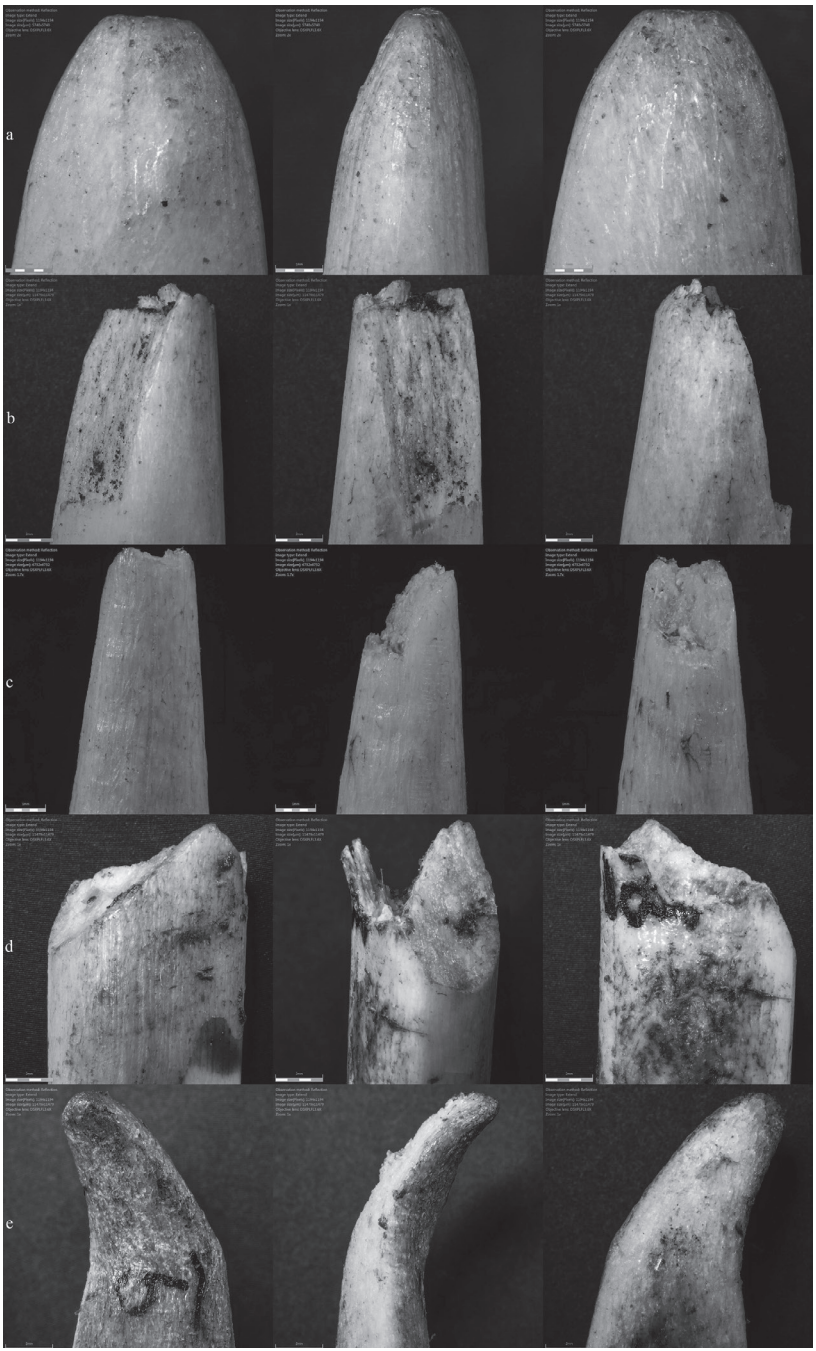

Fig. 2: *Types of tip damage identified on the experimental projectile points: (a) compressive damage; (b) compressive fracture; (c) step fracture; (d) sawtooth fracture; (e) bending damage; left: superior view, center: lateral view, right: inferior view.*

Four tip damage types were identified: compressive damage (Fig. 2a) is characterized by the flattening of the tip due to the impact forces generated at penetration or when a point's penetration is stopped by hard tissue without causing fracture; compressive fractures (Fig. 2b) occur when a point impacting hard tissue is fractured but continues to penetrate the prey until the tongued wall of the fracture is compressed by the hard tissue it impacts; step fractures (Fig. 2c) are characterized by an abrupt wall at or close to an angle of 90˚ relative to the base of the fracture; sawtooth fractures (Fig. 2d) are distinct from step fractures because the walls of the fracture are serrated in a zigzag profile like that of a saw. Because of the limited number of specimens in the latter two categories (step fractures: n = 5, sawtooth fractures: n = 6) and the similarity in the type of material stress and failure that cause them, these two damage types were combined for statistical analysis and data presentation. Compressive damage (n = 19), compressive fractures (n = 29), as well as step and sawtooth fractures (n = 11) were identified on the experimental specimens.

Notably, the intact points total more than a quarter of the sample, which reinforces hypotheses concerning the durability and efficiency of this projectile technology. Indeed, because one of the objectives of the experiments was to test the durability of the projectile points, most shots intentionally targeted dense skeletal elements such as the femoral head and scapula in order to accelerate the production of damage on the armatures. The projection of the hunting weapon into such skeletal elements would have been most

Fig. 3: *Intact experimental antler projectile point embedded in a vertebra.*

likely unintentional in prehistoric time, which would further constrain the likelihood of generating morphometric change by use in a real-life hunting setting. Also, that some experimental specimens embedded in skeletal elements such as vertebra remained intact (Fig. 3) highlights the durability and efficiency of antler projectile armatures.

For the 137 shots recorded, a statistically significant relationship was observed between tip damage type and impacted tissue type (Fig. 4) ($n = 79$; $\chi^2 = 20.5059$; $df = 3$; $P < 0.00013$), as well as between tip damage type and projection force (Fig. 5) ($n = 79$; $\chi^2 = 17.6288$; $df = 3$; $P = 0.00723$). Another statistically significant relationship was identified between tip damage type and point type (Fig. 6) ($n = 79$; $\chi^2 = 18.3187$; $df = 3$; $P = 0.00548$). This result must however be interpreted with caution because simple-base points (lozenge-shaped and spindle-shaped) were more often projected into hard tissue

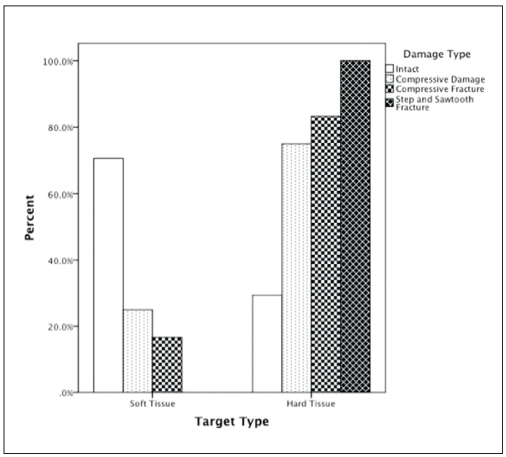

Fig. 4: *Relative frequency of occurrence of damage type in relation to impacted tissue type.*

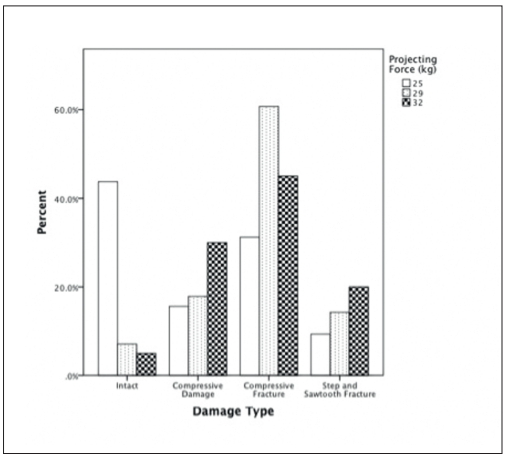

Fig. 5: *Relative frequency of projection force (kg) in relation to impacted tissue type.*

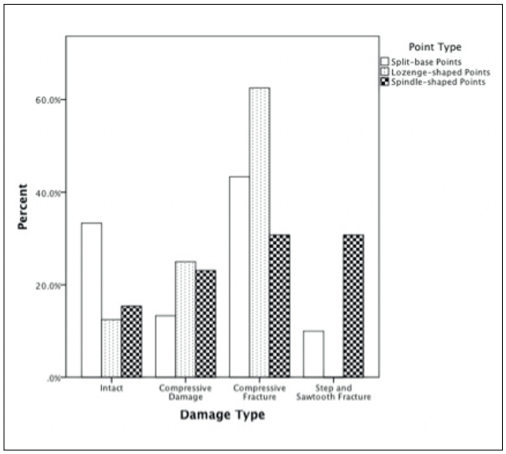

Fig. 6: *Relative frequency of tip damage type compared to the point type.*

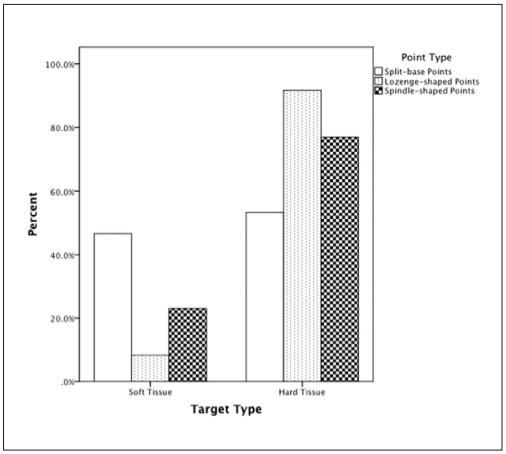

Fig. 7: *Relative frequency of projection of each point type into soft tissue and hard tissue.*

than were split-base points (Fig. 7) (n = 79; χ^2 = 11.3727; df = 2; P = 0.00339). Therefore, the occurrence of one tip damage type over another may well depend more on the nature of the target impacted, as well as the projecting force, than on the point type. It was as this relationship between impacted tissue type and breakage became abundantly clear during the course of the projectile experiments that points began to be intentionally projected into hard tissue in order to generate damage. In one instance, repeated attempts to generate damage by impacting soft tissue resulted in the antler armature becoming so impregnated with body fluids (without any damage to the projectile) that eventually the distal tip simply bent (as would a piece of hard rubber) on impact with bone, a situation that would be extremely unlikely in hunting reality (Fig. 2e).

Next, we will explore the nature of metric transformation associated with each tip damage type. Located at the distal end of a point, damage principally results in a maximum length reduction that can be expressed as a percentage of original dimensions. In absolute figures, the maximum length reduction on the experimental sample ranges from 0.1 to 16 mm, which represents between 0.03% and 17.32% of the original maximum length. Note that the three points with proximal damage were removed from the sample for the remainder of the analysis. The causes and effects of proximal damage will be explored separately, particularly because the hafting method and mechanism must be controlled for when analyzing the variability of damage at the proximal end. This topic lies outside the scope of the current analysis.

The different tip damage types observed generate average maximum length reductions that are significantly different statistically (n = 76; F = 4.1541; df = 1; P = 0.04506) regardless of point type (Fig. 8) (n = 76; F = 2.0434; df = 2; P = 0.1368). Moreover, the ranges of values of maximum length reduction for each tip damage category show little to no overlap. To perform a morphological comparison of the various point types, it is necessary to translate point dimensions into ratios. As stated above, elongation (ratio of thickness at the point of maximum width and maximum length) and flatness (ratio of thickness at the point of maximum width and maximum width) were explored. Comparison of these variables yielded no statistically significant relationship between maximum length reduction caused by use and (1) original maximum length (Fig. 9) (R2 = -0.05028; n = 76; t = -0,436; df = 75; P = 0.6641), (2) flatness (Fig. 10) (R2 = -0.22132; n = 76; t = -1.9654; df = 75; P = 0.0537), or (3) elongation (Fig. 11) (R2 = 0.19106; n = 76; t = 1.6857; df = 75; P = 0.096). This absence of correlation suggests that maximum length reduction depends more on the point's structural and mechanical properties than on its morphometric attributes. On impact, the forces generated on an antler projectile point will tend to propagate along the collagen fibers. If the forces are greater than the yielding properties of antler, the collagen fibers will undergo a plastic deformation until the point's transverse breakage. This fracture usually occurs at the hydroxyapatite joints that link the collagen fibers (Currey et al. 2009).

Lastly, a sample of forty points was resharpened to explore the morphometric changes associated with this procedure. It is a simple matter to resharpen a projectile point's broken tip by reworking (scraping) its surfaces such that the armature regains its penetrating properties. The stigmata generated by resharpening are therefore localized at the distal tip of the point. Note that when resharpening we made sure to reproduce the tip's original morphology. Thus, the morphology of the tip damage constrains the amount of antler that must be removed to reproduce the original design of the point's tip.

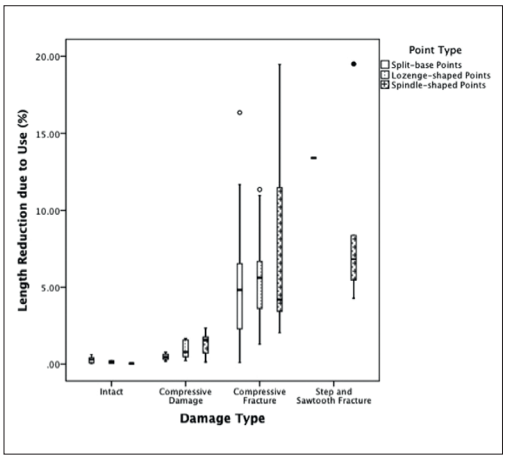

Fig. 8: *Length reduction due to use by damage type and point type.*

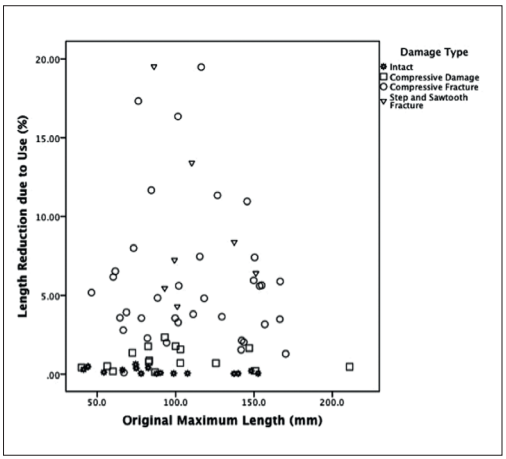

Fig. 9: *Length reduction due to use compared to original maximum length (mm) by damage type.*

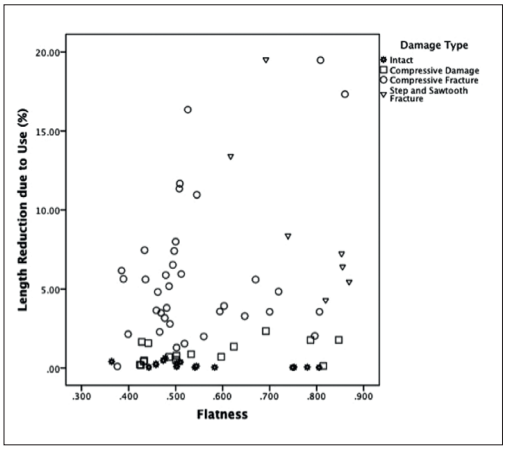

Fig. 10: *Length reduction due to use compared to flatness ratio by damage type.*

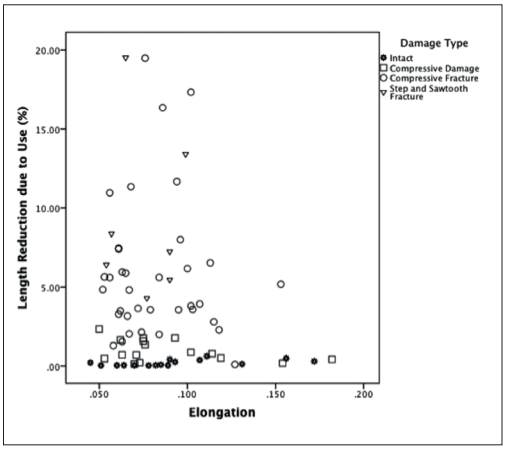

Fig. 11: *Length reduction due to use compared to elongation ratio by damage type.*

Following resharpening, the morphology of each specimen was compared with the range of variation known from the archaeological record to ensure that the morphology of the resharpened experimental projectile point remained within that of known archaeological specimens. The effects of (1) point type and (2) tip damage type on these transformations were examined. Quantitatively, the maximum length reduction, calculated relative to the point's maximum length after use, averages to a loss of 1.47% (SD: 1%) (Fig. 12). This observation is more meaningful when it is noted that no statistically significant differences were identified between the average maximum length reduction and either tip damage type (Fig. 13) ($n = 40$; $F = 0.1689$; $df = 3$; $P = 0.9166$) or point type (Fig. 14) ($n = 40$; $F = 0.9503$; $df = 2$; $P = 0.3973$).

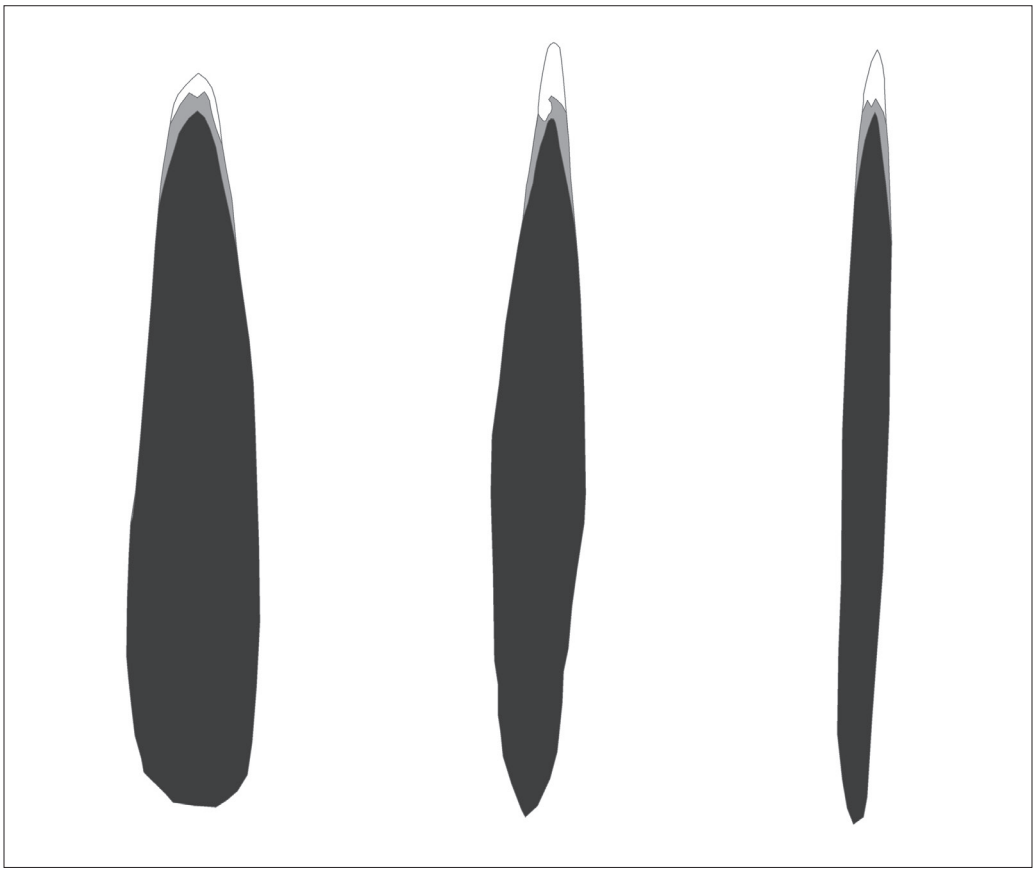

Fig. 12: *Comparison of original form (white), form after use (grey) and resharpened form (black) of three experimental points; left: split-base point, center: lozenge-shaped point, right: spindle-shaped point.*

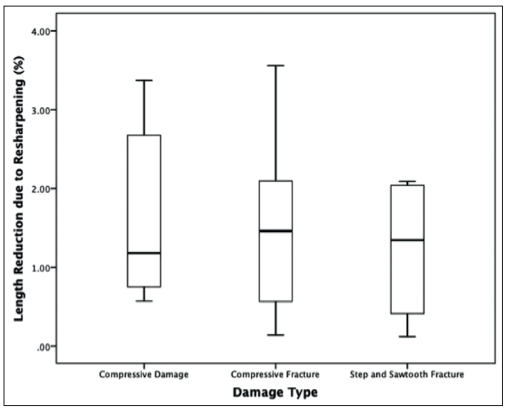

Fig. 13: *Length reduction due to resharpening by damage type.*

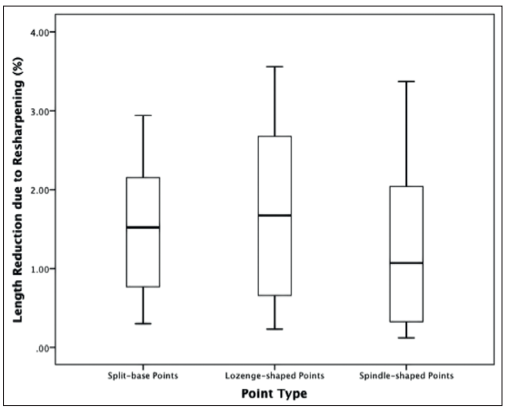

Fig. 14: *Length reduction due to resharpening by point type.*

Discussion

These results allow us to interpret some of the morphometric changes caused by the use and resharpening of Aurignacian projectile points. First, a point's response to the forces exerted on impact varies principally according to the nature of the impacted target and the projecting force, not the point type. Second, the metric changes associated with use can be summarized as a maximum length reduction that depends on the tip damage type, not point type or original morphometric attributes. Therefore, it logically follows that the raw material's mechanical properties play a decisive role in the armature's durability. The makers of Aurignacian material culture would have acquired, gradually and through cumulative experience, the technical knowledge that enabled them to anticipate the performance properties of antler as a raw material and to reproduce aerodynamic and penetrating forms that fit their conception of an efficient and durable hunting weapon.

Our experimental data show that use and resharpening constitute two axes of variability that principally effect a point's distal length, that is the length of the piece distal to the point of maximum width. These two converging processes cannot be isolated on archaeological specimens; i.e., one could never know how many successive episodes of breakage and resharpening any individual archaeological specimen underwent. However, we can isolate the ultimate event in which a projectile point participated prior to deposition, at least in some cases, such as a completely intact point or a point with a distal tip exhibiting identifiable, diagnostic impact damage.

Successive episodes of use and resharpening modify the morphology of the distal portion of the point leaving the proximal portion intact, at least in most cases. It may therefore be possible to quantify the combined contribution of use and resharpening to morphometric variability by comparing the proximal length – which presents less variation over the use life of a point – and the distal length – which is principally impacted by the converging processes of breakage and resharpening. Consequently, we propose the adoption of a new metric, the proximal-distal ratio, which is obtained by dividing the proximal length by the distal length, in order to facilitate the intra- and inter-site comparison of archaeological antler projectile points. It must be stressed that the proximal-distal ratio does not equate to the number of successive episodes of use and resharpening although it is a function of both these processes: Aurignacian antler projectile points are so durable that any specific episode of use does not necessarily produce morphometric changes. For morphometric changes to occur, certain conditions must be met; for example, increasing the force of projection and/or impact of the point on hard tissue will indeed increase the probability of use-induced damage at the point's distal tip, but will not necessarily cause any measurable damage (Fig. 2).

Let us now consider the information conveyed by this ratio, as well as its potential application to the analysis of archaeological material culture. The proximal-distal ratio compares distal length to a constant, that is, proximal length. The range of values of this ratio usually falls between 0 and 1, simply because known Aurignacian antler projectile points usually have distal lengths greater than their proximal lengths. We expect that the proximal-distal ratio of a newly manufactured point should be closer to 0 than 1. Because use and resharpening principally affect the distal tip of the point by reducing the distal length and thus its length relative to the proximal length of the point, the

proximal-distal ratio is expected to move toward 1 over the use life of an individual projectile point.

The comparison of the proximal-distal ratio values of archaeological specimens can be used to infer two types of information. On the one hand, the range of values for preforms and points showing little or no evidence of use would highlight the relative dimensions of the original mental templates (Deetz 1967; Chase 2008) that were reproduced in the raw material by Aurignacian artisans. On the other hand, the value ranges of armatures showing distinct tip damage types caused by their use in hunting activities informs us about the limit at which a point was no longer considered efficiently usable. Therefore, the proximal-distal ratio can serve as a proxy measure of the range of relative dimensions of antler projectile points that Aurignacian hunters considered fit for dispatching prey.

The two ends of a projectile point are subjected to different functional constraints – the tip must penetrate the hide and muscles and cause a lethal injury to prey, while the base must facilitate hafting, as well as sustain and transfer the forces of impact from the point to the foreshaft or shaft. The tip is more prone than the base to damage by use of the projectile, therefore different curation behaviors can be expected according to the locus of damage on the projectile point. It follows that the contour of an antler projectile point conflates two sources of variability, i.e., the mental template of a basal morphometry considered fit for hafting and the various stages of use life affecting the form and dimensions of the distal portion of the point.

This analysis sets forth a heretofore unexplored research perspective. By focusing on proximal attribute and contour of Aurignacian antler projectile points, archaeologists have failed to account for the functional constraints to which the points were subjected and the curation behaviors that produced the observed morphometric variation. Artifacts can be better understood by exploring their functional constraints, as well as the structural and mechanical properties of the raw material, within a broader theoretical framework that highlights how the dynamics between social transmission mechanisms and individual practices can introduce morphometric variability in material culture. Ultimately, the analytical framework outlined above will serve to better understand the notions of form and efficiency held by Aurignacian artisans and perhaps even identify communities of practice (Wenger 1998). We believe this is a requisite step toward gaining a better understanding of the sociocultural implications of morphometric changes and variability in the archaeological record during a period that coincides with the presumed colonization of Europe by *Homo sapiens*.

Conclusion

The observed morphometric variability of Aurignacian antler projectile points can be explained first by the converging processes of use and resharpening and, second, by the nature of the hafting mechanism. Gaining experience and knowledge over time, Aurignacian artisans were able (1) to anticipate the response of the raw material to the forces generated on projectile impact and (2) to reproduce aerodynamic, effective, and durable forms. The decision of whether or not to resharpen a projectile point must have depended on (1) the Aurignacian conception of the efficiency of the relative dimensions

of the proximal and distal length of an armature and (2) raw material availability. If we presume that both raw material (antler) and time (used in manufacture/rejuvenation) were valuable commodities (Shott 1989b), Aurignacian artisans and hunters most likely opted for the reproduction of forms that limit the maximum length reduction during use and resharpening, and thereby increase the use life of the projectile point. The proximal-distal ratio is a proxy that allows quantification and comparison of the notions of ideal form used to perform a specific function, as well as the range of variation that this ideal form could take, from manufacture to discard, while remaining functionally efficient.

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