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RESEARCH ARTICLE

Convergence in the Design of Final Palaeolithic, Mesolithic and Ethnographic Projectile Points

Kamil Serwatka*

* *Independent researcher, Email: kamserw@gmail.com*

Abstract

In traditional hunting and gathering societies, it is a common practice to fashion projectiles for different purposes. The spectrum of the available morphologies for projectiles and their tips is dictated by several kinds of constraints such as aerodynamic and mechanical properties, different hunting strategies, the available game or the range of the shot. This article focuses on a particular aspect of duality in primitive projectile technology interpreted with a fitness landscape model. Using geometric morphometric analysis, the author argues that the duality in projectile morphology and performance characteristics observed in the studied projectile weapon systems is the result of technological and physical constraints placed upon primitive projectile technology. For a more comprehensive explanation of this phenomenon, an optimality model explaining the development of flexible projectile weapon systems is proposed.

Keywords

Projectile Technology, Convergence, Geometric-Morphometrics, Fitness landscape, Projectile Points, Ethnographic Analogies, Final Palaeolithic, Mesolithic

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1. Introduction

In convergence, functional or developmental constraints result in similar forms being developed in independent lineages (O'Brien *et al.* 2018). In the case of archaeological and ethnographic projectile technology, we are often dealing with morphological and functional similarities of points deriving from different spatial and temporal contexts (i.e., Charlin & Gonzalez-Jose 2018; O'Brien *et al.* 2014; Smallwood *et al.* 2018). In the cultural-historical paradigm, such similarities in the form and function of artefactswere often treated as an outcome of contact between toolmakers using information exchange between human populations (Groucutt 2020). At the root of these processes, diffusionists saw mechanisms such as cultural transmission and enculturation (Lymann *et al.* 1997). Recently it is becoming clear that at least some of the cases of morphological and functional similarity in artefacts design are an outcome of convergent evolution in human technology (Groucutt 2020; O'Brien, Buchanan & Eren 2018).

Given that humans tend to come up with similar solutions to common problems it seems reasonable to search for examples of convergence in areas of technology, which are affected by natural constraints more than others. In this regard projectile technology of hunters and gatherers remains a potentially prolific field of research.

Similar designs appear more often in hunting weapons and this is due to invariant laws of physics and mechanics, such as the force of gravity or drag of the air, which remain a strong selective factor influencing the form and performance of primitive arrows, spears and darts (Christenson 1986; Hughes 1998). These natural restrictions act as constraints on projectile technology causing hunters to come up with similar solutions despite different ecological conditions and spatio-temporal contexts.

In this paper, I use the concepts of convergence and fitness landscapes model as a framework for the interpretation of morphological and functional similarities between projectile points deriving from Final Palaeolithic, Mesolithic and ethnographic contexts.

Table 1. Basic characteristics of bimodal projectile weapon systems

Distance	Characteristics	Purpose
Short range projectiles	- Broad lanceolate/oblanceolate points	Induce shock and damageto kill off quickly at close range
	- Heavy	
	- Simple construction	
Long range projectiles	- Narrow points with sharp tip	Enhance penetration to keep the arrow inside prey's body
	- Light	
	- Complex arrows with barbs	

2. Convergence and design constraints of projectile technology

Convergence as a biological phenomenon is based on the fact, that organisms originating from different lineages may develop analogous structures or organs as a response to similar environmental constraints (McGhee 2018). In living organisms, analogous organs or structures occur by means of relatively complicated processes, such as genetic mutation, drift and selection (McGhee 2011). When it comes to man-made tools the case is more down to earth, as convergence in the form and function of strictly utilitarian artefacts, such as projectile points, appears usually as an outcome of the selection of appropriate traits to perform similar tasks. In the case of ancient projectile weapon systems, these traits can be for example penetration depth, velocity or aerodynamic characteristics (Charlin & Cardillo 2018, 110; Hughes 1998).

To properly identify cases of convergence in primitive projectile technology we ought to look at projectiles and their elements from an evolutionary perspective. This approach implies that the archaeological record can be viewed similarly to the way paleobiologists see a fossil bed and that is as populations of "things", that represent hard parts (shells, for example) of past phenotypes (Dunnell 1980; Jones *et al.* 1995; Leonard & Jones 1987; Lyman & O'Brien 1998; O'Brien, Buchanan & Eren 2018). This particular example fits very well with what archaeologists have to cope with when reconstructing prehistoric projectile systems, as most often the "soft" parts of weapons, (i.e., their organic elements) are not preserved and usually the only things that remain are stone points.

Biologists see a bird's nest, a beaver's dam or a twig tool made by a chimpanzee as strictly phenotypic traits (e.g., Dawkins 1990; Turner 2000). Archaeological projectile points were also parts of past phenotypes because they played a significant role in gaining food and other resources and for this reason, their characteristics were shaped by the same evolutionary processes as those which influence their makers and users (Leonard & Jones 1987). Consequentially, in this approach, artefacts are viewed as an extension of human biological phenotype. It should be emphasized, that this notion of "extended phenotype" is nothing new and it was first introduced to archaeology by O'Brien and Holland (1995) and by Lyman and O'Brien (1998) nearly three decades ago.

In the realm of projectile technology, convergence occurs under certain restrictions, which force humans to come up with similar solutions due to the limited range of possibilities (McGhee 2018, 28). In some cases, this produces substantial diversity in the construction and morphology of hunting weapons (Serwatka 2018). This phenomenon is often characterized by the occurrence of certain duality in projectiles ranging from heavy, high-power ones to light and fast. Heavy projectiles are usually tipped with wide projectile points to enhance the impact force and killing power at short range, while lighter projectiles are tipped with narrow points with sharp tips to facilitate penetration and ensure a precise shot (see Serwatka 2018 and Table 1). A weapon system's arrows or darts can be designed to maximize distance or energy based on what is known as the mass/velocity relationship. (Hughes 1998, 370).

The concept of this specific duality in projectile form and function appears earlier in the studies on prehistoric projectile technology and there are several examples of such bimodal projectiles among

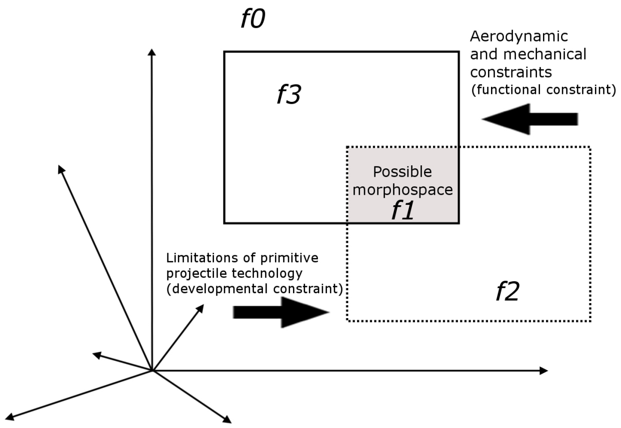

Figure 1. A spatial representation of basic constraints in a theoretical morphospace of projectile points. The solid line represents the invariant aerodynamic and mechanical limitations (functional constraints). Points within that boundary will be functional under physical and aerodynamic conditions. The dotted line represents developmental constraints. Points within that boundary are possible to create under the limitations of primitive projectile technology. Forms f0 are impossible both in terms of aerodynamic and mechanical requirements and primitive projectile technology; forms f1 are functional and developmentally possible; forms f2 are possible to manufacture with primitive projectile technology, but they would be nonfunctional under aerodynamic and mechanical constraints; forms f3 are functional, but impossible to develop due to technological limitations (after McGhee 2011).

traditional hunting societies. For instance, Cundy (1989) in his study on Australian spearthrowers observed that Aboriginal Australians used either small and light darts, which increased the distance of the shot or large and heavy darts, which produced higher energy upon impact and had more killing power.

A similar case, this time in bow and arrow technology, was reported by A.M. and P. Petrequin (1990) among the Danis people living in Western New Guinea. For hunting purposes, the Danis use simple arrows tipped with wide bamboo blades. Such construction causes large wounds and shock upon impact, which ensures a quick kill (Petrequin & Petrequin 1990, 492). Conversely, for warfare, the Danis prefer more complex and accurate arrows, which can be shot from a considerable distance. The points of these arrows are thin and barbed, which helps with deep penetration and causes complex internal injuries by keeping the point inside the wound (Petrequin & Petrequin 1990, 492).

Another interesting ethnographic example of such duality in the construction of arrows is provided by Griffin (1997), who studied the bow and arrow technology of Agta hunters from Northwestern Luzon. In a dense forest environment characterized by seasonal variation, the Agta hunt with self-bow and arrows. Hunters use a variety of projectile tips, which generally range from large, heavy single-bladetips to light, thincompoundtips. (Griffin 1997, 282; see Fig. 4 in this paper.) The selection of the right arrow and projectile point is determined by the size of the prey and the shot's distance. At close range, single-bladed points are utilized. The impact force at close range combined with large and wide points cause shock and sometimes instant death of the prey. The Agta use more precise, multicomponent arrows at fleeing game when a more accurate shot from a distance is needed. Points of these multicomponent arrows are connected to the shaft with a piece of string. Additionally, barbs attached to the narrow, sharp points ensure keeping the distal part of the arrow in the wound, which prevents the animal from escaping as the foreshaft and the string becomes entangled in bushes and scrubs when the animal is escaping. (Griffin 1997, 282).

There seem to be several archaeological examples of this duality in the construction of projectiles. Gurina (1956) reports finding different types of arrows in two graves at the Mesolithic cemetery at Deer Island situated on Lake Onega. The foreshafts deposited in burials were made of bone and still had lithic points attached to them. In each of these burials, the foreshafts and lithic points were different: 100 grave foreshafts had large, lanceolate points and were straight and smooth (see Fig. 4 in this paper). The foreshafts of grave 118a were shorter and possessed three to four short side barbs. These foreshafts had small, elongated tanged points attached at their distal ends (Gurina 1956).

According to the author's previous study, Final Palaeolithic Swiderian points were also parts of such a bimodal projectile weapon system (Serwatka 2018). Analogously to the mesolithic points from Oleni Ostrov, in the Swiderian Culture, we are also dealing with wide lanceolate points and considerably lighter and thinner tanged points. These points differ statistically in terms of weight, shape and the character of impact fractures, which strongly suggests that they were parts of such a bimodal weapon system (Serwatka 2018).

According to Susan Hughes, when weapons can be manufactured with options for increased distance and high energy, hunting flexibility increases (Hughes 1998, 370). The examples listed above show, that such flexibility in the design of primitive projectiles has the potential of appearing independently in different contexts as an analogous trait. For a better understanding of this phenomenon, it is necessary to look at the problem from the perspective of limitations imposed on primitive projectile technology.

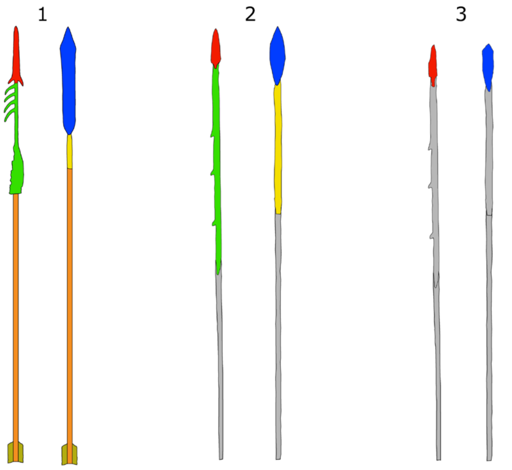

Figure 2. A scheme showing analogous design features in projectiles from three different spatiotemporal contexts: 1: Ethnographic Agta arrows; 2: Mesolithic foreshafts with lithic points; 3: Final Palaeolithic Swiderian points.

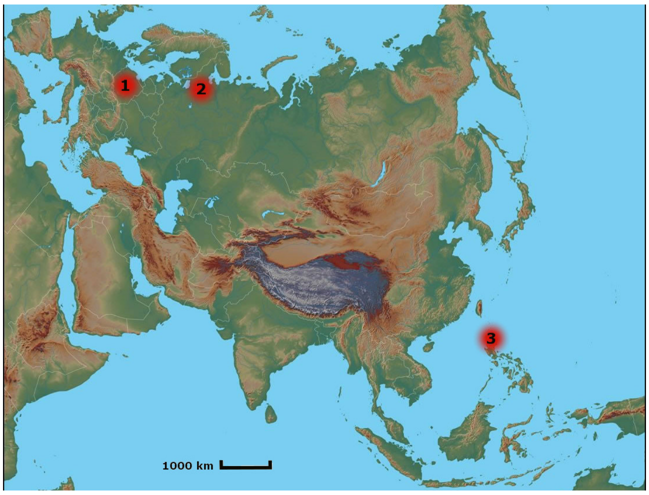

Figure 3. Map showing the location of projectile point contexts discussed in the text: 1: Final palaeolithic Swiderian points from Poland; 2: Mesolithic points from Oleni Ostrov cemetery; 3: Ethnographic Agta points from North-Western Luzon.

First, there are the functional constraints deriving from invariant laws of physics, which are globally universal and independent of ecological conditions, cultural context or time. These include forces such as gravity and the drag of the air. All prehistoric hunting societies must have conformed to these restrictions to make their projectiles functional, which means designing them according to basic rules of mechanics and aerodynamics (Cotterell & Kamminga 1992).

Every primitive projectile weapon system is characterized by an insufficient transfer of energy onto a projectile. This particular problem is caused by the construction of simple propulsion mechanisms, such as self-bows, which are unable to produce much energy, compared to modern bows (Cotterell & Camminga 1992; Hamilton 1982; Hughes 1998; Klopsteg 1943). These constraints are strictly technological as they mainly derive from the ignorance of certain methods for making more powerful propulsion devices (e.g., Bartram 1997). In a more general sense, these restrictions can be viewed as developmental constraints.

Drag increased as a result of the low velocity of prehistoric projectiles, limiting their range and making their trajectory more curved (Burke 1954; Cotterell & Kamminga 1992; Hughes 1998). Since the primary purpose of all hunting weapons is to inflict injuries that would result in the immediate death or immobilization of the prey, this remains a significant limitation of the functionality of primitive projectile weapons. With these restrictions in mind, and following McGhee's scheme of boundaries (McGhee 2018) we can take a spatial approach to visualize basic constraints governing the emergence of such bimodal projectile weapon systems in the area of human technology. Figure 1 shows a spatial representation of two types of constraints imposed on primitive projectile weapons in a theoretical morphospace.

One important conclusion, which derives from the limitations listed above is that primitive hunting weapons were only good enough at a relatively short distance, with the effective range for a self-bow reaching approximately 25 meters (Churchill & Rhodes 2009). Hunters often tried to overcome this difficulty by using strategies to approach the game with concealment and disguise or by bringing the game within the effective range (Hitchcock & Bleed 1994; O'Connell & Hawkes 1988; Verbicky-Todd 1984).

A different way of making low-velocity weaponry more effective is by manipulating the design characteristics of projectiles themselves to improve their key features, such as penetration, killing power and range (Christenson 1986; Hughes 1998). This seems to be the case in the ethnological and archaeological examples given above, where projectiles ranging from high power/short range to low power/long range are developed to be better prepared for different hunting situations.

The examples listed above also raise an important taphonomic issue regarding projectile technology in general. As we gradually move on to more ancient examples of bimodal projectile weapon systems we are facing a gradual depletion of data. The Agta or the Danis example provides full insight into the projectile weapon systems' function and performance, the Mesolithic example provides only partial information deriving from grave goods (projectile points and foreshafts), and Swiderian points can be interpreted as parts of a projectile weapon system only based on their functional and morphometric features. What links these cases is the appearance of specific bimodal projectiles and points with analogous technological, functional and morphological features (Fig. 2).

3. Geometric morphometric analysis and projectile points morphospace

Projectile points morphology reflects functional restrictions such as cutting capacity, penetration depth, aerodynamic characteristics and the trade-off between these features (Hughes 1998). In a taphonomic sense projectile points are "the hard parts" of past projectile weapon systems, which reflect the functional and performance characteristics of past weapons. For these reasons point morphologies and their technological features remain important traits for investigating cases of convergence in past and present projectile weapon systems (Buchanan & Collard 2010; Charlin & Cardillo 2018; O'Brien *et al.* 2014; Smallwood *et al.* 2018). Given the above a detailed analysis of projectile points morphology seems a proper method for investigating cases of convergence in projectile technology.

One way of addressing this issue is through the analysis of morphospaces. The idea of theoretical morphospaces was developed in evolutionary biology as a method for visualizing the spectrum of possible and impossible morphologies in the development of living organisms (McGhee 1999). Morphospaces are continuous and multidimensional spectrums of shapes and it is common to generate them using multivariate statistical methods, such as geometric morphometrics (Mitteroecker & Huttegger 2009). Convergence occurs when forms from different lineages occupy the same spatial region within the morphospace or follow a similar pattern of shape development (McGhee 2018). In the case of this study, generating a spectrum of projectile points forms will help in mapping out if and in which areas of an empirical morphospace convergence in the overall morphology occurs.

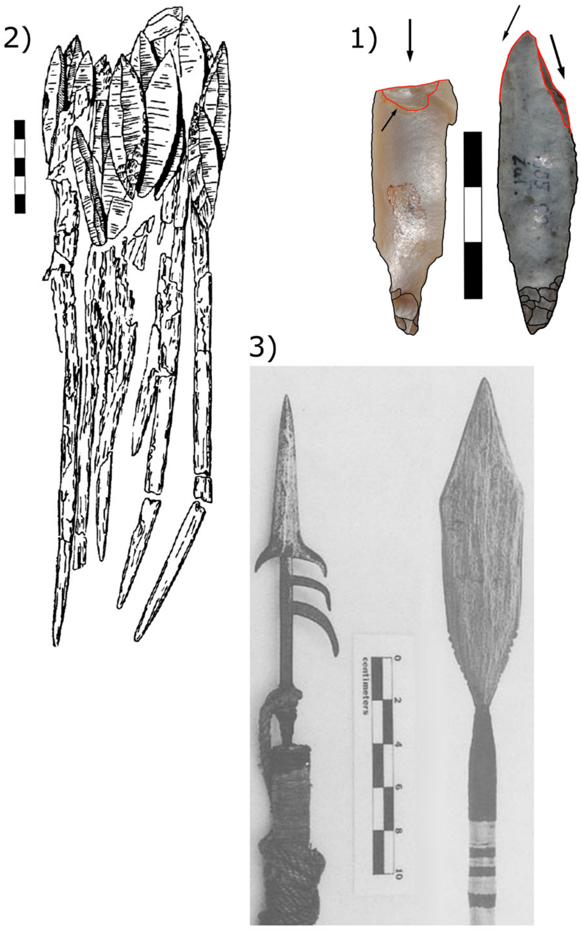

Figure 4. Examples of similar dual point types from three different spatiotemporal contexts: 1) Final Palaeolithic Swiderian points with visible impact fractures; 2) Mesolithic points from Oleni Ostrov still attached to bone foreshafts; 3) Single blade and composite points of the Agta hunters (After Griffin 1997; Gurina 1956; Serwatka 2018 (modified)).

Geometric morphometric analysis is currently one of the basic methods for studying the morphological variation of archaeological and ethnographic projectile points (i.e., Azevedo *et al.* 2014; Borrell & Stefanisko 2016; Charlin & Cardillo 2018; O'Brien *et al.* 2014; Serwatka & Riede 2016). A valuable advantage of geometric morphometric methods is the ability to superimpose and compare shapes of many objects in the course of Procrustes analysis (Rohlf & Slice 1990). Further multivariate statistical ordination methods allow for diverging between different point types taking even slight morphological differences into account. These aims would be hard to achieve using traditional approaches, such as linear measurements.

In this study, an empirical morphospace of point shapes will be generated basedon the result of Canonical Variate Analysis. In contrast to theoretical morphospace, an empirical morphospace is based on a set of real observations, which in this case are outline shapes of actual projectile points deriving from Final Palaeolithic, Mesolithic and ethnographic contexts. The amplitude of such space will be a function of the morphological variation in the dataset.

In Palaeontological Statistics PC software created by Hammer *et al.* (2001), CVA is a discriminant option that produces a scatter plot of specimens along the first two canonical axes (those producing maximal and second to maximal separation between all groups

– see Hammer & Harper 2006) and offers a conjoined module that uses MANOVA to test for the equality of multivariate means between groups. The ability of a CVA to correctly allocate specimens by measuring their distance from the group means is used to evaluate its performance (Sheets *et al.* 2006). The axes with the greatest variance will be used to generate the morphospace.

4. The dataset

The sample comprised digitized photographs and scanned drawings of projectile points from three different contexts: ethnographic (Agta points), Mesolithic (Oleni Ostrov site) and Final Palaeolithic (Swiderian culture) (see Fig. 3–4 and Table 2). The whole sample comprised 284 points. The assemblage of Final Palaeolithic Swiderian points consists of 250 specimens from twelve Polish archaeological sites (see Serwatka 2018) and the assemblage of Mesolithic points from Oleni Ostrov consists of 14 points. The ethnographic sample consists of 12 Agta arrowheads taken from Griffin (1997). All images were processed and digitized for geometric morphometric analysis. These operations included a standardized orientation of all specimens and placement of semi-landmarks.

Table 2. Dataset of projectile points used in the study

Context	n=	Total	Reference
Ethnographic	n=12	n=276	Griffin 1997
Mesolithic	n=14		Gurina 1956
Final Palaeolithic	n=250		Serwatka 2018

There is a specific protocol involved in the orientation method. Using the grid gauge in the GIMP image editing program, all points were oriented along their longitudinal axis of symmetry following this protocol (https://www.gimp.org/). After being oriented, the images were sent to TpsDig (Hammer & Harper 2006), where an outline of each point was drawn around its perimeter, starting at the base's farthest point (Fig. 5). The basal region was picked as the outline beginning point since it is the piece of an artefact which is straightforwardly associated with the shaft or foreshaft and thusly it stays a steady, simple to recognize component in projectile points. Using the TpsDigprogram, the outlines were transformed into a set of forty equidistant semilandmarks.

For Canonical Variate Analysis the dataset was divided into three groups: Swiderian points (n=250), ethnographic points (n=12) and Mesolithic points (n=14)

A Procrustes superimposition (Rohlf & Slice 1990) was carried out using the PAST software following the completion of the artefacts' orientation and digitization (Hammer *et al.* 2001). All of the outlines were superimposed around a centroid during this operation, which corresponds to the 0.0 XY coordinates. To further track deformations concerning that consensus shape, the Procrustes superimposition also computes the mean from all coordinate values (Jungers *et al.* 1995).

5. Results of the Canonical Variate Analysis (CVA)

There was a statistically significant difference between the designated groups' means using MANOVA (Wilk's lambda=0.02615; F=12.38; p<0.005; Pillai trace=1.632; F=10.63; p<0.005).

The CVA plot reveals, that there is a clear separation between the three assemblages of projectile points. All three groups occupy slightly different areas of the plot and there is no overlap between the designated assemblages (Fig. 6). Swiderian points, which are the largest group, are located near the 0.0 value of the CVA plot, where they form a rather tight cluster. Mesolithic points are located farther along axis 1. This group forms a wedge-like distribution, following the positive values of the axis. Ethnographic points stand out the most, as this group is distributed mainly according to axis 2, where it forms two smaller and well-defined clusters.

Following the shape deformations along the axes it was possible to define the overall trajectories of shape change in the generated morphospace. Axis 1 describes a transition from elongated specimens with a pronounced tang and sharp tip to points with elliptical outlines and expanded midsection. Shapes distributed according to axis 2 range from very narrow, needle-shaped points with short tang to broad, lanceolate specimens (Fig. 7). A pattern emerges when the expansion factors are visualized: The expansion of the midsection and gradual atrophy of the tang and shoulders of projectile points account for the majority of the shape changes that progress with increasing values of axis 1 and 2. Based on shape variables obtained in the course of CVA an empirical morphospace was projected (Fig. 8). Total set of two dimensions holding the most variance is used to construct a two-dimensional morphospace of possible form coordinates. Dimensions of the morphospace

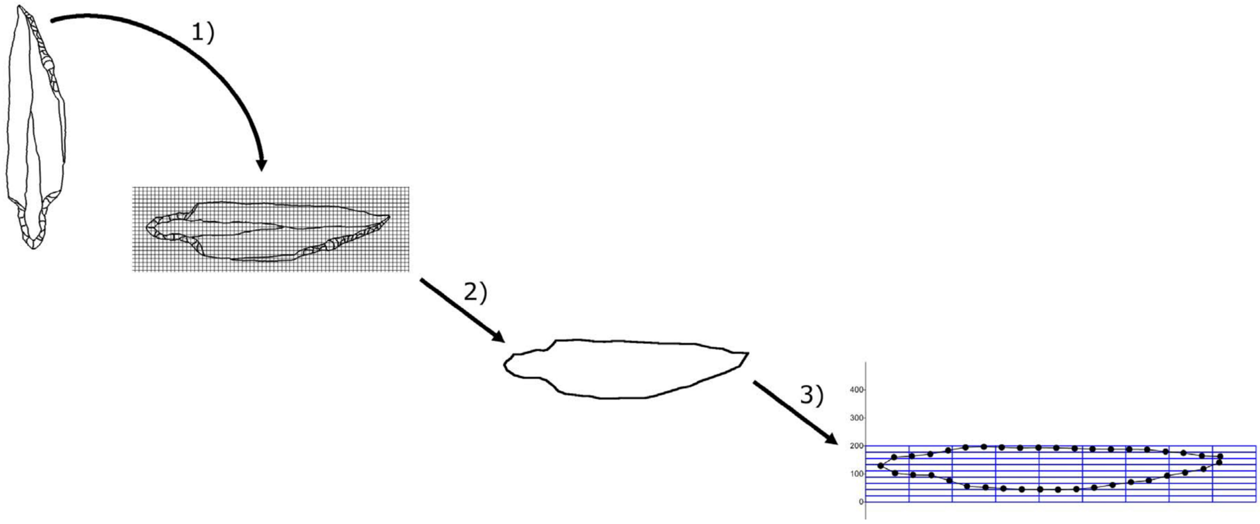

Figure 5. A simplified diagram showing the method of orientation of points outlines for geometric-morphometric analysis.

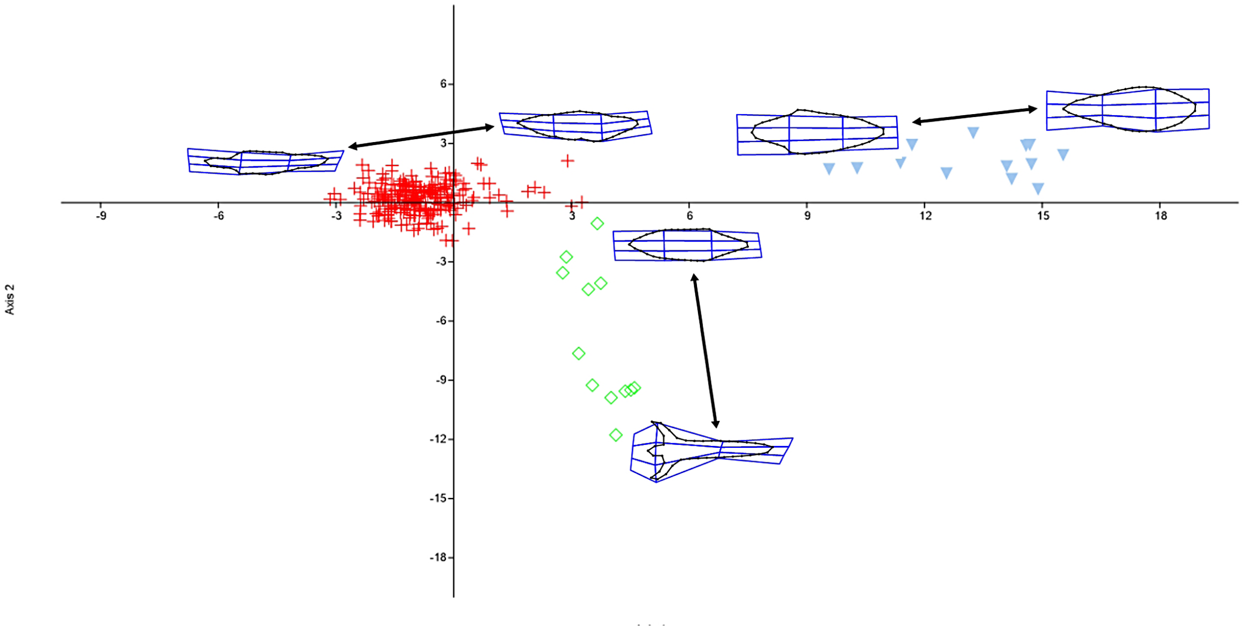

Figure 6. Scatter showing the result of Canonical Variate Analysis.

correspond with CVA axes 1 and 2, which derive from principal components 1 (47.116% of the overall variance) and 2 (15.096% of the overall variance) (see Table 3). Outlines with their expansion factors every 0.5 tick mark were included. The dimensions of the morphospace are geometric parameters, which correspond to the overall point expansion rate according to CVA axes.

The generated morphospace serves as a visual amplification of morphological variability obtained in the course of Canonical Variate Analysis. When looking closer at the position of subsequent shapes it becomes clear, that the morphospace is divided into two sections: one contains outlines of points with a more or less pronounced tang, contracted tip area and expanded midsection and the second part includes lanceolate and oblanceolate points with an expanded tip area. (see Fig. 8). This of course reflects the distribution of shapes on the CVA plot. The separation between these two parts of the morphospace is delimitated by a default shape corresponding to the 0.0 value (Fig. 7).

6. Points design space and fitness landscapes

Proving that convergence in the design of projectiles occurs is a relatively simple task. A more difficult objective would be to clarify why such convergence appears and how it develops. In the author's opinion,

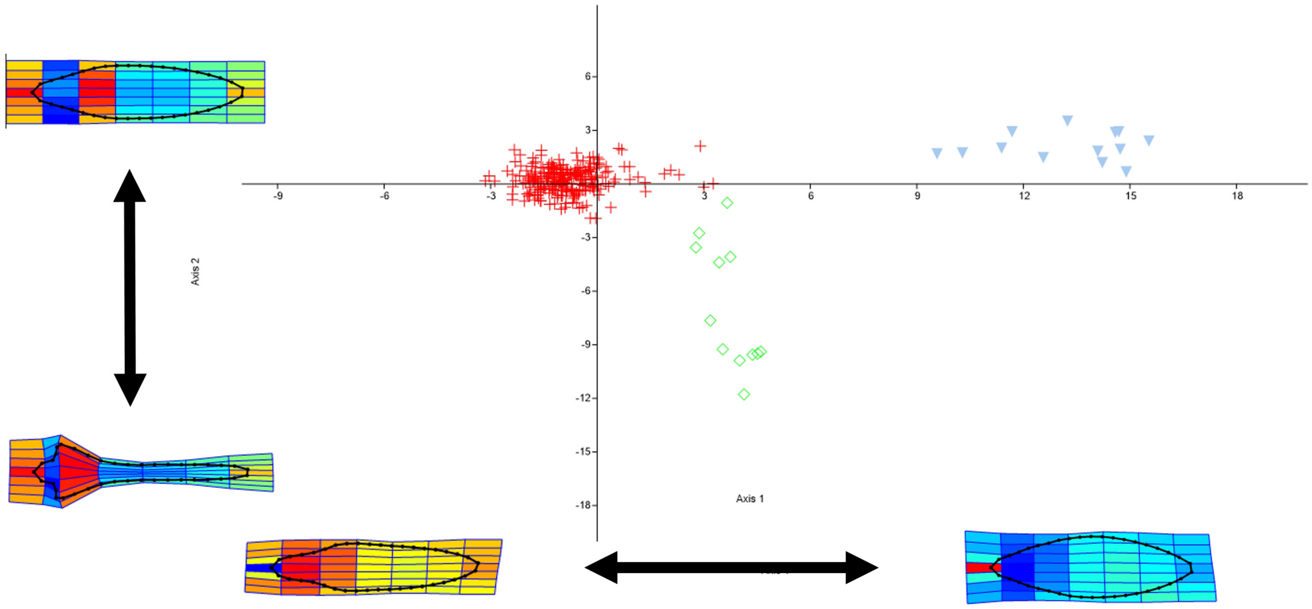

Figure 7. Shape transition according to axes generated with Canonical Variate Analysis. It represents the two main axes of shape change among the studied population of projectile points.

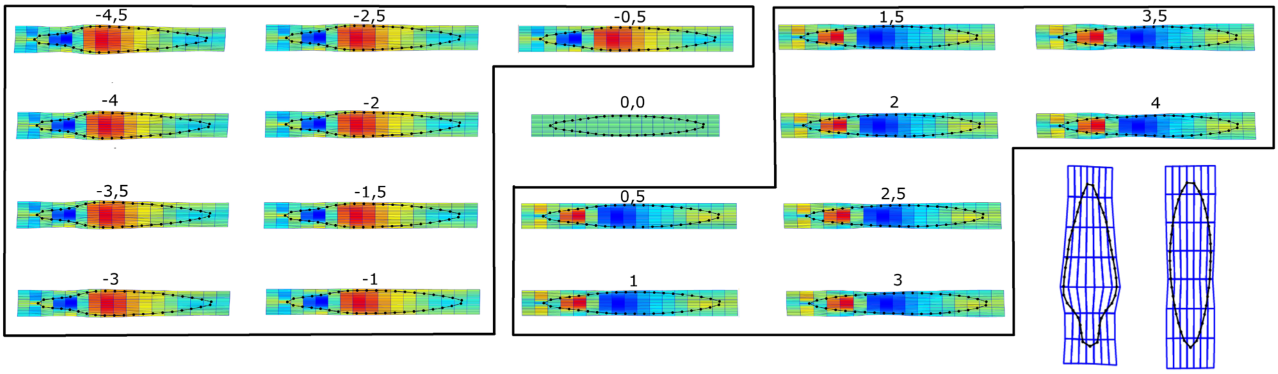

Figure 8. Empirical morphospace generated according to axis 1 of Canonical Variate Analysis. The thin black line separates lanceolate points from tanged points.

this phenomenon can be explained by using a fitness landscape model.

The fitness landscape is a concept in theoretical biology introduced by Sewall Wright almost a hundred years ago (Wright 1932). Since then it has become one of the most fundamental and influential models in evolutionary biology and beyond (i.e., Adami 2012; Laue & Wright 2019; McCanlish 2011; McGhee 2006). Initially, Wright used this concept as a graphical representation of the reproduction success of genotypes in the environment by depicting them as populations moving across a projected geographical landscape full of peaks and valleys (Fig. 9). The fitness assessed to each variant genotype represented the landscape's height on the Z axis, while the combination of all possible genetic variants represented genotype space in these fitness landscapes. The fitness landscape model predicts, that organisms will "climb" these peaks by developing traits, such as specific genes or organs, to maximize fitness.

However interesting and universal this model may seem, we need to keep in mind, that it was developed primarily to describe population dynamics in a strictly deterministic way. In fitness landscape theory, biological fitness refers to an organism's ability to adapt to its environment and thus survive and reproduce. In cultural evolutionary research, fitness can be used to determine the extent to which cultural or technological factors affect human reproduction and survival (Laue & Wright 2019). In the case of utilitarian artefacts, such an approach was introduced by Kuhn and Miller (2015). Their approach views stone tools as patches of utility, which do not provide a direct energy gain, but are being utilized as a mechanical advantage in achieving certain subsistence tasks, such as hunting or butchering. This is reasonable, because tools, similar to environmental patches, are commonly being utilized to the point of failure when they cannot be reutilized or repaired and must be replaced by a new artefact. This process seems analogous to patch exploitation in the natural environment.

The "Artifacts as patches" approach works even better in contexts, where tools are used briefly but intensively. The short use life of such artifacts would play out during a single episode and they have to be designed to perform the intended task most efficiently. A perfect example of such a situation includes projectile hunting weapons and specifically projectile points.

Following this approach, the specific duality in the design of Swiderian, mesolithic and ethnographic projectile points observed in the studied cases as a phenotypic trait, which ensures better fitness and reproductive success in specific hunting conditions. Usually, hunters would make a trade-off by enhancing the most desirable traits at the expense of others (see Witthoft 1968). However, as the ethnographic and archaeological examples indicate, high power-low range and high velocity-long distance projectiles can coexist within the same projectile weapon system to increase hunting flexibility. This selective pressure produces substantial variability in projectile point morphologies ranging from oval shapes to needle-like points coexisting within the same projectile weapon system (Fig. 10).

7. Results and conclusion

The obtained results raise a few interesting issues, both from an evolutionary as well as strictly archaeological perspective.

Geometric-morphometric analysis confirms that points deriving from three different spatiotemporal contexts occupy the same region in the generated morphospace. Along with ethnographic examples, this strongly suggests, that in this case, we are dealing with morphological convergence in points design shape.

In the case of the studied projectile points, we are dealing with two particular types, which evolved independently in different cultures under mechanical, aerodynamical and developmental constraints. The ethnographic examples reveal a simple pattern in projectile design, which seems to occur in the archaeological data as well. In this pattern, we are

Table 3. Factors of the CVA analysis

PC	Eigenvalue	% variance
1	0.00346152	47.116
2	0.00110911	15.096
3	0.000881493	11.998
4	0.000420216	5.7197
5	0.000388703	5.2907
6	0.000216756	2.9503
7	0.000169335	2.3049
8	0.000131097	1.7844
9	8.67552E-05	1.1808
10	7.91117E-05	1.0768

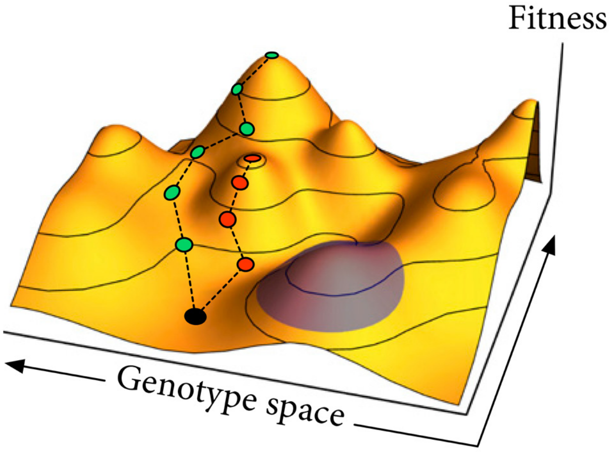

Figure 9. Fitness landscape. The horizontal axes represent the space of different combinations of genotypes, and the vertical axis is individual fitness as a function of genotype (after Van Cleve& Weissman 2015)

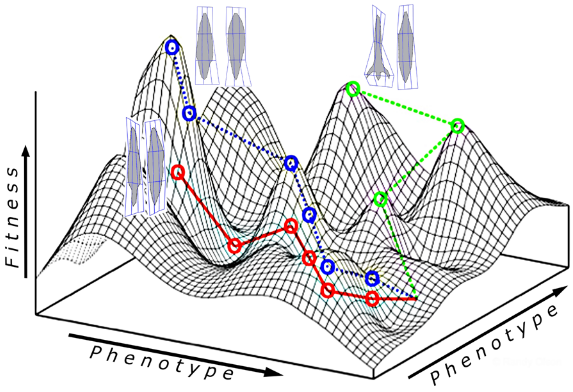

Figure 10. Visualisation of the development of bimodal projectile points as a convergent trait emerging in a rugged fitness landscape. The coloured dots and lines represent pathways of selection of appropriate techno-morphological traits (phenotypes), leading populations to achieve fitness through the application of dual projectiles.

dealing with two types of arrows with different applications: heavier arrows with wide tips are used at close range, while light arrows with slender points are shot at a considerable distance. This mainly results in the formal and functional similarity of projectile points from different contexts.

Certain advantages are coming from the implementation of such bimodal projectiles that make up the overall fitness. First of all, it is a very effective way of dealing with the insufficient transfer of energy of primitive propulsion devices. This improves the performance of projectiles and helps in overcoming the technological constraints of primitive weapons. Secondly, flexible projectile weapon systems allow the hunting of more terrestrial species in changing seasonal conditions and different hunting situations. In this manner, implementing such flexibility to the design of hunting weapons appears as a strictly adaptive trait, which allows for gaining more resources and thus ensures higher reproducibility.

Viewing projectile technology as a fitness landscape we can interpret the convergence in projectile points morphology as striving for evolutionary success. Populations will tend to diversify their projectile points to reach an adaptive peak, which in this particular case means crafting bimodal projectiles (Fig. 10). This conclusion corresponds with the outcomes of geometric morphometric analysis performed in this study. We can interpret the obtained CVA clusters as adaptive peaks (see Fig. 4 and 10). In each of these clusters, we encounter an analogous pattern of points shape change representing the duality in points design and function. Given the chronology and geographical setting of each of these cases, we can assume that this duality emerged independently under certain restrictions as a parallel fitness trait. Therefore, the co-occurrence of points with similar shapes and functions in these contexts can be viewed as an effect of the cultural selection of point morphologies for enhancing biological fitness.

The above conclusions raise an important issue in the taxonomy of projectile points. Natural selective factors, such as the described functional and developmental constraints, seem to play an important role in shaping the techno-morphological features of the described projectile points. This means that the selection of artefacts of the appropriate design under natural restrictions has the potential of creating and shaping artefact variability in the archaeological assemblages. In my opinion, this questions the validity of Swiderian and mesolithic points as "type fossils", given, that their overall design was an outcome of adapting stone points to a specific type of projectile technology. In this manner, these points appear more as a byproduct of technological adaptation, than an actual artefact, especially given their simplistic techno-morphological traits.

Statements

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