Chapter 4
Questioning the Link Between Stone Tool Standardization and Behavioral Modernity

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Abstract For more than 20 years, it has been claimed that standardization is a feature of Upper Paleolithic retouched stone tools, as compared to Middle Paleolithic ones, and reflects the stricter application of mental templates to stone tool-making (e.g., Mellars, Curr Anthropol 30:349–385, 1989a). More recently, this claim has been modified to include stone tool standardization as a feature of modern human behavior (e.g., Klein, J World Prehistory 9:167–198, 1995). It has been argued elsewhere (Chase 1991, Monnier, Cambridge Archaeological Journal 17:341–350, 2007) that standardization and apparent imposition of form in retouched tools reflect factors other than adherence to mental templates. This study tests the notion that standardization is a feature of behavioral modernity by comparing artifact standardization among Middle Paleolithic, Upper Paleolithic, and Neolithic assemblages from western Switzerland. It uses a 2D geometric morphometric approach to quantify variance in shape within selected tool types. The results show that the most highly standardized types occur in the Upper Paleolithic assemblage. Neolithic types are significantly less standardized than Upper Paleolithic types, and are *not* more standardized than Middle Paleolithic ones. This suggests that degree of standardization does not correlate strongly with behavioral modernity; rather, the occurrence of highly standardized tools in many Upper Paleolithic assemblages is a feature unique to the Upper Paleolithic, and the reasons for it most likely do not directly reflect mental templates or any other cognitive factors.

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Introduction

In recent years, there has been much discussion concerning the criteria upon which a definition of modern human behavior should be based (e.g., Klein 1995, 2000, 2008; McBrearty and Brooks 2000; Henshilwood and Marean 2003; d'Errico 2003). The technological criteria used in these definitions often include blade production and standardization of retouched stone tools. A frequently cited example of evidence in support of standardization as an indicator of modern behavior is the Howiesons Poort (HP) type backed tools of the Upper Paleolithic (UP), such as those occurring at the Klasies River main site in South Africa (Wurz 1999). Although the precocious nature of the Howiesons Poort industry was noted ever since its initial discovery, it was Deacon (1989) who stressed the standardization of the backed tools, suggesting they may have been used as symbols to cope with stress during deteriorating environmental conditions. More recently, a study by Wurz (1999) has provided quantitative support for the claim that HP tools are standardized. This study has been widely cited (McBrearty and Brooks 2000; Barham 2002; Henshilwood and Marean 2003; McBrearty 2007; Mellars 2007) in discussions of the apparent "modernity" of many aspects of the Middle Stone Age (MSA). Upon closer examination, however, it becomes apparent that the evidence for standardization provided in this study is somewhat scanty: Wurz looked at only one dimension of standardization, the coefficient of variation (CV) in the length of backed points. Another claim for standardization in the MSA is McBrearty's argument that "African MSA points show formal standardization and stylistic variation across space and time (McBrearty 2007, p. 136)." This claim, however, is primarily based on maps showing the geographic distribution of point styles (McBrearty and Brooks 2000; McBrearty 2007). Given the fact that all such claims for standardization in the African MSA are only weakly supported, this naturally raises the question as to why standardization is so often cited as a criterion of modern human behavior.

The concept of standardization as an indicator of modern behavior has historically been most strongly promoted by Mellars, who in 1989 published two articles which laid the basis for this claim. In the first (Mellars 1989a), he compared lithic technology across the Middle Paleolithic (MP)/Upper Paleolithic (UP) transition, identifying one of the changes in early UP stone tool forms as a higher degree of standardization and "a more obvious degree of 'imposed form' in the various stages of their production and shaping … [which] appear to reflect more clearly conceived 'mental templates' underlying their production" (Mellars 1989a, p. 365). In a separate article included in the proceedings of the Cambridge Human Revolution conference of 1987, he expanded the argument, concluding that increased standardization suggested a greater symbolic or cognitive component on the part of the tool makers (Mellars 1989b). For Mellars, then, who argued that the main feature of modern humans is the capacity for symbolic thinking, standardization of stone tools was one example of this ability. Similar arguments have been used by others. Wurz (1999) cites Byers' action-constitutive theory (Byers 1994) in her argument that standardization among the HP backed tools could be used as evidence of symbolling,

claiming that standardization indicates that behavior was guided by conventional social rules (Wurz 1999, p. 46). McBrearty attributes variation in form among MSA points to style, which she says indicates not only arbitrary, conventional dictates reflective of symbolic communication, but also the boundaries of linguistic or ethnographic groups (McBrearty 2007, p. 136). Regarding HP type tools, Henshilwood and Marean also state that "their imposed form and morphological standardization have clear symbolic significance" (Henshilwood and Marean 2003, p. 630).

This inclination to infer symbolic ability from standardization is challenged by a growing body of work which demonstrates that stone tool standardization and "imposed form" reflect factors other than cognitive ones (Chase 1991; Marks et al. 2001; Monnier 2006b, 2007; Nowell 2002). In some senses, this reflects the persistence of a traditional paradigm, similar to the one that associates blade technology with modern human behavior and that has now been debunked (Bar-Yosef and Kuhn 1999). The purpose of the present study was to contribute to this issue by testing the association between stone tool standardization and behavioral modernity.

The Historical Roots of the Standardization Argument

The paradigm that views increased standardization of stone tools as reflecting increased cognitive abilities has been persistent because it appeals to our intuitive sense that technology has progressed throughout the course of human history. It stems from the formative period of the field in the mid- to late-nineteenth century, when stone tools were seen as becoming increasingly finely worked and perfected through time. According to Trigger (1996), this view was a product of the Enlightenment ideals that pervaded scientific thought in Western Europe in the seventeenth century, lasting into the eighteenth and nineteenth centuries in some fields. These ideals posited that technological and cultural progress have been the main features of human development, and they meshed well with an account of human prehistory that confirmed this view (see Monnier 2006a, for a recent summary). It should therefore not be a surprise that some of our most cherished "facts" are rooted in these ideals. One of these "facts," or perhaps artifacts, is the notion that retouched stone tools become more standardized through time. De Mortillet, for example, stated that Acheulean handaxes became more finely and elegantly worked as they approached the Mousterian (de Mortillet 1883, p. 254). Two decades later, Commont used increasing refinement and perfection of handaxes as one of his criteria for defining phases of the Lower Paleolithic, such as pre-Chellean, Chellean, and Acheulean (Commont 1908). Similar statements can be found many decades later, in papers from a conference devoted to elucidating the Lower/Middle Paleolithic transition (Ronen 1982). It is clear from many of the contributors' comparisons of stone tools between the Lower and Middle Paleolithic that they viewed stone tools as evolving from rough precursors during the Lower Paleolithic to perfected forms by the end of the Middle Paleolithic (Monnier 2006b).

Mellars built on this concept, presenting it as a critical feature of the MP/UP transition (Mellars 1989a, b, 1991, 1996, pp. 133–136). He also linked standardization to the concept of the imposition of arbitrary form. This notion can be traced to Holloway's (1969) classic paper, which proposed that one of the most important elements of human culture is the imposition of arbitrary form upon the environment. Holloway argued that the act of transforming lithic raw material into stone tools is an example of imposition of arbitrary form because "there is no necessary relationship between the form of the final product and the original material" (Holloway 1969, p. 401). This led him to conclude that the shapes of stone tools are symbolic; he further suggested that stone tool-making and language are similar cognitive processes. Around the same time, James Deetz presented his notion of mental templates as "the idea of the proper form of an object [which] exists in the mind of the maker" (Deetz 1967, p. 34). Mellars used both the concept of the imposition of arbitrary form and the notion of mental templates to suggest that the makers of European Middle Paleolithic stone tools did not have the same cognitive abilities as the makers of early Upper Paleolithic stone tools, because the former artifacts were less standardized, exhibiting less imposed form and therefore more poorly defined mental templates.

Testing Standardization

Surprisingly, few studies have tested Mellars' claim that Upper Paleolithic stone tools are more standardized than Middle Paleolithic ones. One of the earliest is Chazan's comparison of measures of standardization and efficiency among Near Eastern and Western European Middle and Upper Paleolithic assemblages, which he used to test the hypothesis that the MP/UP transition was a result of the development of language (Chazan 1995). Chazan used several measures of standardization, one of which was a comparison of the distribution of tools in each assemblage according to metric attributes. He devised another measure of standardization which he called the "index of selection," in order to determine whether specific blanks were selected for retouch (selection of blanks of a specific size or shape would increase standardization among the tools made on these blanks). Unfortunately, this measure is flawed due to the fact that it does not take into account the fact that the original blank size and shape of the retouched pieces most likely changed as a result of retouch. Chazan concluded that there were no substantial differences in standardization between Upper and Middle Paleolithic assemblages. However, a number of commentators on the article found serious flaws with his analysis which, at the very least, call these conclusions into question (Belfer-Cohen 1995; Corbey and Roebroeks 1995; Graves-Brown 1995; Monnier 1995; van Peer 1995; Shea 1995).

In a study on the standardization of Howiesons Poort typed backed tools, Wurz (1999) used Chazan's "index of selection" to assess the size range of blanks that were chosen for the production of backed artifacts at Klasies River main site. She concluded that because more backed artifacts fall into smaller size classes than

"total blade blanks" (she did not specify whether this category includes retouched blades in addition to unretouched ones), smaller blanks were selected for the production of backed artifacts. In other words, she claims that the Klasies River hominins deliberately standardized the backed artifacts by selecting smaller blanks for their production. However, like Chazan's work, this approach ignores the real possibility that the size of the backed artifacts does not reflect the original size of the unretouched blank. Not only did blades likely lose some length as they were backed, but it is also possible that they were segmented, thereby losing a great deal of length. Wurz also tested the suggestion that backed artifacts are less standardized in the MSA than in the Later Stone Age (LSA). She used the CV of length to quantify standardization, and compared Howiesons Poort type backed artifacts from Klasies River main site, Nelson Bay Cave, and others with LSA "Wilton" backed artifacts. Finding that the CV of length is not appreciably greater in the LSA than in the MSA artifacts, she concluded that both types of artifacts "were designed with a comparable mental 'picture'" (Wurz 1999, p. 44). It is important to note, however, that she did not assess the variation for any metrical attribute other than length, such as width or laminarity. In sum, Wurz' data are an inadequate demonstration of standardization among HP backed tools.

In 2001, Marks and colleagues tested the "clarity of mental templates" between modern humans and Neanderthals by comparing burin standardization between Upper Paleolithic and Middle Paleolithic assemblages from the Near East and Western Europe (Marks et al. 2001). They used the CV of metric attributes which showed that the Upper Paleolithic burins are not more metrically standardized than the Mousterian burin sample. They also compared the diversity of burin types across assemblages, concluding that MP single burin types are not more diverse than the UP single burin types. In addition, they studied blank selection, the diversity of the shapes of retouched edges, and diversity in the position of the burin on the blank. None of these measures supported the idea that Upper Paleolithic burin assemblages are more standardized than Middle Paleolithic ones.

Finally, one of us (Monnier 2006b) investigated standardization among retouched stone tools in Middle Paleolithic assemblages from Western Europe. The purpose of that study was to test the notion that retouched tools become more standardized throughout the Middle Paleolithic. Using a variety of measures, including the CV of metric attributes, to quantify both standardization and the number and location of retouch types on each tool, no support for the notion that standardization increases through time in major tool classes of the three sites studied was found in that work.

Background to the Present Study

The previous discussion shows that several innovative measures have been developed to test for differences in standardization, either across the MP/UP or MSA/LSA transitions, or throughout the MP. There are two main problems with these studies, however.

The first is that none of the measures used to quantify standardization is a robust measure of shape. While length/width and width/thickness ratios provide simple shape statistics, they are only poor approximations of the actual shape of the tools. The second problem inherent in the studies that compared standardization across the MP/UP transition relates to the lack of comparability between Middle and Upper Paleolithic tool types. Middle Paleolithic assemblages tend to be dominated by scrapers and denticulates; Upper Paleolithic assemblages are dominated by end-scrapers, burins, and backed blades or bladelets. Marks et al. (2001) were able to solve this problem by finding a tool type common to both the UP and the MP sites in their study. However, in other cases, the problem of comparability between UP and MP contexts is often further exacerbated by blank shape differences. Many MP assemblages are dominated by flake-based technologies, whereas UP assemblages are dominated by blade technologies. In addition, there is the frequently mentioned issue that blades are more standardized in shape than flakes, which means that tools made from blades could appear more standardized than those made on flakes simply because blade blanks are more standardized to begin with. This leads to the circular, and unprovable, argument that blade technologies were used precisely because they produced standardized blanks.

In order to test the relationship between standardization and behavioral modernity, the present study sought to correct the methodological problems described above in two ways. First of all, geometric morphometric techniques were used to better represent shapes and shape differences of the tools. While this approach is most commonly used in the biological sciences, and especially in biological anthropology (see, e.g., Bookstein et al. 2004); Lycett and colleagues (Lycett et al. 2006; Lycett 2007; Lycett and von Cramon-Taubadel 2008) have successfully applied landmark morphometrics to lithic analyses. Geometric morphometric analysis is particularly well-suited to the study of stone tool standardization because it combines detailed models of tool shape with the rigorous methodologies of multivariate statistics. While previous standardization studies have only been able to compare one (e.g., length) or two (e.g., length:width ratio) variables at most, landmark studies can incorporate these traditional variables together with additional points that elucidate the artifactual shape between them. Finally, the mathematical transformations commonly used in geometric morphometrics remove isometric size differences between specimens. This is particularly important in standardization studies, where size and shape are easily confounded. While both factors undoubtedly play a role in standardization, it is crucial that they be addressed independently, so that the precise factors affecting standardization can be identified.

This study also sought to improve upon previous studies of standardization in MP and UP assemblages by adding two samples that are also associated with modern humans but from another time period. The Upper Paleolithic, it has often been pointed out, is not representative of the behavior of modern people everywhere, so our inclusion of Neolithic flaked stone assemblages from the same region provided a useful control. If stone tool standardization is a feature of modern human behavior, one would expect it to be greater in Neolithic as well as Upper Paleolithic assemblages than it is in Middle Paleolithic assemblages.

We tested the association between increased standardization and behaviorally modern humans by looking at the amount of variance present in different tool types from different modern human and Neanderthal localities. A strict interpretation of the "standardization hypothesis" would suggest that all tools associated with behaviorally modern humans conform to a more precise mental image than tools associated with more primitive human populations. A more relaxed interpretation might allow modern humans the *capacity* for greater standardization, whereby standardization is not uniformly sought, but might vary instead by tool types. Alternatively, if results show no difference in standardization, random differences, or standardization according to other factors (such as locality or raw material), this would support hypotheses that the degree of uniformity may reflect factors other than the mental capacity for generating preconceived templates.

Materials

In order to control for as many local factors as possible, the assemblages used in this study were chosen from a small region in western Switzerland and are all within 70 km of each other. This region encompasses the northern shore of Lake Neuchâtel and a nearby valley in the Jura Mountains. The Neolithic and Upper Paleolithic sites are located within 12 km of each other on the shore of the lake; the Middle Paleolithic site is 70 km to the North in a valley of the Jura.

Neuchâtel-Monruz

This site was discovered in 1989 during construction of the A5 autoroute along the northern and western shores of Lake Neuchâtel (Bullinger et al. 2006b). A salvage excavation was undertaken from 1989 to 1992, part of which entailed the removal of a 6×12-m block of the site for later excavation (Arnold 2006). The site contained both Azilian and Magdalenian occupations; the Magdalenian occupation was dated to 13,000 BP by C14 on charcoal taken from hearths. The Magdalenian level contained numerous hearths, well-preserved fauna, lithic and bone industries, ochre, and personal adornment items made from worked shell and jet. The lithic industry comprises more than 45,000 pieces larger than 1 cm; 1,354 of these are retouched tools, consisting of backed bladelets, burins, piercers, endscrapers, and pièces esquillées. Although 60% of the raw materials consist of a local, rather coarse-grained flint (Hauterive), the bulk of the retouched tools are made on much finer-grained flints imported from the Jura mountains to the north, between 80 and 150 km away. The retouched tools, analyzed by Bullinger et al. 2006a, are dominated by an abundance of backed bladelets, as well as burins and *perçoirs*. A random sample of complete (unbroken) backed bladelets and endscrapers was included in this study.

Auvernier-Port and Auvernier-la-Saunerie

The Auvernier sites are a series of Middle and Late Neolithic and Late Bronze Age villages located along a 1 km stretch of the northern shore of Lake Neuchâtel. The locality "La Saunerie" was discovered in the mid-nineteenth century and excavated by the Swiss archaeologist Paul Vouga from 1920 to 1930, who defined the Swiss lacustrine Neolithic on the basis of the stratigraphy of this site (Boiseaubert 1982). It was subsequently excavated by André Leroi-Gourhan and Samuel Perret from 1948 to 1950, by Christian Strahm from 1964 to 1965, and by Jean-Luc Boiseaubert from 1972 to 1975. The excavations during the 1960s and 1970s were carried out as part of a salvage project during the construction of the national highway RN 5. They revealed many other localities, such as Auvernier-Port, which has been dated to the Cortaillod period (approximately 3900–3400 BCE) of the Middle Neolithic. Dendrochronology of the pillars at Saunerie has revealed that the trees were cut between 2600 and 2434 BC, thereby dating the main component of the site to that period. The material culture from this site has been used to define a new facies, "Auvernier," of the Final Neolithic.

Although many publications on Auvernier-la-Saunerie exist, the lithic assemblage has not yet been published in its entirety. Much of Auvernier-Port also remains unpublished. The study of the material curated at the Laténium museum comprised 267 retouched artifacts from Auvernier-Port and 280 retouched artifacts from Auvernier-la-Saunerie, which were typed according to Honegger's (2001) typology of Middle and Final Neolithic retouched lithic artifacts. Because the raw materials used in prehistoric times in the region have been extensively studied (Affolter 2002), it was possible to identify some of the main differences between the two industries, such as differences in source material. At La Saunerie, almost 15% of the lithic component consists of large blades of Grand-Pressigny flint, imported from central France. These blades are often heavily retouched and reworked, and most often appear as retouched blades, knives, and endscrapers, although they sometimes have notches at the distal and proximal ends typical of laterally hafted knives or "saws" (like the bifacially worked *scie à encoches*). Other than the imported Grand-Pressigny materials, the inhabitants at La Saunerie made significant use of the local coarse-grained "Hauterive" chert. At Auvernier-Port, on the other hand, no Grand-Pressigny material is present at all. The industry is dominated (almost 50%) by fine-grained flints imported from the foothills of the Jura mountains 80–150 km to the north, especially "Kimmeridgien," a light-colored grey flint which often patinates black. This material seems to have been flaked on site (as opposed to the Grand-Pressigny flint at Saunerie, which was mostly imported as blades) using prismatic blade technologies.

Alle-Pré Monsieur

This open-air Mousterian site was discovered in 1992 during construction of the trans-Jura autoroute (Stahl Gretsch and Detrey 1999). It is located on a slope bordering the alluvial plain of the Allaine River, in a valley of the Jura Mountains

of western Switzerland. During the two seasons of excavation, over 100,000 worked lithics were recovered from approximately 157 m^2 and 12 archaeological layers. Fauna was unfortunately not preserved. Taphonomic issues include slippage of some of the artifact-bearing sediments downslope, which reversed the stratigraphy in several instances; absolute dating was attempted but failed. Nevertheless, a Mousterian affiliation for the site is possible due to the large percentage of Levallois cores and typical Mousterian retouched flake tools such as sidescrapers and déjeté scrapers. The most abundant archaeological layer, layer 2, which has been suggested by sedimentological analyses to date to the Eemian, or first portion of MIS 5, was used in this study. This layer yielded over 28,000 lithics, of which over 700 are Levallois flakes and 1,500 are retouched tools. The layer also yielded over 2,000 cores, half of them Levallois. One of us (G.F.M.) studied the entire retouched assemblage from this level and typed it according to Bordes' (1961) typology.

Selection of Artifacts for Inclusion in the Study

Many more artifacts were studied and photographed (see Methods) than were included in the analysis. The selection of artifact types for inclusion here was done only after all the assemblages had been studied. The reason for this was a desire to compare, as much as possible, the variance between similar tool types across different sites and time periods. Thus, once counts were tallied and the types most common across the assemblages were identified, all the artifacts from those types were included in this analysis.

Methods

We used 2D landmarks to capture and quantify the variation in shape of different tool types from different sites. Artifact shapes were collected from digital photographs of 297 artifacts from the four sites. Artifacts from Auvernier-Port and Auvernier-la-Saunerie were photographed at the Laténium museum in Neuchâtel using a Nikon D200 camera, macro lens, and lighting apparatus generously provided by the museum. Artifacts from Monruz were photographed at the Laténium annex using a Canon PowerShot A95 camera mounted on a light box. Artifacts from Pré Monsieur were photographed using the same equipment at the Office of Culture of the Jura canton in Porrentruy.

Orientation of the Artifacts and Location of the Landmarks

Since stone tools have few true landmarks, in the sense of "homologous anatomical loci that do not alter their topological positions relative to other landmarks" (Zelditch et al. 2004, p. 24), locating landmarks was a challenge. In fact, other than

the point of percussion and possibly the end points of the platform, there are no landmarks that can reliably be found on all stone tools. Since this study was concerned with retouched tools, we used a series of semilandmarks oriented on the artifacts according to tool axis. Tool axis was defined visually as the line bisecting the tool along its axis of maximum symmetry. While a more common way of orienting lithic tools is along the flaking axis of the tool blank, the removal of the platform on many of the tools precluded the use of this method.

The endpoints of the axis of tool symmetry provided two type II landmarks (Bookstein 1991). In order to better capture the tool morphology in a repeatable and consistent manner, however, a "comb" (see Fig. 4.1) with 12 equally spaced lines was applied to the photograph of each artifact, with a perpendicular line along the tool axis. Additional type III semilandmarks were thereby defined as the points at which the lines of the comb intersect the periphery of the artifact (all data are available for viewing online, see Monnier and McNulty 2009).

Combs were generated on digitized photographs using the software MakeFan6 (Sheets 2003), and landmarks were placed with a stylus using a Gateway Tablet notebook PC running tpsDig (Rohlf 2006). To calculate mean configurations and to visualize shape differences, landmarks for all artifacts within a tool type from a single site (e.g., backed bladelets from Monruz) were separately superimposed by generalized Procrustes analysis (Gower 1975; Bookstein 1991; Goodall 1991; Dryden and Mardia 1998) in the software CoordGen (Sheets 2003). Since there is no consensus on whether one should allow semilandmarks to "slide" during superimposition, both methods were tried in this study and the impact found to be negligible. Results reported here are based on semilandmarks that were not slid. Superimposed landmark configurations for each tool type from each site are illustrated in Figs. 4.2–4.9.

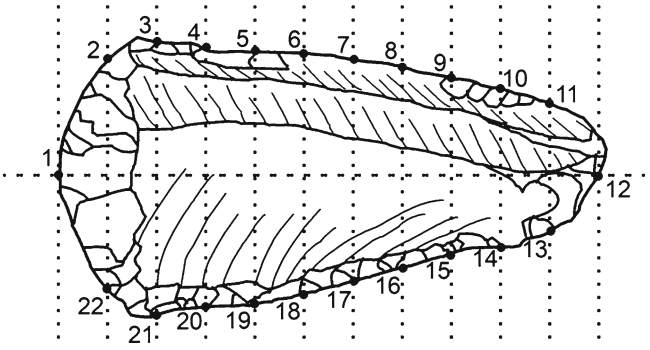

Fig. 4.1 Position of landmarks on each artifact according to the placement of "comb" along the axis of maximum symmetry of tool

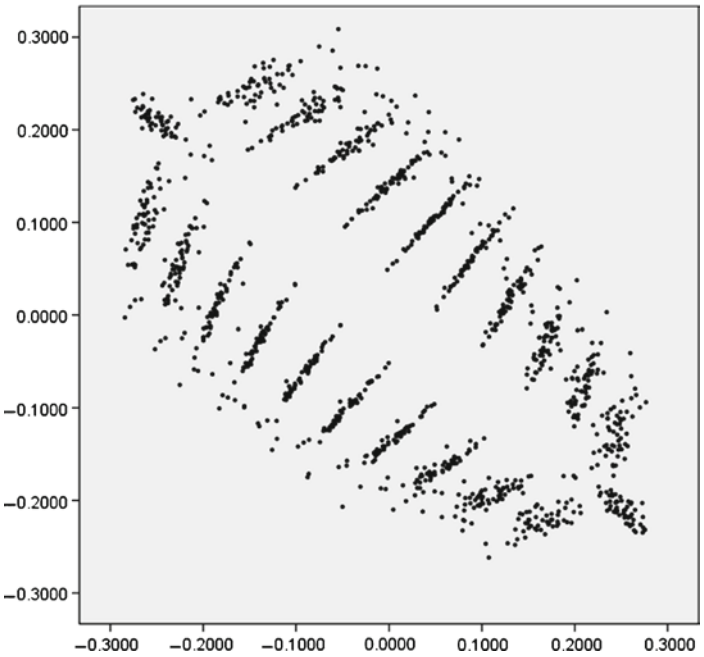

Fig. 4.2 Superimposed landmark configurations for Auvernier-Port retouched blades ($N=59$)

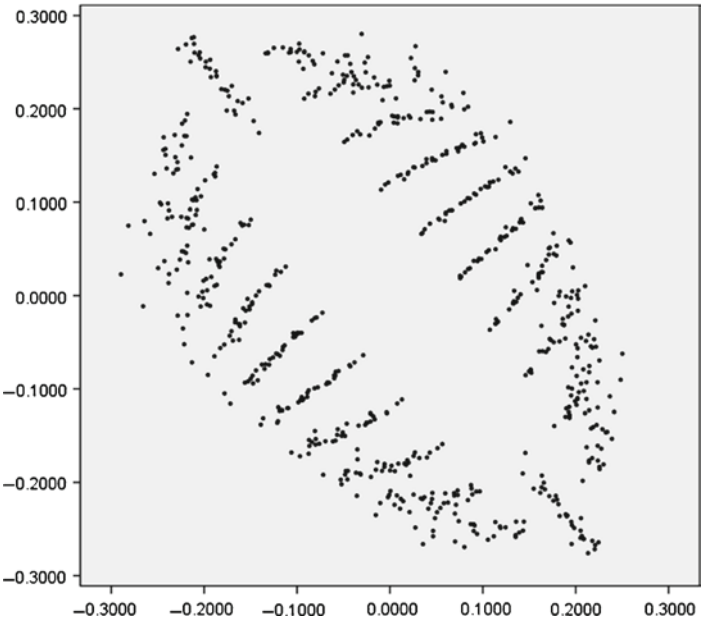

Fig. 4.3 Superimposed landmark configurations for Auvernier-Port endscrapers ($N=32$)

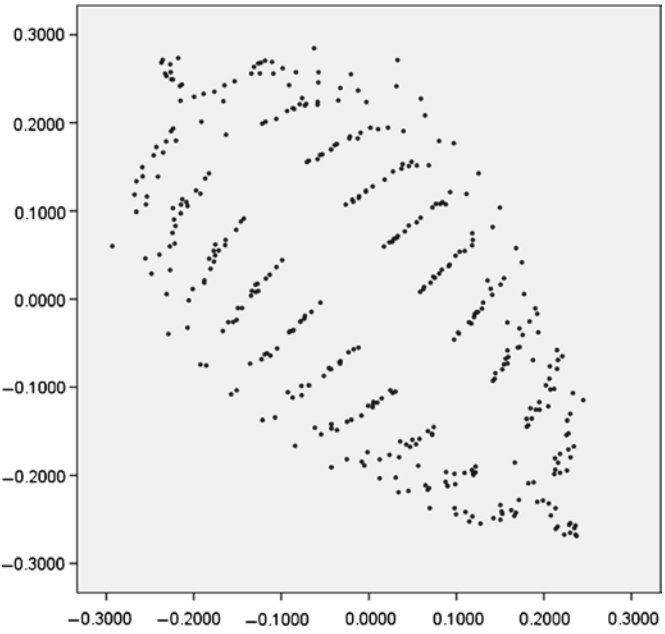

Fig. 4.4 Superimposed landmark configurations for Auvernier-Saunerie retouched blades ($N=18$)

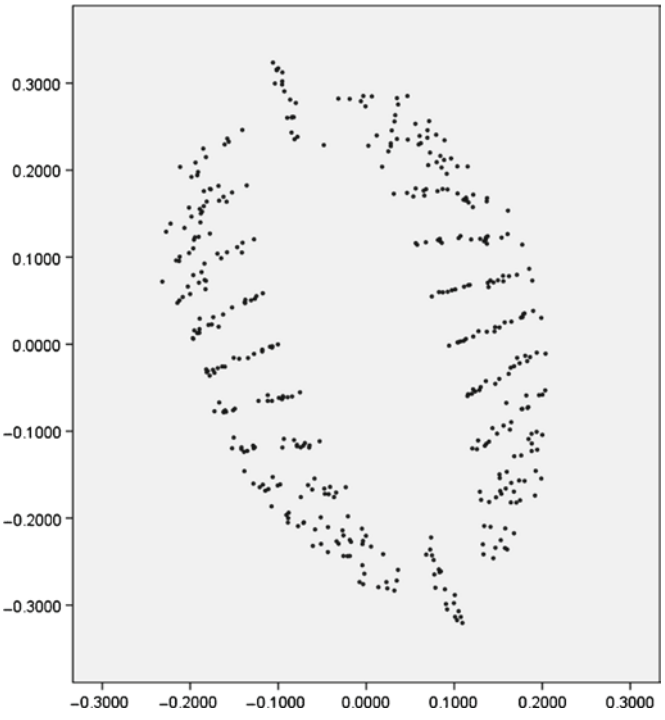

Fig. 4.5 Superimposed landmark configurations for Auvernier-Saunerie endscrapers ($N=20$)

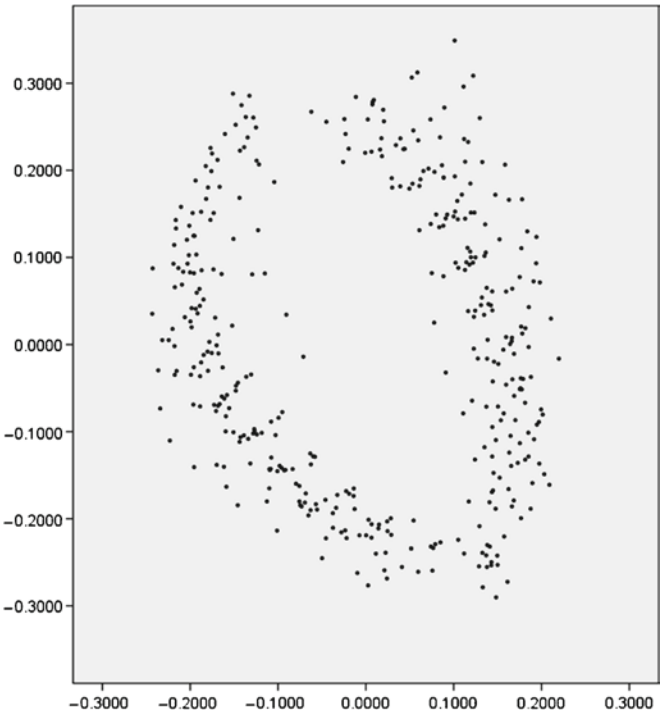

Fig. 4.6 Superimposed landmark configurations for Auvernier-Saunerie unifacially retouched flakes ($N = 18$)

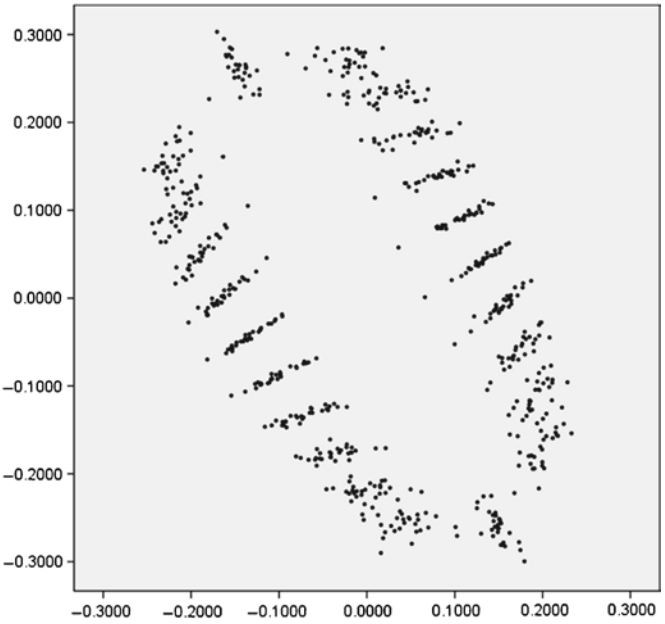

Fig. 4.7 Superimposed landmark configurations for Monruz endscrapers ($N = 29$)

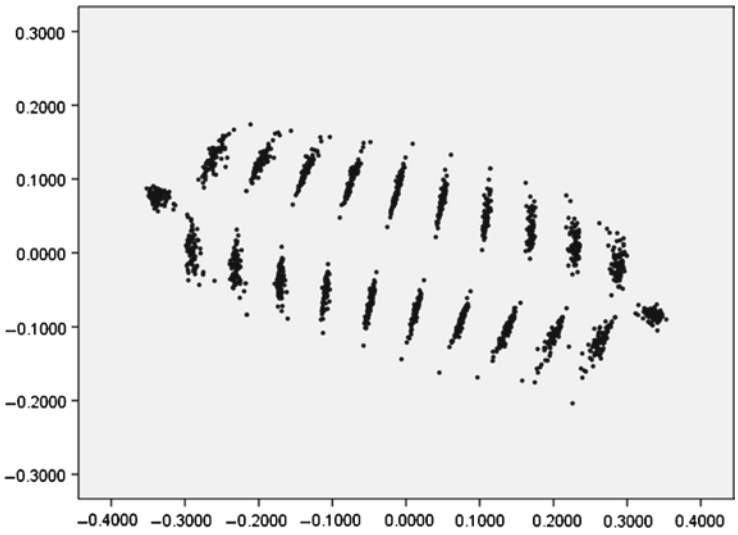

Fig. 4.8 Superimposed landmark configurations for Monruz backed bladelets ($N=82$)

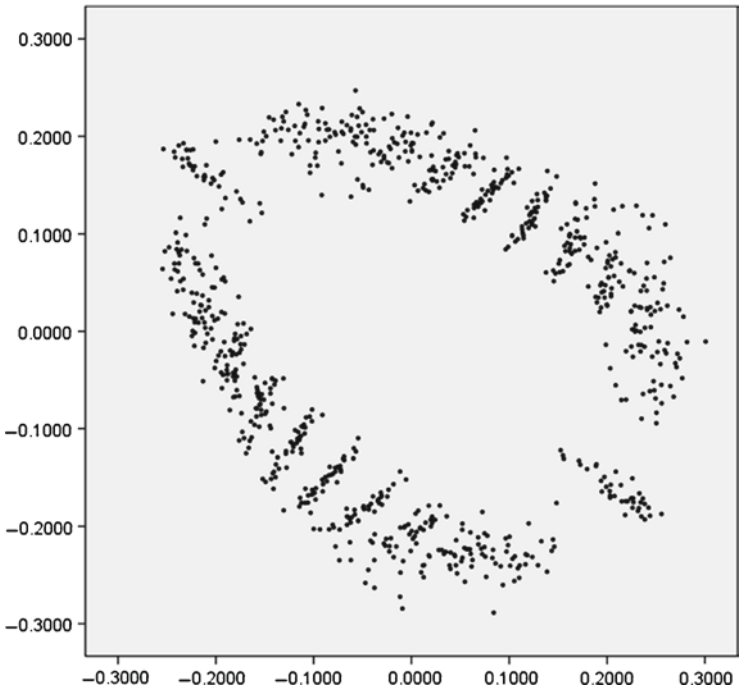

Fig. 4.9 Superimposed landmark configurations for Pre Monsieur convex single sidescrapers ($N=39$)

Calculation of Shape Variance

Since tool variation may not be comparable from one tool type to the next, specimens were separated into categories according to maximum comparability of tool type. This resulted in three sets of comparable tool types which span multiple time periods. Set 1 contains the endscrapers from Monruz, Auvernier-Saunerie, and Auvernier-Port. Set 2 contains the types "retouched flakes" from Auvernier-Saunerie and "single convex sidescrapers" from Pré Monsieur. Set 3 contains retouched blades from Auvernier-Saunerie and Auvernier-Port, and backed bladelets from Monruz.

The first step in evaluating the association between degree of standardization and behavioral modernity was to calculate the total variance in all superimposed landmark configurations for each tool type at each site. Mathematically, this variance is equivalent to the average Procrustes squared distance between each specimen in the category and the category mean configuration. These values summarized the amount of shape difference, i.e., the degree of standardization, exhibited for each tool type at each site. To determine whether standardization in comparable tool types (i.e., within but not between sets) was significantly different by locality, we applied a non-parametric Kruskal–Wallis test to both set 1 and set 3 tools, with specimens' Procrustes distances to their locality means as the dependent variable. Significant results were further elucidated by post hoc pairwise tests.

Differences in standardization between pairs of localities within a tool set were tested using non-parametric permutation tests. Because unequal sample sizes can significantly affect the results of these tests (McNulty et al. 2006), permutations were based on randomly generated balanced samples such that permuted groups had an equal probability of being populated by specimens from either test group. Permutation tests were carried out in SAS 9.1 based on programming code modified from McNulty (2005). Importantly, permutations were not done on the coordinate data, as this would involve calculating the means of permuted groups and thereby artificially inflating the variance within these randomized samples due to potential mean shape differences between sites. Instead, permutations were done specifically on the component of variance associated with each specimen, i.e., its Procrustes squared distance to its original group mean. Each permutation test was repeated 10,000 times, generating a probability distribution from which we tested the null hypothesis that the original difference in variance between the two groups was sampled from a common variance shared by both groups. Corrections for multiple comparisons were not used due to the small number of comparisons (not more than three for any tool type), and with only one exception significant p-values were well below the threshold of the most conservative (e.g., Bonferroni) corrections. In no case were experiment-wise alpha values above 0.05.

Results

The variances in shape within each sample are summarized in Table 4.1. The lowest variances occur among Neuchâtel-Monruz' backed bladelets (var = 0.008) and endscrapers (var = 0.015). The highest variances come from the Neolithic sites, especially Auvernier-Saunerie retouched blades (var = 0.035), unifacially retouched flakes (var = 0.031), and endscrapers (var = 0.028). The endscrapers from Auvernier-Port (var = 0.034) are also among the most variable tool type included in the study. Interestingly, the variance among sidescrapers from Pré Monsieur falls in the middle of this range (var = 0.022). In other words, the least variable (most standardized) tool types are those from the Upper Paleolithic site; the most variable are from the Neolithic sites. Nevertheless, such comparisons across tool types may not be informative since one might expect differences in the amount of standardization in tools of different shapes and functions.

Results of significance tests within tools sets (Table 4.2) are highly pertinent, however. Both endscrapers and blade/bladelet tool sets exhibited significant differences among localities. Pairwise permutation tests demonstrated which localities

Table 4.1 Summary information and variances for each sample

	Site	Period	Likely Hominin	Tool type	*N*	Variance
Set 1	Auvernier-Saunerie	Late Neo	Modern	Endscrapers	20	0.028
	Auvernier-Port	Mid-Neo	Modern	Endscrapers	32	0.034
	Neuchâtel-Monruz	UP	Modern	Endscrapers	29	0.015
Set 2	Auvernier-Saunerie	Late Neo	Modern	Retouched flakes	18	0.031
	Pré Monsieur	MP	Neanderthal	Sidescrapers	39	0.022
Set 3	Auvernier-Saunerie	Late Neo	Modern	Retouched blades	18	0.035
	Auvernier-Port	Mid-Neo	Modern	Retouched blades	59	0.024
	Neuchâtel-Monruz	UP	Modern	Backed bladelets	82	0.008

Table 4.2 *p*-Values for Kruskal–Wallis tests of differences in variance within tool sets and for permutation tests of differences between samples in each set (*p*-values significant at the 0.05 level are in **bold**)

	Samples compared	Tool type	Permutation test results
Set 1 ($p = 0.0048$)	Saunerie vs. Port	Endscrapers	$p = 0.4848$
	Monruz vs. Port	Endscrapers	$\mathbf{p = 0.0065}$
	Monruz vs. Saunerie	Endscrapers	$\mathbf{p = 0.0366}$
Set 2	Pré Monsieur vs. Saunerie	Sidescrapers vs. retouched flakes	$p = 0.2370$
Set 3 ($p < 0.0001$)	Saunerie vs. Port	Retouched blades	$p = 0.2827$
	Monruz vs. Port	Backed bladelets vs. retouched blades	$\mathbf{p < 0.0001}$
	Monruz vs. Saunerie	Backed bladelets vs. retouched blades	$\mathbf{p < 0.0001}$

Kruskal–Wallis *p*-values are given next to the set number. Set 2 has only two samples and was therefore only tested using a pairwise permutation test

are different for these sets and provided a significance test for the sidescrapers/retouched flakes. These results indicate that the variances among tool types from Monruz are always significantly different from the variances among comparable tool types from the Neolithic contexts. More precisely, among both endscrapers and retouched blades, the artifacts from Monruz are significantly less variable in shape (i.e., more standardized) than those from either Auvernier-Port or Auvernier-Saunerie. Regarding the Middle Paleolithic assemblage from Pré Monsieur, there is unfortunately no direct comparison that can be made between tools from this site and any from Monruz. However, we decided to compare convex sidescrapers from Pré Monsieur with retouched flakes from Auvernier-Saunerie. While these tool types are not identical, we deemed them to be comparable, since they both involve lateral retouch on flakes. The difference between the two variances was not significant. In other words, the Neolithic retouched flakes are *not* more standardized than the Middle Paleolithic sidescrapers, which is contrary to the expectations of the standardization hypothesis, in which tools created by modern humans should be more standardized than those created by Neanderthals. While it is tempting to interpret this result as meaning that both Pré Monsieur and Saunerie tools *lack* standardization, it in fact demonstrates that they are equally standardized.

Discussion

The idea of standardization is intuitively satisfying in the context of cultural evolution, particularly when considering more than two million years of lithic technological change. However, like any trait associated with human evolution, general trends that seem obvious when one considers the broad scale of change may lose explanatory power when applied to the smaller branches or segments of our lineage. Add to this the complexity of cultural adaptation and reticulation and such trends become more difficult to apply generally.

That behaviorally modern humans would have a greater capacity to envision and shape stone tools is an attractive hypothesis that coincides with historical concepts of modernity. But to support this hypothesis – specifically to provide evidence that modern humans had a superior ability to form "mental templates" and "impose form" on their tools – one should be able to demonstrate this broadly, if not exclusively, across multiple modern technologies, multiple modern cultures, multiple tool functions, and multiple raw materials. Moreover, evidence should address the myriad alternative explanations, such as function, technology (Chase 1991), raw material, reduction, and even typology (Dibble 1989) that may also explain variance in standardization (see also Monnier 2006b). Unfortunately, such a test is difficult to conceive. One cannot make reasonable comparisons in standardization between different types of tools, yet the very nature of cultural change means that there is little overlap in tool types between MP and UP assemblages.

This project represents one specific test of the hypothesis that standardization is a feature of behaviorally modern humans, and it builds on work by previous researchers (Chazan 1995; Wurz 1999; Marks et al. 2001; Monnier 2006b).

Unlike the studies by Chazan (1995) and Wurz (1999), however, our results do not support the notion that standardization reflects linguistic or mental categories. We emphasize that other factors must be considered before differences in standardization can be applied to cognitive factors. Secondly, this study methodologically improves upon previous studies of standardization (Marks et al. 2001; Monnier 2006b) by applying a new measure of artifact shape which is much more comprehensive than the traditional linear measurements.

The most salient result is the lack of difference in standardization between the MP Pré Monsieur sidescrapers and the retouched flakes from the Neolithic site of Auvernier-Saunerie. According to the standardization hypothesis, we would expect the Neolithic tools, which were made by modern humans, to be more standardized than the Middle Paleolithic ones, which were made by Neanderthals. This shows that our intuitions are not always correct. An explanation for this result can be found by studying the results of the variance differences between the UP site Monruz and the Neolithic Auvernier sites. For both tool types (endscrapers and backed bladelets), the Monruz tools are more standardized than the corresponding Neolithic tools. We believe that there is a simple explanation for this result. The Monruz tools appear to be highly specialized: they are made on imported, high-quality raw material which was knapped into series of blades and bladelets (Bullinger et al. 2006b) and most likely hafted. The Neolithic tools were also made on high-quality, exotic raw material (in the case of Auvernier-Saunerie, on Grand-Pressigny flint from France, over 400 km away) and some of them were certainly hafted in wooden shafts (which we know from instances of preserved hafted retouched blades and flakes). However, the Neolithic retouched blades and endscrapers are much more highly reduced than the Upper Paleolithic artifacts. This is especially true at Auvernier-Saunerie, where the large imported blades of Grand-Pressigny flint were heavily reworked, often around the entire periphery of the tool. These blades were sometimes heavily retouched laterally, achieving the morphology of long, narrow "rods," while others were truncated and turned into endscrapers (with retouched lateral edges). There is continuous overlap between these two categories (retouched blades and endscrapers), much as has been demonstrated for Mousterian tool types by Dibble (1984). This overlap could therefore introduce greater variability within the type categories in the Auvernier sites than exists at Monruz. These results make it difficult to reconcile standardization with a better capacity for mental imaging or imposition of form; presumably, the Neolithic and Magdalenian populations had similar mental and behavioral capabilities. Yet their production of similar forms, forms that ought to derive from equally detailed mental templates, shows a significant difference in standardization.

Ultimately, the idea of "standardization" seems to be a poor arbiter for which human groups were behaviorally modern and which groups were not. In that sense, there is little evidence to suggest that modern humans had a greater mental capacity to generate idea templates or to impose these ideas on their natural world. The factors leading to standardization as well as the behavioral and cognitive differences between early modern humans and their relatives comprise an exciting and fruitful avenue of research. However, the traditional imposition of a linear form on the *concept* of standardization

has obscured the real diversity that was present in these groups, and impeded our knowledge of the generative processes that resulted in modern human behavior.

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