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# A geometric morphometrics-based assessment of blade shape differences among Paleoindian projectile point types from western North America

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ABSTRACT

Blade shape features in the type definitions of Clovis, Folsom, and Plainview projectile points. However, the accuracy of these assessments has never been evaluated. Here we report a study in which geometric morphometrics and multivariate statistics were used to compare the shapes of the blades of Clovis, Folsom and Plainview points from the Southern Plains of North America. In the course of the analyses, we controlled for the impact of three potential confounding factors: allometry, differences in raw material quality, and resharpening. The analyses show that blade shape distinguishes Clovis points from both Folsom points and Plainview points, but does not distinguish Folsom points from Plainview points. The analyses also show that the similarities and differences in blade shape among the types are independent of allometry, raw material quality, and resharpening. These findings suggest that the type definitions for Clovis, Folsom and Plainview need to be altered. They also have implications for typing specimens that lack other defining characters (e.g. channel flakes, flutes). Lastly, the absence of resharpening effects raises questions about the validity of the reduction thesis.



## 1. Introduction

Clovis, Folsom, and Plainview projectile points are crucial to our understanding of the Paleoindian period in western North America. Clovis points are found throughout the region. They first appear ca. 13,340 calendar years before present (calBP) and disappear ca. 12,830 calBP (Holliday, 2000). Folsom points are mostly found in the Great Plains and Rocky Mountains. According to the conventional chronology, they follow Clovis points in time. They appear ca. 12,830 calBP and disappear ca. 11,900 calBP (Holliday, 2000; Taylor et al., 1996). Plainview points are generally restricted to the Great Plains. Their dating is not secure, but they are thought to overlap with Folsom points on the younger end of the latter's time range (Holliday et al., 1999).

Blade shape features in the definitions of all three types (Wormington, 1957). Clovis and Plainview points are described as having parallel to slightly convex sides, while Folsom points are suggested to be lanceolate or lozenge shaped. However, the accuracy of these assessments has never been evaluated. With this in mind, we used geometric morphometrics and multivariate statistics to compare the shapes of the blades of a sample of points from the Southern Plains of North America that have been previously identified as Clovis, Folsom, and Plainview. In the course of the study, we controlled for the confounding effects of size-related shape change or "allometry". We also controlled for the impact of raw material and resharpening, since these have been claimed to affect the distinctiveness of lithic artifact types (Andrefsky, 2009; Dibble, 1995; Flenniken and Raymond, 1986; Flenniken and Wilke, 1989; Hoffman, 1985; Odell, 2001; Shott, 2005).

## 2. Materials and methods

The sample comprised 28 Clovis, 47 Folsom, and 111 Plainview points (Table 1). Published sources were used to assign the points to type. The main means of typing points employed in the sources are chronometric dating, faunal association, and co-occurrence with other easily typed points. None of the points was typed solely on the basis of blade shape.

In order to analyze the full range of variability associated with each point type, only points from assemblages recovered from unmixed contexts were included in the sample. Incorporating isolated specimens found on the surface would have increased the size of our sample, but it likely would also have biased our results. The reason for this is that isolated, surface-collected points that have been typed are necessarily distinctive and therefore tend to be less morphologically variable than assemblages of points, which

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**Table 1**
The number of projectile points from each assemblage by type used in the analysis.

| Site/assemblage | Type | Number of points | References |
|---|---|---|---|
| Blackwater Draw | Clovis | 22 | Boldurian and Cotter, 1999; Cotter, 1937, 1938; Hester, 1972; Howard, 1935; Warnica, 1966 |
| Domebo | Clovis | 3 | Leonhardy, 1966 |
| Miami | Clovis | 3 | Holliday et al., 1994; Sellards, 1938, 1952 |
| Blackwater Draw/ Mitchell Locality | Folsom | 2 | Boldurian, 1990 |
| Blackwater Draw | Folsom | 12 | Boldurian and Cotter, 1999; Hester, 1972 |
| Cooper | Folsom | 10 | Bement, 1999a,b; Johnson and Bement, 2009 |
| Lake Theo | Folsom | 3 | Buchanan, 2002; Harrison and Killen, 1978; Harrison and Smith, 1975 |
| Lubbock Lake | Folsom | 6 | Johnson, 1987 |
| Shifting Sands | Folsom | 14 | Amick et al., 1989; Hofman et al., 1990 |
| Milnesand | Plainview | 39 | Johnson et al., 1986; Sellards, 1955; Warnica and Williamson, 1968 |
| Plainview | Plainview | 10 | Holliday, 1997; Knudson, 1983; Sellards et al., 1947 |
| Ryan's | Plainview | 11 | Hartwell, 1995 |
| Ted Williamson | Plainview | 51 | Buchanan et al., 1996; Johnson et al., 1986; Warnica and Williamson, 1968 |

often include specimens that have been typed by other means. Consequently, including isolated points in the sample would have falsely increased the chances of finding blade shape differences among the types.

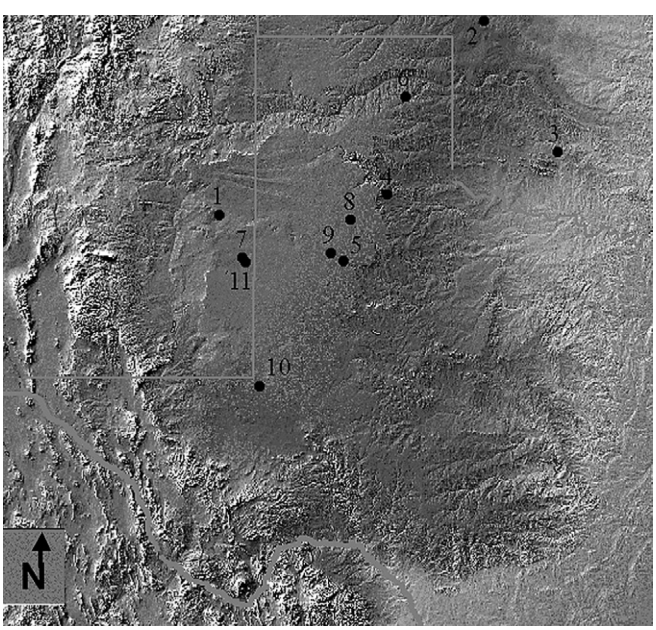


**Fig. 1.** Orthophotograph of the Southern Plains including portions of western Oklahoma, west Texas, and Eastern New Mexico showing the locations of assemblages in the analysis. Site names: 1 = Blackwater Draw. 2 = Cooper. 3 = Domebo. 4 = Lake Theo. 5 = Lubbock Lake. 6 = Miami. 7 = Milnesand. 8 = Plainview. 9 = Ryan's. 10 = Shifting Sands. 11 = Ted Williamson.

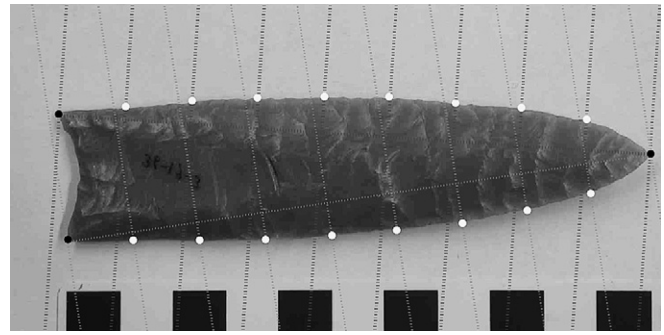

**Fig. 2.** Digital image of a projectile point with the locations of three primary landmarks (black circles) and 16 secondary landmarks (white circles) marked on the projectile point. The lines superimposed on the point image were produced using the MakeFan program.

The points come from 13 assemblages recovered from 11 sites. All the sites are located in the Southern Plains (Fig. 1). The Southern Plains consists of the Southern High Plains and the Rolling Plains. The former is an almost featureless plateau covering over 130,000 km$^2$ of western Texas and Eastern New Mexico (Holliday, 1995). Also known as the Osage Plains, the Rolling Plains are more topographically variable than the Southern High Plains. They lie to the east of the latter, and cover west-central Missouri, southeastern Kansas, and most of central Oklahoma. They also extend into north-central Texas. Ten of the sites are located in the Southern High Plains, and three in the Rolling Plains.

Three of the assemblages have been typed as Clovis (Blackwater Draw, Domebo, Miami), six as Folsom (Blackwater Draw, Blackwater Draw-Mitchell Locality, Cooper, Lake Theo, Lubbock Lake, Shifting Sands) and four as Plainview (Milnesand, Plainview, Ryan's, Ted Williamson). All the Clovis assemblages are associated with

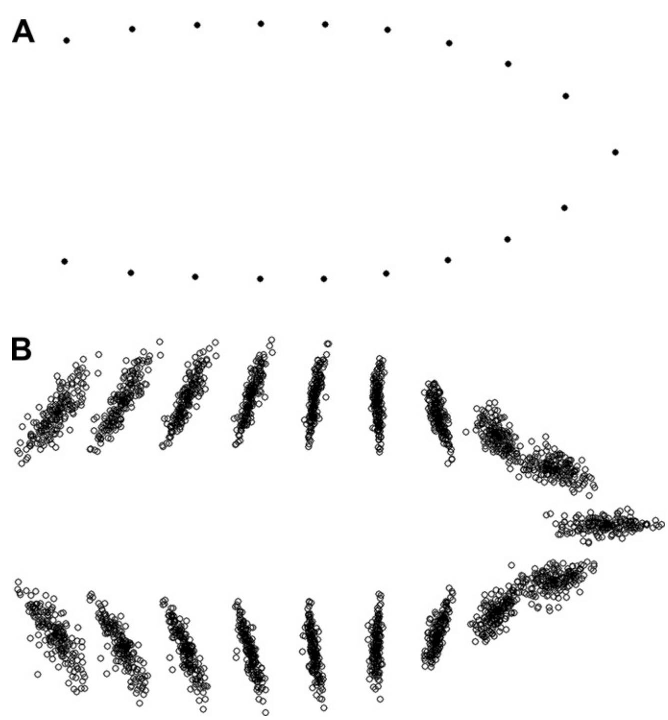


**Fig. 3.** Results of the superimposition method using the generalized orthogonal least-squares Procrustes procedure. A) Consensus configuration of 186 projectile point landmark configurations. B) Variation in projectile point landmark configurations after being translated, scaled, and rotated.

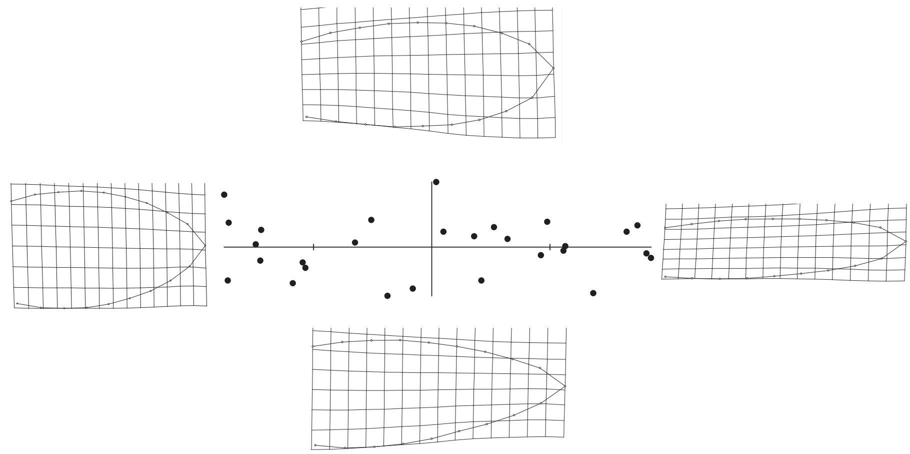


**Fig. 4.** Bivariate plot of relative warp 1 (91.9%) against relative warp 2 (3.6%) for all Clovis specimens. The four projectile point images are deformations from the consensus configuration that are used to display the shape space defined by the first two relative warps.

mammoth kills. Some of the Folsom assemblages were recovered from campsites (Blackwater Draw-Mitchell Locality and Shifting Sands). The others were recovered from bison butchering locales (Blackwater Draw, Cooper, Lake Theo, and Lubbock Lake). The Plainview assemblages are from a campsite (Ted Williamson), two bison butchering sites (Milnesand and Plainview), and a cache (Ryan's).

We have used a number of the points in previous studies. The samples of Folsom and Plainview points used in this study differ from the samples used by Buchanan (2006) and Buchanan et al. (2007). Buchanan (2006) focused on Folsom points from the Southern Plains made only of Edwards chert in order to measure shape change with distance from source. This restriction was removed in the present study and seven points made of raw materials other than Edwards chert were added to the sample. Seven Folsom points used by Buchanan (2006) were excluded from the study reported here because they were insufficiently complete. Buchanan et al. (2007) also employed a number of incomplete specimens in their analysis of Plainview points. These specimens were also not included in the study reported here. Lastly, we excluded points from three Plainview assemblages that Buchanan et al. (2007) concluded are problematic: Blackwater Draw, Warnica-Wilson, and Lubbock Lake FA5-17. The Blackwater Draw assemblage appears to be from a mixed context. The Warnica-Wilson assemblage comprises material from a campsite combined with a surface collection of isolated points from the surrounding county. The Lubbock Lake FA5-17 assemblage was excluded because the points it contains likely represent a unique type.

The data collection methods we utilized are from the field of geometric morphometrics (e.g. Adams et al., 2004; Bookstein, 1991; Bookstein et al., 1985; Cardini and Elton, 2008, 2009; Cobb and O'Higgins, 2007; Collard and O'Higgins, 2001; Dryden and Mardia, 1998; Goodall, 1991; Marcus et al., 1996; Mitteroecker and Gunz, 2009; O'Higgins, 1999, 2000; O'Higgins and Collard, 2002; O'Higgins and Jones, 1998; Rohlf and Bookstein, 1990; Rohlf and Marcus, 1993; Slice, 2005, 2007; Zelditch et al., 2004). These methods allow patterns of variation in shape and size to be investigated within a well understood statistical framework that yields easily interpreted numerical and visual results. The methods deal with coordinate data as opposed to the interlandmark distances of traditional morphometrics, and operate within a non-Euclidean shape space (Kendall, 1984), the geometric and statistical properties of which are both well defined and highly desirable (O'Higgins, 1999, 2000).

The steps taken in the acquisition, processing, and extraction of blade shape variables were as follows:

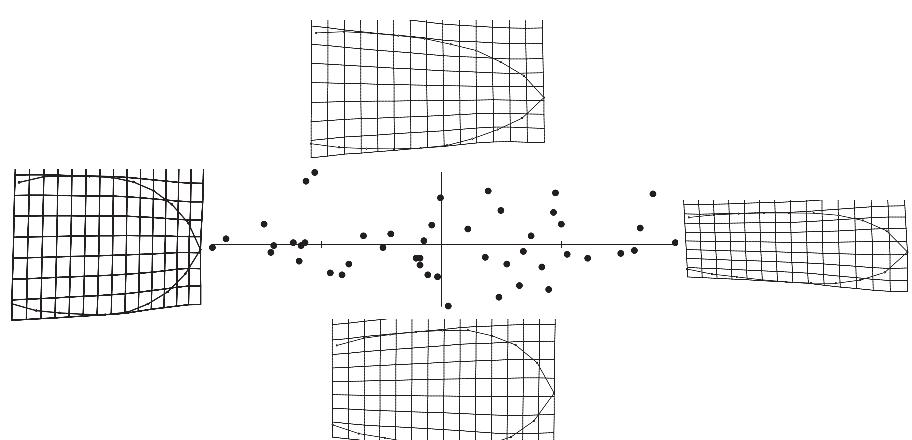


**Fig. 5.** Bivariate plot of relative warp 1 (88.2%) against relative warp 2 (5.2%) for all Folsom specimens. The four projectile point images are deformations from the consensus configuration that are used to display the shape space defined by the first two relative warps.

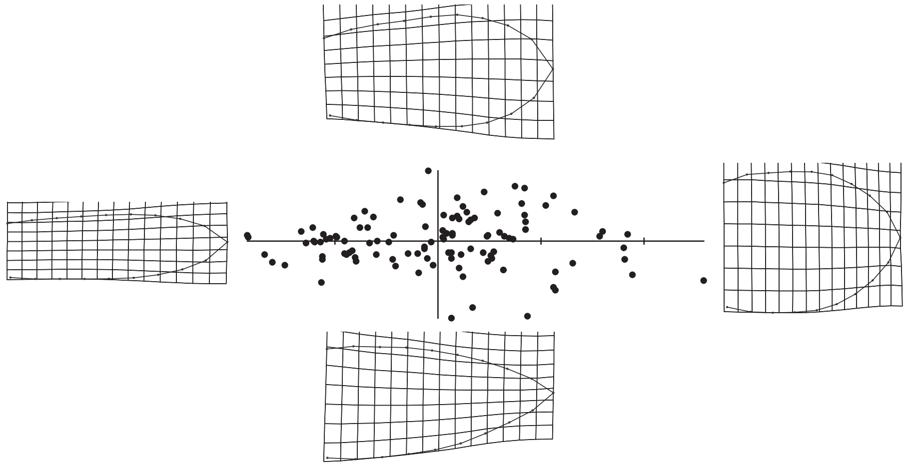


**Fig. 6.** Bivariate plot of relative warp 1 (84.7%) against relative warp 2 (6.8%) for all Plainview specimens. The four projectile point images are deformations from the consensus configuration that are used to display the shape space defined by the first two relative warps.

1. *Image acquisition*. Digital images of points were used to capture landmark data. Points were laid flat with their distal ends facing to the right in each photograph (Fig. 2). For nearly flat objects like projectile points a two-dimensional approach produces limited information loss (Velhagen and Roth, 1997).
2. *Choice and digitization of landmarks*. We used three primary and 16 secondary landmarks to capture blade shape. Two of the primary landmarks are situated at the base of the point, and are defined by the junctions of the base and the blade edges of the point. The third primary landmark is located at the tip, which is defined by the junction of the two blade edges. Line segments with equally spaced perpendicular lines or "combs" were used to place the secondary landmarks along the edges of the blades. Two combs were superimposed on each image using the MakeFan6 shareware program (www.canisius.edu/~sheets/morphsoft.html). The upper comb was placed between the upper base landmark and the tip, while the lower comb was placed between the lower base landmark and the tip. Each comb consisted of eight lines and therefore yielded eight secondary landmarks. The 19 landmarks digitized for each artifact are illustrated in Fig. 2. The landmarks were digitized using tpsDig2 shareware (Rohlf, 2004).
3. *Superimposition of landmarks*. The superimposition of landmarks was accomplished using the generalized orthogonal least-squares Procrustes procedure (Rohlf, 2003; Rohlf and Slice, 1990). Although the artifacts were all photographed using the same procedure and were orientated similarly, the landmark configurations had to be aligned to avoid minor discrepancies arising from the digitizing process. Generalized Procrustes Analysis (GPA) uses three steps to align the landmarks associated with each specimen. First, GPA centers the set of landmark coordinates at their origin, or centroid, and scales all the configurations to unit centroid size. Centroid size is a measure of the overall size of a specimen computed as the square root of the sum of the squared distances from all the landmarks to the centroid. Next, the GPA procedure determines the mean or consensus configuration. Lastly, GPA rotates each landmark configuration so as to minimize the sum-of-squared residuals for the sample. Steps 2 and 3 are repeated iteratively until convergence is achieved.
4. *Projection to tangent Euclidean space*. After the GPA has been performed, landmarks associated with each specimen correspond to locations in Kendall's shape space (Slice, 2001). In order to perform traditional statistical analyses on the matrix of shape coordinates, the specimens in the shape space must be projected to a tangent Euclidean space (Rohlf, 1998). To obtain the smallest amount of shape variation in tangent space, the consensus configuration is used as the point of tangency. The consensus configuration derived from the GPA procedure is shown in Fig. 3. Using the consensus configuration as the point of tangency, we tested if the amount of shape variation in the point data is small enough to permit statistical analyses to be performed in the linear tangent space approximate to Kendall's non-linear shape space. This is accomplished by regressing the distances in the tangent space against the Procrustes distances to determine if the relationship is linear. Procrustes distances are the distances between all pairs of specimens in Kendall's shape space (Bookstein, 1991). This test was carried out using the tpsSmall program (Rohlf, 2004). The correlation between the two distances was strong (correlation = 0.9999; root MS error = 0.0001), indicating a good fit between the specimens in shape space and the linear tangent space.
5. *Extraction of partial warps and the uniform component*. Partial warps and the uniform component were computed using the

**Table 2**
Results from multivariate analysis of variance tests of shape variables by projectile point type.

| Types compared | *F* | *p*-value |
|---|---|---|
| Clovis, Folsom, Plainview | 2.33 | 0.0002* |
| Clovis, Folsom | 4.13 | 0.0002* |
| Clovis, Plainview | 2.46 | 0.0002* |
| Folsom, Plainview | 1.70 | 0.0218 |

*Significant at the 0.0125 alpha level in accordance with the Bonferroni correction.

**Table 3**
Classification results from a discriminant function analysis of shape variables by projectile point type. Percentages are shown in parentheses after the number of points in a predicted group.

| Type | Predicted group membership | | | Total |
|---|---|---|---|---|
| | Clovis | Folsom | Plainview | |
| Clovis | 20 (71.4) | 0 | 8 (28.6) | 28 |
| Folsom | 0 | 27 (57.4) | 20 (42.6) | 47 |
| Plainview | 5 (4.5) | 12 (10.8) | 94 (84.7) | 111 |

**Table 4**
Classification results from a discriminant function analysis of shape variables by projectile point type of points made from Edwards chert. Percentages are shown in parentheses after the number of points in a predicted group.

| Type | Predicted group membership | | | Total |
|---|---|---|---|---|
| | Clovis | Folsom | Plainview | |
| Clovis | 12 (92.3) | 0 | 1 (7.7) | 13 |
| Folsom | 0 | 33 (84.6) | 6 (15.4) | 39 |
| Plainview | 3 (5.9) | 12 (23.5) | 36 (70.6) | 51 |

tpsRelw program (Rohlf, 2004). A partial warp is an eigenvector of the bending energy matrix that describes local deformation along a coordinate axis. A uniform component expresses global information on deformation. The first uniform component accounts for stretching along the $x$-axis of a configuration, whereas the second uniform component accounts for variation along the $y$-axis. Together, the partial warps and the uniform component comprise the weight matrix and represent all information about the shape of specimens. Partial warp scores and the uniform component can be used in standard multivariate analyses (Rohlf et al., 1996; Slice, 2005).

6. *Relative warps computed from partial warps.* Relative warps are the principal components of shape variables, in this case the partial warps and the uniform component scores. The relative warps reflect the major patterns of shape variation within a group. Relative warps were computed using the tpsRelw program (Rohlf, 2004).

After extracting the shape variables, we carried out a qualitative comparison of the shapes of the blades of the three sets of specimens. We plotted each set of specimens in the shape space defined by the first two relative warps, created hypothetical specimens at the extremes of the axes representing the first two relative warps, and then compared the hypothetical specimens. This analysis was carried out with the aid of tpsRelw.

We then carried out MANOVAs and ANOVAs to test for blade shape differences among the three types. In the MANOVAs we focused on the partial warp scores and uniform component matrices. We began with a MANOVA in which specimens assigned to all three types were included and type was used as the grouping variable. Since this MANOVA indicated that at least two of the groups of points had significantly different blade shapes, we proceeded to compare the three sets of points on a pairwise basis. Because MANOVA assumes that group distributions are multivariate-normal with homogeneous covariance matrices, we estimated $p$-values from a null distribution simulated by random permutation (5000 iterations). Bonferroni correction was used to reduce the likelihood of false positives occurring in the post hoc comparisons (Beal and Khamis, 1991). In the ANOVAs we focused on the relative warp scores and used type as the grouping variable. As in the MANOVAs, Bonferroni correction was used in the post hoc comparisons. The MANOVAs were conducted in MATLAB 6.0 (release 12) using statistical functions written by Strauss (2008); the ANOVAs were carried out in SPSS 10.0.1.

Next, we investigated how well blade shape discriminates among the three types. This was accomplished by subjecting the partial warps and uniform component matrices to a discriminant function analysis (DFA) in which point type was used as the grouping variable. This analysis was conducted in SPSS 10.0.1.

Lastly, we evaluated three potentially confounding factors: allometry, raw material quality, and resharpening. To control for allometric effects, we subjected the partial warps and uniform components to multivariate analysis of covariance (MANCOVA). We performed one MANCOVA analysis that focused on the slopes of lines fitted to the three sets of specimens, and one that concentrated on the intercepts of the aforementioned lines. Point area was used as the proxy for point size in both analyses. The point areas were taken from Buchanan (2005, 2006) and Buchanan et al. (2007). We used Buchanan's (2005, 2006) and Buchanan et al.'s (2007) point areas rather than the centroid sizes generated by the GPA because Buchanan (2005, 2006) and Buchanan et al. (2007) included landmarks demarcating the basal portion of points. The base is important to take into account when assessing point area because it ranges from concave to convex in shape both among and within types. Thus, overall point area is a better proxy for point size than centroid size derived from the landmarks defining blade shape. The MANCOVAs were carried out in tpsRegr.

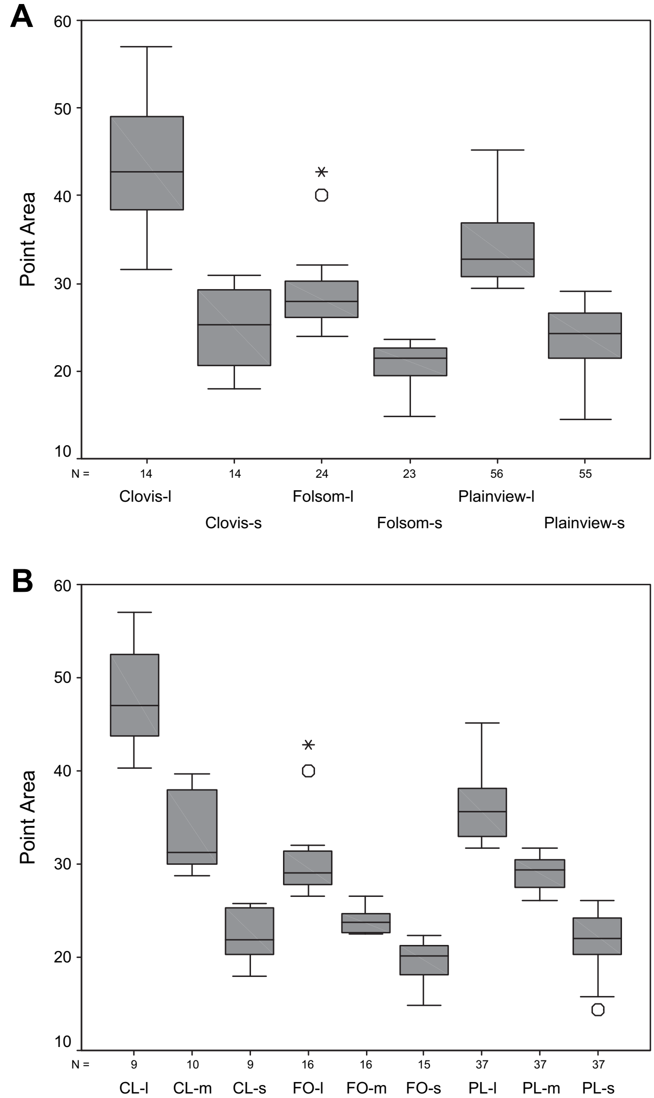


**Fig. 7.** Boxplots of projectile point area by type and size grade. A) boxplot of point area by type and two size grades (l = large, s = small), B) boxplots of point area by type and three size grades (l = large, m = medium, s = small). Boxes and whiskers represent the distribution of the data in quartiles, the horizontal black line within the box indicates the median, and the open circles and asterisks represent outliers and extreme values, respectively.

To determine whether the quality of different raw materials influences the differences in blade shape among the types we identified the raw material types and sources represented in our sample and then conducted raw material-specific DFAs of the partial warp scores and uniform component matrices. Four

**Table 5**
Classification results from a discriminant function analysis of shape variables by two size grades (large and small) within types. Percentages are shown in parentheses after the number of points in a predicted group.

| Type | Predicted group membership | | | | | | Total |
|---|---|---|---|---|---|---|---|
| | Clovis-small | Clovis-large | Folsom-small | Folsom-large | Plainview-small | Plainview-large | |
| Clovis-small | 7 (50) | 3 (21.4) | 0 | 0 | 3 (21.4) | 1 (7.1) | 14 |
| Clovis-large | 1 (7.1) | 11 (78.6) | 0 | 0 | 0 | 2 (14.3) | 14 |
| Folsom-small | 0 | 0 | 14 (60.9) | 1 (4.3) | 4 (17.4) | 4 (17.4) | 23 |
| Folsom-large | 0 | 0 | 1 (4.2) | 15 (62.5) | 2 (8.3) | 6 (25) | 24 |
| Plainview-small | 3 (5.5) | 0 | 6 (10.9) | 4 (7.3) | 33 (60) | 9 (16.4) | 55 |
| Plainview-large | 0 | 1 (1.8) | 0 | 3 (5.4) | 9 (16.1) | 43 (76.8) | 56 |

categories of raw material type were recognized: 1) quartzite, 2) Edwards chert, 3) Alibates agate, and 4) unknown cherts. Quartzites are found throughout the region and are considered to be of lower quality than the cherts and agates (Holliday and Welty, 1981). Edwards chert is found in Cretaceous limestone deposits that occur in the eastern portion of the Edwards Plateau region of central Texas. Primary outcrops of Alibates agate occur along the northern edge of the Southern High Plains in the Canadian River drainage where erosion has exposed the Quartermaster Formation. The category "unknown cherts" was used for points made of chert that could not be sourced to a specific geological outcropping. Determinations were made by visual inspection when possible. In other cases, we relied on published identifications.We carried out two sets of analyses to assess whether the similarities and differences in blade shape among types are influenced by resharpening. In these analyses, we used point area as a proxy for amount of resharpening on the grounds that smaller points are more likely to have been resharpened than larger points. In the first set of resharpening analyses, we evaluated if the distribution of point sizes was comparable among types. Because our sample comprises points from assemblages with different sample sizes and from different site types, we wanted to ensure that the points were comparable in terms of size and therefore reduction intensity. We used size grades to compare point size distributions. We used median point area to divide each of the three groups of points into "small points" and "large points". We also created three size groups—small, medium, and large—by splitting the three groups of points into thirds. We used boxplots to visually compare the distributions of size grades by type, and then used ANOVAs and post hoc comparisons with type/size grade as the grouping variable to test for differences. In the second set of resharpening analyses, we subjected the shape data to DFAs in which type/size grade was used as the grouping variable, and then tested for differences in the proportions of misclassified points between the size groups. We carried out one DFA with each group of points divided into "small points" and "large points", and one with each group of points divided into "small points," "medium points," and "large points". As in the analyses that focused on allometric effects, the point areas were taken from Buchanan (2005, 2006) and Buchanan et al. (2007).

**Table 6**
Misclassification rates from a discriminant function analysis of shape variables by two size grades (large and small) within types. Results of significance tests for the difference in proportions misclassified between small and large points are given in the last two columns. Bootstrapped *p*-values are derived from 5000 iterations.

| Type | Number misclassified | Percent misclassified | *p*-value | Bootstrapped *p*-value |
|---|---|---|---|---|
| Clovis-small | 7/14 | 50 | 0.0984 | 0.2432 |
| Clovis-large | 3/14 | 21 | | |
| Folsom-small | 9/23 | 39 | 0.9085 | 1.0000 |
| Folsom-large | 9/24 | 38 | | |
| Plainview-small | 22/55 | 40 | 0.0533 | 0.0680 |
| Plainview-large | 13/56 | 23 | | |

## 3. Results

Figs. 4–6 show bivariate plots of the first two relative warps for each type. In all three figures the first relative warp is plotted on the abscissa, and the second relative warp on the ordinate. Each figure has four images. These are shown to give an idea of the shape space defined by the first two relative warps for each type. The images reflect the deformation of landmarks from the consensus configuration at the positive and negative ends of each axis.

The variation along the first relative warp is similar in the three groups of points. It pertains to the relationship between width and length. Points at the left hand end of the axis are short and wide, whereas those at the right hand end are long and thin. The variation along the second relative warp is also similar in the three groups of points. The variation along this axis has to do with the location of the point of maximum width relative to the base and tip. Points at the upper end of the axis are wide near the base and narrow at the tip, whereas those at the lower end are wide at the tip and narrow at the base.

The Clovis shape space is defined along the first relative warp by elliptic blades to the left or negative end and by linear blades to the right or positive end (Fig. 4). Along the second relative warp the Clovis shape space is defined by lanceolate blades at the upper, positive end, and deltoid blades at the lower, negative end. The Folsom shape space is defined along the first relative warp by obtuse blades to the left, negative end, and by linear blades to the right, positive end (Fig. 5). Along the second relative warp the Folsom shape space is defined by deltoid blades at the upper, positive end, and oblanceolate blades at the lower, negative end. The Plainview shape space is similar to Folsom, except the axes are reversed (Fig. 6). Thus, while the variation along the first and second relative warps is similar in the three groups of points, there are visible differences in shape between Clovis on the one hand, and Folsom and Plainview on the other.

Table 2 summarizes the results of the MANOVA. As noted earlier, the MANOVA in which specimens assigned to all three types were included indicated that at least two of the three types have distinctive blade shapes. The MANOVA in which Clovis and Folsom specimens were compared was significant, as was the MANOVA in which Clovis and Plainview were compared, albeit slightly less so than the Clovis *vs* Folsom one. In contrast, the MANOVA in which Folsom and Plainview were compared was not significant. Thus, the MANOVA analyses suggest that blade shape distinguishes Clovis points from Folsom points and Clovis points from Plainview points, but does not distinguish Folsom points from Plainview points.

The ANOVAs indicated that the scores for the first two relative warps were significantly different (relative warp 1: $F = 7.928$, df $=$ 183,185, $P = 0.000$; relative warp 2: $F = 20.392$, df $=$ 183,185, $P =$ 0.000). All the comparisons were significant in the post hoc

**Table 7**
Classification results from a discriminant function analysis of shape variables by three size grades (large, medium, and small) within types. Percentages are shown in parentheses after the number of points in a predicted group.

| Type | Predicted group membership | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | Clovis-small | Clovis-medium | Clovis-large | Folsom-small | Folsom-medium | Folsom-large | Plainview-small | Plainview-medium | Plainview-large | |
| Clovis-small | 7 (77.8) | 0 | 1 (11.1) | 0 | 0 | 0 | 1 (11.1) | 0 | 0 | 9 |
| Clovis-medium | 0 | 7 (70) | 1 (10) | 0 | 0 | 0 | 0 | 1 (10) | 1 (10) | 10 |
| Clovis-large | 1 (11.1) | 0 | 7 (77.8) | 0 | 0 | 0 | 0 | 1 (11.1) | 0 | 9 |
| Folsom-small | 0 | 0 | 0 | 9 (60) | 0 | 1 (6.7) | 1 (6.7) | 3 (20) | 1 (6.7) | 15 |
| Folsom-medium | 0 | 0 | 0 | 2 (12.5) | 10 (62.5) | 0 | 2 (12.5) | 1 (6.3) | 1 (6.3) | 16 |
| Folsom-large | 0 | 0 | 0 | 0 | 1 (6.3) | 9 (56.3) | 1 (6.3) | 1 (6.3) | 4 (25) | 16 |
| Plainview-small | 0 | 0 | 0 | 4 (10.8) | 4 (10.8) | 0 | 21 (56.8) | 7 (18.9) | 1 (2.7) | 37 |
| Plainview-medium | 1 (2.7) | 0 | 0 | 0 | 1 (2.7) | 0 | 4 (10.8) | 26 (70.3) | 5 (13.5) | 37 |
| Plainview-large | 0 | 0 | 1 (2.7) | 0 | 0 | 1 (2.7) | 3 (8.1) | 3 (8.1) | 29 (78.4) | 37 |

analysess that focused on the second relative warp scores. However, in the post hoc comparisons that focused on the first relative warp the only differences were between Clovis and Folsom and between Clovis and Plainview were significant ($P = 0.000$ and 0.010, respectively). The differences between the Folsom and Plainview points were not significant ($P = 0.204$). As such, like the MANOVAs, the ANOVAs suggest that blade shape distinguishes Clovis points from Folsom points and Clovis points from Plainview points, but does not distinguish Folsom points from Plainview points.

The results of the DFA in which types were used as the grouping variable are summarized in Table 3. There was no misclassification between Clovis and Folsom points. Twenty-nine percent of Clovis points were misclassified as Plainview points, and five percent of Plainview points were misclassified as Clovis points. Forty-three percent of Folsom points were misclassified as Plainview points, and 11 percent of Plainview points were misclassified as Folsom points. Thus, the lowest level of misclassification occurred with Clovis and Folsom, an intermediate level with Clovis and Plainview, and the highest with Folsom and Plainview. Therefore, the results of the DFA in which types were used as the grouping variable were consistent with the results of the MANOVAs and ANOVAs. They suggest blade shape distinguishes Clovis points from Folsom points and is also reasonably effective at distinguishing Clovis points from Plainview points. In contrast, it does not distinguish Folsom points from Plainview points.

We will now turn to the results of the confounding factor analyses. In the first of these analyses we used MANCOVA to assess the impact of allometry. The MANCOVA that focused on the slopes of lines fitted to the three sets of specimens yielded a non-significant result (Wilks' value = 0.59, Fs = 1.3, df = 68,294, $P = 0.073$), while the MANCOVA that focused on the intercepts of the aforementioned lines yielded a significant result (Wilks' value = 0.43, Fs = 2.3, df = 68,298, $P = 0.000$). Thus, there is no evidence that allometry is a confounding factor. Size affects shape in the same way in the three types, but the shapes of the three sets of points are significantly different at all sizes.

Our assessment of the raw materials used to make the points indicated that the majority of points are made from Edwards chert ($n = 103$ or 55.4 percent), followed by unknown cherts ($n = 38$, or 20.4 percent), Alibates agate ($n = 32$, or 17.2 percent) and quartzites ($n = 13$, or 7 percent). The DFAs for unknown cherts, Alibates agate, and quartzites correctly classified all points to type. In the DFA of the Edwards chert points there was no misclassification between Clovis and Folsom points, but some misclassification between Clovis and Plainview points, and between Plainview and Folsom points (Table 4). Thus, there is also no evidence that raw material quality is a confounding factor. Points made from the poorest quality raw material, quartzite, are not more difficult to distinguish than points made from the higher quality raw materials, chert and agate.

We performed two sets of analyses to evaluate the influence of resharpening on our results. In the first analysis we examined the size distribution of points within types. Fig. 7a shows the distribution of point area by type and two size grades. ANOVA and post hoc comparisons indicates that large Clovis points are larger than all other sets, but that small Clovis points are not different from large and small Folsom and small Plainview. Fig. 7b shows the distribution of point area by type and three size grades. The ANOVA and post hoc comparisons indicated that small Clovis points are not different from medium and small Folsom, and small Plainview points and small Plainview are not different from medium Folsom. Thus, the lower range of point area appears to be similar across the types, which suggests that differences in reduction intensity is not a significant confounding factor in our analyses.

The results of the first DFA that was carried out to assess the impact of resharpening on the similarities and differences in blade shape among the three sets of points are presented in Table 5. The differences in misclassification rate between the small and large points were not significant (Table 6). The results of the second DFA

**Table 8**
Misclassification rates from a discriminant function analysis of shape variables by three size grades (large, medium, and small) within types.

| Type | Number misclassified | Percent misclassified |
|---|---|---|
| Clovis-small | 2/9 | 22 |
| Clovis-medium | 3/10 | 30 |
| Clovis-large | 2/9 | 22 |
| Folsom-small | 6/15 | 40 |
| Folsom-medium | 6/16 | 38 |
| Folsom-large | 7/16 | 44 |
| Plainview-small | 16/37 | 43 |
| Plainview-medium | 11/37 | 30 |
| Plainview-large | 8/37 | 22 |

**Table 9**
Results of significance tests for the difference in proportions misclassified between small and medium and small and large points within types. Bootstrapped *p*-values are derived from 5000 iterations.

| Comparison | *p*-value | Bootstrapped *p*-value |
|---|---|---|
| Clovis-small to Clovis-medium | 0.6981 | 1.0000 |
| Clovis-small to Clovis-large | 1.0000 | 1.0000 |
| Folsom-small to Folsom-medium | 0.8864 | 1.0000 |
| Folsom-small to Folsom-large | 0.8323 | 1.0000 |
| Plainview-small to Plainview-medium | 0.2227 | 0.3378 |
| Plainview-small to Plainview-large | 0.0412 | 0.0784 |

*Significant at the 0.05 alpha level.

that was carried out to assess the impact of resharpening on the similarities and differences in blade shape among the three sets of points are presented in Table 7. The differences in misclassification rate between the small, medium, and large points were not significant (Tables 8 and 9). As such, there is no evidence that resharpening evidence is a confounding factor either.

It appears, then, that the finding that blade shape distinguishes Clovis points from both Folsom points and Plainview points, but does not distinguish Folsom points from Plainview points is independent of allometry, raw material quality, and any effects that resharpening has on blade shape.

## 4. Discussion and conclusions

The visual comparisons of the shape spaces associated with each type revealed differences in shape between Clovis on the one hand, and Folsom and Plainview on the other. The MANOVAs and ANOVAs also indicated that the blades of the Clovis points are a different shape from those of the Folsom and Plainview points, while the blades of the Folsom and Plainview points are the same shape. The DFA by type was consistent with the preceding analyses. There was no misclassification between Clovis and Folsom points, and only limited misclassification between Clovis and Plainview points. In contrast, many Folsom points were incorrectly classified as Plainview points and vice versa. Thus, taken together, the visual comparisons, MANOVAs, ANOVAs and DFA suggest that blade shape distinguishes the Clovis points from the Folsom and Plainview points, but not the Folsom points from the Plainview points.

This finding appears to be independent of allometry, raw material quality, and resharpening effects. The results of the MANCOVA analyses demonstrated that while size affects shape in the same way in the three types, the shapes of the three sets of points are significantly different at all sizes. In the raw material-focused DFA, points made from low quality raw material were misclassified no more frequently than points made from high quality raw materials. The first set of resharpening analyses showed that although there were differences among the types in the larger size grades, the smaller size grades contained similarly sized points. In the second set of resharpening analyses points that were small and therefore most likely to have been resharpened were misclassified no more frequently than points that were large and therefore less likely to have been resharpened. Thus, the control analyses indicate that blade shape distinguishes the Clovis points from the Folsom and Plainview points even when size-related shape change, raw material, and resharpening are taken into account.

Our study has obvious implications for Paleoindian research. To reiterate, according to Wormington's (1957) type definitions, Clovis and Plainview points have parallel to slightly convex sides, while Folsom points are lanceolate or lozenge shaped. This suggests that in cases where other defining characters (e.g. channel flakes, flutes) are missing the potential confusion is between Plainview and Clovis points. However, our results suggest that Clovis and Plainview points do not in fact have the same shape blades. Rather, it is Folsom and Plainview points that have the same shape blades. The corollary of this is that in cases where other defining characters are missing the potential confusion is not between Plainview and Clovis points, but between Plainview and Folsom points.

One interesting question our results raise is why Folsom and Plainview points have the same shape points. There would appear to be two possible explanations for the overlap. One is that Folsom and Plainview inherited the same shape blade from their most recent common ancestor. The other possibility is that Folsom and Plainview points have blades of the same shape due to convergent evolution. The available evidence suggests that Folsom and Plainview points were used primarily for hunting bison (Meltzer, 2006; Sellards et al., 1947). Natural selection is known to occasionally produce similar characteristics in distantly related taxa that experience similar ecological conditions (Sanderson and Hufford, 1996), and there is reason to believe that cultural selection may sometimes do the same (Collard et al., 2008). Thus, it is possible that different Paleoindian populations could have independently invented blades of the same shape, perhaps because the shape is optimal for bringing down bison. It should be possible to determine which of these hypotheses is most likely to be correct with a combination of phylogenetic analysis (e.g. Buchanan and Collard, 2007; Lycett, 2007, 2009; O'Brien et al., 2001) and experiments to determine performance characteristics (e.g. Cheshier and Kelly, 2006; O'Brien et al., 1994).

Before ending it seems worth highlighting the results of the analysis in which we controlled for the effects of resharpening. Over the last 40 years many lithic analysts have embraced what Shott (2005) has called the "reduction thesis" (e.g. Dibble, 1995; Flenniken and Raymond, 1986; Flenniken and Wilke, 1989; Hoffman, 1985; Odell, 2001; Shott, 2005). The reduction thesis is that resharpening causes variation in stone tool size and shape to be continuous rather than discrete. This claim has profound implications for archaeology. If correct, it invalidates two of the traditional mainstays of lithic analysis—the notion that each type represents a distinct tool or part of a composite tool, and the use of type proportions to infer cultural affinity and activity variation. As Shott (2005:123) has put it, within the framework of the reduction thesis "a type's presence in an assemblage no longer means 'Kind of Tool or Activity X' but instead 'Amount of Reduction Y'".

To reiterate, we found no evidence that resharpening blurred the distinction between Clovis on the one hand, and Folsom and Plainview on the other. The rate of misclassification of small points was no worse than the rate of misclassification of larger points. Thus, the results of the analyses in which we controlled for the effects of resharpening are not consistent with the reduction thesis. Contrary to what the reduction thesis predicts, the smallest, most retouched points are not misclassified more often than the largest, least retouched points.

The obvious explanation for the failure of the resharpening control analyses to support the reduction thesis is that our sample is atypical, that western north American Paleoindian projectile points are a rare case in which lithic variation is discontinuous. However, there is another possibility. The studies that have supported the reduction thesis have relied on either visual inspection or a small number of metric variables to compare artifacts (e.g. Flenniken and Raymond, 1986; Hoffman, 1985). Thus, it is possible the reason our results do not support the reduction thesis is that the reduction thesis is a misconception resulting from reliance on insufficiently precise methods of data capture and analysis. Given the importance of the reduction thesis for archaeology, there is a pressing need to determine which of these possibilities is correct. This should be achievable by repeating the studies that have supported the reduction thesis with geometric morphometric techniques and multivariate statistical methods.

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