Points and prey: a quantitative test of the hypothesis that prey size influences early Paleoindian projectile point form

Briggs Buchanan [a,b,*], Mark Collard [a,b], Marcus J. Hamilton [c,d,e], Michael J. O'Brien [b]

[a] Laboratory of Human Evolutionary Studies, Department of Archaeology, Simon Fraser University, British Columbia, Canada
[b] Department of Anthropology, University of Missouri, Columbia, MO, USA
[c] Department of Anthropology, University of New Mexico, Albuquerque, NM, USA
[d] Department of Biology, University of New Mexico, Albuquerque, NM, USA
[e] Santa Fe Institute, Sante Fe, NM, USA

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ABSTRACT

Understanding the causes of variation within and between projectile point types is an important task for Paleoindian archaeologists since they rely heavily on points to investigate such things as settlement dynamics and hunting practices. One long-held explanation for the variation in early Paleoindian point form is that prey size influenced the size and shape of projectile points. The study reported here evaluated this hypothesis with standard and geometric morphometric data recorded on Clovis and Folsom points from the Southern Plains and Southwest that are associated with mammoth or bison remains. Points used to hunt mammoth were found to be larger and of a different shape than points used to hunt bison, which supports the hypothesis. However, when both point type and prey size were taken into account, the results ran counter to predictions. Potential explanations for this discrepancy are discussed.

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1. Introduction

Clovis and Folsom are the two best-known early archaeological complexes in North America. Clovis assemblages have been found throughout the contiguous United States, southern Canada, and northern Mexico (Holliday, 2000; Sanchez, 2001). The oldest Clovis assemblage dates ca. 13,300 calendar years before present (calBP) and the youngest ca. 12,800 calBP (Holliday, 2000). So far, Folsom has been found only in western North America, mainly in the Great Plains and Rocky Mountains. It appeared shortly after 13,000 calBP and disappeared around 11,900 calBP (Taylor et al., 1996; Holliday, 2000; Collard et al., 2010).

Projectile points are the key diagnostic artifacts of Clovis and Folsom assemblages. Clovis points are bifacially flaked and fluted with parallel to slightly convex sides and concave bases (Wormington, 1957). Folsom points are lanceolate or lozenge shaped (Wormington, 1957). They also tend to be smaller and lighter

than Clovis points and have more-invasive flutes. Both point types are thought to have been used with darts delivered by atlatl (Hutchings, 1997).

Prey size has been argued to be a major influence on the size and shape of Clovis and Folsom points. An early statement to this effect can be found in Cotter (1938). In explaining the variation in the size of Clovis and Folsom points recovered from Blackwater Draw, New Mexico, Cotter hypothesized that large points were designed to hunt mammoth, medium-sized points were intended for bison and game of moderate size, and small points were made for small game. Among the other authors who have linked the form of Clovis and Folsom points to prey size are Sellards (1952), Hemmings (1970) and Haynes (1964). The former two authors argued that large Clovis points were used to hunt mammoth, whereas smaller Clovis points were used for smaller game such as bison and horse. Haynes (1964) suggested that the change from Clovis points to Folsom points coincided with the shift from hunting mammoth to the hunting of bison.

Currently, the status of these claims is uncertain. Experimental studies indicate that a projectile point's size and shape can affect its ability to penetrate hide and its durability, which is consistent with the hypothesis (Odell and Cowan, 1986; Frison, 1989; Hughes, 1998; Cheshier and Kelly, 2006; Sisk and Shea, 2009; Waguespack et al.,

* Corresponding author. Laboratory of Human Evolutionary Studies, Department of Archaeology, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, Canada V5A 1S6 . Tel.: +1 778 878 0737.
E-mail address: bbuchana@sfu.ca (B. Buchanan).

2009). However, Haury et al. (1953, 1959) challenged the link between prey size and point form in the case of Clovis. These authors pointed out that Clovis points of a wide range of sizes are associated with mammoth at the sites of Naco and Lehner in Arizona, and argued that this indicates that Clovis Paleoindians did not preferentially use large points to hunt mammoth.

In view of this uncertainty, we tested the hypothesis that prey size influenced Clovis and Folsom projectile point form by comparing the size and shape of points associated with the remains of either Columbian mammoth (*Mammuthus columbi*) or ancient bison (*Bison antiquus*). Adult Columbian mammoth are estimated to have been eight times heavier than adult ancient bison ($\sim$8000 kg versus $\sim$900 kg) (Smith et al., 2003). Thus, we reasoned that, if the hypothesis is correct, there should be significant differences in the size and shape of projectile points associated with the two species.

2. Materials and methods

The study included 74 complete, previously typed projectile points (Table 1). Eleven are Clovis points associated with bison remains, 36 are Clovis points associated with mammoth, and 27 are Folsom points associated with bison.

Bison remains have been recovered from a number of Clovis sites (Waguespack and Surovell, 2003), but only four sites have yielded complete Clovis points that can be linked with bison remains—Blackwater Draw, Jake Bluff (Oklahoma), Murray Springs (Arizona), and Lehner (Fig. 1). At Blackwater Draw, Sellards excavated a Clovis bison kill from the Gray Sands at the south end of the North Pit (Hester, 1972). The assemblage included the remains of least seven animals and three complete Clovis points. At Jake Bluff, remains of at least 14 bison were found at the bottom of an arroyo along with four complete Clovis points (Bement and Carter, 2003). Area 4 at Murray Springs yielded the remains of at least 11 bison plus three complete Clovis points (Haynes and Huckell, 2007). A complete Clovis point and bison remains were also recovered from Area 3 at Murray Springs, but the point was equally close to mammoth remains, so it cannot be linked to either species. Several complete Clovis points were found in association with animal remains at Lehner (Haury et al., 1959). One was recovered from within the ribs of a bison. We included all the complete Clovis points from Blackwater Draw, Jake Bluff, and Murray Springs that are associated with bison remains in our sample of Clovis-bison points. We also included the complete point from the bison kill at Lehner.

In order to reduce the potential confounding effects of ecological and cultural variation, we limited our sample of Clovis-mammoth points and Folsom-bison points to the two regions in which Clovis bison kills have been found, the Southern Plains and Southwest. The specimens in our sample of Clovis-mammoth points come from three sites on the Southern Plains—Blackwater Draw, Domebo (Oklahoma), and Miami (Texas)—and three sites in the Southwest—Escapule (Arizona), Lehner, and Naco (Fig. 1). The specimens in our sample of Folsom-bison points come from six sites on the Southern Plains—Blackwater Draw, Cooper (Oklahoma), Folsom (New Mexico), Lake Theo (Texas), Lipscomb (Texas), and Lubbock Lake (Texas) (Fig. 1). All the points in our Clovis-mammoth sample are unambiguously and exclusively associated with the remains of mammoth, and all the points in our Folsom-bison sample are unambiguously and exclusively associated with bison remains.

We obtained both size and shape data from the points. The former comprised values for three measurements—length, width, and thickness. These values were either taken from published sources or recorded by BB with digital calipers. The only points for which it was impossible to generate a complete set of size data

were the six Folsom-bison points from Lipscomb. We did not include values for thickness for these points because we could not find the relevant values in the literature and were unable to measure the points directly.

The shape analysis methods we used are from the field of geometric morphometrics (e.g., Bookstein, 1991; Bookstein et al., 1985; Dryden and Mardia, 1998; Rohlf and Bookstein, 1990; Slice, 2005, 2007). The methods allow patterns of variation in shape and size to be investigated within a well-understood statistical framework that yields relatively 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).

Following Buchanan and Collard (2010), the steps taken in acquiring, processing, and extracting shape variables were as follows:

1. *Image acquisition.* Digital images of points were used to capture landmark data. For nearly flat objects such as 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 20 secondary landmarks to capture point shape. Two primary landmarks were located at the base of the point and were defined by the junctions of the base and the blade edges. The third primary landmark was located at the tip. Line segments with equally spaced perpendicular lines were used to place the secondary landmarks along the edges of the blades and the base. These "combs" were superimposed on each image using the MakeFan6 shareware program (www.canisius.edu/~sheets/morphsoft.html). The 23 landmarks digitized for each artifact are shown in Fig. 2. The landmarks were digitized using tpsDig2 shareware (Rohlf, 2004).
3. *Superimposition of landmarks.* This procedure was carried out to reduce the confounding effects of the digitizing process and to control for size differences among the specimens (Rohlf, 2003; Rohlf and Slice, 1990). Landmark superimposition entails three steps. First, the set of landmark coordinates are centered at their origin or "centroid," and all the configurations are scaled to unit centroid size. Next, the consensus configuration is computed. Lastly, each landmark configuration is rotated so as to minimize the sum-of-squared residuals from the consensus configuration. The superimposition of landmarks was carried out using the tpsSuper program (Rohlf, 2004).
4. *Projection to tangent Euclidean space.* In order to carry out traditional statistical analyses, it was necessary to project the landmarks to tangent Euclidean space (Rohlf, 1998; Slice, 2001). This procedure was also carried out using the tpsSuper program (Rohlf, 2004). We conducted a regression of the distances in the tangent space against the Procrustes distances to determine the fit between the specimens in shape space and linear tangent space. 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 that the projection was adequate.
5. *Extraction of partial warps and the uniform component.* Partial warps are eigenvectors of the bending-energy matrix that describe local deformation along a coordinate axis. Uniform components express global information on deformation. The first uniform component accounts for variation along the x-axis of a configuration, whereas the second uniform component accounts for variation along the y-axis. Together, partial warps and uniform components represent all information about the

Table 1
Complete Clovis and Folsom projectile points recovered in association with mammoth or bison.

Type	Site	No. of points	Catalog nos.[a]	Provenience information	Faunal association	Age and sex	References
Folsom	Blackwater Draw	2	937-27, 937-59	Locus 4A D, Station A	Bison	Unknown	Hester, 1972: Figs. 39 and 40; Sellards, 1952: 54–58
Folsom	Cooper	5	D, G, J, P, HH	Recovered from the upper kill bonebed	Bison	Unattributed (calves, yearlings, 2–7 year olds; males and females)	Bement, 1999a,b
Folsom	Cooper	6	R, S, U, V, Y, Z	Recovered from the middle kill bonebed	Bison	Unattributed (calf, yearlings, 2–5 year olds; males and females)	Bement, 1999a,b
Folsom	Cooper	1	T	Recovered from the lower kill bonebed	Bison	Unattributed (calf, yearling, 2–7 year olds; females)	Bement, 1999a,b
Folsom	Folsom	1	AMNH 20.2.5865	Six inches from bison skeleton	Bison	Unattributed[b] (calves, yearlings, mature; males and females)	Meltzer, 2006
Folsom	Folsom	1	DMNS 1262/1A	Found near a rib	Bison	Unattributed (calves, yearlings, mature; males and females)	Meltzer, 2006
Folsom	Folsom	1	CAVO-116	Found in skull	Bison	Unattributed (calves, yearlings, mature; males and females)	Meltzer, 2006
Folsom	Lake Theo	2	A917-40, A917-79	Recovered from bonebed	Bison	Unknown	Buchanan, 2002; Harrison and Smith, 1975
Folsom	Lipscomb	1	17002–39	Recovered from the west edge of the central bone concentration	Bison	Unknown	Hofman et al., 1989; Schultz, 1943
Folsom	Lipscomb	1	17003–39	Associated with proximal radius	Bison	Unknown	Hofman et al., 1989; Schultz, 1943
Folsom	Lipscomb	1	17007–39	Associated with distal humerus	Bison	Unknown	Hofman et al., 1989; Schultz, 1943
Folsom	Lipscomb	1	17015–39	Associated with radius	Bison	Unknown	Hofman et al., 1989; Schultz, 1943
Folsom	Lipscomb	1	17022–39	Associated with skull	Bison	Unknown	Hofman et al., 1989; Schultz, 1943
Folsom	Lipscomb	1	17023–39	Associated with radius	Bison	Unknown	Hofman et al., 1989; Schultz, 1943
Folsom	Lubbock Lake	1	892–71	Station I, associated with bison remains	Bison	Unknown	Johnson, 1987: 105; Sellards, 1952: 53
Folsom	Lubbock Lake	1	TTU-A1	Associated with remains of bison	Bison	Unknown	Johnson, 1987: 105
Clovis	Blackwater Draw	3	937-729, 937-739, 937-741	"Sellards' Clovis bison kill" at south end of the North Pit, 1955	Bison	Unknown	Hester, 1972: 46, 47
Clovis	Jake Bluff	4	a, b, c, d	Recovered from the bonebed	Bison	Unattributed (calves, yearlings, mature)	Bement and Carter, 2003
Clovis	Lehner	1	A-12681	Recovered between the ribs of bison	Bison	Unknown	Haury et al., 1959
Clovis	Murray Springs	3	110 (949), 111 (952/1007), 116 (1067)	Area 4, the Bison Kill	Bison	Unattributed (2 yearlings, a 2-year old, 5 heifers, and 3 mature cows)	Haynes and Huckell, 2007
Clovis	Blackwater Draw	1	25312 (A183)	North Bank, southwest of Mammoth #2, El Llano dig no. 1, 1963	Mammoth	Nearly mature	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	25313 (A186)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1963	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	25314 (A200)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1963	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	25315 (A201)	North Bank, Mammoth #4 bonebed near skull, ribs, and vertebrae, El Llano dig no. 1, 1963	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	25316 (A202)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1963	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	25317 (A209)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1963	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	24123 (EL10)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1963	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	24122 (EL229)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1962-3	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	24124 (EL30)	North Bank, Mammoth #4 bonebed, El Llano dig no. 1, 1962-3	Mammoth	Large adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	24125 (EL47)	North Bank, Mammoth #1 bonebed, El Llano dig no. 1, 1962-3	Mammoth	Young adult	Hester, 1972; Warnica, 1966
Clovis	Blackwater Draw	1	36-19-2 (9-4)	5 cm below vertebra of mammoth #1	Mammoth	Adult, 34 AEY, male	Cotter, 1937; Boldurian and Cotter, 1999; Saunders and Daeschler, 1994
Clovis	Blackwater Draw	1	36-19-3 (9-22)	Between distal end of ulna and proximal end of humerus of mammoth #2	Mammoth	Adult, 35 AEY, female	Cotter, 1937; Boldurian and Cotter, 1999; Saunders and Daeschler, 1994

Table 1 (*continued*).

Type	Site	No. of points	Catalog nos.[a]	Provenience information	Faunal association	Age and sex	References
Clovis	Blackwater Draw	1	36-19-12 (9-33)	Near scapula of mammoth #2	Mammoth	Adult, 35 AEY, female	Cotter, 1937; Boldurian and Cotter, 1999; Saunders and Daeschler, 1994
Clovis	Domebo	1	64.8.2	In an area of disarticulated ribs and vertebrae	Mammoth	Immature, female (?), (13–14 feet high)	Leonhardy, 1966
Clovis	Domebo	1	64.8.3	Near a pair of articulated vertebrae	Mammoth	Immature, female (?), (13–14 feet high)	Leonhardy, 1966
Clovis	Escapule	1	ES-2	Among mammoth ribs	Mammoth	Mature, 15–25 AEY	Hemmings and Haynes, 1969
Clovis	Lehner	1	A-12676	5 cm from mammoth rib	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY[c])	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12677	Under mammoth rib	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12678	Under mammoth ilium	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12679	Against distal end of mammoth leg bone	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12682	Against mammoth long bone	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12683	15 cm from mammoth ribs	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12684	Touching mammoth ilium	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12685	10 cm from mammoth vertebral corpus	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Lehner	1	A-12686	15 cm from mammoth jaw	Mammoth	Unattributed (seven immature and 6 mature, ranging in age from 2 to 29AEY)	Haury et al., 1959; Saunders, 1980
Clovis	Miami	2	976-1, 976-2	Found between mammoth ribs	Mammoth	Unattributed (2 juveniles [0.5 and 3–4 AEY], and 1–3 mature [32 AEY])	Holliday et al., 1994; Sellards, 1938
Clovis	Miami	1	976–3	Refit point in two sections: the base within ribs, the tip recovered near atlas	Mammoth	Mature	Holliday et al., 1994; Sellards, 1938
Clovis	Naco	1	A-11912	Found at the base of skull	Mammoth	Mature	Haury et al., 1953
Clovis	Naco	1	A-11913	Near left scapula	Mammoth	Mature	Haury et al., 1953
Clovis	Naco	1	A-10899	Within ribs	Mammoth	Mature	Haury et al., 1953
Clovis	Naco	2	A-10900, A-10902	In rib area	Mammoth	Mature	Haury et al., 1953
Clovis	Naco	1	A-10901	On articular facet of atlas	Mammoth	Mature	Haury et al., 1953
Clovis	Naco	1	A-10903	In contact with overlapping ribs	Mammoth	Mature	Haury et al., 1953
Clovis	Naco	1	A-10904	Exact location unknown but recovered from the Naco mammoth	Mammoth	Mature	Haury et al., 1953

[a] Numbers in parentheses are field numbers.
[b] Unattributed designation is given when projectile points cannot be associated with particular individuals within a bonebed.
[c] AEY, African equivalent years are based on tooth eruption and wear schedules in African elephants applied to mammoth tooth eruption and wear (see (Saunders, 1980) for discussion).

shape of specimens (Rohlf et al., 1996; Slice, 2005). The partial warps and uniform components were computed using the tpsRelw program (Rohlf, 2004).

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

Once the size and shape data were generated, we carried out a set of analyses in which we tested the hypothesis that prey size influences point form by grouping the points according to whether they were found with mammoth or bison and then comparing the two groups of points. We began by using the *t*-test to compare lengths, widths, and thicknesses of the two groups of points. Bonferroni correction was used to reduce the occurrence of false positives (Beal and Khamis, 1991). Subsequently, we carried out a visual comparison of the shapes of the two groups of points. We plotted each group of points in the shape space defined by the first two relative warps and then displayed the shapes of points at the extremes of the axes representing the first two relative warps. Thereafter, we used MANOVA and the *t*-test to evaluate the
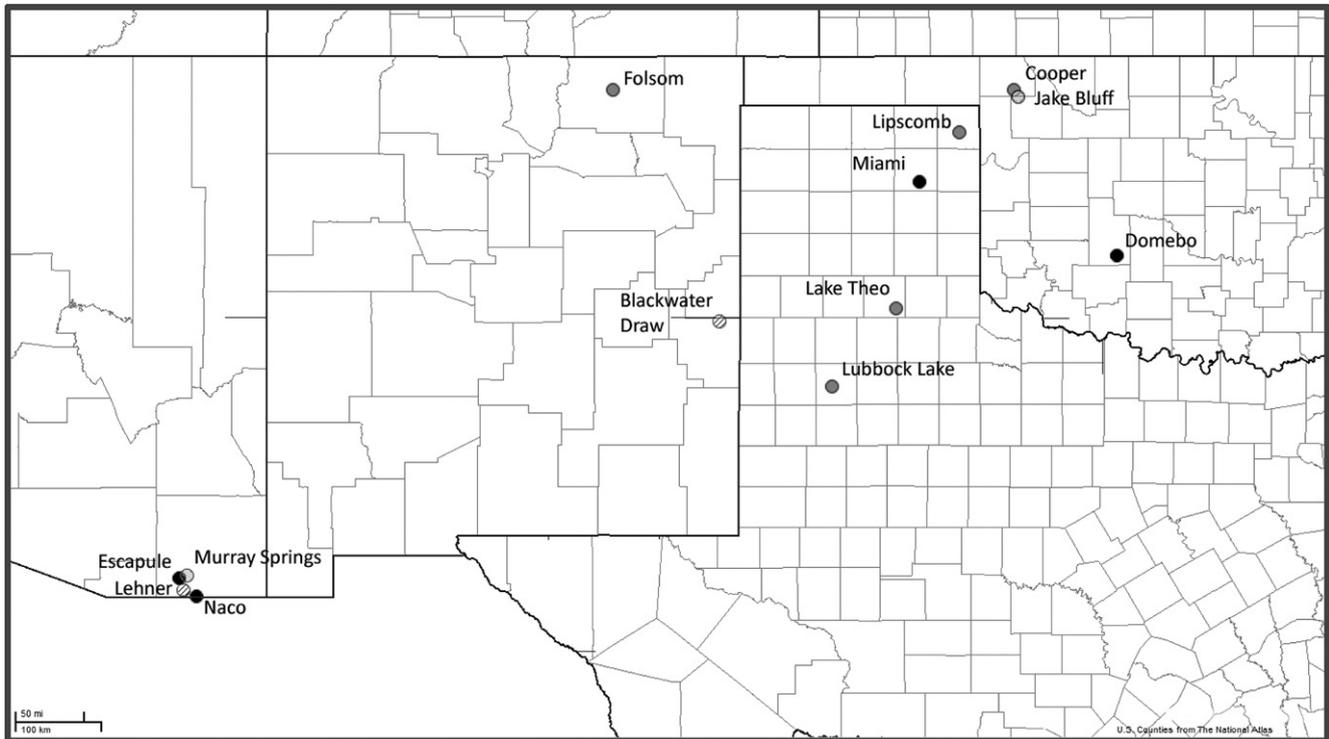
Fig. 1. Map of the Southern Plains and Southwest regions showing locations of assemblages used in the analysis. Sites marked with black circles have Clovis points associated with mammoth, sites marked with light gray circles have Clovis points associated with bison, sites marked with striped circles have Clovis points associated with mammoth and bison, and sites marked with dark gray have Folsom points associated with bison.

statistical significance of the shape differences between the two groups. In the MANOVA we focused on the partial warp scores and uniform component matrices. 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). In the t-tests we focused on relative warp scores and used prey type as the grouping variable.

Subsequently, we ran a similar set of analyses using three groups of points—Clovis-mammoth points, Clovis-bison points, and Folsom-bison points. Again, we began by focusing on point size. This time, rather than using the t-test to compare the groups of points, we employed ANOVA followed by post hoc comparisons. Next, we carried out a qualitative comparison of the shapes of points in the three groups. As in the previous set of analyses, we plotted each group of points in the shape space defined by the first

two relative warps and then displayed the shapes of points at the extremes of the axes representing the first two relative warps. Lastly, we carried out MANOVAs and ANOVAs to test for shape differences among the three groups of points. In the MANOVAs we focused on the partial warp scores and uniform component matrices. We began with a MANOVA in which "Clovis-mammoth," "Clovis-bison," and "Folsom-bison" were used as the grouping variables. Since this MANOVA indicated that at least two groups of points had significantly different point shapes, we proceeded to compare the three groups 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 occurrence of false positives in the post hoc comparisons (Beal and Khamis, 1991). In the ANOVAs we focused on the relative warp scores and used point type–prey type as the grouping variable. As in the MANOVAs, Bonferroni correction was used in the post hoc comparisons.

The t-tests and ANOVAs were carried out in PASW (SPSS) 18 and the qualitative comparisons in tpsRelw. The MANOVAs were conducted in MATLAB 6.0 (release 12) using statistical functions written by R.E. Strauss (retrieved March 2008 from http://www.faculty.biol.ttu.edu/Strauss/Matlab/matlab.htm).

3. Results

3.1. Impact of prey size on point form

Descriptive statistics for the three size variables are presented in Table 2. These indicate that mammoth points are, on average longer, wider, and thicker than bison points.

Fig. 2. Digital image of a projectile point with the locations of three primary landmarks (black circles) and 20 secondary landmarks (white circles) marked along the edges. The lines superimposed on the point image were produced using the MakeFan program.

Table 2
Descriptive statistics for length, width, and thickness variables for the two groups of points—points associated with mammoth and points associated with bison.

	n	Minimum	Maximum	Mean	Standard deviation
Mammoth					
Length	36	26.56	117.24	72.51	25.39
Width	36	15.97	36.60	26.69	5.52
Thickness	36	4.19	9.77	7.51	1.41
Bison					
Length	38	20.80	83.10	43.21	14.35
Width	38	15.30	34.60	21.46	4.23
Thickness	32	3.00	11.10	4.86	2.01

The length, width, and thickness differences between the two groups of points are highly significant according to the t-test (length, with unequal variances: $t = 6.10$, df $= 54.66$, $p = 0.000$; width, with equal variances: $t = 4.59$, df $= 72$, $p = 0.000$; thickness, with unequal variances: $t = 6.36$, df $= 54.69$, $p = 0.000$).

The first two relative warps for mammoth and bison points are depicted in Figs. 3 and 4, respectively. Mammoth point shape space is defined along the first relative warp by narrow, linear blades with U-shaped bases to the left (negative) end, and by wide, deltoid blades with U-shaped bases to the right (positive) end (Fig. 3). Along the second relative warp, mammoth point shape space is defined by deltoid blades with U-shaped bases at the upper (positive) end, and by lanceolate blades with V-shaped bases at the lower (negative) end. The bases of the bison points are U-shaped. Bison point shape space is defined along the first relative warp by linear blades to the left end, and by obtuse blades to the right end (Fig. 4). Along the second relative warp, bison point shape space is defined by lanceolate blades at the upper end and by oblanceolate blades at the lower end. Thus, visual comparison suggests that although there are some similarities along the first relative warp axis, mammoth point shape space and bison point shape space are different.

The MANOVA indicated that the shapes of the mammoth points and the bison points are significantly different ($F = 2.25$, df $= 42.31$, $p = 0.008$). This result agrees with the visual comparison.

The t-tests indicated that the scores for the first relative warp (representing 88% of the variation) and the second relative warp (representing 5.1% of the variation) are significantly different by

group (relative warp 1: $t = -5.94$, df $= 72$, $p = 0.000$; relative warp 2: $t = 3.94$, df $= 72$, $p = 0.000$). The remaining relative warps are not significantly different by group. As such, the results of the t-tests also suggest that there are significant shape differences between the mammoth points and bison points.

In sum, then, the results of the first set of analyses suggest that both size and shape distinguish points associated with mammoth from points associated with bison. These findings are consistent with the hypothesis that prey size influences early Paleoindian projectile point form.

3.2. Impact of prey size and point type on point form

Descriptive statistics for the length, width, and thickness for the three groups of points—Clovis-mammoth points, Clovis-bison points, and Folsom-bison points—are presented in Table 3. These indicate that Folsom-bison points are smaller than both Clovis-mammoth and Clovis-bison points, and that Clovis-mammoth points and Clovis-bison points are similar in size.

The ANOVAs identified the existence of significant differences in length, width, and thickness (length: $F = 23.66$, df $= 71.73$, $p = 0.000$; width: $F = 15.93$, df $= 71.73$, $p = 0.000$; thickness: $F = 67.00$, df $= 65.67$, $p = 0.000$). The post hoc comparisons indicated that there are significant differences between Clovis-mammoth and Folsom-bison points, and between Clovis-bison and Folsom-bison points (length: $p = 0.000$ and 0.038, respectively; width: $p = 0.000$ and 0.014, respectively; thickness: $p = 0.000$ and 0.000, respectively). In contrast, the differences between Clovis-mammoth and Clovis-bison points are not significant for width ($p = 0.824$) and thickness ($p = 1.000$), and are equivocal for length ($p = 0.054$). Thus, the ANOVAs did not support the hypothesis. They indicated not only that Clovis-bison points do not differ significantly in size from Clovis-mammoth points, but also that Clovis-bison points are significantly larger than Folsom-bison points.

The shape space for Clovis-mammoth points was described above. The shape spaces for Clovis-bison and Folsom-bison points are illustrated in Figs. 5 and 6, respectively. The bases of the Clovis-bison points are V-shaped. Clovis-bison point shape space is defined along the first relative warp by deltoid blades to the left end, and by linear blades to the right end (Fig. 5). Along the second relative warp, Clovis-bison point shape space is defined by
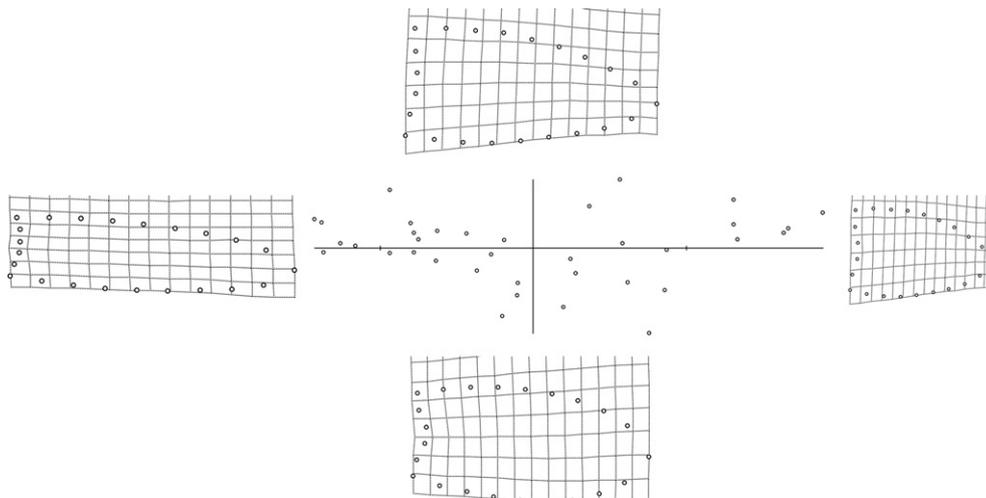

Fig. 3. Bivariate plot of relative warp 1 (88.4%) against relative warp 2 (4.8%) for Clovis points associated with mammoth. The four projectile-point images are deformations from the consensus configuration that are used to display the shape space defined by the first two relative warps.
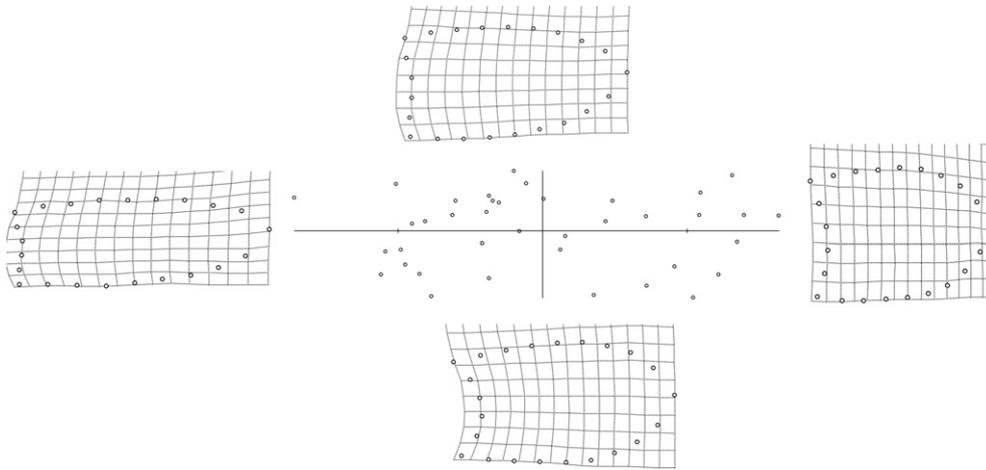
Fig. 4. Bivariate plot of relative warp 1 (82.2%) against relative warp 2 (6.7%) for all points associated with bison. The four projectile-point images are deformations from the consensus configuration that are used to display the shape space defined by the first two relative warps.

oblanceolate blades at the upper end, and by linear blades at the lower end. The bases of the Folsom-bison points are U-shaped. Folsom-bison point shape space is defined along the first relative warp by oblanceolate blades to the left end, and by short, lanceolate blades to the right end (Fig. 6). Along the second relative warp, Folsom-bison shape space is defined by linear blades at the upper end, and by lanceolate blades at the lower end. Thus, visual comparison suggests that as far as shape is concerned both groups of Clovis points differ from the Folsom-bison points, but do not differ appreciably from each other.

Table 4 summarizes the results of the MANOVA. This analysis indicated that at least two of the three groups have distinct point shapes. In terms of the pairwise comparisons, only the comparison between Clovis-mammoth and Folsom-bison points returned a significant difference. In other words, the MANOVA is consistent with the visual comparison to the extent that it indicates that the shapes of Clovis-mammoth and Clovis-bison points are indistinguishable, and that the shapes of Clovis-mammoth and Folsom-bison points are different. However, the MANOVA also suggests that the difference between the shapes of Clovis-bison and Folsom-bison points identified in the visual comparison is not significant.

The ANOVAs indicated that the scores for the first relative warp (representing 88.04% of the variation) and the second relative warp (representing 5.06% of the variation) were significantly different by

group (relative warp 1: $F = 24.98$, df $= 71.73$, $p = 0.000$; relative warp 2: $F = 9.89$, df $= 71.73$, $p = 0.000$). The other relative warps were not significantly different by group. Comparisons between Clovis-mammoth and Folsom-bison points were significant in the post hoc tests of the first and second relative warp scores ($p = 0.000$ and 0.000, respectively). In contrast, the comparisons between Clovis-mammoth and Clovis-bison points were not significant (first relative warp: $p = 0.184$; second relative warp: 0.592). The comparison between Clovis-bison and Folsom-bison points was significant for the first relative warp scores ($p = 0.006$) but not for the second relative warp scores ($p = 0.181$). As such, like the MANOVAs, the ANOVAs suggested that point shape distinguishes Clovis-mammoth points from Folsom-bison points but does not distinguish Clovis-mammoth points from Clovis-bison points. However, unlike the MANOVA, the ANOVA revealed that a portion of shape (relative warp 1) distinguishes Clovis-bison points from Folsom-bison points.

Overall, the results of the second set of analyses are inconsistent with the hypothesis that prey size influences early Paleoindian projectile point form. They indicate not only that Clovis-mammoth and Clovis-bison points do not differ significantly in size and shape, but also that there are significant differences in size and shape between Clovis-bison and Folsom-bison points.

4. Discussion

We used Clovis and Folsom projectile points that are associated with either mammoth or bison to test the longstanding hypothesis that prey size influenced early Paleoindian projectile point size and shape. In the first set of analyses we tested the hypothesis by grouping points according to whether they were found with mammoth or bison and then comparing the two groups (Clovis-mammoth points versus Clovis-bison and Folsom-bison points). In the second set of analyses, we tested the point form-prey size hypothesis by comparing the size and shape of Clovis points that are associated with mammoth, Clovis points that are associated with bison, and Folsom points that are associated with bison.

The two sets of analyses yielded conflicting results. The results of the first set of analyses were consistent with the predictions of the hypothesis. We found mammoth points to be significantly larger in length, width, and thickness than bison points. We also found the shapes of mammoth and bison points to be significantly different. In contrast, the results of the second set of analyses were inconsistent with the predictions of the hypothesis. The results of

Table 3
Descriptive statistics for length, width, and thickness variables for the three groups of points—Clovis points associated with mammoth (Clovis-mammoth), Clovis points associated with bison (Clovis-bison), and Folsom points associated with bison (Folsom-bison).

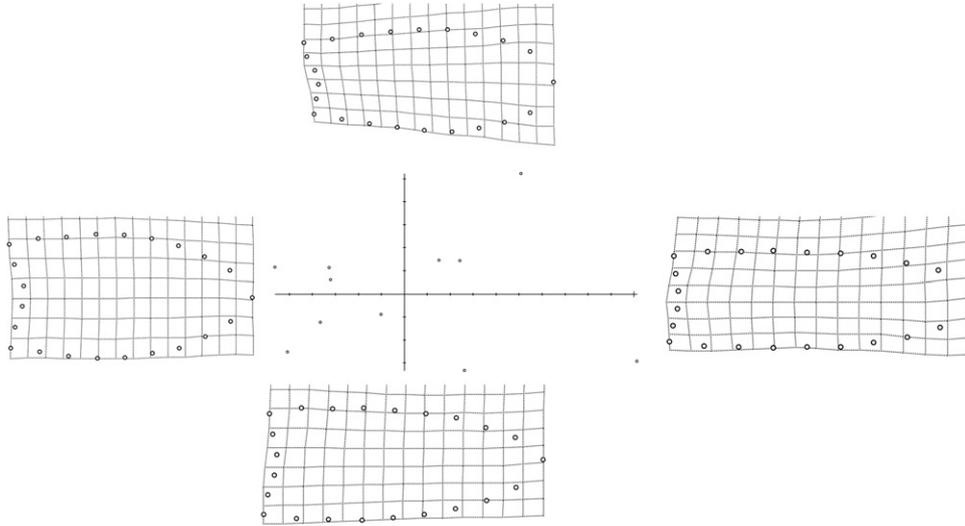|	n	Minimum	Maximum	Mean	Standard deviation
Clovis-mammoth					
Length	36	26.56	117.24	72.51	25.39
Width	36	15.97	36.60	26.69	5.52
Thickness	36	4.19	9.77	7.51	1.41
Clovis-bison					
Length	11	39.90	83.10	56.04	14.64
Width	11	17.40	34.60	24.93	5.81
Thickness	11	5.40	11.10	7.20	1.68
Folsom-bison					
Length	27	20.80	61.00	37.98	10.61
Width	27	15.30	24.15	20.05	2.30
Thickness	21	3.00	4.50	3.63	0.49

Fig. 5. Bivariate plot of relative warp 1 (62.7%) against relative warp 2 (16.6%) for Clovis points associated with bison. 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.

the comparisons of the Clovis-mammoth and Folsom-bison points were as predicted: Clovis-mammoth points are significantly larger than Folsom-bison points, and there are significant shape differences between the two groups of points. However, the results of the other comparisons were not as predicted. Not only are Clovis-mammoth points statistically indistinguishable from Clovis-bison points in terms of size and shape, but also Clovis-bison points are significantly different from Folsom-bison points in size and shape.

Four potential confounding factors need to be considered before these findings can be accepted as valid. The first is the size of our sample of Clovis-bison points. We included all the available complete, bison-associated Clovis points in our sample, but with an n of 11, the latter is still less than half the size of the sample of Folsom-bison points ($n = 27$) and less than a third the size of the sample of Clovis-mammoth points ($n = 36$). It is possible, therefore, that the Clovis-bison point sample is less representative than the other two samples and that if we had been able to employ a larger sample of Clovis-bison points, we would have found a significant

difference between them and the Clovis-mammoth points. However, this is unlikely. For the comparison of Clovis-mammoth points and Clovis-bison points to be biased against the hypothesis, small points would have to be underrepresented in the Clovis-bison sample (If the bison-point sample is biased in the other direction—i.e., large points are underrepresented—then the difference between the Clovis-mammoth and Clovis-bison samples would have been even smaller and less significant). But there is no reason to suspect that small points are underrepresented in the sample of Clovis-bison points. Folsom points are, on average, smaller than Clovis-bison points, and they have been recovered from similar contexts and in one case the same site (Blackwater Draw) as Clovis points. So, if preservation and recovery factors have preferentially acted against small points, the sample of Folsom points should be smaller than the sample of Clovis-bison points. This is not the case. As we mentioned earlier, Folsom points are more than twice as numerous as Clovis-bison points. Accordingly, it is unlikely that the small size of our sample of Clovis-bison points
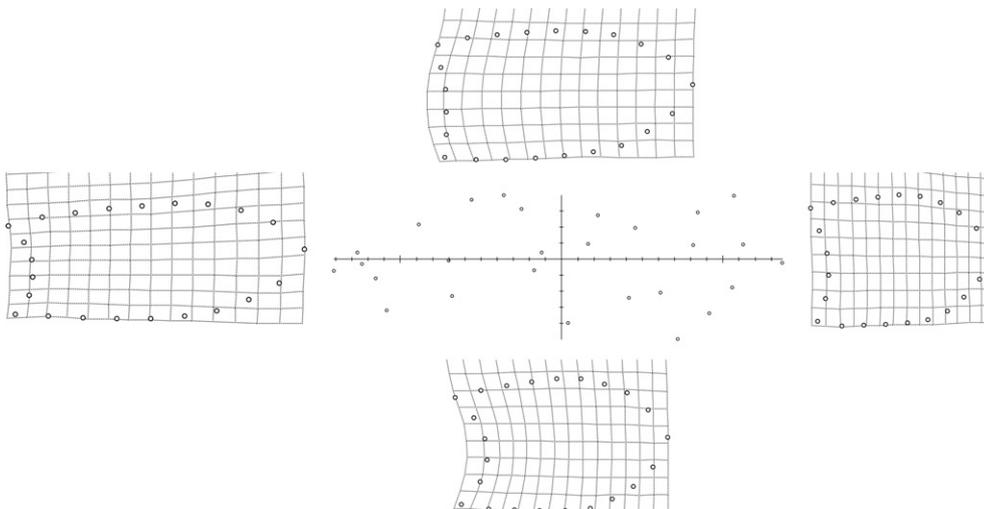

Fig. 6. Bivariate plot of relative warp 1 (82.5%) against relative warp 2 (7.2%) for Folsom points associated with bison. The four projectile-point images are deformations from the consensus configuration that are used to display the shape space defined by the first two relative warps.

Table 4
Results from the multivariate analysis of variance tests of shape variables by the three groups of points—Clovis points associated with mammoth (Clovis-mammoth), Clovis points associated with bison (Clovis-bison), and Folsom points associated with bison (Folsom-bison).

Groups compared	F	p-value
Clovis-mammoth, Clovis-bison, Folsom-bison	2.586	0.0002[a]
Clovis-mammoth, Clovis-bison	1.429	0.4026
Clovis-mammoth, Folsom-bison	5.099	0.0002[a]
Clovis-bison, Folsom-bison	>0.001	0.3424

[a] Significant at the 0.0125 alpha level in accordance with the Bonferroni correction.

accounts for the failure of the second set of analyses to support the prey-size hypothesis.

The second potential confounding factor is the developmental age of mammoth specimens with which the Clovis-mammoth points are associated. If some of the smaller points were used to hunt immature and therefore smaller mammoth, it may skew the analyses toward rejecting the prediction that Clovis points used to hunt mammoth should be larger than Clovis points used to hunt bison. To assess this possibility, we collated published estimates of developmental age for as many of the mammoth specimens as possible. We then divided the Clovis-mammoth point sample into points associated with immature mammoths and points associated with mature mammoths. The sample included two points from Domebo associated with an immature mammoth (Table 1). In addition, 11 points were recovered from mammoth kills that include immature as well as mature individuals and cannot be associated with any particular specimen. Two of the points are from the Miami site and nine from the Lehner site (Table 1). The remaining 23 Clovis-mammoth points are unambiguously associated with adult specimens. Next, we ran t-tests to determine if the points that are associated with immature mammoths are smaller than the points associated with adult mammoths. The t-tests indicated that the lengths, widths and thicknesses of the two groups of points are statistically indistinguishable (length: $t = 0.088$, df $= 34$, $p = 0.930$; width: $t = 0.465$, df $= 34$, $p = 0.645$; thickness: $t = 0.190$, df $= 34$, $p = 0.851$). Thus, there is no reason to believe that age-related variation in the size of mammoths influenced the results of the analyses.

The third potential confounding factor is the quality of the raw materials used to make the points. Low-quality raw materials (such as quartz, felsite, and quartzite) are more difficult to flake, and the use of low-quality raw materials has been recognized as a factor in the ability of flintknappers to produce a desired tool form (Andrefsky, 1994). Therefore, it is reasonable to assume that flintknappers making points from low-quality raw materials may have had difficulty making large points of a desired form. Thus, if one of the groups of points consists of relatively more points made from low-quality raw materials, it might influence the analyses of point form. To evaluate this possibility we first identified six raw materials in our sample: chert, quartzite, felsite, chalcedony, quartz, and obsidian. Determinations of raw materials were made by visual inspection when possible, and in other cases we relied on published identifications. We then divided the points into two groups—one of lower-quality raw materials and the other of higher-quality materials. The flaking properties of quartz, felsite, and quartzite were considered to be of lower quality than chert, chalcedony, and obsidian (Holliday and Welty, 1981; Tallavaara et al., 2010). We then identified the overall proportion of different raw materials used to make the points. Chert is the most abundant (83.8%), followed by chalcedony (5.4%), quartz (4.05%), quartzite (2.7%), felsite (2.7%), and obsidian (1.35%). Clovis-bison points have the most points made from lower-quality material (2/11, 18.2%), Clovis-mammoth points

have the second-most points made from lower-quality material (5/36, 13.9%), and Folsom-bison points have no specimens made from lower-quality material. We then conducted t-tests between the lower-quality and higher-quality groups for length, width, and thickness of points for Clovis-mammoth points and Clovis-bison points. T-tests were not performed on the Folsom-bison points because they were manufactured using only higher-quality materials. T-tests comparing points made from higher-quality and lower-quality material within the Clovis-mammoth point sample showed no difference in length ($t = 0.63$, df $= 34$, $p = 0.531$), width ($t = 1.11$, df $= 34$, $p = 0.276$), or thickness ($t = 0.12$, df $= 34$, $p = 0.903$). Similarly, t-tests comparing points made from higher-quality and lower-quality materials within the Clovis-bison point sample showed no difference in length ($t = -0.73$, df $= 9$, $p = 0.487$), width ($t = -0.70$, df $= 9$, $p = 0.499$), or thickness ($t = -1.75$, df $= 9$, $p = 0.114$). To explore these results further we plotted the distribution of points made from higher-quality materials (chert, chalcedony, and obsidian) and from lower-quality materials (quartzite, felsite, and quartz) (Fig. 7). Of the points made from lower-quality material, the three quartz points (from Lehner, two associated with mammoth and one with bison) cluster on the small end of the distribution. Post hoc, Bonferroni-corrected comparisons revealed that the quartz points are not different from points made from higher-quality materials in terms of length, width, or thickness (length: $p = 0.551$; width: $p = 0.186$; thickness: $p = 1.000$). They differ from points made from lower-quality materials in terms of length and width (length: $p = 0.034$; width: $p = 0.008$) but not thickness ($p = 0.275$). However, the points made from quartz do not represent the minimum measurements for length, width, or thickness of points in the Clovis-mammoth or Clovis-bison point samples. As such, the evidence suggests that raw-material quality does not significantly impact the distribution of point sizes within the sample. Next, we evaluated the potentially confounding effect of raw-material quality on the results of the point shape analyses. To determine whether the quality of different raw materials influences variation in point shape among the groups, we conducted discriminant function analyses (DFAs) of the partial warp scores and uniform component matrices by lower-quality and higher-quality materials. For raw-material quality to have a confounding effect on the point shape analyses, we expected that points made of lower-quality materials to be misclassified more often than points made of higher-quality materials, the assumption being that lower-quality materials limit the ability of the flintknapper to produce points of a desired size and shape. The results of the DFA by raw-material quality and group revealed that no points were misclassified indicating that raw-material quality also did not affect the point shape analyses.

Lastly, the potential confounding effects of resharpening need to be considered. Resharpening of dull or broken stone tools can change their original shape (Frison, 1968). Therefore, we reasoned that if resharpening occurred preferentially in one group of points, this might affect the results of our analyses. Because the object of our first set of analyses is size, we had no way of controlling for this factor, but we did evaluate the effects of resharpening on point shape using size as a proxy for the effects of resharpening. Thus, to evaluate the effects of resharpening on point shape, we ran DFAs on the partial warp scores and uniform component matrices by group and size grade by dividing the points within each group into two subgroups based on mean length. We expected that if resharpening is a confounding factor, then the shorter points within each group of points, and thus the points more likely to have been resharpened, would be more likely to be misclassified than the larger points (Buchanan and Collard, 2010). In the DFA by group and point-size category (small and large), two points were misclassified: a large-Clovis-mammoth point was misclassified as a small Clovis-
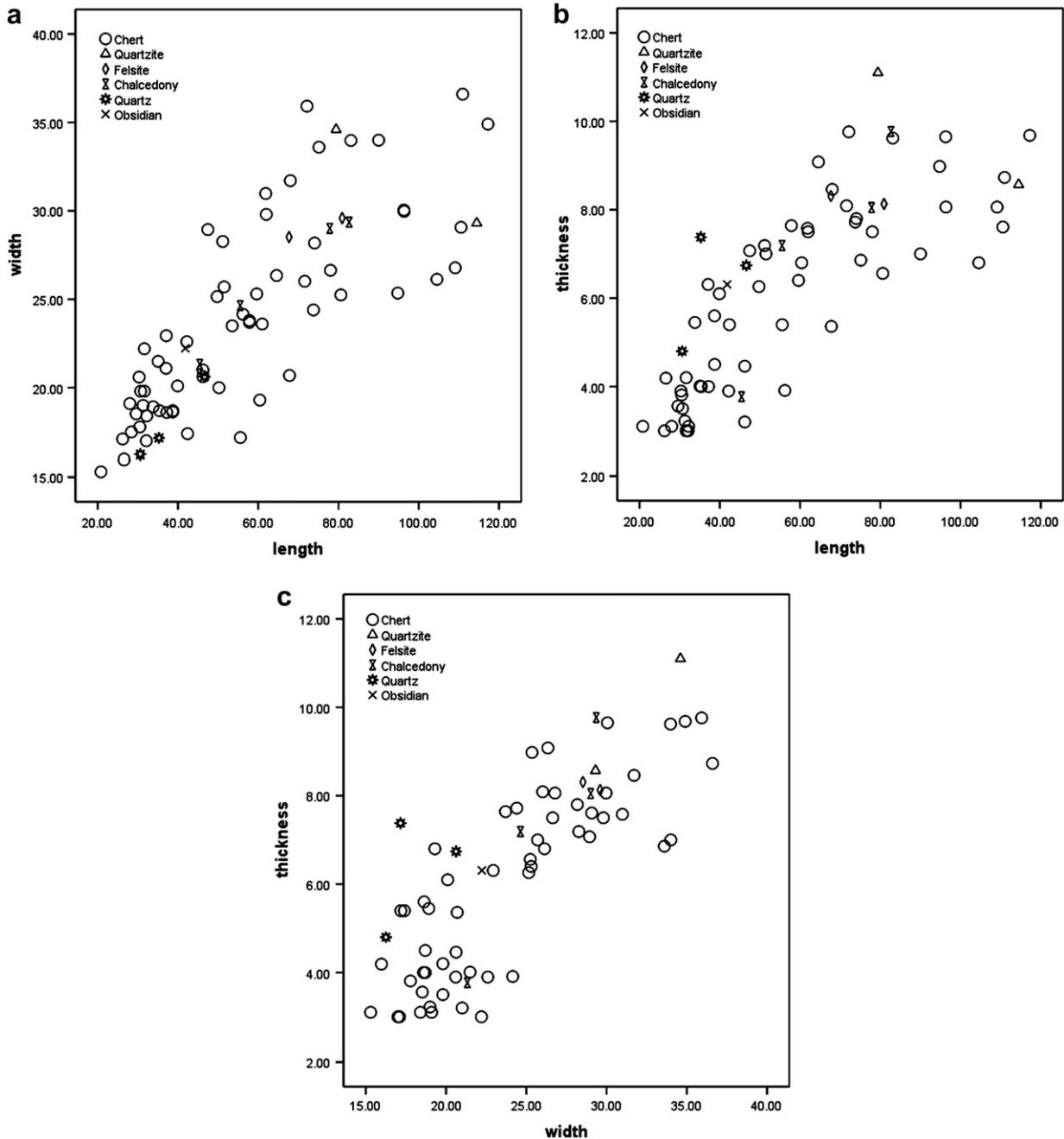
Fig. 7. Plots of (a) length by width, (b) length by thickness, and (c) width by thickness for Clovis points associated with mammoth, Clovis points associated with bison, and Folsom points associated with bison by raw-material type.

mammoth point, and a small Folsom-bison point was misclassified as a large Folsom-bison point. Importantly, the DFAs showed that smaller points—those more likely to have been resharpened—were not misclassified more often than larger points. This suggests that our results cannot be explained by the confounding effects of resharpening.

Given that our results appear to be independent of the main potential confounding factors, how do we explain them? How do we account for the fact that the prey-size hypothesis is supported when the points are grouped solely on the basis of the prey species with which they are associated, but not supported when the comparison is made between prey species within Clovis?

There are two obvious potential explanations for the discrepancy in our results. The first is that Clovis hunters focused on mammoth and only occasionally hunted bison when the opportunity arose. According to this hypothesis, Clovis hunters would occasionally have used points designed for killing mammoth to take bison. This hypothesis would be plausible if bison were encountered rarely on the landscape. To evaluate the possibility we estimated the proportion of mammoth to bison that were available to Clovis hunters in the Southern Plains and Southwest, with the expectation that bison were rare relative to mammoth. We identified eight sites where Clovis points were recovered in association with mammoth or bison. The MNI of mammoth and bison at these sites is 27 and 38, respectively. The greater number of bison at these sites compared to mammoth suggests that the discrepancy in our results is not a consequence of Clovis bison hunting being only an incidental activity.

Another possible explanation for the Clovis-mammoth and Clovis-bison samples being statistically indistinguishable is adaptive lag—Clovis populations did not start hunting bison on a regular basis until the later part of the Clovis period. This hypothesis implies that adjusting a weapon system that is optimized for hunting mammoth so that it is optimized for hunting bison takes time. This is hinted at in our dataset. The size variation in Clovis-bison points is intermediate between Clovis-mammoth and Folsom-bison points. Histograms of length, width, and thickness for the three groups of points show that Clovis-mammoth points are the most variable, followed by Clovis-bison points and then Folsom-bison points (Fig. 8). The histograms also show that Folsom-bison points cluster on the small end of the variation for length, width, and thickness; for length and width, Clovis-bison points are intermediate between Folsom-bison points and Clovis-mammoth points. Indeed, if the samples of points represent a time sequence, with Clovis-mammoth points at the older end, Folsom-bison points at the younger end, and Clovis-bison points between

the two, the histograms could be interpreted as a cultural selection process toward overall smaller points. The similarity of Clovis-bison point shape to that of both Clovis-mammoth and Folsom-bison points along relative warp 2 also suggests that Clovis-bison points could be intermediate between Clovis-mammoth points and Folsom-bison points.

The dating of the point assemblages is a way to test the possibility of a cultural evolutionary sequence from Clovis-mammoth points to Clovis-bison points to Folsom-bison points. For the adaptive lag hypothesis to be supported, early Clovis points should be associated with mammoth and late Clovis points with bison remains. Tentative support for this scenario is provided by analyses of Clovis and Folsom radiocarbon-dated occupations reported by Collard et al. (2010). These authors found that the youngest reliably dated Clovis occupation is the Jake Bluff Clovis bison kill, on the Southern Plains, and that the other Clovis sites with reliable associations with bison—Murray Springs, Lehner, and Blackwater Draw, all in the Southwest—are also on the young end of the range for
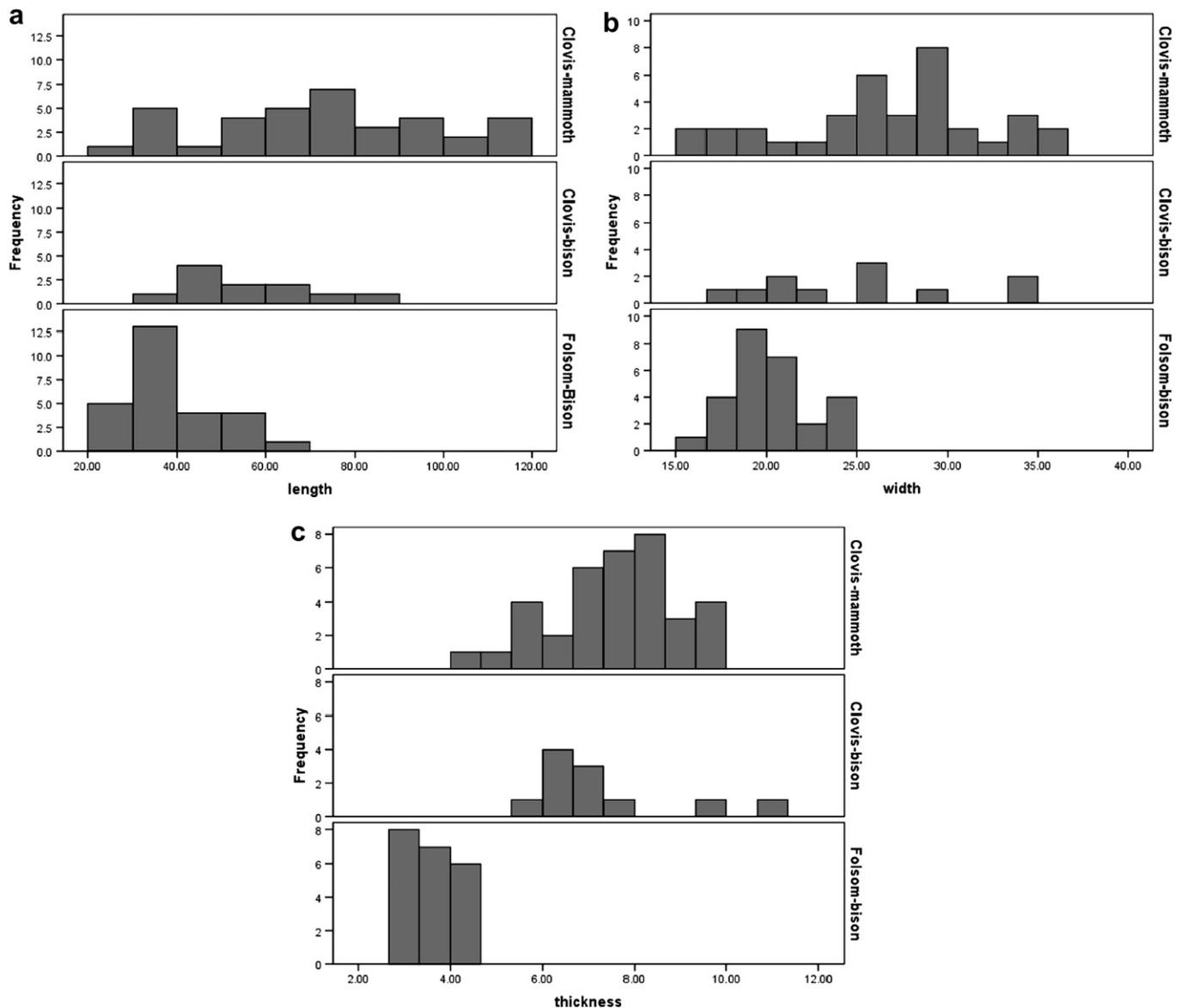

Fig. 8. Histograms for Clovis points associated with mammoth, Clovis points associated with bison, and Folsom points associated with bison for (a) length, (b) width, and (c) thickness measures.

dated Clovis occupations (five of the six youngest Clovis occupations). However, we should note that in some cases, such as Murray Springs and Blackwater Draw, radiocarbon dates were not derived directly from the bison kills. If further evidence supports this trend, it would indicate that concentrated bison hunting by Clovis peoples was a relatively late occurrence during the Clovis period. With respect to this hypothesis, it is worth noting that Bement and Carter (2003) argue that the Jake Bluff Clovis bison kill postdates the extinction of the mammoths, and suggest that Clovis hunters turned to hunting bison when other megafauna became scarce. If this hypothesis is correct, it could explain why Clovis bison kills are relatively young. It may be that they increase in frequency as the number of mammoth on the landscape declines.

5. Conclusions

The hypothesis that early Paleoindian points were designed specifically for the type of prey being hunted has been considered since the establishment of the Clovis point type (Cotter, 1938). A number of authors have since argued that larger points were used to hunt larger prey and that smaller points were used to hunt smaller prey. Despite the potential importance of this hypothesis for explaining variation in early Paleoindian point form, there had been no direct investigation of this hypothesis. Here we provide a quantitative test of the predictions that there should be significant differences in the size and shape of projectile points associated with prey of different body sizes. We used a sample of Clovis points associated with mammoth or bison and Folsom points associated with bison, and found support for the general prediction that prey size correlates with point size and shape. Points used to hunt mammoth were larger and of a different shape than points used to hunt bison. However, when we analyzed the points by prey type and point type, we found that, contrary to expectations, point size and shape did not distinguish Clovis points found with mammoth from Clovis points found with bison. Thus, our findings suggest there is no simple relationship between point size and prey size. Our results are independent of four confounding factors—sample size, age-related variation in mammoth body size, raw-material quality, and resharpening effects. We considered two possible explanations for the discrepancy in our results, one of which remains plausible—that bison hunting was a late occurrence in Clovis and thus Clovis points were in the process of being adapted to hunting bison rather than mammoth.

Acknowledgments

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