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Social learning and technological evolution during the Clovis colonization of the New World



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ABSTRACT

A long-standing debate in Pleistocene archaeology concerns the sources of variation in the technology of colonizing hunter-gatherers. One prominent example of this debate is Clovis technology (13,350-12,500 calendar years before present), which represents the earliest widespread and currently recognizable remains of hunter-gatherers in North America. Clovis projectile points appear to have been made the same way regardless of region, but several studies have documented differences in shape that appear to be regional. Two processes have been proposed for shape variation: (1) stochastic mechanisms such as copy error (drift) and (2) Clovis groups adapting their hunting equipment to the characteristics of prey and local habitat. We used statistical analysis of Clovis-point flake-scar pattern and geometric morphometrics to examine whether drift alone could cause significant differences in the technology of Stone Age colonizing hunter-gatherers. Importantly, our analysis was intraregional to rule out a priori environmental adaptation. Our analysis confirmed that the production technique was the same across the sample, but we found significant shape differences in Clovis point populations made from distinct stone outcrops. Given that current archaeological evidence suggests stone outcrops were "hubs" of regional Clovis activity, our dichotomous, intraregional results quantitatively confirm that Clovis foragers engaged in two tiers of social learning. The lower, ancestral tier relates to point production and can be tied to conformist transmission of tool-making processes across the Clovis population. The upper, derived tier relates to point shape, which can be tied to drift that resulted from increased forager interaction at different stone-outcrop hubs and decreased forager interaction among groups using different outcrops. Given that Clovis artifacts represent the earliest widespread and currently recognizable remains of hunter-gatherers in North America, our results suggest that we need to alter our theoretical understanding of how quickly drift can occur within a colonizing population and create differences among socially learned technological characters.

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Introduction

Clovis artifacts represent the earliest widespread and currently recognizable remains of hunter-gatherers in late Pleistocene North America (Anderson, 1990; Steele et al., 1998; Anderson and Gillam, 2000; Haynes, 2002; Barton et al., 2004; Meltzer, 2009; Bradley et al., 2010; Sholts et al., 2012; Smallwood, 2012; Holliday and Miller, 2013; Miller et al., 2013; Sanchez et al., 2014; Smallwood and Jennings, 2014). By far the most iconic artifacts of the Clovis culture are bifacially flaked stone projectile points that have

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http://dx.doi.org/10.1016/j.jhevol.2015.01.002 0047-2484/© 2015 Elsevier Ltd. All rights reserved. parallel to slightly convex sides, concave bases, and a series of flake-removal scars—termed "flutes"—on one or both faces that extend from the base to about a third of the way to the tip (Wormington, 1957; Bradley, 1993; Bradley et al., 2010; Buchanan and Collard, 2010, Fig. 1). Clovis points have been found throughout the contiguous United States, northern Mexico, and southern Canada (Wormington, 1957; Haynes, 1964; Anderson and Faught, 2000; Sanchez, 2001; Anderson et al., 2005; Sanchez et al., 2014). Current estimates, based almost entirely on radiocarbon dating, are that the Clovis culture appeared in the American West and Southwest ca. 13,350–12,800 calendar years before present (calBP) and in the East ca. 12,800–12,500 calBP (Haynes et al., 1984; Levine, 1990; Holliday, 2000; Waters and Stafford, 2007; Gingerich, 2011).



Figure 1. Clovis point (Williamson County, TN).

One long-standing debate in Pleistocene archaeology concerns the sources of lithic technological variation among colonizing populations of hunter-gatherers, namely by what means, and how quickly, the frequency of cultural traits change through time. Variation, of course, is a key element in any system of descent with modification (i.e., an evolutionary system; Darwin, 1859; Lyman and O'Brien, 1998; O'Brien and Lyman, 2000; Mesoudi et al., 2004; Eerkens and Lipo, 2005; Mesoudi, 2011; Schillinger et al., 2014a:129,b), and both heritable and non-heritable sources of variation contribute to the stone-tool forms observed in, and production techniques inferred from, the paleoanthropological record (O'Brien and Lyman, 2000; Lycett and von Cramon-Taubadel, 2015). For example, among Lower Paleolithic hominins presumably dispersing from sub-Saharan Africa into other regions such as the Near East, Europe, and the Indian subcontinent over a relatively longer period of time, cultural-evolutionary processes, raw material, and resharpening have all been found to contribute to technological variation in varying amounts on particular traits (Lycett and von Cramon-Taubadel, 2008, 2015; Lycett, 2008, 2009). Alternatively, on a relatively shorter time scale, during the Homo sapiens colonization of Europe between 60,000 and 30,000 years ago, recent work (Tostevin, 2012; Nigst, 2012) has examined whether independent innovation, cultural transmission, or a combination of these two factors were predominately responsible for lithic technological evolution in different geographic regions and archaeological cultures such as the Bohunician, Aurignacian, and Szeletian. Indeed, with respect to the Aurignacian in particular, there is wide agreement that in western and central parts of Europe, the appearance of Aurignacian technology reflects human dispersal (Mellars, 2009; Pettitt and White, 2012), which has led to questions involving how and why chronologically later Aurignacian technological variation in the west is similar to or different from that of potential "homelands" in southeastern Europe, the Levant, or even farther east (Olszewski and Dibble, 2006; Dinnis, 2012).

Variation in Clovis points represents a prominent example in this debate regarding the sources of lithic technological variation, especially in terms of shape. Numerous studies have documented differences—often subtle differences—in shape (plan-view form; Meltzer, 1988, 1993; Anderson, 1990; Storck and Spiess, 1994; Morrow and Morrow, 1999; Buchanan and Hamilton, 2009; Hamilton and Buchanan, 2009; Smallwood, 2010, 2012; Buchanan et al., 2014), but there is a lack of agreement over the cause(s) of the variation. Two principal processes have been proposed: (1) stochastic mechanisms such as copy error (drift; Bentley et al., 2004) introduced variation (Morrow and Morrow, 1999; Buchanan and Hamilton, 2009) and (2) Clovis groups adapted their hunting equipment to the characteristics of prey and local habitat, resulting in regionally distinct point shapes (Buchanan et al., 2014).

Other studies have focused not on the shape of Clovis points but rather on how they were manufactured. Several researchers have proposed that the points were made with similar production techniques, irrespective of geographic locality (Bradley, 1993; Morrow, 1995; Collins, 1999; Tankersley, 2004; Bradley et al., 2010), but only recently has the proposal been subjected to quantitative analysis. For example, Smallwood (2012) found shared aspects of Clovis technology across the southeastern United States. In a quantitative assessment, Sholts et al. (2012) used laser scanning and Fourier analysis to examine flake-scar patterns-relics of the tool-making process—on a sample of 34 Clovis points from sites in the Southwest, Southern Plains, and Northern Plains, and five points from a site in Maryland. Their analysis suggested that flaking patterns were similar across these regions, and they concluded that there was a continent-wide standardization of Clovis technology "without evidence for diversification, regional adaptation, or independent innovation" (Sholts et al., 2012:3024). If so, and regardless of which hypothesis might account for variation in shape, patterns of flake removal appear to have been less sensitive than point shape to either adaptive change driven by environmental conditions (selection) or the vagaries of cultural transmission (drift).

The two sources of variation in point shape—drift and selection—are not mutually exclusive and could both simultaneously contribute to interregional differences (O'Brien et al., 2014; see also Kuhn, 2012; Hiscock, 2014; Mackay et al., 2014; Lycett and von Cramon-Taubadel, 2015). Colonizing populations do not necessarily stay in constant contact with one another, especially as geographic distance between them increases, and thus over time point shapes can begin to drift. Similarly, colonizing populations may begin to adapt point shape to the environmental conditions they encounter, which are different from those encountered by other groups. But even granting some variation in shape, it is apparent that, with respect to Clovis groups, it occurred within fairly narrow bounds (Buchanan et al., 2014).

In terms of learning models for Clovis-point manufacture, a good case can be made for some kind of biased transmission across North America (Sholts et al., 2012; O'Brien et al., 2014), with "biased" referring to the various factors that can affect one's choice of whom or what to copy (e.g., copy the majority, copy the most successful model; Boyd and Richerson, 1985; Bettinger and Eerkens, 1999; Laland, 2004). Given that the manufacture of a Clovis point is a complex procedure that would have required a significant amount of investment both in terms of time and energy to learn effectively (Crabtree, 1966; Whittaker, 2004; Bradley et al., 2010), biased-learning strategies could have played a key role in fluted-point technologies (Hamilton, 2008; Hamilton and Buchanan, 2009). Sholts et al. (2012:3025) proposed that learning could have taken place at chert outcrops-quarry sites-where "Clovis knappers from different groups likely encountered each other [which] would have allowed knappers to observe the tools and techniques used by other artisans, thereby facilitating the

sharing of technological information." This sharing of technological information, Sholts and colleagues propose, created the uniformity in production seen in their sample.

Current archaeological evidence suggests that Clovis foragers used stone outcrops as "hubs of regional Clovis activity" (Waters et al., 2011:208; see also Carr, 1975, 1986; Gardner, 1983; Anderson, 1990, 1995, 1996; Havnes, 2002; Collins et al., 2003; Lepper, 2005; Patten, 2005; Collins, 2007; Smallwood, 2010, 2012), forming a "staging area," or "core," of Paleoindian exploitive areas (Smith, 1990; Anderson, 1990, 1995, 1996; Tankersley, 1995). Stone outcrops clearly would have provided a necessary resource to Pleistocene foragers (Haynes, 1980), but for a thinly scattered mobile population such as Clovis, outcrops would have also acted as ideal meeting spots because once found, they would serve as predictable places on an emerging map of a landscape (Lepper, 1989; Meltzer, 2009). Finding outcrops may also have been relatively easy, perhaps entailing little more than following alluvial gravel trains upstream to the outcrop (Anderson, 1990, 1995; Meltzer, 2004).

Bradley et al. (2010) suggest that evidence for social interaction and learning can be seen in tools from the Gault site in central Texas, which is situated on an outcrop of Edwards chert. The tools appear to depict skill-level variation and exhibit evidence that "two or more individuals often worked on the same core" (Bradley et al., 2010:176). Some researchers have speculated that the particular choice of stone outcrop, and its distinctively colored cryptocrystalline chert, served as an indicator of group membership and thus facilitated the flow and exchange of information, services, and goods within a group (Ellis, 1989; Wright, 1989).

In the analysis reported here, we used a sample of 115 Clovis points to test several implications of the above studies with reference to flake-scar pattern and point shape. Whereas Sholts et al. (2012) used points from widespread regions of North America, our sample was from the eastern riverine subarea of the unglaciated Midcontinent (Lepper, 2005, Fig. 2), a relatively homogeneous "no analog" environment during the Clovis period (Shuman et al., 2002; Webb et al., 2003; Williams et al., 2004; Gill et al., 2012; Liu et al., 2013). We restricted the sample to a small, homogeneous region to maximize the probability that any patterned variation in point shape should be attributable not to differential environmental adaptation by Clovis groups but rather to decreased social interaction among them.

To explore Sholts et al.'s (2012) 'quarry hypothesis', we divided our sample into three chert subgroups-Wyandotte, Upper Mercer, and Hopkinsville-on the basis of Tankersley's (1989) identification (see Boulanger et al., 2015). The main outcrops of each chert type are shown in Fig. 2. The fact that the Clovis points from each of the three chert groups substantially geographically overlap further rules out environmental influences on point shape (Fig. 2), because within the sample area Clovis groups, if they were using different quarries, were exploiting the same parts of the landscape. We reasoned that if the three point groups showed differences in shape, the differences were a result of drift brought about by the particular social geography of outcrop hubs. In other words, as individual groups began focusing on one type of chert and increased intragroup interaction around particular outcrops, there was decreased intergroup interaction and transmission (Tehrani and Collard, 2002, 2009; Lycett, 2013). In addition to assessing whether points from different outcrops were technologically and morphologically distinct, we also evaluated potential non-heritable factors such as raw-material differences and resharpening.



Figure 2. Map of the study area showing locations (by county) of Clovis points included in the sample by chert type. Same-colored dots often contain multiple specimens. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Materials and methods

Sample

The data for the 115 Clovis points were derived from technical illustrations in Tankersley (1989), who developed a consistent fourstep method to create accurate, to scale, flake-by-flake two dimensional facsimiles of hundreds of fluted points from Indiana, Kentucky, and Ohio (Tankersley, 1989). Tankersley (1989:91) described the method as follows:

First the face of a fluted point is gently pressed into a flat surface of olive green plastilina (modeling clay) until the point's basal and lateral edges are in the same plane as the surface of the clay. The point is then gently lifted from the impression with the aid of a stiff dental pick. The result is a finely detailed clay mold of a fluted point face. Second, a plaster cast is made from the clay mold by pouring a soupy mixture of plaster into the mold. A cut section of aluminum screen can be placed on the exposed surface of the wet plaster to strengthen the cast for transport. The plaster air-dries in 30-120 min, depending upon the temperature and humidity of the casting area. The result is a detailed cast of a single fluted point face. Third, after the cast completely dries, the flake scars are highlighted with graphite. A two dimensional facsimile of the point is produced by photocopying the graphite highlighted cast on a white background. And finally, the photocopied facsimile is traced onto velum in black ink. This procedure results in an accurate, to scale, flake by flake illustration of the artifact.

The 115 points were made from cherts from the three principal outcrops in the study area: Wyandotte, Indiana (n = 44); Hop-kinsville, Kentucky (n = 25); and Upper Mercer, Ohio (n = 46). Although there are more points made from these three cherts in Tankersley (1989), they are broken, whereas the 115 points analyzed here represent all the unbroken specimens.

Geometric morphometric methods

Shape data were obtained from the points in a similar manner as in Buchanan et al. (2014). The procedure involved acquiring digital images of point illustrations to capture landmark data. We used three landmarks and 20 semilandmarks to capture point shape. Two landmarks were located at the base of the point and were defined by the junctions of the base and the blade edges. The third landmark was located at the tip. Line segments with equally spaced perpendicular lines were used to place the semilandmarks along the edges of the blades and base. These "combs" were superimposed on each image using MakeFan6 (www. canisius.edu/~sheets/morphsoft.html). Placement of landmarks along the equally spaced segments of the combs allows semilandmarks to be compared across specimens. The landmarks and semilandmarks were digitized using the tpsDig program (Rohlf, 2010).

Following the digitization process, we subjected the landmark data to general Procrustes analysis, the first step of which is to superimpose the landmark configurations in order to reduce the confounding effects of the digitizing process and to remove size differences among the specimens (Rohlf and Slice, 1990; Rohlf, 2003). Landmark superimposition entails three steps. First, landmark coordinates are centered at their origin or 'centroid', and all configurations are scaled to unit centroid size. Second, the consensus configuration is computed. Third, each landmark configuration is rotated to minimize the sum-of-squared residuals

from the consensus configuration. The results of the superimposition are presented in Fig. 3. The superimposition of landmarks was carried out using tpsSuper (Rohlf, 2004).

In addition to conducting the general Procrustes analyses on the overall dataset we carried out three separate general Procrustes analyses on the Hopkinsville, Upper Mercer, and Wyandotte samples. We did this to get separate consensus or average landmark configurations for each outcrop. We then visually compared the average configurations for each of the samples to assess whether any differences were visible to the naked eye.

After completing the general Procrustes analysis and preliminary visual assessment, we conducted a canonical variate analysis (CVA) to determine how well point shape distinguishes Clovis points made from the three cherts. CVA is used to find shape features that best distinguish among multiple groups (Klingenberg and Monteiro, 2005). To visualize the differences among the chert groups, we plotted the canonical variates in bivariate space. Next, we ran significance tests of the Mahalanobis distances among the three groups. Significance was determined using p-values derived from a permutation test that compared the observed difference between means with a distribution of pairwise mean differences from 1000 random permutations of the data. We used transformation grids to show changes in point shape associated with each canonical variate. In these figures, shape change is in units of D, Mahalanobis distance units. We used Morphol 1.03d (Klingenberg, 2011) to conduct the CVA, calculate the Mahalanobis distances, carry out significance testing, and construct the transformation grids.

Assessing flake-scar pattern

We developed an innovative yet simple method for quantifying flake-scar pattern. This method can distinguish between flake-scar pattern resulting from point production versus that resulting from resharpening, while allowing independent assessments of both. Given our robust sample sizes for each chert-based population, our flake-scar-pattern data were amenable to statistical significance testing.

We based our method on the work of Bradley et al. (2010:177, 106), who state, "Clovis flaked stone technology exhibits a bold, confident, almost flamboyant strategy" that "focuses on the removal of large well-formed flakes." Thus, we formulated a straightforward, quantitative measure of 'boldness': the number of flake scars divided by the square area of a fluted point. The smaller the value, the 'bolder' a fluted point's flaking pattern (Fig. 4). In addition to calculating total flake-scar boldness, we also calculated inner point flake-scar boldness in order to control for the potential confounding factor of resharpening (Fig. 4).

The method was carried out in Adobe Illustrator and is depicted in Fig. 4. Two Clovis points are shown (Fig. 4, column 1). The top one is Upper Mercer Specimen #67, and the bottom one is Wyandotte Specimen #8 (Tankersley, 1989). Observations suggest that the top point exhibits a 'bolder' flake-scar pattern than does the bottom point. To describe this quantitatively, we first traced (in blue) a perimeter outline of each point (Fig. 4, column 2). The area of this original outline was calculated using the Telegraphics plugin 'Patharea Filter' (http://telegraphics.com.au/sw/product/patharea). This perimeter outline was then reduced by 50% in length, which reduced its area to 25% of the original point outline area, and was automatically centered by Illustrator relative to the original point perimeter (Fig. 4, column 3). Next, a new layer was created, and in this layer every flake scar outside the reduced blue outline was marked by a red dot (Fig. 4, column 4). Another new layer was then created, and in this layer every flake scar inside the blue outline was marked by a blue dot (Fig. 4, column 5). Total flake-scar boldness



Figure 3. Results of the superimposition method using the generalized orthogonal least-squares Procrustes procedure: top, consensus configuration of 115 Clovis-point landmark configurations; bottom, variation in point landmark configurations after being translated, scaled, and rotated.



Figure 4. Two Clovis points are shown (column 1), one with "bolder" flaking (top) than the other (bottom). To describe this quantitatively, we first traced (in blue) a perimeter outline of each point (column 2). This perimeter outline was then reduced by 50% in length, which reduced its area to 25% of the original point outline area, and was centered relative to the original point perimeter (column 3). Every flake scar outside the reduced blue outline was marked by a red dot (column 4), while every flake scar inside the blue outline was marked by a blue dot (column 5). "Total flake-scar boldness" was calculated by dividing all dots (red and blue) by the area of the original outline. "Inner flake-scar boldness" was calculated by dividing all dots (red and blue) by the references to colour in this figure legend, the reader is referred to the web version of this article.).

was then calculated by dividing all dots (red and blue) by the area of the original outline. The results make sense given that our observationally bolder Upper Mercer point possesses a smaller value (0.05397) than the Wyandotte point (0.07820). However, because flake scars resulting from resharpening might obscure the flakescar pattern originating from point production, we also calculated 'Inner flake-scar boldness', which divided the number of blue dots by the area of the reduced perimeter outline. Once again, the bolder Upper Mercer point exhibits a smaller value (0.01729) than the Wyandotte point (0.05762), but this time the difference between the two points with respect to flake-scar boldness is more pronounced. Also, notice that for each point 'Inner flake scar boldness' yields a smaller value than 'Total flake scar boldness', which again makes sense because the former eliminates flake scars resulting from resharpening.

In total, 12,287 flake scars were recorded from our 115 points. Because the counts of flake scars from our sample are significantly different from an underlying normal population, we conducted nonparametric statistics to compare flake-scar patterns among points from the three chert outcrops. We used the Kruskal–Wallis test to compare the three groups of points. The tests were carried out using the shareware software PAST (version 3.02a; Hammer et al., 2001).

Results

Analysis of flake-scar pattern

We assessed flake-scar pattern among our three material groups in two ways. First, we analyzed the flake-scar patterns of each Clovis point's entire face. A Kruskal–Wallis test indicated that there were no differences among the three populations (H = 2.976; p = 0.2259; Fig. 5a). Second, point resharpening might influence overall flake-scar pattern, but resharpening scars will be limited predominately to the outer edges of a point's face. Thus, we subsequently analyzed the flake-scar pattern of the inner area of each Clovis point to more robustly assess flake-scar pattern resulting from the original production techniques. This inner area was defined as the central 25% square area of a point's face (see Materials and methods). Once again, a Kruskal–Wallis test indicated that there were no differences in flake-scar pattern among the three chert groups (H = 2.819; p = 0.2442; Fig. 5b).

Analysis of point shape

Fig. 6 shows the consensus configurations for each of the three chert groups derived from the generalized Procrustes analysis. In spite of the fact that Fig. 6 shows only the average point shape of each chert population, there are clear differences visible to the naked eye. Points made of Hopkinsville chert are wider in the middle and base of the point compared with Upper Mercer points, and are wider along the entire width compared with Wyandotte points. Hopkinsville points also have a shallower basal concavity relative to that of both the Wyandotte and Upper Mercer points, whereas the latter possess a steeper blade slope toward the tip than do the Hopkinsville points. Points made of Wyandotte are narrower than points made of Upper Mercer. The Wyandotte points also possess basal lateral edges that are more parallel to the point's overall axis, whereas the Upper Mercer and Hopkinsville points' basal lateral edges flare outwards.

The results of the CVA indicate that the first two canonical variates account for all of the variation in the dataset. The first canonical variate (CV1) incorporates 73.81% of the variation in the dataset and the second canonical variate (CV2) 26.19%. A bivariate plot of the two canonical variates shows that points made from Upper Mercer and Wyandotte cherts overlap considerably along the left half of the CV1 axis (Fig. 7). Points made from Hopkinsville chert occur in the right half and do not overlap the other two cherts to a significant degree. All three cherts overlap on the CV2 axis.

Mahalanobis distances among the groups of points made from the three different cherts are consistent with the visual observations: Upper Mercer and Wyandotte have the closest Mahalanobis distance (1.916), whereas Hopkinsville and Wyandotte are the farthest apart (3.645). However, significance tests of the Mahalanobis distances separating the three groups indicate that the point shapes from all three groups are significantly different (Table 1). The transformation grid of shape change along the CV1 axis indicates that as one moves toward the right-hand (positive) side, points are wider, particularly in the midsection of the points, which produces some outward flaring of the base, and have shallower basal concavities (Fig. 8a). Along the CV2 axis, as one moves up (positive) the graph, points are wider, have a less steep blade slope toward the tip, and have deeper basal concavities (Fig. 8b). The distribution of Hopkinsville points on the upper end of CV1 indicates that they on average have wider midsections, outward



Figure 5. Flake-scar pattern box-plots comparing the three raw material groups' total flake-scar pattern (a) and inner flake-scar pattern (b). There are no significant differences among the three populations in either case.



Figure 6. Consensus or average landmark configurations for each of the three chert sources, derived from the generalized Procrustes analysis procedure. Hopkinsville (left, red), Wyandotte (center, blue), and Upper Mercer (right, green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).



Figure 7. Bivariate plot of canonical variate 1 (73.81%) against canonical variate 2 (26.19%). Red circles are points made from Hopkinsville chert, green circles are points made from Upper Mercer chert, and blue circles are points made from Wyandotte chert. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

flaring bases, and shallower basal concavities compared with points made of Upper Mercer and Wyandotte cherts. Upper Mercer points are located primarily toward the top of the CV2 axis, indicating that they on average have deep basal concavities compared

Table 1

Mahalanobis distances and permutation tests of Mahalanobis distances for Clovispoint shapes by chert source.^a

	Hopkinsville	Upper Mercer	Wyandotte
Hopkinsville Upper Mercer Wyandotte	<0.0001 <0.0001	3.374 <0.0001	3.645 1.916

^a The lower triangle of the matrix shows p-values based on 10,000 permutations, and the upper triangle shows Mahalanobis distances between chert sources.

with Hopkinsville points and less steep blade slopes toward the tip than Wyandotte points. Points made from Wyandotte are located more in the lower left quarter of the graph, indicating that they are on average narrower and have more parallel basal edges compared with Upper Mercer and Hopkinsville points.

We carried out an additional CVA after removing three outliers from the original analysis as a check on our results. We plotted 95% confidence ellipses for each of the three groups in the bivariate plot of CV1 against CV2 (Fig. 9). Three points, one from each rawmaterial group, plotted outside of these confidence ellipses. We removed the three outliers and re-ran the CVA. The results are qualitatively the same as those from the original analysis. The significance tests of the Mahalanobis distances separating the three groups indicate that the point shapes from all three groups are significantly different (Table 2). The results of this second test indicate that the outliers found in each of the three groups did not significantly bias the results of the first CVA.

Evaluation of potential non-heritable factors

We considered two potential confounding, non-heritable factors. The first is that shape differences are the result of differential rawmaterial constraints. Given that a point's shape is a result of flaking, if raw-material differences were responsible for the differences in point shape, we should see differences in flake-scar pattern. We do not. Further, there is now a substantial archaeological and experimental literature that demonstrates that the inherent external properties (size, shape, presence of cortex, and surface regularity) and internal properties (elasticity, brittleness, hardness, homogeneity, granularity, and isotropy) of different raw materials do not determine stone-tool morphology (Brantingham et al., 2000; Sharon, 2008; Archer and Braun, 2010; Buchanan and Collard, 2010; Clarkson, 2010; Eren et al., 2011; Bar-Yosef et al., 2012; Smallwood, 2012; Wang et al., 2012; Buchanan et al., 2014; Gurtov and Eren, 2014; Lycett and von Cramon-Taubadel, 2015). This conclusion holds for vastly different stone types such as basalt, flint, and obsidian (Eren et al., 2014) and even between tools made of stone versus





Figure 8. Deformation grids for the pairwise comparison of mean point shapes for canonical variate 1 (left) and canonical variate 2 (right). The grid is warped to indicate shape change along the canonical variate axes. The landmarks are numbered circles showing the average landmark configuration, and lines indicate the direction and magnitude of change as one moves in the positive direction on the x- or y-axis (measured in 10 Mahalanobis-distance units).



Figure 9. Bivariate plot of canonical variate 1 (73.81%) against canonical variate 2 (26.19%) showing 95% confidence ellipses for each chert source. Red circles are points made from Hopkinsville chert, green circles are points made from Upper Mercer chert, and blue circles are points made from Wyandotte chert. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

those made of bone (Costa, 2010). Therefore, given that the three raw materials in the present analysis are all high-quality cherts, and the points in the sample have a similar flake-scar pattern, the argument that material differences are responsible for the differences in point shape cannot be sustained.

The second potentially confounding factor is that the shape differences among the three subgroups are the result of differential

Table 2

Mahalanobis distances and permutation tests of Mahalanobis distances for Clovispoint shapes by chert source within the eastern riverine subarea of the unglaciated midcontinental United States after removing three outlying points, one from each of the chert sources.^a

	Hopkinsville	Upper Mercer	Wyandotte
Hopkinsville Upper Mercer Wyandotte	<0.0001 <0.0001	3.499 <0.0001	3.826 1.915

^a The lower triangle of the matrix shows p-values based on 10,000 permutations, and the upper triangle shows Mahalanobis distances between chert sources.

amounts of resharpening. We assessed this possibility by recording flake scars in both the outer and inner portions of each point. We created an ad hoc index of resharpening by taking the ratio of outer to inner flake scars and dividing this by point area. Because resharpening occurs around the margins of fluted-point blades, and resharpening is associated with numerous small flake removals, it follows that points with more resharpening will have a larger outer-to-inner flake-scar ratio. We then divided this ratio by point area to correct for any potential point size effects. When we compared our size-corrected ratio of resharpening among points from the different outcrops, we found no inter-outcrop differences (H = 2.231, p = 0.3277).

Discussion

Our analysis of Clovis-point shape revealed significant differences among samples from three distinct stone outcrops from the eastern riverine subarea of the unglaciated midcontinental United States. Because the analysis was intraregional and points from different outcrops were being used to exploit the same environment, the differences cannot be attributed to adaptation (selection). Nor can shape differences be attributed to potential nonheritable factors such as differential raw-material constraints or varying amounts of resharpening. Our results are thus consistent with the hypothesis that drift contributed significantly and predominately to shape differences among the three Clovis point populations.

The rise of significant shape differences by means of drift has implications for the initial evolution of material culture among colonizing populations of hunter-gatherers. Several studies have noted increasing stylistic diversification and shrinking 'style zones' of projectile points in the late Paleoindian period (post-11,500 calBP; Tankersley, 1989; Anderson, 1995; Meltzer, 2009; O'Brien et al., 2014). Meltzer (2009:286) suggests that this process can be read "as a relaxation in the pressure to maintain contact with distant kin, a reduction in the spatial scale and openness of the social systems, and a steady settling-in and filling of the landscape. Later Paleoindians no longer spanned the continent as their ancestors had, and their universe had become much smaller." We agree completely with this statement. Although drift has been invoked as an explanation for continent-wide shape differences in Clovis points (Morrow and Morrow, 1999; Buchanan and Hamilton, 2009), our results demonstrate that the origins of drift-based projectile-point stylistic diversification-Meltzer's (2009) 'social relaxation'-can be definitively traced to the Clovis period in the Upper Midwest.

Despite the asserted small and thinly scattered populations often attributed to the Clovis culture, the intraregional, interoutcrop differences in point shape presented here suggest a relaxing of social links not generally thought characteristic of a colonizing population. Some researchers may take this to mean that the rapid and widespread occurrence of Clovis artifacts across North America does not represent a colonizing population. However, given current archaeological and chronometric evidence that indicates Clovis, especially in the Midwest and Northeast, was a colonizing population (Meltzer, 2002, 2004; Hamilton and Buchanan, 2007; Ellis, 2008, 2011; Lothrop et al., 2011; Eren, 2013), it is more likely that we need to alter our theoretical understanding of how quickly during human dispersals drift can occur and create differences among particular socially learned technological characters. As Boyd and Richerson (2010:3790) point out, "social learning processes are very rapid, and... they can maintain behavioural differences among neighbouring human groups despite substantial flows of people and ideas between them." Our results suggest that during human dispersals, when maintaining strong social connections between kin is perhaps most important to avoid local population extinction (Meltzer, 2004), significant technological variation resulting from drift can still occur virtually instantaneously.

This latter proposal is perhaps underscored by the fact that, unlike our analysis of Clovis-point shape, our analysis of flake-scar pattern found no significant differences among the three chert samples. This result supports the recent quantitative work of Sholts et al. (2012) and Smallwood (2012) as well as several observational studies (Bradley, 1993; Morrow, 1995; Tankersley, 2004; Bradley et al., 2010), which show that, despite increased interaction around outcrop hubs, there existed a highly standardized Clovispoint-making practice continent-wide. In other words, dispersing Clovis groups were still socially connected across large regions of North America and directly transmitting technological knowledge (Meltzer, 2002, 2003, 2004, 2009; Ellis, 2008; Sholts et al., 2012; Smallwood, 2012). This conclusion is consistent with Clovis stone-acquisition patterns, which show long distances between stone outcrops and the ultimate location of artifact discard, as well as geographic overlap of artifacts made from distinct stone types (Kilby, 2008; Holen, 2010; Ellis, 2011; Boulanger et al., 2015). Indeed, our sample of Clovis points shows substantial geographic overlap of points made from Wyandotte, Upper Mercer, and Hop-kinsville cherts.

Taken together, our dichotomous results of point-shape diversity and tool-making uniformity indicate that Clovis foragers engaged in two tiers of social learning. The lower, and more ancestral, tier relates to point flake-scar pattern and can be tied to conformist transmission of tool-making processes across the Clovis population. The upper, and more-derived, tier relates to point shape. In this case it can be tied to drift that resulted from increased forager interaction at different stone-outcrop hubs. These results are predicted by current understanding of cognition and memory systems (Washburn, 2001; Thulman, 2013), by learning experiments (Mesoudi and Whiten, 2008; Atkisson et al., 2012; Kempe and Mesoudi, 2014), as well as by phylogenetic analyses of modern ethnographic material culture (e.g., Tehrani and Collard, 2002, 2009) suggesting that technological design-for example, point shape—should have more potential for change than manufacturing techniques (see also Tostevin, 2012; Mackay et al., 2014).

Our results have implications for claims of Clovis material culture, and that of colonizing and foraging populations more generally, being adapted to specific environments. As acknowledged above, depending on the scale of analysis, multiple sources of variation may be acting on Clovis-point shape (O'Brien et al., 2014; see also Lycett and von Cramon-Taubadel, 2015). Thus, our results do not automatically invalidate recent interregional analyses that suggest environmental adaptation (selection) played a significant role in point-shape variation on a continental scale (e.g., Buchanan et al., 2014). However, because our analyses have demonstrated that significant shape differences can arise through drift alone, we emphasize that any claim for environmental adaptation cannot rest exclusively on the mere co-variation between artifact shape and environment (Meltzer, 1991; Eren, 2012; Meltzer and Bar-Yosef, 2012; Eren et al., 2013), especially as time and distance between populations increase. Other kinds of analyses, such as functional experiments with replica points, must be invoked to support claims of Clovis point environmental adaptation (Buchanan et al., 2014). As Lycett (2008:2642) notes, "Unless there is strong evidence for a departure from neutrality, it is unnecessary to evoke processes other than drift as an explanation for the factors producing given patterns of variability (Bentley et al., 2004, 2007; Shennan, 2006; Bentley, 2007)."

One should remember that in addition to being from a localized environment, the large Clovis-point populations analyzed here are virtually contemporaneous (<<500 radiocarbon years) relative to a paleoanthropological time-scale. This sort of geotemporal resolution is often impossible to obtain in analyses of older Stone Age artifacts, and thus it may be difficult to identify instances of predominantly drift-based technological change in earlier periods. Nevertheless, that principally drift-based differences in lithic technology were revealed in our analyses despite the relative contemporaneity of our artifact populations lends strong support to the notion that over longer time scales drift likely played an important, if not primary, role in particular aspects of Paleolithic assemblage variability (e.g., Brantingham, 2003; Lycett, 2008; Lycett and von Cramon-Taubadel, 2008; Kuhn, 2012; Mackay et al., 2014), even if we cannot necessarily disentangle its exact proportional role from that of nondrift factors such as selection or from non-heritable factors such as rawmaterial type or differential resharpening (Lycett and von Cramon-Taubadel, 2015).

Still, despite the evidence presented here, the importance of drift in the formation of Paleolithic assemblages is likely to raise some eyebrows. In this regard, skeptics should note that Schillinger et al.'s (2014a) controlled cultural-transmission-chain experiments demonstrated that reductive-only (irreversible) manufacturing processes produced significantly greater levels of shape-copying error than additive-reductive (reversible) manufacturing processes. As such, Schillinger et al.'s (2014a:140) results suggest that tool-shape traditions produced through reductive processes—such as stone Clovis points—"will be inherently unstable, tending always toward variation and diversification in the absence of any stabilizing mechanism." In other words, stone-tool shape change via drift should always be initially predicted as the null hypothesis (Lycett, 2008), even among colonizing hunter-gatherers who likely possess tight social links in their shared reductive manufacturing traditions and other behaviors.

One might be tempted to infer that as Clovis-point shape evolved, so too did the rest of a complex composite projectile system often attributed to Clovis foragers (Frison, 1989; Frison and Bradley, 1999). However, given that this surmised system was almost certainly constructed from an additive-reductive manufacturing process, it seems more reasonable to infer, again based on Schillinger et al.'s (2014a) results, that it was significantly more stable than its lithic ammunition. Instead, we suspect that the overall composite projectile system was flexible enough that Clovis points of all different shapes and sizes could be reliably used with it. If true, the drift-based Clovis-point shape changes evident from our results can be attributed not only to increased social interaction among colonizing foragers at individual stoneoutcrop hubs but to the wiggle room afforded by a composite projectile system that may itself have been under strong selective pressure.

To conclude, following the approach adopted here or that used by others (e.g., VanPool, 2001; Lycett, 2008; Lycett and von Cramon-Taubadel, 2008) we encourage researchers to look for evidence of predominantly or partially drift-based technological change, or the lack thereof, in other prehistoric hunter-gatherer colonization pulses. One intriguing example is illustrated by the late Pleistocene (re)colonization of southern Germany by Magdalenian foragers. Jochim et al. (1999) explain that as Magdalenian people moved from northern France into southern Germany soon after the latter's deglaciation, stylistic similarities remained strong across these two broad and environmentally distinct regions-similarities that can be attributed to social interaction, active processes of sharing, and imitation of motifs. This seems analogous to the Clovis colonization of North America. However, we would not be surprised if quantitative assessment of stone or bone implement forms also revealed significant inter- (France versus Germany) and intra- (Germany) regional differences that could be attributed to processes of drift during this Magdalenian colonization pulse.

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