Size, shape, scars, and spatial patterning: A quantitative assessment of late Pleistocene (Clovis) point resharpening

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A B S T R A C T

Resharpening is considered to be a common technique for extending the use life of stone tools in certain prehistoric contexts. For Clovis peoples, the earliest well-documented North Americans, resharpening is believed to have been particularly important because foraging territories were unknown or poorly known. Gardner (1983, Archaeol East N Amer 11, 49–64) proposed a spatial model of Clovis point resharpening wherein the effects of resharpening increase with distance from stone outcrop. Here we report a study that quantitatively assesses Gardner’s model using a large sample of Clovis points from three high-quality chert sources in the Midwest. To investigate the predictions of the model, we used least-cost pathway distances from outcrop locations to each Clovis point and three measures of point resharpening. Our expectations, derived from the model, are that as distance from outcrop increases, points should show evidence of increased resharpening and therefore be smaller in size; should deviate from the classic shape; and should exhibit greater outer-to-inner flake-scar ratios. Our results indicate that there is no spatial patterning of these three measures of point resharpening and therefore do not support Gardner’s model. Further analyses suggest that resharpening was not a significant source of Clovis-point variation at the population level and that Clovis points in the Midwest may not have served as the long-life tools as has been generally assumed.

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1. Introduction

Archaeological evidence of tool production and reuse commonly is used to infer the degree to which prehistoric hunters planned foraging treks and how much and in what form raw materials were brought with them (Andreisky, 1994, 2009; Bamforth, 1986, 1991; Kelly, 1988; Nelson, 1991; Ricklis and Cox, 1993; Shott, 1995). These types of studies tend to model stone-tool use by mobile hunter–gatherers as a series of decisions that depend on the spatial distribution of stone sources and prey: When stone and prey are scarce and unevenly distributed across the landscape, foragers typically respond by designing tools to have long use lives, which means they can be maintained and reused multiple times (Bamforth, 1986; Bleed, 1986; Hayden et al., 1996). In particular, several studies have suggested that bifacially flaked stone weapon tips, or points, were manufactured for long use lives and were often resharpened (Bement, 2002; Buchanan, 2006; Charlin and González-José, 2012; Ellis, 2004; Hofman, 1991, 1992; Hoffman, 1985; Kelly, 1988; Nelson, 1997; Sellet, 2004; Shott, 2005, 2010; Shott and Ballenger, 2007).

The earliest well-documented hunter–gatherers in North America were Clovis peoples (Anderson, 1990; Anderson and Gillam, 2000; Barton et al., 2004; Bradley et al., 2010; Haynes, 2002; Meltzer, 2009; Sanchez et al., 2014; Sholts et al., 2012; Smallwood, 2012; Smallwood and Jennings, 2014), who lived ca. 13,500–12,800 calendar years before present (calBP) in the American West and Southwest and ca. 12,800–12,500 calBP in the East (Gingerich, 2011; Haynes et al., 1984; Holliday, 2000; Levine, 1990; Waters and Stafford, 2007). Technological planning and tool design are considered to have been particularly important to Clovis peoples (Goodyear, 1985; Kelly and Todd, 1988; Meltzer, 2004, 2009). This is because as colonizing populations Clovis groups would have faced uncertainty associated with exploring, foraging in, and settling an unknown or poorly known landscape (Meltzer, 2004). Presumably, this uncertainty would have been partially offset through technological “forward thinking” by designing tools that were long lasting (Eren and Andrews, 2013). Recent analyses of non-weaponry implements (e.g., endscrapers, sidescrapers, spurs) used by Clovis groups have supported this inference (Andrews et al., 2015; Eren, 2013; Loebel, 2013). It has long been presumed that Clovis points were also designed for long use lives (Bradley et al., 2010; Cox, 1986; Gramly, 1984; Gramly and Funk, 1990; Haynes, 1980; Kelly and Todd, 1988; Shott, 2013; Stanford and Bradley, 2012), the common assumption...
being that Clovis points were resharpened multiple times until they became useless as weapon tips.

One long-standing spatial model of Clovis-point production and resharpening was developed by Gardner (1983) more than 30 years ago (see also Gardner, 1977; Mullet, 2009). Gardner’s model posits several expectations for Clovis-point variation. According to his model, based on sites in the Flint Run area of Virginia, Clovis peoples established base camps in and around outcrops of high-quality stone. At these base camps, Clovis flintknappers carried out extensive tool manufacture, including point production. Gardner suggested that points made and lost or discarded near the outcrop would be more representative of the “classic” Clovis point: bifacially flaked and having parallel to slightly convex sides, a concave base, 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 (Bradley, 1993; Bradley et al., 2010; Wormington, 1957). As foragers moved away from chert outcrops on hunting trips, they used and resharpened points, which eventually were discarded at kill sites and hunting camps or simply lost. After multiple episodes of resharpening, Clovis points decreased in size and deviated from the classic form.

Here we report a study that quantitatively assesses Gardner’s (1983) spatial model of point resharpening using a sample of 115 Clovis points from three high-quality chert sources in the Midwest (Fig. 1). Points in this sample were found up to 500 km away from their source locations. To investigate the predictions of Gardner’s model, we use least-cost pathway distances from outcrop locations to each Clovis point to estimate the movement of foragers across the landscape. Our expectations, derived from the model, are that as distance from outcrop increases, points should show evidence of increased resharpening and therefore be smaller in size; should deviate from the classic shape found closer to the outcrops; and should exhibit a greater outer-to-inner flake-scar ratio.

2. Materials and methods

2.1. Materials

Our sample of Clovis points comes from Tankersley’s dissertation (1989), Late Pleistocene Lithic Exploitation and Human Settlement in the Midwestern United States (also available from the Paleoindian Database of the Americas, www.pidba.com). Tankersley made technical illustrations of points using a four-step method to produce accurate, to-scale, flake-by-flake two-dimensional facsimiles of Clovis points from Indiana, Kentucky, and Ohio. 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 to 120 minutes, 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 points in our sample likely date to the middle of the Clovis date range (Brose, 1994; Waters et al., 2009) and were made from cherts that calculated point size, one that measured point shape, and one that measured flake-scar patterning.

2.2. Assessing point resharpening

We employed three methods to evaluate point resharpening: one that calculated point size, one that measured point shape, and one that measured flake-scar patterning.

2.2.1. Point size

The operating assumption behind measuring point size is that a smaller size means that a point was resharpened more often (Buchanan and Collard, 2010a, 2010b; Hofman, 1991, 1992; see also Ioviță, 2010, 2011; Ioviță and McPherron, 2011; Sable et al., 2012; Shott, 1989; Surovell, 2009). Following Buchanan and Collard (2010a, 2010b), we used point area in our analysis rather than length because area is a closer approximation of overall point size. We used Adobe Illustrator to calculate point area rather than length because area is a closer approximation of overall point size. We used Adobe Illustrator to calculate point area, first tracing the perimeter and then using the Telegraphics plugin “Patharea Filter” (http://telegraphics.com.au/sw/product/patharea) to calculate the area.

2.2.2. Point shape

Point shape has been linked to resharpening by examining allometric relationships in point-shape characteristics over a range of points of different sizes (Buchanan, 2006; Shott and Ballenger, 2007). One expectation for allometric change in points undergoing serial resharpening is the rapid reduction in blade length relative to basal measurements (Bradley et al., 2010; Buchanan, 2006; Shott et al., 2007). Some researchers have suggested that Clovis blade shape changes over multiple resharpening events, from excursive to incurvate (Miller and Gingerich, 2013).

We used a suite of shape-analysis methods from biology called geometric morphometrics (GM). Within the GM framework, shape is defined as the geometric properties of an object that are invariant to location, scale, and orientation (Slice, 2005). GM methods deal with coordinate data as opposed to the interlandmark distances of standard morphometrics and allow patterns of variation in shape to be investigated within a well-understood statistical framework that yields easily interpreted numerical and visual results (for detailed reviews of GM see Adams et al., 2004; Bookstein, 1991; Bookstein et al., 1985; Dryden and Mardia, 1998; O’Higgins, 1999, 2000; Rohlf and Bookstein, 1990; Rohlf and Marcus, 1993; Slice, 2005, 2007; Webster and Sheets, 2010; Zelditch et al., 2004).

We obtained shape data from each of the three samples of points made from the different cherts in Tankersley’s dataset using the procedure described in Buchanan et al. (2011, 2014). In short, the procedure involves acquiring digital images of point illustrations to capture landmark data. We used 3 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 digitization, we subjected the landmark data from each sample of points to separate 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, 2003; Rohlf and Slice, 1990). 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 in order to minimize the sum-of-squared residuals from the consensus configuration. Results of the superimposition for each sample of points are presented in Fig. 2. The superimposition of landmarks was carried out using tpsSuper (Rohlf, 2004).

Fig. 2. Results of the superimposition method using the generalized orthogonal least-squares Procrustes procedure. A) consensus configuration showing landmark variation for the Wyandotte sample, B) consensus configuration showing landmark variation for the Hopkinsville sample, and C) consensus configuration showing landmark variation for the Upper Mercer sample.
Next, we extracted relative warps for each dataset. 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 of specimens. We used relative warps to reduce the number of shape variables. We then 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 to visualize shape difference in the defined shape space. Relative warps were computed using tpsRelw (Rohlf, 2008).

### 2.2.3. Flake-scar patterning

Several researchers have used flake-scar patterning to monitor bifacial reduction and resharpening (Andrefsky, 2006; Clarkson, 2002; Smallwood, 2010), the underlying assumption being that bifaces at earlier stages of reduction are expected to have larger, more widely spaced flake scars, whereas subsequent reduction or resharpening produces smaller, more closely spaced flake scars along the edges of a biface (Smallwood, 2010). Along the same lines as Andrefsky (2006), Clarkson (2002), and Smallwood (2010), we developed a method for measuring flake-scar patterning on points that results from resharpening (see Eren et al., 2015). This method was carried out in Adobe Illustrator and is depicted in Fig. 3. We first traced (in blue) a perimeter outline of each point, which we then used to calculate point area as described above. We then reduced the outline by 50% in length, which reduced its area to 25% of the original outline area. The reduced outline was automatically centered by Adobe Illustrator relative to the original point perimeter. Next, a new layer was created, and in this layer flake scars outside the reduced blue outline were marked by a red dot. Another new layer was then created, and in this layer flake scars inside the blue outline were marked by a blue dot. A flake-scar count ratio was then calculated by dividing the number of outer flake scars by the number of inner flake scars. Following the logic of similar methods, we interpreted relatively higher ratios of outer-to-inner flake-scar counts on complete points to be indicative of more resharpening.

### 2.3. Calculation of least-cost pathways

Tankersley (1989) provided only county-level provenience for the points in his dataset. In order to associate these points with spatial locations, we assigned each point the geographic centroid of the county in which it was recovered. Approximate locations for each chert outcrop were obtained from published descriptions. A base map covering the study area was extracted from the 1-arc-second (ca. 30 m) void-filled Shuttle Radar Topography Mission (SRTM) elevation dataset and projected into Universal Transverse Mercator (UTM) zone 16N, 1983 North American datum (data available from the U.S. Geological Survey at http://eros.usgs.gov). A secondary raster depicting degree slope was then derived from the elevation base map. Next, cost-distance rasters were extracted from the derived slope data using each chert-outcrop location to produce separate raster layers with associated backlink rasters. Subsequently, least-cost paths were calculated for each point to its associated outcrop. Topologies of the resultant paths were simplified and then smoothed using a Bézier interpolation. Path length was calculated for each line segment and stored within a geospatial data file. All analyses were carried out in ESRI ArcGIS 10.2.1 using core functionality in conjunction with Spatial Analyst and 3D Analyst extensions.

### 2.4. Statistical analyses and test predictions

We conducted statistical analyses to assess relationships among the resharpening variables and the least-cost pathway distances from each outcrop. The variables included point area, relative warp 1 and relative warp 2 describing point shape, and outer-to-inner flake-scar count ratio. Descriptive statistics for point area, number of interior flake scars, and number of outer flake scars are provided in Table 1. The sample distributions of the distance and measurement variables were

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**Table 1**

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Point area (mm²)</th>
<th># Interior flake scars</th>
<th># Outer flake scars</th>
<th>Distance to source (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wyandotte</td>
<td>Mean = 1754.79</td>
<td>Median = 1532.60</td>
<td>Mean = 99.79</td>
<td>Mean = 290</td>
</tr>
<tr>
<td></td>
<td>Standard deviation = 1143.98</td>
<td>Standard deviation = 9.12</td>
<td>Standard deviation = 46.64</td>
<td>Standard deviation = 226</td>
</tr>
<tr>
<td>Upper Mercer</td>
<td>Mean = 1432.16</td>
<td>Median = 16.97</td>
<td>Mean = 84.08</td>
<td>Mean = 156</td>
</tr>
<tr>
<td></td>
<td>Standard deviation = 746.62</td>
<td>Median = 17.00</td>
<td>Median = 78.00</td>
<td>Median = 140</td>
</tr>
<tr>
<td>Hopkinsville</td>
<td>Mean = 1395.84</td>
<td>Median = 15.32</td>
<td>Mean = 82.64</td>
<td>Mean = 173</td>
</tr>
<tr>
<td></td>
<td>Standard deviation = 746.62</td>
<td>Median = 12.00</td>
<td>Median = 78.00</td>
<td>Median = 140</td>
</tr>
</tbody>
</table>

Fig. 3. Flake-scar count-ratio method. For this example we used a Clovis point made from Wyandotte (specimen #348), we describe the process moving from left to right. First, the specimen shown on the far left is presented as originally drawn by Tankersley. Second, the next point to the right, shows the perimeter outline traced in blue. Third, the perimeter outline reduced by 50% in length, which reduced its area to 25% of the original point outline area, and centered relative to the original point perimeter. The fourth point shows the flake scars outside the reduced blue outline marked by red dots, while the fifth point also shows flake scars inside the blue outline marked by blue dots. Lastly, the flake-scar count ratio was calculated by dividing the outer flake-scar count (the number of red dots) by the inner flake-scar count (the number of blue dots) to produce the ratio. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Table 2
Results of nonparametric correlations and ordinary least-squares statistical analyses between resharpening variables and least-cost pathway distances for complete points made of Wyandotte chert (n = 44).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Spearman’s correlation r</th>
<th>Spearman’s correlation p</th>
<th>Ordinary least squares Pearson’s r^2</th>
<th>Ordinary least squares Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>−0.112</td>
<td>0.469</td>
<td>0.001</td>
<td>−0.178</td>
</tr>
<tr>
<td>RW1</td>
<td>−0.301</td>
<td>0.047</td>
<td>0.071</td>
<td>&lt;−0.001</td>
</tr>
<tr>
<td>RW2</td>
<td>−0.150</td>
<td>0.332</td>
<td>0.022</td>
<td>&lt;−0.001</td>
</tr>
<tr>
<td>Flake-scar ratio</td>
<td>−0.035</td>
<td>0.824</td>
<td>0.005</td>
<td>−0.001</td>
</tr>
</tbody>
</table>

* None of the correlations are significant at the critical level of p = 0.024 based on Benjamini and Yekutieli’s (2001) method for controlling the false-discovery rate.

Significantly different from an underlying normal distribution. Transformations of these data did not result in approximations to normal; therefore, we opted to use nonparametric statistical tests. We conducted a set of four Spearman’s correlations among the resharpening variables and the least-cost-pathway distances for points made of Wyandotte, Hopkinsville, and Upper Mercer cherts. Because we carried out multiple tests, we used Benjamini and Yekutieli’s (2001) method for controlling the false-discovery rate. In addition to the correlations, we ran ordinary least-squares regression analyses to obtain estimates of the slope of the best-fit line and the coefficient of determination (r^2) for each pair of variables. Tests were carried out using the free software PAST (version 3.02a; Hammer et al., 2001).

After completing the tests, we compared the results with predictions derived from Gardner’s (1983) model. To reiterate, Gardner’s model posited that Clovis points found farther from an outcrop will exhibit increasing evidence of resharpening. From this we reasoned that our three measures of point resharpening should correlate with increasing least-cost distance from the outcrops. Specifically, we expect a significant positive correlation between point area and least-cost distances. We also expect a significant correlation among the shape variables (relative warps 1 and 2) and the least-cost distances in a manner that is consistent with resharpening, including reduction of blade length, incurve blade shape, and any deviation from the “classic” lanceolate Clovis form. Last, we expect a significant positive correlation between increasing outer-to-inner flake-scar ratio and least-cost distance.

3. Results

3.1. Wyandotte

Spearman’s correlation among point area and the least-cost pathway distances from the Wyandotte outcrop to each point is not significant (Table 2). The shape space for the Wyandotte sample is shown in Fig. 4. The first two relative warps account for 86.46% of the overall shape variation in the Wyandotte dataset. Relative warp 1 (RW1; 80.15% of the variation) captures variation in blade length, blade shape, and width. Relative warp 2 (RW2; 6.31% of the variation) accounts for blade shape and basal-shape differences. Neither RW1 nor RW2 is correlated with least-cost pathway distances (Table 2). Last, the ratio of the number of outer-to-inner flake scars also is not correlated with least-cost pathway distances. In sum, none of the resharpening variables exhibit a significant statistical relationship with distance from the Wyandotte chert source as predicted by Gardner’s model.

3.2. Hopkinsville

Spearman’s correlation between point area and the least-cost pathway distances from the Hopkinsville outcrop to each point is not significant (Table 3). The shape space for the Hopkinsville point sample is displayed in Fig. 5. The first two relative warps account for 83.38% of the overall shape variation in the Hopkinsville dataset. RW1 (74.12% of the variation) captures variation in blade length, blade shape, and width. RW2 (9.26% of the variation) accounts for blade shape and basal-shape differences. RW1 is not correlated with least-cost pathway distances, but RW2 is significantly negatively correlated with least-cost distance (Fig. 6). Points with decreasing values of RW2 exhibit deeper concave basal cavities and blade edges that have steeper slopes. The latter shape character is consistent with resharpening. Last, the ratio of the number of outer-to-inner flake scars is not correlated with least-cost pathway distances. Taken together, analysis of the Hopkinsville points mostly indicates that resharpening does not increase with distance from source, although a small amount of shape variation is consistent.

Fig. 4. Bivariate plot of relative warp 1 (80.15%) against relative warp 2 (6.31%) for Clovis points made from Wyandotte chert. The four images are deformations from the consensus configurations and display shape space defined by the first two relative warps.
3.3. Upper Mercer

Spearman’s correlation between point area and the least-cost pathway distances from the Upper Mercer outcrop to each point is not significant (Table 4). If we take a less conservative approach and do not control for the false-discovery rate, point area is significantly correlated with least-cost distances, but the correlation is positive and opposite of the predicted relationship (Fig. 7). The shape space for the Upper Mercer sample is shown in Fig. 8. The first two relative warps account for 87.82% of the overall shape variation in the Upper Mercer dataset. RW1 (81.41% of variation) captures shape differences in blade length, blade shape, and width. RW2 (6.42% of variation) accounts for blade-shape and basal-shape differences. Neither RW1 nor RW2 is correlated with least-cost pathway distances (Table 4). Last, the ratio of the number of outer-to-inner flake scars is not correlated with least-cost pathway distances. Thus, none of the resharpening variables exhibit a significant statistical relationship with distance from the Upper Mercer chert source as predicted by Gardner’s model.

4. Discussion

The results of our analyses of Clovis points made from three high-quality cherts in the Ohio, Indiana, and Kentucky region are inconsistent with Gardner’s (1983) hypothesis that as Clovis hunters traveled farther from chert outcrops, they would have needed to resharpen their points after multiple use events. Gardner predicted that Clovis points were smaller and more deviant from the classic shape as a consequence of multiple resharpening episodes. Our findings indicate that for points made from Wyandotte and Upper Mercer cherts, none of the measures of resharpening that we employed—point size, point shape, or flake-scar patterning—correlated with least-cost distance from an outcrop. For points made from Hopkinsville chert, point size, the majority of point-shape variation, and flake-scar patterning also did not correlate with least-cost distance from the outcrop. A small proportion of shape variation (9%) in points made from Hopkinsville did correlate with least-cost pathway distance in a manner that is consistent with resharpening. As least-cost distance increases, Hopkinsville points were shown to have decreasing values of RW2, indicating that the slope of the blade edge to the tip increases. This narrowing of the blade is generally consistent with more resharpening. However, it should be noted that Hopkinsville points with negative RW2 values still retain a classic Clovis shape, with excursive blades and concave bases. Overall, the overwhelming majority of our results do not support Gardner’s spatial model of Clovis-point resharpening.

We can think of four possibilities that may explain the lack of evidence for spatially patterned Clovis point resharpening at the population level in this region. The first is that our methods for measuring resharpening may not actually be measuring what we think they are. In other words, point size, shape, and flake-scar patterning may not be capturing the effects of resharpening adequately. Although this possibility is plausible, all three measures have been used in previous studies measuring resharpening, some of which used experimental evidence to justify the approach (e.g., Andrefsky, 2006; Buchanan and Collard, 2010a, 2010b; Clarkson, 2002; Shott and Ballenger, 2007; Shott et al., 2007; Smallwood, 2010). It is difficult to accept that none of the measures were able to monitor the expected patterned reduction of points through resharpening, although much more archaeological and experimental methodological work is necessary with respect to measuring resharpening on bifacial tools.

The second possibility is that our point sample is biased against specimens that have been resharpened extensively. To reiterate, our sample consists of 115 complete Clovis points from Ohio, Indiana, and Kentucky documented by Tankersley (1989). If the majority of specimens in our sample were lost or discarded prior to being used, this could have biased our sample. In particular, bias could be introduced through caching, which is the act of depositing usually complete unused tools at locations far from outcrop sites with the intention of returning to that location to

![Fig. 5. Bivariate plot of relative warp 1 (74.12%) against relative warp 2 (9.28%) for Clovis points made from Hopkinsville chert. The four images are deformations from the consensus configurations and display shape space defined by the first two relative warps.](image-url)
retrieve its contents (Kilby, 2008). Therefore, caching has the potential to confound the predictions of Gardner’s model and to skew evidence for resharpening more generally. This possibility is unlikely because none of the points in our sample are described by Tankersley (1989) as coming from a recognized cache and, according to Tankersley (1989), the points were recovered from a variety of contexts including “food-related sites,” “lithic-related sites,” and “isolated find spots.” It is expected that points would have been discarded (or lost) after use at food- and lithic-related sites and possibly also at isolated find spots. This contextual evidence suggests that our point sample is unlikely to be biased against resharpening.

The third possibility is that Paleoindian mobility was complex, perhaps including return trips to outcrops. We reasoned that if the latter scenario occurred often it should be detectable in the archaeological record. Our expectation is that if groups made return trips to outcrops, we would expect to find a bimodal distribution in our resharpening measures, with one peak consisting of large, unresharpened points discarded during the initial foraging trek and a second peak consisting of small, resharpened points discarded during the return trip. To evaluate this possibility, we carried out an additional set of analyses that tested for the presence of bimodality in our data. We conducted a series of Hartigans’ dip tests using the free software R and the package “diptest” (Hartigan and Hartigan, 1985). Table 5 shows that the sample distributions for point area, RW1, RW2, and flake-scar ratio for each of the raw materials are not significantly different from unimodal distributions. This result suggests that Paleoindian foragers were not, upon a return to an outcrop, jettisoning heavily resharpened points alongside larger, less resharpened or less resharpened Clovis points.

This leaves the fourth and most likely possibility—that Clovis points at the population level were not designed nor exploited as “long-life” tools as has been commonly asserted (e.g., Goodyear, 1989; Kelly and Todd, 1988; Stanford, 1991). Rather, it seems likely that hunters took complete, unused points with them on foraging treks and when points became lost or unserviceable, they were replaced with new points rather than being resharpened. Or, rather than carrying complete points, hunters transported the raw material to make points. An efficient way of doing this would be to carry flakes and make points out of them when the need arose (Eren and Andrews, 2013; Kuhn, 1994). A corollary of this is that points made on flakes are likely to be smaller than points made from larger nodules procured at an outcrop. It is thus interesting that several Paleo Crossing (Ohio) fluted points and preforms made from Wyandotte chert, whose source is 450–510 km southwest of the site, and previously interpreted to be heavily resharpened based on their size (Brose, 1994; Barrish, 1995; Eren, 2006), show morphological and technological evidence of being made on flakes. Shott (1993) (see also Smallwood, 2010) made similar observations about the Leavitt site (Michigan) Paleoindian assemblage. He noted that some of the fluted points in the assemblage exhibited portions of the original flake blank on which they were knapped, stating that “bifaces [at Leavitt] probably were produced from biface-core blanks in a manner similar, if not identical, to that described for certain uniface blanks” (Shott, 1993:95). Thus, small points may not be small because they were heavily resharpened but because they were manufactured on a small template to begin with. Alternatively, perhaps Clovis hunters could have replaced lost or unserviceable points using flake blanks and, eventually, using the biface cores from which the flakes had been detached (Kelly, 1988).

One way to further evaluate the likelihood of the fourth possibility is to investigate the relationship between point size and the other variables used to measure resharpening. In other words, whereas our results above suggest that resharpening is not spatially patterned, we can also examine whether there is significant evidence for resharpening

![Fig. 6. Bivariate plot of point shape, relative warp 2, by least-cost pathway distance (km) of Clovis points made from Hopkinsville chert. The line is the best fit line described by the ordinary least-squares equation.](image-url)

### Table 4

Results of nonparametric correlations and ordinary least-squares statistical analyses between resharpening variables and least-cost pathway distances for complete points made of Upper Mercer chert (n = 46).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Spearman’s correlation</th>
<th>Ordinary least squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>p⁰</td>
</tr>
<tr>
<td>Area</td>
<td>0.328</td>
<td>0.026</td>
</tr>
<tr>
<td>RW1</td>
<td>−0.219</td>
<td>0.144</td>
</tr>
<tr>
<td>RW2</td>
<td>−0.245</td>
<td>0.101</td>
</tr>
<tr>
<td>Flake-scar ratio</td>
<td>0.163</td>
<td>0.290</td>
</tr>
</tbody>
</table>

⁰ None of the correlations are significant at the critical level of p = 0.024 based on Benjamini and Yekutieli’s (2001) method for controlling the false-discovery rate.
at the population level. The three scenarios we described in the preceding paragraph entail replacement of new points rather than resharpening and predict that smaller points should not exhibit more evidence of resharpening than larger points. To test this prediction, we carried out an additional set of correlations on an outcrop-by-outcrop basis between point area and point shape and the ratio of outer-to-inner flake scars. Interestingly, point area is not correlated with the ratio of flake scars or with RW2 for any of the chert types. The only significant correlations are between point area and RW1 (Table 6). These correlations show that larger points are narrower and have slightly more curvate blade edges than smaller points. We should note that the relationship between point area and RW1 is positive for Wyandotte and Hopkinsville and negative for Upper Mercer, but the shape relationships are the same in all three; it is the RW1 axis that is reversed for the Upper Mercer sample. The relationship between area and shape described by RW1 could reflect resharpening or the manufacture of smaller points made on flakes; however, based on the lack of a correlation between area and flake-scar ratio, the latter is more likely.

We note that our results do not necessarily suggest that individual Clovis points were not on occasion resharpened. Rather, our results indicate that resharpening was not a significant source of Clovis-point variation at the population level. Although this conclusion is contrary to most assertions and intuitive impressions, it is consistent with other quantitative assessments of Clovis-point resharpening (Buchanan and Collard, 2010a, 2010b; Buchanan et al., 2014). In particular, Shott’s (2010) analysis of reduction distributions of 460 Paleoindian points from the eastern
Midwest indicated that some types were not heavily resharpened (Shott, 2010). His analyses revealed that some post-Clovis points (Barnes) showed evidence of more resharpening than Clovis points, which he noted was contrary to the accepted beliefs of most Paleoindian archeologists at the time (Shott, 2010).

Our finding that Clovis points were not continuously resharpened “long-life” tools has important implications for understanding Clovis behavior. Foremost is that Clovis-point maintenance must have been governed by a different set of rules than what is commonly regarded as a sequential process of resharpening and reuse with distance in later Paleoindian complexes such as Folsom and Dalton (Hofman, 1991, 1992; Shott and Ballenger, 2007). This difference may be the result of Clovis foragers being more closely tied to the colonization process than post-Clovis foragers (Ellis, 2011). Colonizing foragers were less familiar with a landscape relative to post-Clovis groups, and the latter may have faced greater pressures to ensure a hunt was successful and thus more likely to ensure the point in the haft was fresh and as large as possible, given the available stone resources, and did not possess microwear defects that could have sabotaged hunting efforts (Eren, 2013). Interestingly, we see the opposite pattern of maintenance in Clovis versus post-Clovis unifacial stone tools (Andrews et al., 2015), with the former exhibiting evidence consistent with continuous resharpening whereas the latter does not. The low levels of point resharpening and high levels of uniface resharpening by Clovis peoples, and the inverse pattern in post-Clovis, is entirely consistent with the greater uncertainty likely faced by Clovis foragers, who were tied more closely to the colonization process (Ellis, 2011; Eren, 2013).

Our findings also raise questions about the underlying assumptions of several previous studies that have addressed Clovis-point use. In particular, our findings contradict one of the principal reasons Goodyear (1989) suggested that Clovis foragers appeared to consistently select high-quality raw material: It facilitated tool maintenance, resharpening, and recycling. Our results require some revision to this hypothesis because if fluted points at the population level were not significantly resharpened, then these implementations were unlikely to have been a motivating factor for the selection of high-quality chert. Instead, we wonder whether it was the Clovis unifacial stone-tool component, which does possess evidence of resharpening at the population level (Andrews et al., 2015; Eren, 2013), that was largely responsible for Clovis raw-material choice.

Another implication of our results is that resharpening is unlikely to bias assemblage-level analyses of Clovis fluted points. Some researchers have suggested that resharpening acts to significantly confound assemblage-level comparative and phylogenetic analyses by altering the size, shape, and flake-scar patterning of Clovis points (Shott, 2013; Thulman, 2012). The corollary of accepting a significant role for resharpening is that the point base may be the only unmodified and culturally significant portion of the point (Thulman, 2012; White, 2013). Our findings question these assumptions. The results of our study are clearly more consistent with the model presented by Lynch and von Cramon-Taubadel (in press) which suggests there is no reason to suspect that “lithic senescence” is overwhelming or obliterating variation produced by cultural-evolutionary forces. Furthermore, any resharpening that was carried out may have been culturally patterned and therefore retain inter-cultural differences (Buchanan and Collard, 2010a, 2010b; Eren and Prendergast, 2008; Iovita, 2010; Lynch and von Cramon-Taubadel, in press). In sum, our results indicate that there is little evidence for spatially-patterned Clovis resharpening and the idea that Clovis points were long-life tools that were serially resharpened in the Midwest. Based on this finding we suggest that researchers should not simply assume that resharpening has significantly modified points prior to undertaking an empirical analysis.

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