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North American Clovis Point Form and Performance II: An Experimental Assessment of Point, Haft, and Shaft Durability

Metin I. Eren [a,b], Michelle R. Bebber [a], Dan Wilcox[a], Brett Story[c] and Briggs Buchanan[d]

[a]Department of Anthropology, Kent State University, Kent, OH, USA; [b]Department of Archaeology, Cleveland Museum of Natural History, Cleveland, OH, USA; [c]Department of Civil and Environmental Engineering, Lyle School of Engineering, Southern Methodist University, Dallas, TX, USA; [d]Department of Anthropology, University of Tulsa, Tulsa, OK, USA

ABSTRACT
This study presents the results of an experimental assessment of Clovis projectile durability, or the ability of Clovis point forms and their hafts to withstand impact damage. This work is the second contribution in a series of experimental studies aimed at shedding light on the functional performance of distinct Clovis point forms. For this experiment we fired seven replica Clovis point forms, representing the average and extremes of observed Clovis form, into wood boards until damaged. The resulting damage to the point, haft lashings, and shaft were recorded on each of the 203 specimens. Statistical comparison of the damage indicated differences among the point forms in the amount of damage to the points, haft lashings, and shafts. We show that these results indicate a broad inverse relationship with penetration capability, suggesting a functional trade-off that may have influenced Paleoindian point design.

KEYWORDS
Clovis

Introduction

Why is there variation in North American Clovis point form over time and space? We continue to address this question in the present study, which is a sequel to our first published experiment on the topic (Eren et al., 2020), and will in turn be followed by several others. Thus, rather than repeat the rather lengthy introduction presented by Eren et al. (2020), we refer the reader to that study, and will only provide a short synopsis here.

As Clovis technology rapidly spread across North America during the late Pleistocene (Meltzer, 2021; see also Bradley et al., 2010; Eren & Buchanan, 2016; Jennings & Smallwood, 2019; Prasciunas & Surovell, 2015; Sholts et al., 2012; Waters et al., 2020; Waters & Stafford, 2007), significant size and shape variation in bifacially-flaked fluted point plan-view form emerged (e.g. Buchanan et al., 2014; O'Brien et al., 2014, 2016; O'Brien, Buchanan, et al., 2016; Smith et al., 2015). Some of this variation has been shown to be neutral (e.g. Eren et al., 2015; Hamilton & Buchanan, 2009; Morrow & Morrow, 1999; Smallwood, 2012), having likely emerged via mechanisms such as copy-error, differential time-budgets, production tool traditions, and non-functional transmission biases (e.g. Schillinger et al., 2014a, 2014b, 2015, 2016, 2017). Some small amounts of Clovis point variation might be attributed to factors such as raw material differences, knapping skill, or resharpening (Eren et al., 2020). Less known is whether the selection of functional traits played a role in the evolution of Clovis point form variation.

Fortunately, there is a clear prediction consistent with the hypothesis that function contributed to Clovis point plan-view form variation: if function played a role in Clovis point form differences across North America, then there should be differences in task performance among distinct point forms. Differences in task performance can be inferred via experimental archaeology (Eren et al., 2016, 2020; Jennings et al., 2021; Outram, 2008). By undertaking a multi-year, multi-function experimental assessment – at varying levels of internal and external validity (cf., Eren et al., 2016; Lycett and Eren, 2013; Mesoudi, 2011) – we have investigated numerous performance tasks of different Clovis point forms to tease out whether different forms perform differently. Our first experiment examined whether seven different Clovis point plan-view forms differentially penetrated a target (Eren et al., 2020), a factor critical to killing prey (e.g. Mika et al., 2020; Sitton et al., 2020). The results of that experiment showed that several of the Clovis point forms exhibited statistically different penetration depths, *consistent with* the hypothesis that selection for functional characteristics may have contributed to Clovis point evolution.

CONTACT Metin I. Eren meren@kent.edu
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Here, we assess whether different Clovis point plan-view forms potentially influenced the durability of the stone point itself, the haft (the adhesive and/or lashings), and the wooden shaft. With respect to the stone point, durability can be assessed in two ways: (1) whether or not it breaks and (2) how much of it remains after breakage. Regarding the first way, several studies have suggested that stone points will break upon first impact or after a few uses (e.g. Bebber et al., 2020; Cheshier & Kelly, 2006; Ellis, 1997; Fauvelle et al., 2012; Hunzicker, 2008; Loendorf et al., 2018; Lowe et al., 2019; Lowrey, 1999; Maguire et al., 2021; Odell & Cowan, 1986; Sisk & Shea, 2009; Titmus & Woods, 1986; Wood & Fitzhugh, 2018), although there may be ways to increase durability in this first sense (e.g. Cheshier & Kelly, 2006). Nevertheless, because of the high likelihood of points breaking after only a small number of shots, a more profitable way of assessing durability may be via the second way, i.e. how much of the point remains after breakage (e.g. Cheshier & Kelly, 2006; Maguire et al., 2021). Haft and shaft durability have been experimentally assessed less frequently (but see Cheshier & Kelly, 2006; Hunzicker, 2008), but upon the impact lashings can rupture, points can come loose from their adhesive, or shafts can split.

With respect to Clovis, several experiments of stone point durability have documented individual replica Clovis points breaking upon impact (e.g. Frison, 1989; Frison & Todd, 1986; Huckell, 1979; Odell & Cowan, 1986; Smallwood, 2010). Systematic experimental assessment of point, haft, or shaft durability with specific reference to Clovis is uncommon although a small number of such studies have been conducted. For example, static materials testing has suggested Clovis fluting increased point durability via stress redistribution and damage relocation (Story et al., 2019; Thomas et al., 2017). Werner et al. (2019) experimentally examined whether ground or sharp proximal lateral edges influenced the durability of lashings. Richard (2015) experimentally compared porcelain-cast Clovis and Folsom specimens' durability, while Snyder (2017) experimentally examined both point and haft durability among several Paleoindian point types, which included eight replica Clovis specimens. In the present study, we examine all of the factors mentioned above: stone point durability, lashing rupture, adhesive failure (i.e. loose points), and shaft splitting.

Materials and methods

Defining Clovis projectile point shape variation and selecting models, production of stone tools, and hafting of stone tools

For this study, we selected seven Clovis points representing the extreme bounds of known Clovis point shape space to replicate in stone and use in our experiments (see Eren et al., 2020: Figure 4). These points are from six Clovis assemblages: Simon, (two from) Shoop, Vail, Anzick, Rummells-Maske, and Bull Brook. Thirty ground specimens of each of these point types were produced using lapidary equipment by the Neolithics Flintknapping Supply House (www.neolithics.com), and then hafted by Thunderbird Atlatl (www.thunderbird.com). We note, as we have elsewhere, that we do not know exactly how Clovis points were hafted (Thomas et al., 2017, p. 29), and encourage other ballistics studies that make use of different hafting configurations. The detailed procedures for Clovis point selection, point production, and hafting are provided by Eren et al. (2020).

Although we originally intended to shoot 210 projectiles (30 specimens multiplied by seven types), a production oversight resulted in 23 hafted Vail points. We thus shot 203 projectiles for this study. The summary statistics of each point type's overall projectile mass, point length, point width, point thickness, haft binding length, haft binding width, haft binding thickness, projectile shaft length, and shaft diameter are presented in Tables 1–7.

We acknowledge that there may be some question about our use of ground chert points as our experimental specimens, rather than flaked points. To allay this concern, we note that Lowe et al. (2019) directly compared the frequency of breakage and amount of point damage between ground, percussion-flaked, and pressure-flaked points in a durability experiment. Their results showed no significant difference between the ground sample and either flaked sample in each durability assessment.

Experimental procedures

Our experiment was performed at the Kent State University Experimental Archaeology Laboratory (Figure 1). We shot each of the seven hafted experimental Clovis point samples with a 29 lbs. PSE compound bow mounted on a Spot-Hogg Hooter Shooter. We used a stationary target, which was approximately 2 meters from the compound bow. This distance allowed adequate room for the specimens to travel once fired without drastically losing speed or dropping. The target in this study was one inch (2.54 cm) thick sheets of oak wood. Following Lowe et al. (2019), we used wood in our durability experiment for three reasons. First, wood in the form of tree trunks, branches, logs, or stumps could have been accidentally struck frequently in prehistory. Second, commercially available wood boards can be purchased at any hardware store and thus enhance replicability.

Table 1. Summary statistics of the Simon point sample. There was a production oversight in hafting, resulting in two points not possessing haft bindings; hence, $n = 28$ for haft binding length, haft binding width, and haft binding thickness.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	30	30	30	30	28	28	28	30	30
Mean	126.7	182.1	41.0	7.4	38.5	40.0	15.3	71.0	12.1
Standard deviation	7.2	3.7	1.1	0.7	9.8	1.6	1.0	0.0	0.5
Minimum	110.0	176.0	38.0	6.0	24.2	38.0	13.8	71.0	11.0
Q1	124.0	179.3	40.5	7.0	32.4	39.0	14.5	71.0	12.0
Median	126.5	182.5	41.0	7.2	36.0	39.8	15.0	71.0	12.0
Q3	130.0	185.0	42.0	8.0	40.6	40.9	16.0	71.0	12.0
Maximum	149.0	189.0	44.0	9.0	61.0	46.0	17.0	71.0	13.0
Range	39.0	13.0	6.0	3.0	36.8	8.0	3.2	0.0	2.0

Table 2. Summary statistics of the Shoop #1 point sample.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	30	30	30	30	30	30	30	30	30
Mean	58.6	34.8	21.1	5.7	29.2	22.9	13.9	71.0	11.9
Standard deviation	4.5	1.5	0.9	0.5	3.0	0.8	0.6	0.2	0.2
Minimum	47.0	31.5	19.0	4.8	24.0	21.0	13.0	70.0	11.0
Q1	57.0	34.1	20.4	5.2	27.0	22.1	13.5	71.0	11.7
Median	58.5	35.0	21.0	6.0	29.6	23.0	14.0	71.0	12.0
Q3	62.0	36.0	22.0	6.0	31.6	23.5	14.0	71.0	12.0
Maximum	65.0	37.0	22.7	6.3	35.5	24.1	15.0	71.3	12.0
Range	18.0	5.5	3.7	1.5	11.5	3.1	2.0	1.3	1.0

Table 3. Summary statistics of the Shoop #2 point sample.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	30	30	30	30	30	30	30	30	30
Mean	59.2	36.2	21.0	5.7	25.5	22.3	13.6	71.0	12.0
Standard deviation	3.0	1.2	0.8	0.6	2.0	0.7	0.7	0.2	0.1
Minimum	54.0	33.0	19.1	4.9	21.7	21.0	12.0	70.0	11.6
Q1	57.0	36.0	20.4	5.1	24.0	22.0	13.0	71.0	12.0
Median	60.0	36.0	21.0	6.0	25.4	22.0	13.5	71.0	12.0
Q3	61.0	37.0	21.6	6.0	27.0	23.0	14.0	71.0	12.0
Maximum	64.0	38.0	22.0	7.0	29.5	24.0	15.5	71.3	12.2
Range	10.0	5.0	2.9	2.1	7.8	3.0	3.5	1.3	0.6

Table 4. Summary statistics of the Vail point sample. Unfortunately, seven Vail points were lost during the hafting production phase, resulting in an $n = 23$.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	23	23	23	23	23	23	23	23	23
Mean	67.2	67.3	28.9	6.3	21.6	31.4	13.9	71.2	12.0
Standard deviation	5.3	1.0	1.0	0.7	2.9	0.7	0.6	0.4	0.1
Minimum	57.0	66.0	27.0	5.0	15.7	30.0	13.0	71.0	11.8
Q1	63.0	66.7	28.0	5.9	20.0	31.0	13.7	71.0	12.0
Median	68.0	67.0	29.0	6.0	22.6	31.2	14.0	71.0	12.0
Q3	70.5	68.0	29.8	7.0	23.3	32.0	14.0	71.2	12.0
Maximum	76.0	70.0	30.2	7.5	27.9	33.0	15.0	72.0	12.4
Range	19.0	4.0	3.2	2.5	12.1	3.0	2.0	1.0	0.6

Table 5. Summary statistics of the Anzick point sample.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	30	30	30	30	30	30	30	30	30
Mean	66.4	69.3	26.6	5.7	31.1	31.8	13.4	71.3	12.0
Standard deviation	4.3	1.6	1.0	0.5	5.4	0.9	0.6	0.4	0.1
Minimum	57.0	66.0	25.0	5.0	20.3	29.0	12.0	71.0	11.4
Q1	63.4	68.0	26.0	5.2	28.0	31.1	13.0	71.0	12.0
Median	66.5	69.2	26.9	6.0	31.5	32.0	13.4	71.0	12.0
Q3	69.8	70.1	27.3	6.0	35.0	32.2	14.0	71.5	12.0
Maximum	73.0	72.0	28.0	6.6	40.9	33.0	14.0	72.0	12.2
Range	16.0	6.0	3.0	1.6	20.6	4.0	2.0	1.0	0.8

Table 6. Summary statistics of the Rummells-Maske point sample.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	30	30	30	30	30	30	30	30	30
Mean	83.6	96.5	37.7	6.6	44.1	36.4	15.1	71.0	11.9
Standard deviation	4.7	2.3	0.8	0.6	5.1	1.1	0.8	0.3	0.3
Minimum	66.0	87.0	36.0	5.5	31.5	32.7	13.0	70.0	10.9
Q1	82.0	96.0	37.0	6.0	40.3	36.0	15.0	71.0	12.0
Median	84.0	97.0	37.9	6.8	44.2	37.0	15.0	71.0	12.0
Q3	86.8	97.0	38.0	7.0	48.8	37.0	15.5	71.0	12.0
Maximum	91.0	101.0	39.0	8.0	52.2	38.0	17.0	72.0	12.3
Range	25.0	14.0	3.0	2.5	20.7	5.3	4.0	2.0	1.4

Table 7. Summary statistics of the Bull Brook point sample.

	Projectile mass (g)	Point length (mm)	Point width (mm)	Point thickness (mm)	Haft binding length (mm)	Haft binding width (mm)	Haft binding thickness (mm)	Shaft length (cm)	Shaft diameter (mm)
Sample (*N*)	30	30	30	30	30	30	30	30	30
Mean	66.1	66.4	25.9	6.3	37.3	28.2	14.5	71.0	11.9
Standard deviation	4.0	1.7	0.8	0.5	4.9	0.8	0.8	0.2	0.3
Minimum	57.0	62.0	23.3	5.8	26.0	25.3	13.4	71.0	11.0
Q1	65.0	66.0	25.5	6.0	34.9	28.0	14.0	71.0	12.0
Median	66.0	66.9	26.0	6.0	37.7	28.0	14.0	71.0	12.0
Q3	68.8	67.0	26.0	6.9	41.0	29.0	15.0	71.0	12.0
Maximum	73.0	70.0	28.0	7.7	44.0	29.0	16.8	72.0	12.0
Range	16.0	8.0	4.7	1.9	18.0	3.7	3.4	1.0	1.0

Finally, wooden boards are inexpensive and easily disposable once an experiment is finished.

Each projectile ($n = 203$) was shot into the oak board until either the point or haft was damaged (Figure 2). Damage was usually immediate: 200 (98.5%) projectiles broke upon the first shot; only three (1.5%) were shot twice; no projectile was shot more than twice.

Following Eren et al. (2020), we did not control for velocity in our experiment. Instead, each projectile was pulled to a standardized bow draw length of 56 cm. This procedure was selected because a person cannot produce at will more energy to achieve a greater velocity with a heavier point, nor would they necessarily use less energy to achieve a slower velocity with a lighter point. Thus, following Eren et al. (2020), velocity data in the present study reflect that the more massive projectiles travel slower than the smaller ones as if all seven point forms were fired by a single hypothetical individual. To measure velocity, we used a Gamma Master Model Shooting Chronograph throughout the experiment (Eren et al., 2021). The Chronograph readings result in "error" if there is a change in sunlight, cloud cover, or some other minor variable. As a result, we recorded a proportion of the possible stone point velocity readings per point type. In this present study, there was tremendous variation in the frequency of successful velocity readings for reasons we are currently unsure of (Table 8). For example, the Chronograph successfully recorded only 7 out of 30 Anzick projectiles (23.3%), but 18 out 30 Bull Brook projectiles (60.0%).

Figure 1. The experimental set-up used for assessing projectile durability. Protective plastic sheet to protect against projectile rebound (a); oak board (b); chronograph (c); compound bow and projectile (d); foam boards to protect against stone point breakage after each shot (e); the Spot Hogg Hooter Shooter (f); magic Sagittarius socks for good data (g); bullet-proof sheet to prevent stone shrapnel from flying into the rest of the lab (h). The wooden board could be moved up and down via metal fastenings (i) to ensure a clean section of wood board was shot.

Figure 2. Rummells-Maske specimen 4 after being shot into the oak board. Notice the split lashings.

Nevertheless, the mean recorded velocities of each of the seven point types make sense given their mass and are nearly identical to those reported by Eren et al. (2020). These readings fall well within the range of human atlatl throwing velocities (Whittaker et al., 2017).

Statistical analysis of durability

Our analyses of durability focused on damage to the replica stone points, haft, lashings, and shaft. To analyze damage to the points we measured the length of the point remaining after firing each hafted replica into the wood backstop and incurring damage. We calculated the fraction of the point remaining by dividing the original point length by the length of the point after receiving damage. Next, we used stepwise regression to determine if any of the size variables – mass, width, and thickness – influence length of point remaining. The results of the stepwise regression indicate that only point thickness remains in the final model ($F = 44.09$, $p < 0.000$).

Given that thickness varied among the replicas and was a parameter that was not linked to the actual Clovis points modeled – and thickness had *intended* to

Table 8. Velocity (m/s) summary statistics for each point sample.

	Simon	Shoop #1	Shoop #2	Vail	Anzick	Rummells-Maske	Bull Brook
Sample (*N*)	12	14	12	12	7	15	18
Mean	22.6	33.3	33.7	31.9	32.3	27.0	30.3
Standard deviation	2.4	1.7	2.0	4.3	4.5	3.9	2.3
Minimum	15.1	30.7	29.6	25.8	26.9	22.7	27.1
Q1	23.0	32.2	32.7	28.7	29.3	23.8	28.6
Median	23.0	33.3	33.3	31.7	32.0	27.9	29.8
Q3	23.5	34.4	35.1	36.1	35.2	28.7	32.1
Maximum	24.3	36.4	37.3	38.9	38.4	37.5	36.4
Range	9.2	5.7	7.7	13.1	11.5	14.8	9.3

Table 9. Frequency of shots until damage to either the point or the haft.

	Simon	Shoop #1	Shoop #2	Vail	Anzick	Rummells-Maske	Bull Brook
Damage on first shot	28 (93.3%)	30 (100.0%)	30 (100.0%)	23 (100.0%)	30 (100.0%)	29 (96.6%)	30 (100.0%)
Damage on second shot	2 (6.6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (3.3%)	0 (0%)

Table 10. Frequency of stone point-only break, haft-only break, or both per point type.

	Simon	Shoop #1	Shoop #2	Vail	Anzick	Rummells-Maske	Bull Brook
Stone point-only break	30 (100.0%)	0 (0%)	0 (0%)	2 (8.7%)	16 (53.3%)	11 (36.6%)	9 (30.0%)
Haft-only break	0 (0%)	2 (6.6%)	4 (13.3%)	1 (4.3%)	0 (0%)	1 (3.3%)	0 (0%)
Both	0 (0%)	28 (93.3%)	26 (86.6%)	20 (87.0%)	14 (46.6%)	18 (60.0%)	21 (70.0%)

be the same among the experimental specimens, but production realities made this goal difficult to achieve – we used an analysis of covariance (ANCOVA) statistical design to control for thickness and subsequently compare the proportion of point remaining between the seven point forms. The ANCOVA is a form of general linear model that assesses differences in mean values of a dependent variable, in this case, the proportion of point remaining, across different categories of an independent variable (or a treatment), for this experiment, this is the seven replica Clovis point forms, while statistically controlling for the effects of a covariate, point thickness.

For the analysis of the proportions of haft damage, split shafts, split lashings, and loose points we first correlated each with average measures of mass, width, and thickness using Spearman's nonparametric rank procedures. Next, we compared the observed proportions using Chi-square tests of proportions and Bonferroni-corrected pairwise comparisons of each combination of proportions.

Statistical analyses were conducted using SPSS v. 25. All data used to carry out these analyses are available in the Supplementary Materials.

Results

As indicated above, the overwhelming majority of Clovis point replicas incurred damage on the first shot (200 of 203, or 98.5%) and only three points were damaged after the second shot (Table 9). Thus, our analyses focus on aspects of damage to the point and the haft and shaft rather than when damage occurred, and we report on the results in that order. Table 10 shows the frequency per point type of whether the stone point suffered damage, the haft in general suffered damaged, or both the point and the haft suffered damage (Figures 3 and 4).

Summary statistics of the broken point length as a proportion of original point length per point type is shown in Table 11 and Figure 5. The overall results of the ANCOVA indicate that the proportion of the point remaining differs significantly between the groups of replica points (Type III SS = 0.799, df = 7; $F = 11.5$; $p <$ 0.000). The estimated marginal means for each group of replica Clovis points, adjusted for differences in thickness, demonstrates that the Rummells-Maske form incurs the least amount of damage, whereas Anzick sustains the most damage (Table 12). Pairwise comparisons of the proportion of point remaining after controlling for thickness shows that Anzick has the greatest number of significant differences (Table 13). Anzick has significantly more point damage compared to Simon, Vail, and Rummells-Maske. The only other difference is between Rummells-Maske and Bull Brook with Bull Brook having less damage than Rummells-Maske.

Table 14 shows the frequency of split shafts, split lashings, or loose points per point type. Spearman's rank correlations between the proportion of points with haft damage in general (split shafts + split lashings + loose points), split shafts, split lashings, and loose points and the average of point mass, length, and width shows

Figure 3. Examples of broken points with hafts intact.

that heavier, longer, and wider point forms incurred less damage (Table 15). Point thickness does not correlate with any of the attributes and none of the measures of size correlate with split shafts.

Figure 4. Examples of broken points with haft and shaft damage.

Comparing the observed proportions of points with haft damage, split shafts, split lashings, and loose points shows that Simon was undamaged (Table 16). On the other hand, all of the Shoop #1 and Shoop #2 specimens exhibited haft damage and loose points and high proportions of split shafts and lashings. To further investigate the differences in proportions we statistically compared the observed proportions for each damage category. The overall differences in proportions within each category are significantly different (Table 16). Pairwise comparisons of the proportions of haft damage show that, as expected, Simon has significantly less haft damage compared to the other points. Additional differences include Shoop #1 and Shoop #2 having proportionally more haft damage than Rummells-Maske and Anzick. Anzick also has less damage than Vail. For the proportion of split shafts, Simon has significantly less than Shoop #1, Vail, and Shoop #2 (Table 17). Shoop #1 has a higher proportion of split shafts than Rummells-Maske. Vail sustained split shafts in greater proportion compared to Rummells-Maske, Anzick, and Bull Brook. Lastly, Shoop #2 has a higher proportion of split shafts compared to Bull Brook.

In comparing the proportion of loose points, Simon has statistically fewer occurrences than the other points (Table 18). Shoop #1 has statistically more loose points than Rummells-Maske, Anzick, and Bull Brook. Vail has more loose points recorded than Anzick. Shoop #2 has more loose points than Anzick and Bull Brook. In addition, Rummells-Maske has fewer loose points than Shoop #2. For split lashings, Simon has fewer cases than all of the points except Anzick (Table 18). Shoop #1 also has more split lashings than Anzick. Lastly, Rummells-Maske and Anzick have fewer split lashings than Shoop #2.

Discussion

Projectile point durability – or lack thereof – is a performance characteristic that prehistoric hunter-gatherers may have sought (Cheshier & Kelly, 2006; Ellis, 1997; Engelbrecht, 2015; Odell & Cowan, 1986). For Clovis foragers exploring, colonizing, and settling a relatively new and largely empty North American continent (Amick, 2017; Anderson, 1990; Eren & Buchanan, 2016; Jennings & Smallwood, 2019; Meltzer, 2021), on one hand point form characteristics that increased durability may have been selected for as insurance against situations whereby resupply stone outcrops may not have been known or easily accessed. On the other hand, point form characteristics that increased breakage upon impact may have also been selected for by Clovis foragers to ensure a kill shot and increase the chances of

Table 11. Summary statistics of broken point length as a proportion of original point length per point type. These data do not control for thickness. See also Figure 5.

	Simon	Shoop #1	Shoop #2	Vail	Anzick	Rummells-Maske	Bull Brook
Sample (N)	30	30	30	23	30	30	30
Mean	0.93	0.83	0.82	0.86	0.76	0.93	0.83
Standard deviation	0.10	0.08	0.18	0.05	0.13	0.03	0.04
Minimum	0.44	0.69	0.00	0.75	0.27	0.90	0.71
Q1	0.94	0.79	0.78	0.83	0.76	0.91	0.81
Median	0.95	0.83	0.83	0.87	0.78	0.93	0.84
Q3	0.97	0.87	0.93	0.89	0.81	0.95	0.85
Maximum	0.99	1.00	1.00	1.00	0.92	1.03	0.93
Range	0.56	0.31	1.00	0.25	0.65	0.14	0.22

supplying energy and nutrition to their low-density populations.

Similar arguments for and against durability may apply to hafts. Wooden shafts and hafting are likely a much larger time investment than is stone point knapping (Cheshier & Kelly, 2006), and point form characteristics that improved shaft durability may have been selected for. However, albeit less convincing, a case could be made that some damage to a shaft could be advantageous if it allows for a quicker reload of a new stone point.

Here, we presented a ballistics experiment that tested whether there was a difference in stone point and haft durability among seven Clovis plan-view point forms. These forms depict one way of representing the center (Bull Brook) and extremes (Simon, Shoop, Anizck, Vail,

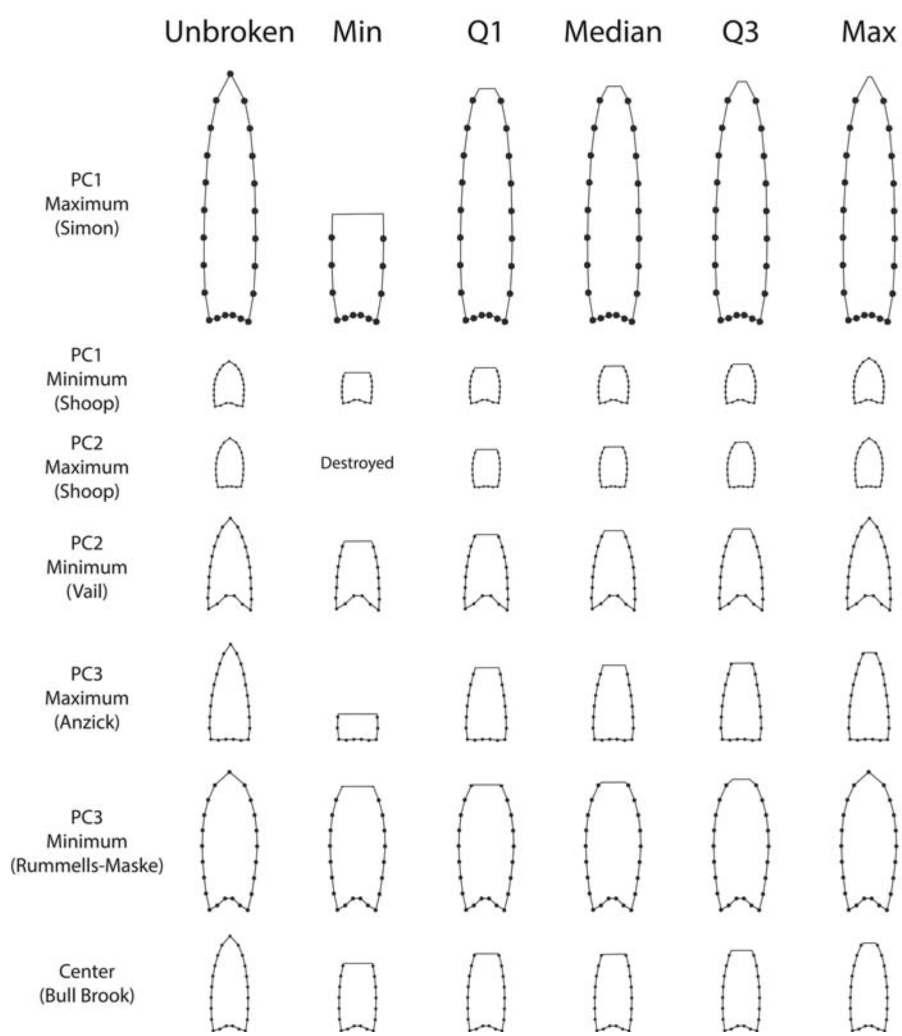

Figure 5. Visual representation of the summary statistics of percentage point length remaining as a percentage of original point length. See also Table 12.

Table 12. Estimated marginal means of proportion of point remaining after incurring damage.

			95% Confidence Interval	
Clovis replica point	Mean	Std. error	Lower bound	Upper bound
Simon	0.898	0.023	0.853	0.943
Shoop #1	0.849	0.019	0.811	0.886
Vail	0.864	0.021	0.823	0.905
Rummells-Maske	0.922	0.019	0.884	0.959
Shoop #2	0.838	0.019	0.800	0.876
Anzick	0.772	0.019	0.734	0.810
Bull Brook	0.832	0.018	0.796	0.868

Rummells-Maske) of Clovis point variation (Eren et al., 2020). Broadly, our experimental results support the widely-touted notion that stone points – when used as projectiles – are merely disposable ammunition, breaking after only one or a small number of uses (Cheshier & Kelly, 2006; Ellis, 1997; Wilson et al., 2020). Yet, even after controlling for point thickness, our results demonstrated significant, and in some cases dramatic, differences in both point length remaining and haft durability. These results are consistent with the hypothesis that Clovis foragers in different contexts may have designed their point plan-view forms – consciously or unconsciously – for different amounts of durability. Had our results shown no relationship between durability and Clovis point plan-view form, then the case for durability being a factor that Clovis people selected for or against, diminishes (Sitton et al., 2020). As it stands, our results support durability as a potential factor that influenced the evolution of Clovis points.

We cannot emphasize enough the qualifying words "*may* have designed" and "*potential* factor" in the preceding paragraph. Simply demonstrating that durability differences exist among Clovis point forms is not enough to *conclude* that durability was selected for or against by Clovis people. It is entirely possible that durability differences incidentally arose through drift (Bebber et al., 2017). Or, another potential functional factor – such as penetration depth (Eren et al., 2020) – may have been the target of Clovis selection, and changes in point, haft, or shaft durability were merely concomitant to it. Along these lines, Cheshier and Kelly (2006, p. 362) rightly note that "artifact design is a balance between several often conflicting desires." Furthermore, Buchanan and Hamilton (2020) derived and fit optimal size allometries for a large sample of lanceolate point forms dating to the Paleoindian period and showed that these forms were broadly designed to resist breakage while maximizing penetration depth.

When taken together, the experimental penetration depth results of Eren et al. (2020: Table 3) and the durability results presented here support this idea of an inherent conflict in artifact design. As shown in Figure 6, there seems to be general opposition in penetration depth and durability in the seven point forms, suggesting that the selection of one functional factor may automatically, though coincidentally, influence the performance of another functional factor. As such, it may not be accidental the point form that represents the center of Clovis variation in our study – Bull Brook – seems to balance well both penetration and durability simultaneously (Figure 6, Row 5). However, the Vail form, too, appears to balance penetration and durability well. Future studies will explore in further detail the

Table 13. Matrix of multiple pairwise comparisons of mean proportion of point remaining after incurring damage between Clovis point replica groups. Above the diagonal are mean difference values and below the diagonal are Bonferroni adjusted *p*-values associated with the mean differences.

	Simon	Shoop #1	Vail	Rummells-Maske	Shoop #2	Anzick	Bull Brook
Simon	–	0.050	0.034	−0.023	0.060	0.126*	0.066
Shoop #1	1	–	−0.016	−0.073	0.010	0.076	0.016
Vail	1	1	–	−0.057	0.026	0.092*	0.032
Rummells-Maske	1	0.204	0.883	–	0.083	0.149*	0.089*
Shoop #2	1	1	1	0.073	–	0.066	0.006
Anzick	0.003*	0.71	0.030*	<0.000*	0.229	–	0.060
Bull Brook	0.489	1	1	0.016*	1	0.540	–

*Indicates a significant difference after Bonferroni adjustment for multiple comparisons.

Table 14. Frequency of split shafts, split lashings, or loose points per point type. Each percentage is calculated from the total sample; i.e. the tally of split shafts, split lashings, and loose points are calculated independent of each other. Thickness is not controlled for in these data.

	Simon	Shoop #1	Shoop #2	Vail	Anzick	Rummells-Maske	Bull Brook
Sample (*n*)	30 for split shaft and loose point; 28 for split lashings	30	30	23	30	30	30
Haft damage	0 (0%)	30 (100.0%)	30 (100.0%)	21 (91.3%)	14 (46.7%)	19 (63.3%)	21 (70.0%)
Split shaft	0 (0%)	16 (53.3%)	19 (63.3%)	16 (69.6%)	7 (23.3%)	1 (3.3%)	4 (13.3%)
Split lashings	0 (0%)	23 (76.6%)	26 (86.6%)	15 (65.2%)	9 (30.0%)	11 (36.6%)	15 (50.0%)
Loose point	0 (0%)	30 (100.0%)	30 (100.0%)	21 (91.3%)	14 (46.7%)	18 (60.0%)	20 (66.6%)

Table 15. Spearman's nonparametric correlations between average measures of mass, length, width, and thickness of the seven replica Clovis points and the proportion of haft damage in general (split shafts + split lashings + loose points), split shafts, split lashings, and loose points after experimental firings.* = Statistically significant.

		Mass	Length	Width	Thickness
Haft damage	Correlation Coefficient	−0.811	−0.919	−0.811	−0.450
	p-value	0.027*	0.003*	0.027*	0.310
Split shaft	Correlation Coefficient	−0.571	−0.679	−0.607	−0.643
	p-value	0.180	0.094	0.148	0.119
Split lashings	Correlation Coefficient	−0.786	−0.893	−0.821	−0.429
	p-value	0.036*	0.007*	0.023*	0.337
Loose point	Correlation Coefficient	−0.811	−0.919	−0.811	−0.450
	p-value	0.027*	0.003*	0.027*	0.310

Table 16. Multiple proportion test for the incidence of haft damage, split shafts. Split lashings, and loose points across the seven points (degrees of freedom = 6 for all tests).

	χ^2	*p*-value
Haft damage	101.73	<0.000
Split shaft	67.03	<0.000
Split lashings	63.65	<0.000
Loose point	100.49	<0.000

morphometric tension between penetration depth and durability as they relate to the distribution of Clovis point forms in different regions of North America.

Further thoughts on haft damage

Six of the seven Clovis point forms used in our experiment suffered haft damage. In contrast, the recent experimental study by Werner et al. (2019) exploring lashing damage on points with ground ($n = 30$) and sharp ($n = 30$) proximal-lateral edges showed that haft damage was negligible. In the second part to that study, the 60 lanceolate points were shot into a moose antler. Although the stone points suffered substantial damage, the lashings and wooden shaft suffered virtually no damage. The results of Werner et al. (2019) thus contrast with the results presented here where haft damage was common. Although the target in each study was different (moose antler versus oak board), we do not think that was the reason for the difference. However, we offer three other possibilities here, none of which are mutually exclusive but can be assessed in future experiments.

First, although the stone points in each study were hafted by Thunderbird Atlatl, the lashing material and adhesive was different. In Werner et al. (2019), the lashings were bovine silk fiber and the adhesive was bone glue. Here, the lashings were hemp fiber and the adhesive was Kodak gelatin-based glue (Eren et al., 2020). The differential strength of the lashings, as well as the interaction of the lashings, adhesive, point, and shaft, could be influencing the differential haft damage apparent between the two studies.

Second, more simply, the amount of lashings and adhesive might be dictating haft damage. In other words, perhaps the haft materials themselves are comparable, but there was a difference in *how much* of the materials were used.

Third, velocity could be playing an important role in haft damage. The projectile specimens in Werner et al. (2019) were shot at a mean velocity of 24.11 m/s. The Simon point form used in the present durability study possessed the slowest velocity (22.6 m/s) of our seven forms, and one comparable to that reported by Werner et al. (2019). Also comparable to Werner et al. (2019) results, the Simon point form suffered no haft damage (Table 15).

Given the discrepancies between our experimental findings concerning haft damage and those of Werner et al. (2019), we suggest that our haft damage results be considered as a relative measure within our study (between the Clovis point forms) until future experiments can address some of the

Table 17. Matrix of pairwise comparisons of proportions using Bonferroni *p*-value adjustment.

	Simon	Shoop #1	Vail	Rummells-Maske	Shoop #2	Anzick	Bull Brook
Simon	–	<0.000*	<0.000*	1	<0.000*	0.332	1
Shoop #1	<0.000*	–	1	0.001*	1	0.707	0.054
Vail	<0.000*	1	–	<0.000*	1	0.043*	0.002*
Rummells-Maske	<0.000*	0.017*	0.860	–	0.087	1	1
Shoop #2	<0.000*	1	1	0.017*	–	0.087	0.004*
Anzick	0.002*	0.002*	0.038*	1	<0.000*	–	1
Bull Brook	<0.000*	0.077	1	1	0.076	1	–

Above the diagonal are *p*-values for pairwise comparisons of the incidence of split shafts and below the diagonal are *p*-values for pairwise comparisons of the incidence of broken hafts.

Table 18. Matrix of pairwise comparisons of proportions using Bonferroni *p*-value adjustment. Above the diagonal are *p*-values for pairwise comparisons of the incidence of split lashings and below the diagonal are *p*-values for pairwise comparisons of the incidence of loose points.

	Simon	Shoop #1	Vail	Rummells-Maske	Shoop #2	Anzick	Bull Brook
Simon	–	<0.000*	<0.000*	0.018*	<0.000*	0.080	0.001*
Shoop #1	<0.000*	–	1	0.087	1	0.016*	1
Vail	<0.000*	1	–	1	1	0.482	1
Rummells-Maske	<0.000*	0.008*	0.492	–	0.004*	1	1
Shoop #2	<0.000*	1	1	0.008*	–	0.001*	0.116
Anzick	0.002*	<0.000*	0.038*	1	<0.000*	–	1
Bull Brook	<0.000*	0.036*	1	1	0.037*	1	–

issues raised above. Yet, when taken together, the results presented here and those from Werner et al. (2019) also speak to the costs and benefits of different hafting materials, and the choices prehistoric foragers may have had to make with respect to the design of their composite technologies and weapon systems (e.g. Wilson et al., 2020). At times the raw materials used might have been environmentally constrained; other times not. But a lithic analyst's focus on the stone artifacts sometimes makes it easy to forget the intricate interplay those artifacts had with perishable components of their technology (Whittaker, 2010; see also Adovasio et al., 2014; Adovasio & Dillehay, 2020; Hurcombe, 2008; Miller, 2014).

Further thoughts on shaft damage and Clovis bone points

We note that the wooden shafts in our study split often, but not always, along a diagonal, creating a natural bevel (Figure 4). Using a cast of one of the Sheriden Cave bone points (Redmond & Tankersley, 2005), we were intrigued to find that it often fit flush against this broken shaft bevel (Figure 7). We readily admit that this fit could be fortuitous, but we wondered whether the proximal shape of Clovis bone points or rods could be due to their possible role as replacements specifically for this type of shaft break. Speculatively, we could envision a Clovis group returning to a cache like Sheriden Cave, Easy Wenatchee, or Anzick (Huckell & Kilby, 2014; Kilby, 2008; O'Brien, Lyman et al., 2016) to not only

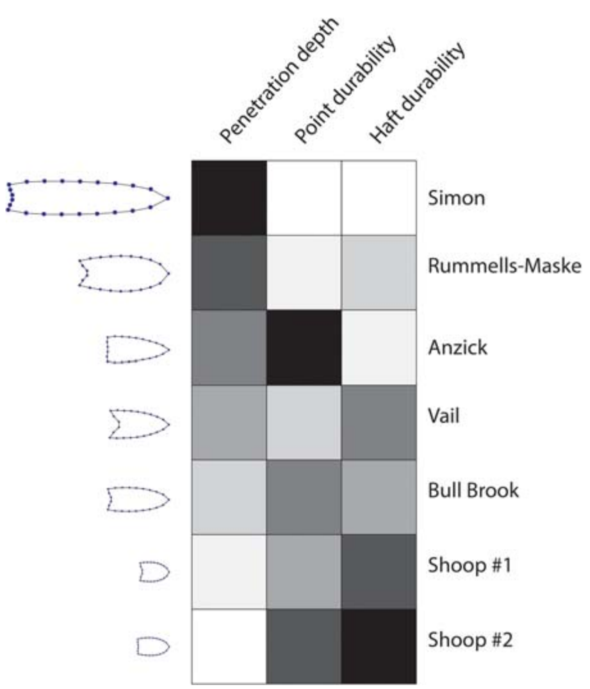

Figure 6. There appears to be a conflict between Clovis projectile point penetration potential and point durability. Darker shades represent poorer performance, i.e. less penetration depth or less durability. Rankings were tabulated from Eren et al. (2020: Table 3) and from Tables 12 and 15 in the current study.

Figure 7. A Clovis bone point cast from Sheriden Cave fits flush against a natural bevel in a broken wood shaft.

replace their broken or lost stone points, but to affix beveled bone points to broken, but highly valuable, wooden dart shafts. In this case, bi-beveled bone rods might be interpreted simply as "preforms" to bone points, and whichever bevel fits best to the broken dart shaft gets affixed to it, while the opposite bevel is sharpened and used as is, or ground into a point. Future experiments using replica bone points and split shafts will be useful in determining if this hypothetical design is plausible.

Conclusion

This paper described an experiment designed to test the durability of different replica Clovis point plan-view forms and their hafts. We used a similar experimental set-up described in the first paper in the series of functional experiments by Eren et al. (2020). In the study presented here, the focus was on point and haft durability. We fired hafted replica Clovis points into oak boards and recorded the resulting damage to the points, hafts, and shafts. We then statistically compared the damage across the seven different Clovis forms. We reasoned that if point durability differed among the different forms of Clovis points, then durability may have been a functional consideration for Clovis flintknappers. Our experimental findings demonstrated that there are statistical differences in the amount of damage points incur. The frequency of haft damage in terms of split lashings, split shafts, and loose points also differed among point forms. This finding indicates that different Clovis point forms have different durability. Thus, this study demonstrates that different Clovis forms in use by Clovis hunters in the late Pleistocene had differential capabilities of withstanding damage to the stone points, hafts, and shafts and that functional factors may have contributed to the evolution of Clovis points.

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Notes on contributors

Metin I. Eren is an Associate Professor of Anthropology at Kent State University and a Research Associate at the Cleveland Museum of Natural History

Michelle R. Bebber is an Assistant Professor of Anthropology at Kent State University.

Daniel Wilcox is an M. A. candidate in Anthropology at Kent State University.

Brett Story is an Associate Professor in the Department of Civil and Environmental Engineering at the Southern Methodist University Lyle School of Engineering.

Briggs Buchanan is an Associate Professor of Anthropology at the University of Tulsa.

ORCID

Metin I. Eren http://orcid.org/0000-0003-3576-6076
Michelle R. Bebber http://orcid.org/0000-0002-6084-8420

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