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North American Clovis Point Form and Performance III: An Experimental Assessment of Knife Cutting Efficiency

Anna Mika[a], Briggs Buchanan[b], Robert Walker[c], Alastair Key[d], Brett Story[e], Michelle Bebber [e][a] and Metin I. Eren [a,a,r]

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

ABSTRACT

This study is an experimental assessment of Clovis knifeuse.This work is the third contribution in a series of experiments aimed at shedding light on the functional performance of distinct Clovis "point" forms. Here, we used seven replica Clovis point forms, representing the average and extremes of observed Clovis form, in two cutting tasks: rope cutting and day cutting. Statistical comparison of cutting time, our measure of cutting efficiency, indicated differences among the knife forms in both tasks. These results, especially when considered with previous penetration and durability studies, are largely consistent with the hypothesis that selection of functional attributes contributed to Clovis point variability and evolution across North America. We also show that better knives serve as poorer points, and vice versa, but better knives are more durable than poorer knives. We conclude with discussion of knife use, allometry, and knife use in other time periods.

KEYWORDS

North America; Clovis; knives; experimental archaeology; cultural evolution; late Pleistocene

Introduction

The present study represents the third part of our experimental exploration of whether different Clovis point plan-view forms perform differently at specific functional tasks. Overall, we wish to better understand whether Clovis point plan-view form evolution *(sensu* Lycett, 2011, 2015; Mesoudi, 2011) occurred primarily due to drift or, alternatively, whether drift plus the selection of functional attributes jointly contributed to Clovis point plan-view evolution. To understand whether functional factors played a role in this evolution, we *first* need to understand whether there are functional differences among Clovis point plan-view forms, and what specifically those functional differences are. If no functional differences exist, then arguing for the selection of functional attributes makes little sense. But if functional differences are documented experimentally, then future work can examine the contexts and patterns of Clovis point plan-view form across North America and assess the co-variation of particular forms with specific environments to further support or question the role of functional attribute selection in Clovis point evolution.

Our first two published studies from this project examined Clovis point plan-view form differences with regard to target penetration (Eren et al., 2020) and point, haft, and shaft durability (Eren et al., 2021). In both experiments, different Clovis point plan-view forms demonstrated significant difference in terms of functional performance, and we direct the reader to those studies for further details. Here, we assess whether different Clovis point plan-view forms function significantly differently whenused asknives. We hypothesize that if different Clovis knife forms function significantly differently, then they will yield contrasting cutting efficiency performance data, the latter assessed via time to complete a cutting task. If Clovis knife forms do not function significantly differently, then they will yield similar cutting efficiency data. We also discuss our Clovis knife results in relation to the results of the previous studies (Eren et al., 2020, 2021).

The hypothesis that Clovis points served as knives for butchering, plant cutting, or other "slicing" (c.f. Atkins et al., 2004; Key, 2016) tasks is nothing new and should be considered unsurprising. Based on several lines of evidence, archaeologists have long and consistently suggested that Clovis points were likely multifunctional tools (e.g. Bradley et al., 201O; Eren & Buchanan, 2016; Gramly, 1999; Gramly & Yahnig, 1991; Jennings & Smallwood, 2019; Meltzer, 1993, 2021; Morrow, 2019; Shott

CONTACT Anna Mika amikal@kent.edu
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et al., 2021; Smallwood, 2015; Tune, 2016; Waters et al., 2011) or that specific forms of Clovis point served as knives (e.g. Buchanan et al., 2018; Jennings, 2013; Lyman et al., 1998; Thurmond, 1990). The strongest and most direct evidence for the use of Clovis points as knives comes from microwear analysis. Numerous microwear studies have shown that Clovis points were used in cutting and slicing motions of meat, hide, plants or other materials (e.g. Bebber et al., 2017; Beers, 2006; Eren et al., 2018; Hannus, 2018; Kay, 1996, 2018; Miller, 2013; Miller et al., 2019; Shoberg, 2010; Smallwood, 2010, 2015; Waters et al., 2011; Werner et al., 2017). Butchery experiments, too, have shown that Clovis points or similar bifaces are effective cutting implements, and thus such experiments are also consistent with the hypothesis that they served as knives (Gingerich & Stanford, 2018; Huckell, 1979; Key et al., 2021; Smallwood, 2015).

Materials and methods

Experimental Clovis points/knives

Following Eren et al. (2020, 2021), in this study we used seven different Clovis points representing the extreme bounds of known Clovis point/knife shape space (see Eren et al., 2020, Figure 4). These points/knives (hereafter we refer to the replica Clovis artifacts as knives because in this context they are used only as knives) are from six Clovis assemblages: Simon, (two from) Shoop, Vail, Anzick, Rummells-Maske, and Bull Brook. Craig Ratzat at Neolithics Flintknapping Supply House (www.neolithics.com) produced thirty ground specimens of each of these knife types using lapidary equipment, for a total *n* of 210. Ratzat, unaware of the goals of the experiment, then pressure flaked the edges of all 210 knives so that they would be sharp.

Hafting

Bob Berg at Thunderbird Atlatl (www.thunderbird.com) hafted the knives. He manufactured one-inch ash dowels and then shaped them to fit the seven different knife forms (Figure 1). He dissolved kodak gelatin-based glue in warm water, and then used it with kemp fiber to haft the knife blades onto the dowels. A small electric heated glue pot maintained the correct viscosity of the glue. Berg dipped both the dowel and knife blade into the glue pot. He then dipped a pre-measured amount of fiber into the glue pot. He spread the glue evenly on the fiber and then wrapped the fiber over the wood/stone joint by hand. Care was taken to ensure that there was a good connection free from voids. Berg then allowed the glue to dry for 24 h.

We note, as we have elsewhere, that wedo not know exactly how Clovis points were hafted[1] (Thomas et al., 2017, p. 29) and encourage other cutting studies to explore the use of different hafting configurations and materials (Eren et al., 2021; Wilson et al., 2021).

Knife measurements

We recorded nine measurements on each knife in each set (Figure 2, Table 1): mass (g), total length of the knife (mm), blade length (mm), handle length (mm), blade width (mm), handle width (mm), blade thickness (mm), handle thickness (mm), and hafting width (mm). All knife measurements are available in the supplementary online materials.

Experimental procedure

We presented thirty participants (**N** = 30; 15 females, 15 males) with a set of seven knives corresponding to the seven Clovis forms described above that represent Clovis continental variation. With each knife, participants engaged in two cutting tasks - one blade edge of each knife was used for the first task, while the other blade edge of each knife was used for the second task (note that the blades were symmetrical along their long axis [i.e. perpendicular to the blade edge]).The order of starting knife - i.e. which particular Clovis point form - was randomly assigned to control for potential fatiguing. Participation was volunteer-based, and all involved were unaware of the goals of the study. The age for participants ranged from 20 to 71 years(mean= 27.38 years, median= 24 years, SD= 10.57). Due to COVID protocols, all experiments took place outside, with social distancing, and facial masks.

In the first task, Blue Hawk 0.25-in x 100-ft Twisted Sisal Rope (By-the-Roll) was the cutting substrate (Figure 3). Previous studies have used similar rope in cutting efficiency experiments for its importance in determining tool performance in precision-based tasks (Key et al., 2021; Key & Lycett, 2011, 2018). M.I.E. constructed a device to clamp the rope in place during cutting. Two IRWIN 4-1/2-in Cast Iron Light-Duty Workshop vises were secured by bolts drilled into two blocks of wood. The difference in space between the two vices was approximately 63.5 mm apart. Four, six-inch pieces of rope were inserted into the left clamp and tightened until there was no slack in the rope. The ropes were then twisted three times before being clamped into the right vise and tightened. Participants were instructed to cut through the rope as quickly and

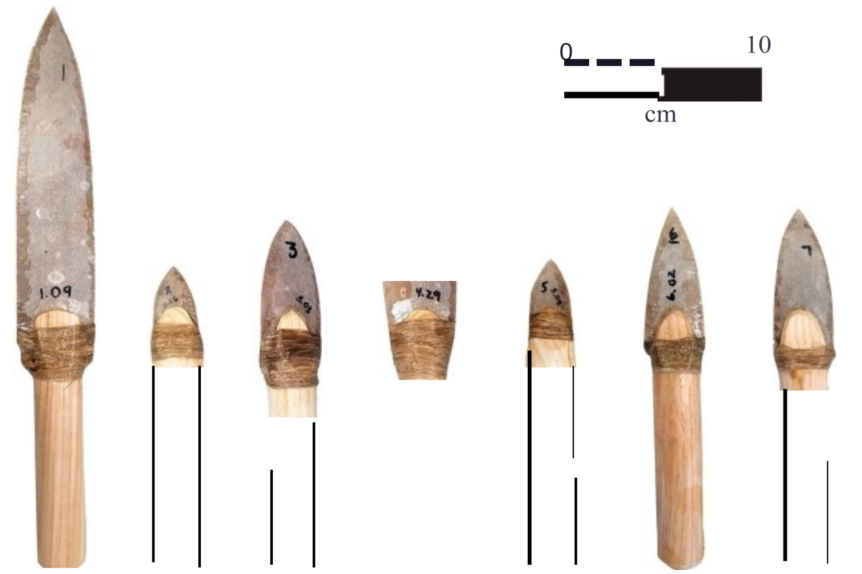

Figure 1. The seven hafted Clovis knife forms we used in the experiments.

efficiently as possible, and to make sure there were no strands left connected by the end of each trial. No instructions pertaining to cutting techniques were mentioned. Time, in seconds, was recorded using a stopwatch and was our measure of cutting efficiency. The timer began at the first stroke and continued until the final cut of rope separated the two halves. The timer paused when participants stopped to adjust their grip and began once cutting recommenced. We replaced the rope after each trial, allowing the participants to take short breaks during the intervals.

In the second task, 103 Red Clay C/06-2 clay was the cutting substrate (Figure 4). Each new package of clay contained two large, cubed blocks whose dimensions were approximately 170 mm x 160 mm x 165 mm. Each large block was then quartered into four smaller rectangular pieces, with dimensions being approximately 42.5 mm x 40 mm x 41.25 mm - these quartered pieces were the blocks participants cut into two "sections." Similarly, to the rope task, we instructed participants to cut through the clay as quickly and efficiently as possible, as though they were slicing through bread. The participants were timed in seconds beginning with the initial slice. The timer stopped once the last slice was completely disconnected from the block or rope.

There were some minor issues that occurred during testing (Table 2). One issue involved a few knife blades falling out of their handles. This occurred six times during Trial 1 - Rope Cutting: twice for Knife #1 (Simon), once for Knife #2 (Shoop #1), and three for Knife #5 (Shoop #2). This impacted Task 2 - Clay Cutting, since the knives were no longer usable for cutting, resulting in incomplete trials. Participants commented on hearing cracking during knife use prior to blade detachment; upon examination of the joint, it was the glue that wasthe cause of the cracking sound. Another issue involved part of the blade edgessnapping off during the final cut. The blade would hit either the wooden platform of the vise, or it would hit the vise itself. In these cases, the blade was still usable for Task 2 - Clay Cutting, since the opposite, non-damaged cutting edge was used for the second task.

All experimental data in this study are available in the supplementary online materials. This study was approved by the Kent State University return to research approval process as well as the Kent State University Risk Mitigation sub-committee.

Biometric variables

We recorded the following biometric variables from each participant: hand length, lengths of digits one, two, and three, grip strengths, and pinch strengths from tip-to-tip and pad-to-side. The objectives in measuring the biometric variables were two-fold. First, we wanted to show that individual subjects inherently

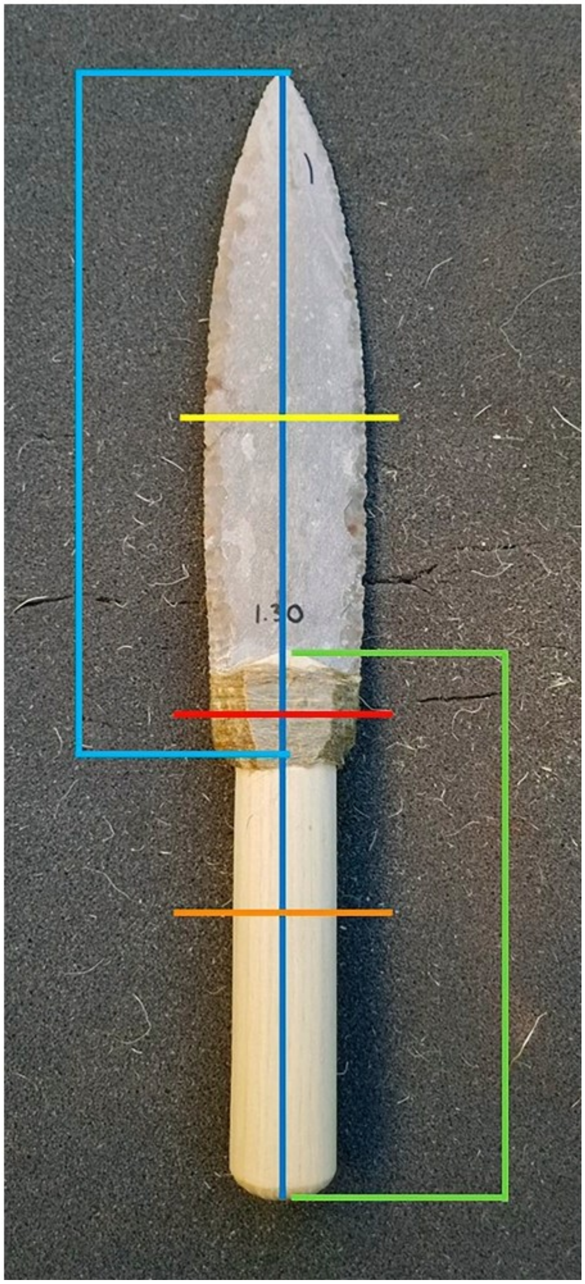

Figure 2. Locations of where morphometric variables were recorded in millimeters (mm): total length of the knife (dark blue), blade length (light blue), handle length (green), blade width (yellow), handle width (orange), blade thickness (yellow), handle thickness (orange), and hafting width (red).

vary in measures relevant to the cutting tasks and second, for a future study that will specifically examine the impact of biometric variation on cutting using Clovis knives. Hand length was measured from the tip of digit three (3D) to the most proximal wrist line. Measurements for digits one to three (1D-3D) were taken from the middle of the tip of the digit, not including the nail, to the distal line where the digit connects to the palm. We also calculated ratios between 1D and 2D. These measurements and ratios are known to impact the efficiency of stone tool usage (Key & Lycett, 2011, 2018). The participants provided signed consent for their biometric data to be published.

We measured grip strength using a Jamar Plus+ Digital Hand Dynamometer. Three trials were performed per left and right hand, with atotal of six trialsoverall per participant. A number 2 handle position was used in all cases to stay consistent across participants (Trampisch et al., 2012). To perform the grip strength tests, the participant began with their left hand, and were instructed to squeeze as hard asthey could using a transverse hook grip (Marzke & Wullstein, 1996). They then used their right hand. This continued until all six alternating-hand trials were completed. After the grip strength tests, participants were allotted a brief, five-minute break before moving onto the next set of strength tests.

We measured pinch strengths using the Jamar Pinch Gauge - Plus+ Digital - 50 Lb. Capacity device.The pinch strengths are commonly used to "record precision manipulative strength" (Key & Lycett, 2018). Beginning with the "Pad-to-Side" Pinch Test, the participant placed their thumb (10) on the superior metal plate and positioned the joint of their proximal and intermediate second digit (2D) on the inferior metal plate, using digits 3D to SD as buffers (Key & Lycett, 2018). They were then instructed to pinch as hard as they could until the numbers stabilized. This procedure was repeated for another two tests, and later averaged. After, the Tip-to-Tip Pinch Strength was performed. Each participant was instructed to place the distal most portion of their thumb (1D) on the superior metal plate and place their distal portion of 2D on the inferior metal plate, while not using 3D to SD for support. They were instructed to pinch as hard as they could until the numbers stabilized.

It is clear from that the biometric measures on individuals vary substantially (Table 3, Figure 5). Based on this observation we include subject in our statistical models described below.

Statistical analysis

Table 1. Mean and standard deviation (SD) of each sample of the seven Clovis knife types. Raw data are available in the supplementary online materials. Mass was recorded in grams (g); other measurements were recorded in millimeters (mm). See also Figure 2.

	Mass		Total knife length		Blade length		Handle length		Blade width		Handle width		Blade thickness		Handle thickness		Hafting length	
Knife type	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
#1 (Simon)	111	7	279	4	184	4	126		39		24		8		24		35	2
#2 (Shoop 1)	39	1	145	3	33	2	125	2	19		24		6		24		23	
#3 (VaiO	47	3	168	4	70	1	124	3	28	1	24	1	7	1	23		31	1
#4 (Rummells-Maske)	72	4	196	4	100	2	126	1	39	2	24	1	8	0	24		34	2
#5 (Shoop 2)	41	1	146	2	33	1	125	1	18	1	24	1	5	1	24		21	1
#6 (Anzick)	47	4	170	4	69	2	123	2	25		23	0	6	0	23		32	1
#7 (Bull Brook)	48	3	169	4	68		123	2	27		24		6	0	23		29	

transformations or using a link function. Weak prior probability distributions(priors) were assigned to all parameter values to ensure model fit using the defaults from the *brms* package. Intercepts and standard deviations of the grouping effects for knife type and subject were assigned student t (df = 3, mean= 0, SD= 2.5) priors. Final models were run with 2 chains for 10,000 iterations. For all parameters r-hat values (a model diagnostic with expected value equal to 1) were exactly 1.00 and signify model convergence. Chains were inspected visually for sufficient mixing to ensure that model results were appropriate.

We carried out a second set of analyses following the methods described above, but in this analysis we added knife thickness to the model as an additional independent variable. We did this because our interest is in the relative effectiveness of knife outline forms and although we attempted to keep thickness the same across knives, it varied.

Results

Table 4 presents the basic descriptive efficiency data for each cutting task per point form.

The cutting task 1, rope cutting, model showed significant effects for both knife type and subject together accounting for 86% of the variance of natural logged time. Accounting for the different abilities of the subjects, as evidenced by the biometric data, the knife used in task 1 had a significant effect on time (Figure 6). The posterior distributions reveal that Knife

Figure 3. Experimental set up for task 1, rope cutting.

Figure 4. Experimental set up for task 2, clay cutting.

Table 2. Knife breakage during testing for cutting tasks 1 and 2. "Broken" refers to specimens whose blades dislodged from their lashings and haft. "Damaged" refers to specimens whose knife blades were damaged with no impact on lashings. "Usable" refers to specimens whose blades were damaged but had intact lashings.

Knife Type	Number of Specimens Broken or Damaged After Task 1	Number of Usable Specimens (From the Subset from the Damaged or Broken Category) Task 1	Number of Usable Specimens After Task 1 (Survivors)	Number of Specimens Broken or Damaged After Task 2	Number of Usable Specimens (From the Subset of Damaged or Broken Category) Task 2	Number of Usable Specimens (Total Survivors)	Total Percentage of Specimens Broken or Damaged (Combined Task 1 and Task 2)
#1 (Simon)	4	2	28	2		27	90.0%
#2 (Shoop 1)	2		29			29	96.7%
#5 (Shoop 2)	4		27			27	90.0%

Table 3. Values for biometric variables.

Biometric variable	Mean	Standard deviation	Minimum	Maximum	Range	Skewness
Age (years)	27.23	10.57	20.00	71.00	51.00	3.315
Hand length (mm)	177.59	11.53	158.80	221.00	6220	1.802
Thumb length D1 (mm)	59.59	5.54	50.71	71.78	21.07	0.386
Index length D2 (mm)	67.65	3.99	60.84	76.24	15.40	0.171
Middle length D3 (mm)	74.06	5.20	64.00	87.15	23.15	0.039
1D:2D Ratio	0.88	0.06	0.76	0.99	0.22	0.152
Grip strength AVG dominant (kg)	32.44	11.15	16.40	63.40	47.00	0.882
Pad-to-side pinch strength AVG (kg)	6.39	1.41	4.08	10.27	6.19	0.632
llp-to-tip pinch strength AVG (kg)	4.21	1.23	1.90	7.00	5.10	0.456

#1 (Simon) the point with the longest blade, was the most efficient in cutting rope. Knives #4 (Rummells-Maske), #6 (Anzick), and #7 (Bull Brook) also were efficient for this task (Table 5). Knives #2 and #5, both from Shoop, and the shortest and widest knives, were the least efficient showing a significant effect after controlling for subject.

Cutting task 2, the clay block cutting model, also showed significant effects for knife type and subject together accounting for 72% of the variance of natural logged time. Again, while accounting for the different abilities of the subjects, the knife used in task 2 had a significant effect on time (Figure 7). The posterior distributions for this model indicate that Knife #1 (Simon) is the most efficient and knives #2 and #5 (both from Shoop) are the least efficient for cutting clay blocks (Table 6).

The results of the second model, including knife type, subject, and knife thickness as independent variables,

Figure 5. Examples of how grip strength (left) and pinch strength (right) were recorded.

Table 4. Summary statistics of Clovis knife cutting efficiency (time in seconds).

Knife type	Mean		Standard Deviation		Minimum		Q1		Median		Q3		Maximum	
	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2	Task 1	Task 2
#1 (Simon)	4.88	5.43	1.83	3.29	1.43	2.31	4.01	3.50	4.61	4.81	5.32	6.00	10.40	18.35
#2 (Shoop 1)	74.69	17.49	49.86	10.04	17.90	6.72	37.16	11.32	61.81	15.12	91.32	19.15	217.60	55.65
#3 (Vai0	14.36	9.76	9.52	3.25	2.50	4.81	7.47	7.46	12.26	9.83	20.47	11.23	48.75	17.56
#4 (Rummells-Maske)	9.57	7.30	5.80	4.59	2.59	2.43	6.07	4.09	8.80	7.09	10.70	8.13	32.13	25.41
#5 (Shoop 2)	53.56	14.90	34.27	6.67	17.16	6.43	27.80	9.97	50.38	13.63	61.02	17.16	145.79	38.46
#6 (Anzick)	9.26	10.02	4.95	5.95	2.91	3.28	6.02	7.07	8.29	8.81	11.87	10.98	27.03	36.40
#7 (Bull Brook)	12.63	9.46	8.39	4.87	4.56	3.03	6.30	6.46	9.44	7.96	15.79	11.25	35.59	25.64

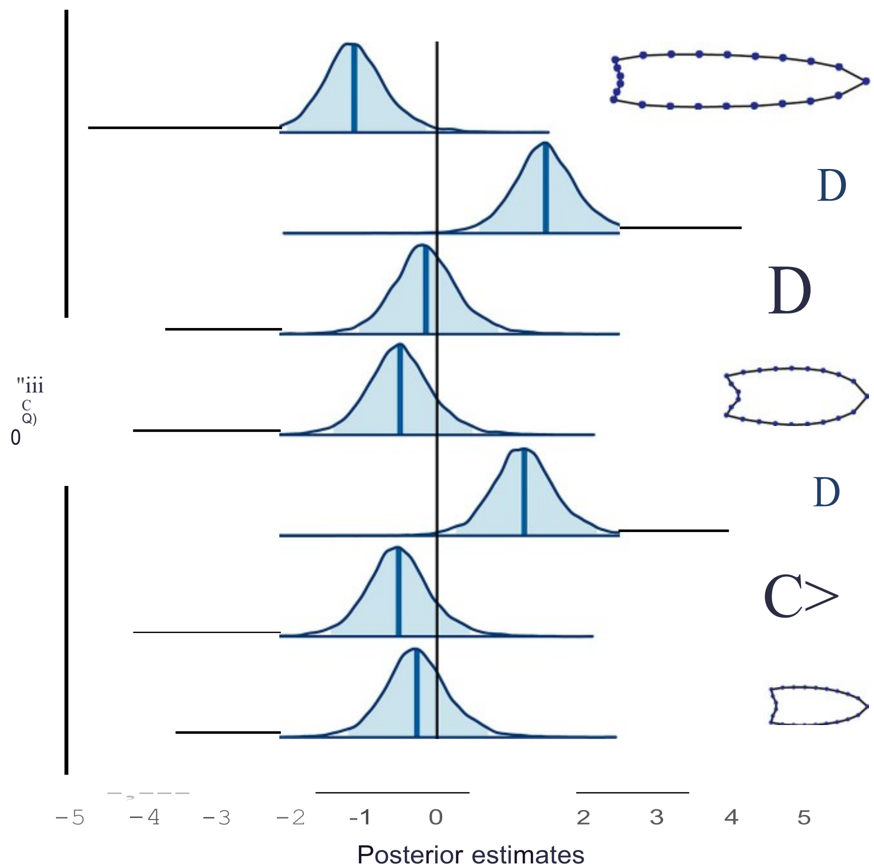

Figure 6. Posterior distributions of cutting times for task 1 (seconds) for seven Clovis knives. 95% credible intervals are shaded, and the vertical line is the median of the posterior distribution. From top to bottom: Simon, Shoop #1, Vail, Rummells-Maske, Shoop #2, Anzick, Bull Brook.

are similar to the model without including knife thickness as reported above. The overall r^2 values for cutting task 1 and task 2 are the same as above (86% and 72% respectively). For cutting task 1, the second model indicates significant effects for both knife type and subject together accounting for thickness (Figure 8). Also like the results reported above, the posterior distributions for thismodel indicate that Knife #1 (Simon) is the most efficient and knives #2 and #5 (both from Shoop) are the least efficient (Table 7). However, in this model the credible ranges narrow slightly. For cutting task 2, the second model accounting for the different abilities of the subjects, the knife type, and thickness had a significant effect on time (Figure 9). The posterior distributions for this model indicate that Knife #1 (Simon) is the most efficient and Knife #2 (Shoop) is

Table 5. Bayesian model 1 results for cutting task 1 by knife type.

Knife type	Estimate	Est. Error	Q2.S	Q97.5
#1 (Simon)	- 1.1232	0.4743	-2.0346	-0.1472*
#2 (Shoop 1)	1.4802	0.4775	0.5758	2.4666*
#3 (VaiO	-0.1503	0.4753	-1.0544	0.8336
#4 (Rummells-Maske)	-0.4992	0.4756	-1.4045	0.4806
#5 (Shoop 2)	1.1873	0.4768	0.2612	2.1741*
#6 (Anzick)	-0.5204	0.4746	-1.4416	0.4515
#7 (Bull Brook)	-0.2709	0.4758	-1.2034	0.6951

*Posterior distributions that do not encompass zero have significant effects.

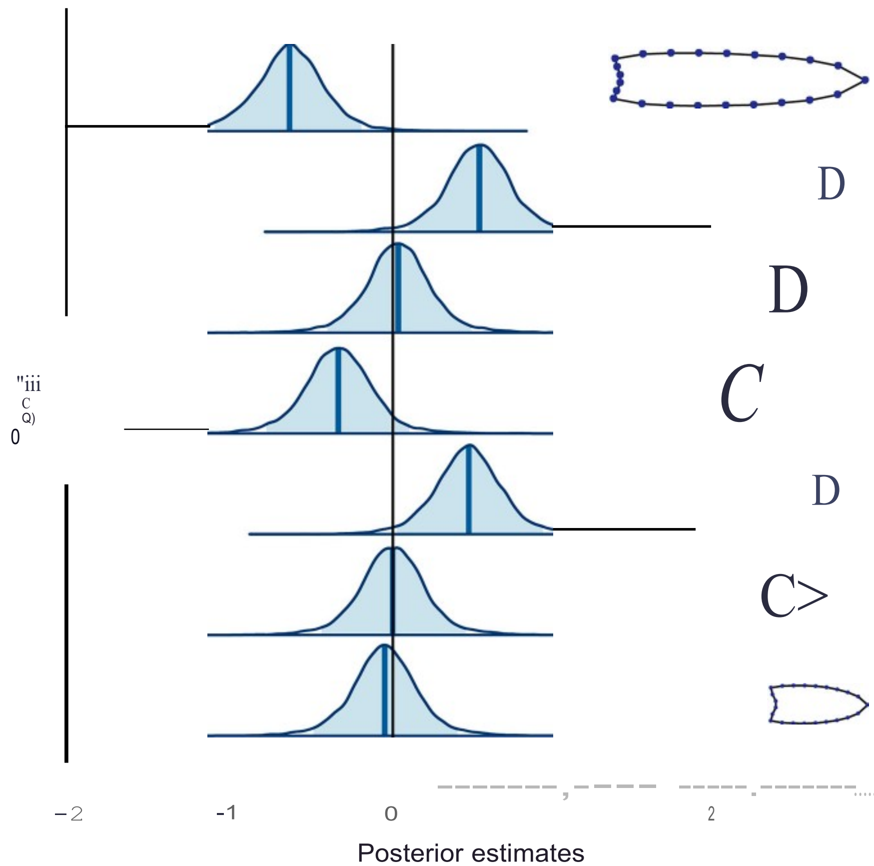

Figure 7. Posterior distributions of cutting timesfor task 2 (seconds) for seven Clovis knives. 95% credible intervals are shaded, and the vertical line is the median of the posterior distribution. From top to bottom: Simon, Shoop #1, Vail, Rummells-Maske, Shoop #2, Anzick, Bull Brook.

the least efficient for cutting clay blocks (Table 8). Different from model 1, this second model of cutting task 2, Knife #5 from Shoop is non-significant.

Discussion

Clovis knives of different plan-view forms performed significantly differently in both cutting tasks. This result is *consistent with* the hypothesis that the selection of functional attributes contributed to Clovis point plan-view evolution. Although we still have more functional tasks to report on (e.g. edge-wear, flight trajectory, hand held spear-thrusting}, we now have three sets of experimental results on Clovis tool function (projectile penetration, impact durability, cutting effectiveness) that show significant performance differences among different forms. Among several challenges moving forward - after the functional experiments are completed - **will** be to understand whether functional differences in toolform were incidental or aresult of selection (Eren et al., 2020, 2021). Toward this end, our experimental results will ultimately need to be tightly integrated into studies of archaeological site context and paleoenvironment, perhaps at multiple geo-spatial scales, and, when better chronometric control is available, perhaps assessed chronologically.

Table 6. Bayesian model 1 results for cutting task 2 by knife type.

Knife	Estimate	Est. Error	Q2.5	Q97.5
#1 (Simon)	-0.6379	0:1.267	-1.0988	-0.1945*
#2 (Shoop 1)	0.5338	0:1.191	0.0975	0.9847*
#3 (VaiO	0.0338	0:1.172	-0.4036	0.4838
#4 (Rummells-Maske)	-0.3367	0:1.205	-0.7807	0.1013
#5 (Shoop 2)	0.4689	0:1.220	0.0242	0.9261*
#6 (Anzick)	-0.0008	0.2170	-0.4398	0.4488
#7 (Bull Brook)	-0.0507	0:1.176	-0.4898	0.3982

*Posterior distributions that do not encompass zero have significant effects.

However, by this point, we hope the essential link between a robust cultural evolutionary understanding of prehistoric technology and experimental archaeology is now obvious (Darwin, 1859; see also Bebber, 2017; Bebber et al., 2019; Broughton & O'Connell, 1999; Lycett, 2011; Lycett et al., 2016; Mesoudi, 2011; Mesoudi & O'Brien, 2008; O'Brien et al., 1994, 1998; Schiffer, 1972; Schillinger et al., 2014; Story et al., 2019). Darwin was able to propose his system of descent with modification because, among other

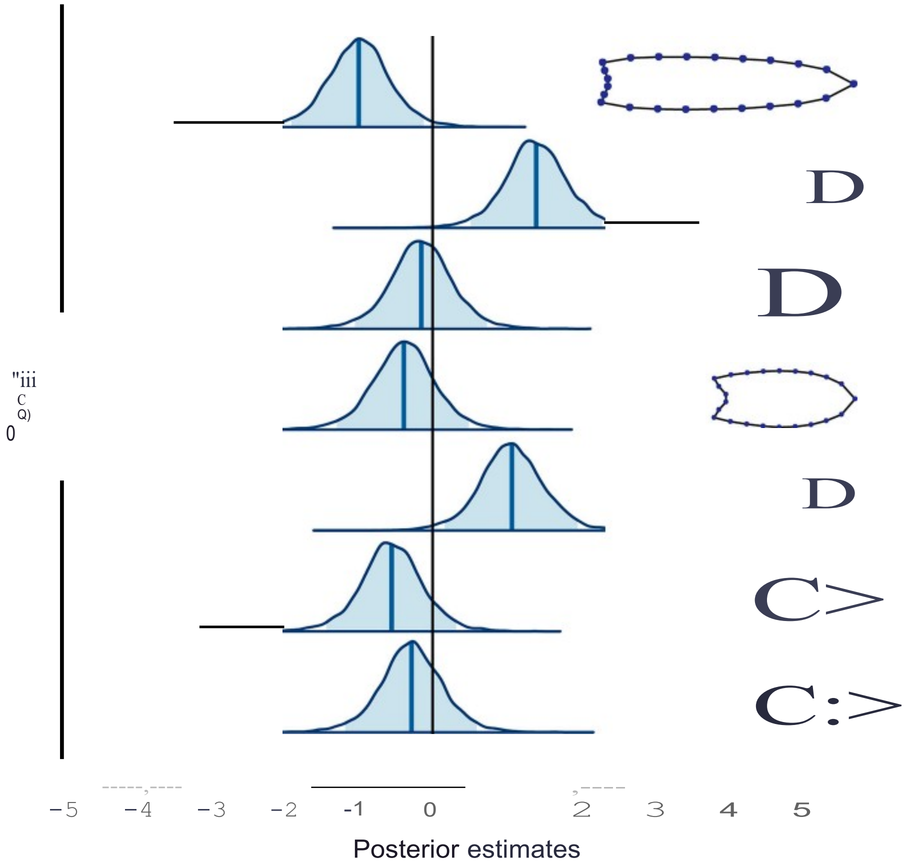

Figure 8. Posterior distributions of cutting times for task 1 (seconds) for seven Clovis knives with knife thickness added as an additional independent variable. 95% credible intervals are shaded, and the vertical line is the median of the posterior distribution. From top to bottom: Simon, Shoop #1, Vail, Rummells-Maske, Shoop #2, Anzick, Bull Brook.

things, he could observe both biographical patterns and organism feature function (or lack thereof). Archaeologists have been very good at documenting prehistoric technological patterns, but only with the rapid maturing of experimental archaeology over the past 20 years[2] (Eren et al., 2016) have archaeologistsbeen able to scientifically "observe" artifact function and assess the relative functionality of different artifact varieties or features. A robust appeal to selection can be made only if functional differences between artifact varieties can be experimentally shown. If not, then archaeologists have greater reason to argue for drift or aesthetics for artifact evolution. Either way, experimental archaeologists are in a prime position to provide vital contributions to cultural evolution in deep time globally.

Table 7. Bayesian model 2 results for cutting task 1 by knife type.

Knife	Estimate	Est. Error	Q2.5	Q97.5
#1 (Simon)	-1.0015	0.4437	-1.9144	-0.1206*
#2 (Shoop 1)	1.4059	0.4457	0.5179	2.3025*
#3 (VaiO	-0.1533	0.4393	-1.0514	0.7362
#4 (Rummells-Maske)	-0.3900	0.4441	-1.2971	0.4909
#5 (Shoop 2)	1.0763	0.4487	0.1654	1.9683*
#6 (Anzick)	-0.5543	0.4382	- 1.4379	0.3206
#7 (Bull Brook)	--0.2856	0.4409	-1.1865	0.5963

*Posterior distributions that do not encompass zero have significant effects.

Eren et al.'s (2021) comparison of experimental Clovis point penetration depth to durability demonstrated that there can be an inherent conflict in artifact design. A comparison of Clovis point penetration depth to Clovis knife cutting effectiveness re-affirms this notion, as deeply penetrating Clovis points functioned poorly as knives, and *vice versa* (Figure 10). However, Figure 10 also shows how an artifact design can possess "coinciding optima" (the co-occurrence of multiple benefits, Lycett & Eren, 2013, p. 2389). In this case, the Simon plan-view form is both durable upon impact and effective at cutting. However, one can think about the coinciding optima of durability and cutting effectiveness another way: in terms of costs. For example, only through the loss of several functional benefits can the Shoop #1 and #2 points achieve deep penetration (although these point designs might possess other as-of-yet-undocumented benefits).

Another question to be investigated revolves around the phenotypic plasticity of the Clovis point/knife form.

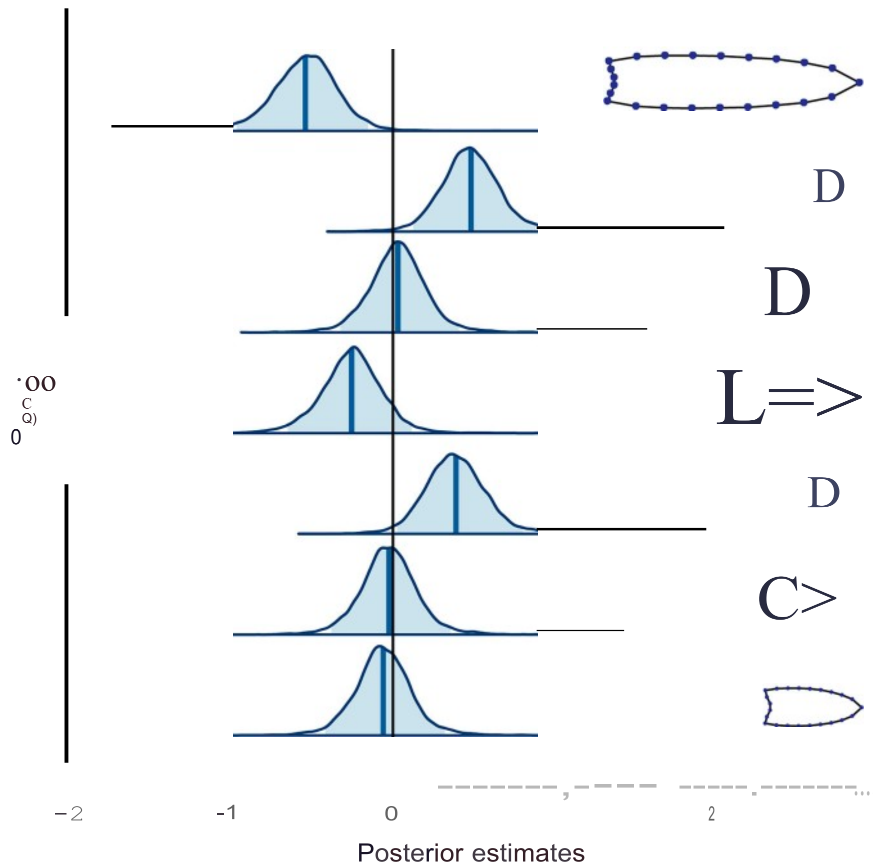

Figure 9. Posterior distributions of cutting times for task 2 (seconds) for seven Clovis knives with knife thickness added as an additional independent variable. 95% credible intervals are shaded, and the vertical line is the median of the posterior distribution. From top to bottom: Simon, Shoop #1, Vail, Rummells-Maske, Shoop #2, Anzick, Bull Brook.

There is little question that Clovis points exhibit tremendous variability (e.g. Buchanan et al., 2014; Smith et al., 2015), and there exists wide-agreement that many Clovis points/knives were likely multi-functional tools, serving as both projectile weapons and knives concurrently. This characterization is supported well in our experimentsfor the Bull Brook, Vail, Anzick, and Rummells Maske forms, which appear to balance penetration, durability, and cutting effectiveness simultaneously (Figure 10). Yet, the Simon and Shoop points appear to be so specialized functionally that we wonder whether it might be fruitful to consider these Clovis forms as polyphenic cultural phenomena. In biology, "polyphenism" is the unique sub-type of phenotypic plasticity where two or more distinct phenotypes are produced by the same genotype due to epi-genetic factors (e.g. Simpson et al., 2011; Yang & Andrew Pospisilik, 2019). Importantly, this phenomenon results in outputs that are not continuous, but rather discrete and multi-stable; a classic example is the worker versus queen bee (Yang & Andrew Pospisilik, 2019). Analogously, we can imagine tool functions as discrete phenotypes, and perhaps some environmental factor or specific context resulted in discrete "knife-only", "point-only", or "multi-functional" Clovis tool variants arising from a flexible, Clovisknapping culture spanning across North America (e.g. Eren et al., 2015; Sholts et al. 2012; Smallwood, 2012). These results are fully consistent with the modularity analysis of Clovis and Folsom points conducted by Buchanan et al. (2018, p. 721, 729-739; cf. Shott & Otarola-Castillo, 2021), who suggested that:

> several classes of Clovis points - intended for different functions - might have been in use during the Clovis period and that the later Folsom points might have served only as weapon tips, the shape of which were constrained by the fluting process.

Table 8. Bayesian model 2 results for cutting task 2 by knife type.

Knife	Estimate	Est. Error	Q2.5	Q97.5
#1 (Simon)	-0.5497	0.2180	-1.0085	-0.1534*
#2 (Shoop 1)	0.4746	0.1996	0.0840	0.8843*
#3 (VaiO	0.0244	0.1936	-0.3743	0.4030
#4 (Rummells-Maske)	-0.2658	0.2055	-0.6976	0.1167
#5 (Shoop 2)	0.3827	0.2049	-0.0106	0.8077
#6 (Anzick)	-0.0320	0.1942	-0.4277	0.3506
#7 (Bull Brook)	-0.0673	0.1943	-0.4662	0.3193

*Posterior distributions that do not encompass zero have significant effects.

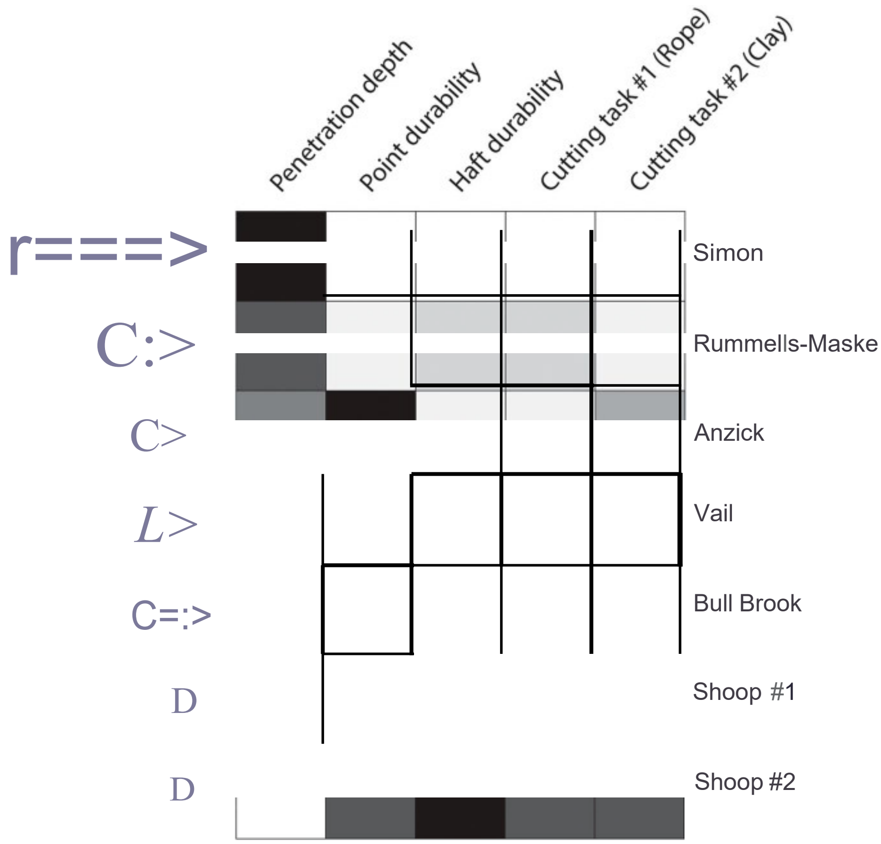

Figure 10. There appears to be a conflict between Clovis knife cutting efficiency and projectile point penetration potential, but linkage between knife cutting efficiency and point durability. Darker shades represent poorer performance, i.e. less penetration depth, less durability, or poorer cutting efficiency. Rankings were tabulated from Eren et al. (2020, Table 3), (Eren et al., 2021, Tables 12 and 1S), and Tables 6 and 7 in the current study.

Further thoughts on Clovis knife use, design, and energy

Differences in energy acquisition and expenditure strategies are key drivers of hunter-gatherer cultural diversity (Kuhn & Miller, 2015; Stiner & Kuhn, 2016; Surovell, 2009; Torrence, 1989). This includes in the lithic archaeological record, where ethnographic and artifact-based examples provide evidence that requirements to satisfy specific energy budget scenarios can leave visible traces in the lithic archaeological record (e.g. Bleed, 2002; Holdaway & Douglass, 2012; Jeske, 1992; Maloney & Hiscock, 2021; Reti, 2016; Stevens & McElreath, 2015). Given that tool-use durations (and associated muscular effort) directly impact the energy required and exerted when completing a given activity, it is reasonable to assume that the differences identified here would have had meaningful energetic implications for Clovis populations. The significance of which is magnified in-line with the frequency of the tool's use.

In turn, there is an argument to be made for the preferential production of Clovis forms similar to or matching Simon, Rummells-Maske, Anzick and Bull Brook, as they would reduce the amount of energy expended. When considered over the entire use-life of a stone knife, these small but significant differences could potentially benefit energy stores, other beneficial activities, and ultimately, survival and reproductive success. In other words, over hundreds or thousands of cutting tasks these minor but significant differences (when compared to Shoop knives) could save individuals many thousands of kilojoules or hours of time. This again raises the question of why Clovis populations, such as those at Shoop, chose to repeatedly produce tool forms that were sub-par in terms of their cutting performance.

On the reasonable assumption that people producing Shoop-like tools were not regularly and repeatedly producing tool types detrimental to their survival, their production likely relates to the variable weighting given to energy, time, and risk budgets when determining an optimal technological solution for their ecological niche. Indeed, other drivers of human behavior, including time and risk budgets, can simultaneously impact tool design factors influencing cutting performance

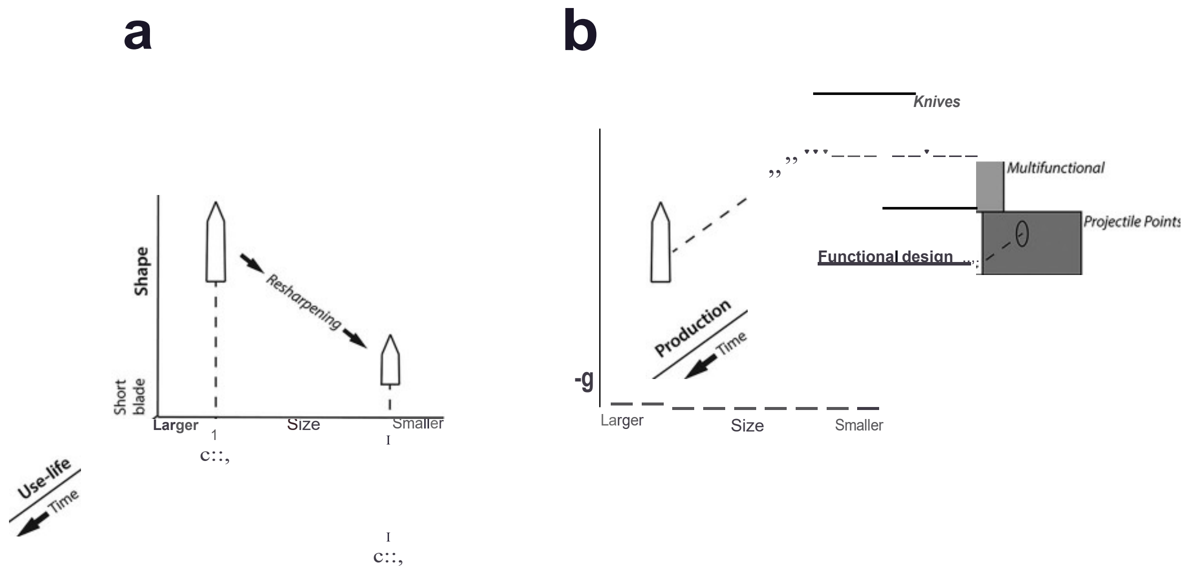

Figure 11. The exact same allometry pattern is shown in both (a) and (b). And in both instances, imagine this is a population of individual Clovis point/knife specimens. In (a), the allometry pattern is consistent with resharpening, in that the larger point with thelonger blade isresharpened into the smaller point with theshorter blade. In (b), the allometry pattern isconsistent with functional design - with no need to invoke resharpening - because the larger point with the longer blade functions as a knife and the smaller point with the shorter blade functions as a projectile point. Of course, interpretations can get interesting (and complex) when these two schematics are put together. And interpretations can become even more complex when other factors (mentioned in the main text) are also considered. There is currently no reason to presume resharpening is the predominate explanation for Clovis point allometric variation.

(Bamforth & Bleed, 1997; Bleed, 2001; Kuhn & Miller, 2015). That is, energetic considerations cannot always be considered alone or in isolation, are often interrelated in complex ways with other elements of the human and artifacts systems that define stone tool-use contexts and ecological scenarios (Shiffer & Skibo, 1987, 1997).

Given the greater penetration capabilities of Shoop points, it is possible that superior hunting success compensated for their energetic costs when used for cutting. Even if their use only resulted in an additional single kill for every 100 attempts, the energy provided could balance the costs (energy, time, risks [injury, other carnivores etc.]) created through extended cutting durations. Alternatively, ecological differences could make Shoop points a preferential technological solution for some groups but not others. Reduced hunting opportunities, even if only for a single season, could make increased penetration depths more important than costs associated with their use in the long term. In other words, the necessity to survive a single season could outweigh the long-term year-long costs associated with reduced cutting performance.

Fundamental differences in energetic baselines for other factors influencing the life-history of Clovis toolkits may also have selected for Shoop points. For example, if populations are relatively close to raw material sources, then the energetic costs of expedient tools (i.e. flakes, see Dominguez-Solera, 2012; Key & Lycett, 2014; Walker, 1978) are substantially reduced and points could more often (although not exclusively) be reserved for use as a projectile. Given the low population densities of people who used Clovis technology (Meltzer, 2021) and their frequent need to travel long distances (e.g. Boulanger et al., 2015; Meltzer, 2021) such toolkits may not always have been an option, but these differences may not have had to be frequent to impact energy, time and risk budget considerations.

It is also important to consider that only two cutting tasks have been examined here and that they do not reflect the diversity of scenarios that stone knives were used in during prehistory. Indeed, while consistent results between both tasks suggest diverse prehistoric cutting activities will return similar relationships, our data only supports this conclusion for cutting actions with linear (forward and back) cutting motions. More dynamic cutting actions, such as "winkling" a joint apart or cutting in a restricted space (e.g. removing fleshfrom within atortoise shell) may provide conditions that alter the relationships observed here. Most notably, there is potential for the greater length of Simon points to reduce maneuverability and increase forces acting on the tool (e.g. torque) in ways that could either be detrimental or beneficial to cutting performance (Tomka, 2001; Key & Lycett, 2020). Further, in some functional contexts flake tools may outperform knives and thus could occasionally be favored over hafted alternatives (Key et al., 2021). This is unlikely to impact the form of knife produced by populations and would only detrimentally impact their frequency of production.

Finally, we would be remiss in not mentioning that our results are consistent with the work of Morrow (1996), whose experimental work anticipated our findings here. His "simple" cutting experiment consisted of three replica lanceolate unhafted bifacial knives of different sizes, each used to saw a wooden dowel (Morrow, 1996, p. 585). Results of this experiment, measured in time, showed that the "small knife was a very ineffective tool and that the large knife was, by far, the most efficient" (Morrow, 1996, p. 586). When the small and medium knives were hafted, still neither performed as well as the unhafted large knife, and the medium knife performed still performed better than the small knife. Overall, Morrow's (1996, p. 587) experiment supports ours, which shows a "strong relationship between tool size and [cutting] functional efficiency".

Further thoughts on Clovis point allometry and use-life

Our experimental results here and elsewhere (Eren et al., 2020, 2021) show that different Clovis point forms function differently at distinct performance tasks. If we extrapolate from our findings and suggest, as others have, the possibility that what archaeologists have commonly classified as Clovis projectile points, may actually consist of different functional forms - projectile points and knives (also see Buchanan et al., 2018) - it is also possible that these different forms followed different use-life sequences. It is highly plausible that a knife would be resharpened dissimilarly from a projectile point.

Another possibility isthat the larger Clovis knivesmay have been maintained and used repeatedly and perhaps when dulled resharpened whereas, based on our previous durability experimental study (Eren et al., 2021), small Clovis projectile points may not have been designed to be used for more than one or two hunting events. For example, knives might have been serially resharpened and underwent a particular allometric reduction pattern whereas any allometric pattern associated with projectile points might only be a consequence of initial conditions of raw material nodule form, manufacturing technique, or damage repair (see Buchanan et al., 2015). Or, even if both knives and points were serially resharpened the overall resharpening pattern of knife-like versus projectile-like implements may be different, and thus could confound allometric patterns when samples are combined.

Our results also question whether allometric patterns exhibited in a population of individual Clovis point specimens from a large geographic area should be attributed only or predominately to use-history (resharpening and repair) (cf. Shott et al., 2021). Instead, functional design may also be significantly contributing to that observed allometric pattern, or conceivably even governing it if resharpening is not occurring to high degrees (e.g. Buchanan et al., 2015). For example, it is certainly possible that larger specimens with long blades may have been regularly resharpened into smaller specimens with short blades (Figure 11(a)). But it is also plausible that larger specimens possessed long blades because they were knives or used as knives more often, and smaller specimens possess shorter blades because they were projectiles or used as projectiles more often (Figure 11(b)). In each scenario, the same allometric pattern results. Importantly, in the latter scenario, an allometric pattern is present in a population of individual Clovis point specimens entirely because of functional design, *without any need to invoke resharpening*. In other words, equating allometry automatically with resharpening is erroneous, as is the notion that resharpening, "requires control before attempting other inferences" (Shott et al., 2021, p. 1). Additionally,recent results by Smith et al. (2021) are consistent with the hypothesis that Clovis blades possess cultural information. Thus if point resharpening is occurring, then it is likely culturally governed (see also Iovita, 2010), rather than a non-heritable procedure that automatically skews or confounds discussions or analyses of culture or cultural evolution.

When dealing with a population of individual Clovis point specimens from a large geographic area, resharpening, functional design, cultural drift, cultural non-functional bias, time, raw material factors, knapper skill, and individual style can all simultaneously, and to equal or unequal degrees, contribute to an allometric pattern (Lycett, 2016; Lycett & von Cramon-Taubadel, 2015). Indeed, almost a decade ago, one of us showed an allometric pattern in a population of Clovis endscrapers that was *consistent* with resharpening (Eren, 2013). But, despite the fact that there are independent lines of evidence suggesting endscrapers were actually resharpened (e.g. Loebel, 2013), Eren (2013:, p. 2107) still concluded that "it is difficult to envision that reduction alone will ever explain a majority of tool shape variation." The primacy of resharpening as an explanation for allometric patterns of Clovis points/knives is currently even more difficult to envision than it is for endscrapers, because for the former we often do not, or cannot, estimate the starting size, volume, or mass of the rock from which the tool was knapped.

The application of these results to other time periods

The results demonstrated here can be potentially extrapolated to other time periods to better inform our understanding of why variation in stone point morphology might have occurred. Indeed, researchers have hypothesized that the variation in Middle Archaic Period stone points represents a difference in tool function. The *Raddatz/Osceola* cluster found in Midwestern United States show a wide variety in overall point size. Based on contextual evidence, Ritzenthaler (1957:, p. 249) asserted that the larger of these stone points were used as knives and the smaller were used as projectiles, a hypothesis which can now be supported by experimental data. Likewise, in several cultural contexts around the world large, flaked stone points are regularly characterized as "knives", based on morphology alone (i.e. Mississippian Ramey Knives, Vermilion et al., 2003; Adena Leaf-shaped Knives, Ohio Archaeologist, 1964; Maya obsidian knives, Spence, 1996; Egyptian Gerzean knives, Kelterborn, 1984). From a functional perspective, these designations as knives are supported by the results of the Clovis cutting experiments presented here.

Notes

1. Based on experiments, Werner et al. (2019) questioned the hypothesis that edge-grinding protected haft lashings from damage. However, Shott et al. (2021, p. 3) state Werner et al.'s (2019) "results seem uncertain." One would not realize it from reading Shott et al. (2021) manuscript, but Werner et al. (2019, pp. 5844-5845) agree entirely, and provide several caveats, suggested follow up studies, and even wrote that "we are hesitant at the present time to reject it [the lashing protection hypothesis] entirely." Additionally, Shott et al. (2021, p. 3) depict Werner et al.'s (2019) recording of lashing damage as confusing. It was not. Ignoring for a moment the fact that the overall experimental results were null because there was virtually no damage to any specimens, Werner et al.(2019, p. 5842) clearly note, and depict in a figure (Werner et al., 2019, Figure 7), that damage recording applied to the lashings in general, not just the lashings along the edge.
2. There are several excellent archaeological experiments before this time; however, we would argue those are exceptions, rather than the rule (Eren et al. 2016). And the occurrence of those early gems does not negate the fact that tremendous strides have been made in experimental archaeology over the last 20 years.

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Notes on contributors

Anna Mika is a M.A. candidate in Anthropology at Kent State University.

Briggs Buchanan, Ph.D., is an Associate Professor in the Department of Anthropology at the University of Tulsa.

Robert Walker, Ph.D. is an Associate Professor in the Department of Anthropology at the University of Missouri.

Alastair Key, Ph.D., is an Assistant Professor in the Department of Archaeology at the University of Cambridge.

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

Michelle Bebber, Ph.D. is an Assistant Professor in the Department of Anthropology at Kent State University.

Metin I. Eren, Ph.D., is an Associate Professor in the Department of Anthropology at Kent State University and a Research Associate in the Department of Archaeology at the Cleveland Museum of Natural History.

ORCID

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

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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