Plains Paleoindian Projectile Point Penetration Potential

METIN I. EREN, *Department of Anthropology, Kent State University, Kent, OH 44224, USA, and Department of Archaeology, Cleveland Museum of Natural History. Email: meren@kent.edu*
MICHELLE R. BEBBER, *Department of Anthropology, Kent State University*
EDWARD J. KNELL, *Division of Anthropology, California State University Fullerton*
BRETT STORY, *Department of Civil and Environmental Engineering, Southern Methodist University*
BRIGGS BUCHANAN, *Department of Anthropology, University of Tulsa*

The iconic Paleoindian projectile points of the northern portion of the North American Great Plains—Clovis, Folsom, Agate Basin, Plainview (Goshen), Hell Gap, Alberta, Scottsbluff, and Eden—span nearly 4,000 radiocarbon years. Here, we apply recent findings from experimental archaeology to a database of 343 Paleoindian points to better understand how well these point types potentially functioned relative to each other in terms of penetration. Given that tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TCSP) inversely correlate with penetration depth, we measured and analyzed these two attributes on each specimen in our database. Our results indicate significant differences in the Paleoindian point types' tip cross-sectional geometries, suggesting that these points were not equally effective at penetration and that there is not a progressive trend in penetration effectiveness from Early to Late Paleoindian times. We conclude with a discussion of hypothetical Paleoindian point evolution and the reasons for the possible selection for or against penetration. The results speak to the assessment of archaeological and ethnographic technologies with full knowledge of their performance potential as gleaned from experimental archaeology. Such knowledge will help anthropologists propose more robust hypotheses involving the evolution of technology and culture, both past and present.

Key words: North America, stone tools, Paleoindian, projectile points

I have been unable to establish any one Paleoindian-type projectile as significantly more lethal than another. . . . My own preference is for the Agate Basin point . . . my second choice of a projectile for its effectiveness on bison is the stemmed Eden type. . . . I have been unable to understand the popularity of the Hell Gap projectile point.
—*George C. Frison (2004:110–11)*

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The iconic Paleoindian projectile points of the northern portion of the North American Great Plains—Clovis, Folsom, Agate Basin, Plainview (formerly known as Goshen in the north; see Buchanan et al. 2020), Hell Gap, Alberta, Scottsbluff, and Eden (Figure 1)—span nearly 4,000 radiocarbon years, beginning with Clovis around 11,600 ^{14}C BP and ending with Scottsbluff/Eden points around 8000 ^{14}C BP. Archaeologists have measured, drawn, and described these points and documented their contexts, which are sometimes associated with Pleistocene fauna. But beyond their general function as a pointed rock on a stick, how well did these types function as weapons, either in some absolute sense or relative to each other? This is a question archaeologists have previously pondered, and as illustrated by Frison's (2004) opening quote, they have offered their own answers and preferences.

It is an important question, too, because it directly bears on the evolution of prehistoric technology more broadly (e.g., Kuhn 2020; Lycett 2011; Mesoudi 2011). Were artifact traits or types initially selected because they provided a degree of functional advantage, or were they initially adopted and sustained in a culture due to some sort of transmission bias or stochastic mechanism (Eren et al. 2020)? If we can demonstrate a functional advantage, then selection can be considered as an explanation for an artifact type's evolutionary success (Story et al. 2019). If we cannot demonstrate a functional advantage, then archaeologists can instead consider other cultural processes, such as transmission bias or drift.[1] A primary challenge for archaeologists wishing to explain the emergence and evolution of a technology is therefore to understand whether certain stone tool variants provide a functional advantage over other variants (Story et al. 2019:2). But how can this challenge be met? One obvious option is with experimental archaeology, the process of recreating and reverse-engineering ancient technologies to understand their manufacture, function, and functional parameters and possible limitations (Wilson et al. 2020:2; see also Eren et al. 2016; Jennings et al. 2021; Outram 2008). Barring the practice of using real artifacts (e.g., Chazan 2013:363), replica artifact production and use is the only way for archaeologists to observe and test inferred artifact function,[2] and to understand the *potential* (Kneubuehl 2011; Lombard 2020:2) functional costs or benefits of one artifact variant relative to another.

With this in mind, we apply results from experimental findings on projectile point tip cross-sectional area (TCSA), and tip cross-sectional perimeter (TCSP), to archaeological specimens to better understand the relative efficacy of different point types in terms of penetrating a target (Sitton et al. 2020; see also Ashby 2005; Bestul and Hurteau 2015; Grady 2017; Hughes 1998; Kneubuehl 2011; Pargeter 2007; Salem and Churchill 2016; Sisk and Shea 2009; Sperrazza and Kokinakis 1968). Point penetration depth is a key element to assess in archaeological, ethnographic, or experimental weaponry because, in absence of poison, it can be directly tied to the success or failure of killing prey or, in some contexts, enemies (e.g., Bebber and Eren 2018; Bebber et al. 2017a, 2020; Cheshier and Kelly 2006; Clarkson 2016; Engelbrecht 2015; Friis-Hansen 1990; Guthrie 1983; Hughes 1998; Hunzicker 2008; Loendorf et al. 2017; Mika et al. 2020; Salem and Churchill 2016; Shea et al. 2002; Tomka 2013;

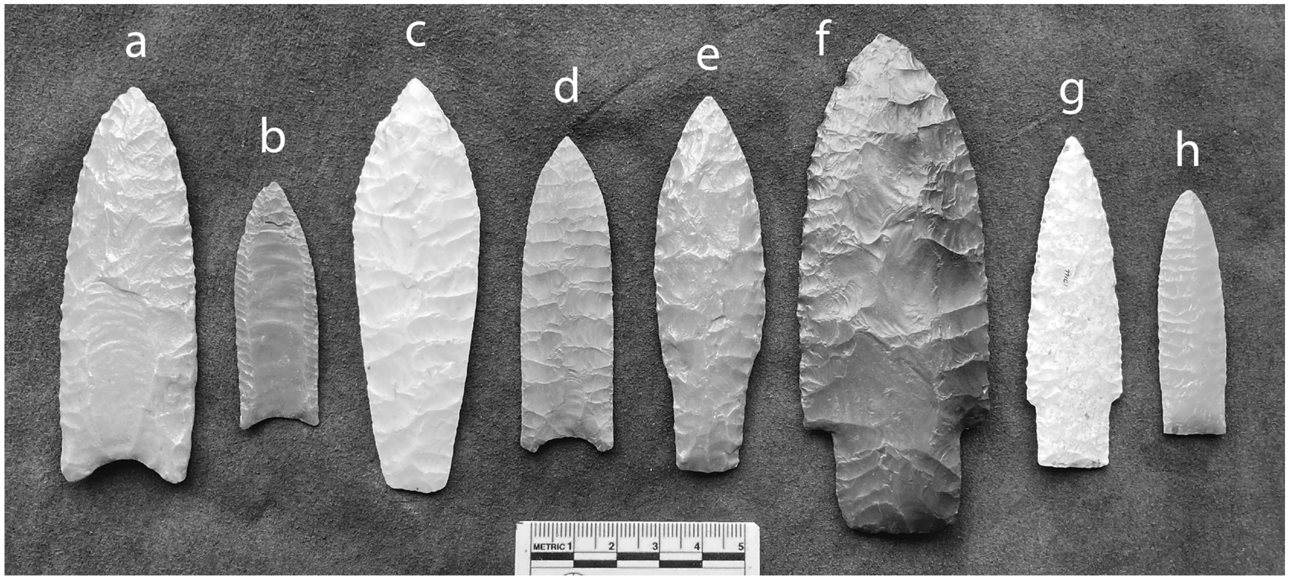

Figure 1. Clovis (a), Folsom (b), Agate Basin (c), Plainview (d), Hell Gap (e), Alberta (f), Scottsbluff (g), and Eden (h) projectile points.

Waguespack et al. 2009; Wood and Fitzhugh 2018). Although many variables potentially influence point penetration depth (e.g., Loendorf et al. 2018), such as the weapon system, the strength or skill of the hunter, or the angle of penetration, we employ TCSA and TCSP as proxies of potential penetration depth for two reasons. First, in principle a decrease in TCSA and TCSP should result in an increase in projectile point penetration (see Grady 2017:11–17; Hughes 1998:353–56). Second, a predominance of archaeological experiments testing TCSA, TCSP, and penetration depth broadly conform to this theoretical prediction (Bebber et al. 2020; Chen 2020; Grady 2017; Howe 2017; Mika et al. 2020; Mullen et al. 2021; Salem and Churchill 2016; Sitton et al. 2020). Finally, TCSA and TCSP apply to all archaeological and ethnographic point types and thereby act as standardized proxies for penetration potential.

In this study we examine tip cross-sectional geometry and relative penetration of a sample of Paleoindian points from the northern portion of the North American Great Plains (including the eastern Rocky Mountains) to explore how this geometry, and hence how this function, may have evolved over the course of the Late Pleistocene and Early Holocene. We first briefly describe the Paleoindian point types examined in this study, focusing on their typical characteristics rather than the full range of variability associated with each type, and previous conclusions about their penetration ability.

PLAINS PALEOINDIAN POINT TYPES

The eight projectile point types considered for this study—Clovis, Folsom, Agate Basin, Plainview, Hell Gap, Alberta, Scottsbluff, and Eden—have different geographic ranges but are all found in the Great Plains and eastern Rocky Mountains. Folsom, Hell Gap, and Alberta are more geographically limited, whereas Clovis points can be found across the United States, Central America, and southern Canada (Eren and Buchanan 2016; Jennings and Smallwood 2019; Meltzer 2021). Plainview points are found across the Plains (Buchanan et al. 2017, 2020), Agate Basin points from the Midwest and eastern United States (Justice 1987), and Scottsbluff and Eden have been identified from the Great Lakes region to the Great Basin (Knell and Muñiz 2013a).

Although we present the oldest and youngest radiocarbon dates associated with each type, it is highly likely that these point types overlap in time to different degrees (e.g., Collard et al. 2010; Hofman 1995; Holliday 2000; Knell and Muñiz 2013a; Sellet 2001) and that more formal modeling of the age ranges for these types is required to better understand the temporal boundaries. It is also important to note that most Late Paleoindian types are poorly dated relative to Early Paleoindian Clovis and Folsom types.

Early Paleoindian

Clovis. Clovis points date to between 11,600 and 10,700 ^{14}C BP (Eren and Buchanan 2016; Prasciunas and Surovell 2015; Waters et al. 2020). They are generally wide and flat, fluted lanceolate points with a maximum width in the proximal half of the point. They often exhibit grinding on the proximal lateral edges, the function of which is currently unknown (Werner et al. 2019). Although there is considerable variation in flaking patterns, overface flake scars are common (Smallwood 2012). Clovis points exhibit flute scars, usually on both faces, which have been shown experimentally to dampen use-related damage (Story et al. 2019; Thomas et al. 2017). Clovis points have been found associated with several species of megafauna, including three species of Proboscideans as well as extinct bison, camel, and horse (DeAngelis and Lyman 2018; Grayson and Meltzer 2015; Sanchez et al. 2014; Waguespack and Surovell 2003). With respect to penetration, Huckell (1982) examined the effectiveness of thrusting spears in penetrating elephant hide and found that they penetrated from 7.5 to 27.4 cm in depth, with three of five thrusts penetrating more than 20 cm. In a similar type of experiment, Frison (1989) used an atlatl to launch replica Clovis points into the carcasses of recently killed African elephants. He reports that several of the shots reached into the body cavity and would have been lethal, but he provided no quantitative evidence to support this assertion. Finally, Eren et al. (2020) recently showed that Clovis point variants penetrated a clay target significantly differently, clay having previously been shown to be an ethical substitute for meat (Key et al. 2018). As a group, however, the projectiles in Eren et al.'s (2020) study ranged from 14 to 22 cm in mean penetration depth. We refer the reader to Eren et al. (2021) for a discussion of Clovis fluted point efficacy, which unfortunately was not available at the time of this manuscript's acceptance.

Folsom. Folsom points date from 10,700 to 10,300 ^{14}C BP (Buchanan et al. 2021; Surovell et al. 2016). Folsom points are small and flat, fluted lanceolate points, with a maximum width usually found in the distal half of the point. Their flatness primarily stems from the removal of two full-face flutes, a removal process that is intricate and risky (Patten 2005; Sellet 2013). The purpose of these full-face flute removals is currently unknown, but there are several untested hypotheses (Ahler and Geib 2000, but see MacDonald 2010; Meltzer 2006, 2021; Patten 2002; Thomas et al. 2017). Folsom points are found mostly associated with extinct bison (Amick 1994, 1995; Andrews et al. 2008; Carlson and Bement 2013; Hofman 1992, 2002). With respect to penetration, Hunzicker's (2008) experiments found that 74% ($n = 80$) of Folsom-tipped projectiles penetrated more than 40 cm into an animal carcass, which he deemed "lethal," whereas 26% did not ($n = 38$). However, Hunzicker (personal communication) notes that his study was "not really designed to yield accurate penetration data" because the "carcass" consisted only of the rib cage, beyond which was only air. Bradley (1991:374) states that "experimental uses of hafted Folsom point replicas have . . . not demonstrated a superiority over other thicker Paleoindian styles." We are unaware of the experiments to which Bradley is referring, but we agree with the implicit notion that more functional experiments and comparisons between point styles should be undertaken.

Late Paleoindian

Agate Basin. Agate Basin points date to between 10,500 and 10,000 ^{14}C BP (Holliday 2000). They are long, narrow, and longitudinally flat/thin with parallel to slightly convex margins that converge into bases that are flat to convex or concave (Bradley 1993, 2010; Frison 1991; Pitblado 2003). They are usually horizontally flaked and lenticular to flat in cross-section. Bradley (2010:483–84) and others contend that from a performance perspective these long points were designed to break into segments that knappers could subsequently modify into smaller and somewhat thicker versions of this point style. The refashioning of Agate Basin points was "a very effective way of making recyclable projectiles and possibly the most effective design of any of the specialist bison hunters in the Northwestern Plains and Rocky Mountains" (Bradley 2010:483). The broken segments potentially caused further internal damage, leading to a quicker demise of the animal. With respect to penetration, Frison (1991:243) considers Agate Basin points to "possibly be the most lethal of all Paleo-Indian weaponry" and his personal preference because "its thick, lenticular cross section provides structural strength and enough weight to ensure penetration" (Frison 2004:110).

Plainview. Plainview points, previously referred to as Goshen points, date to between 10,450 to 10,175 ^{14}C BP (Waters and Stafford 2014; see also Frison 1996; Haynes and Hill 2017). They are lanceolate in plan view and thin, with transverse or collateral pressure flaking (Waters and Stafford 2014:541). Plainview points are found at only a handful of sites in the northern Plains and central Rocky Mountains, and the points included in this manuscript represent a northern sample of this broader complex (Buchanan et al. 2020; Haynes and Hill 2017).

Hell Gap. Hell Gap points date to between 10,500 and 9500 ^{14}C BP (Holliday 2000). These points are similar to Agate Basin points but were completed earlier in the production process, and perhaps developed from them (Bradley 1993, 2010). They are medium to large stemmed points that have weakly developed shoulders, a long contracting or tapering stem, and straight to convex bases (Bradley 1993, 2010; Irwin 1968; Pitblado 2003). The blade is usually widest just above the stem, and often short relative to the blade's length due to resharpening. They are typically thinned by percussion and finished with pressure flaking. Frison's (1978, 1991) experiment with thrusting a hafted Hell Gap point into a cow led him to question this point type's popularity compared with Agate Basin points. He contends that Hell Gap points are prone to breaking because the shoulders take the brunt of impact rather than transferring the shock to the sturdier tapered base (Frison 2004:110). With respect to penetration, Frison also found that Hell Gap points open a larger hole upon impact than Agate Basin points but do not penetrate as deeply.

Alberta. Alberta points date to between 10,000 and 9400 ^{14}C BP (Knell and Muñiz 2013a). Huckell's (1978) analysis of the Alberta points from Hudson-Meng, Nebraska, remains the best technological description of this projectile point type. Alberta points are large stemmed points with abrupt, rounded shoulders, triangular blades, slightly blunted tips, and bases that range from straight to slightly concave (Bradley and Frison 1987; Frison 1991; Huckell 1978; Wormington 1957). The shoulders are pronounced relative to Hell Gap points. The blades of some Hudson-Meng specimens are "finished by well-controlled direct percussion, which produced very regular collateral flake scar patterns" that terminated at or near the median ridge (Huckell 1978:181). The Alberta point manufacturing process at Hudson-Meng is relatively unique, however, since most Alberta points lack this specialized finishing technique (Bradley and Stanford 1987:204). Frison (2004:110; also 1991) observes that the shock of impact is directed toward the shoulder and base of Alberta points. Otherwise, we know of no substantial performance-related comments or experimental studies for Alberta points.

Scottsbluff. Scottsbluff points date to between 9400 and 8000 ^{14}C BP (Knell and Muñiz 2013a). Scottsbluff I points (we do not consider the wider, more triangular Scottsbluff II points here; Wormington 1957:267) are square-base stemmed points with small but square shoulders and a long, narrow blade (Bradley and Stanford 1987:207; also see Fogle-Hatch 2015; Knell and Muñiz 2013b; Wormington 1957). The points are finished with parallel to sub-parallel pressure flakes that range from transverse (resulting in a biconvex cross-section) to comedial (resulting in a diamond cross-section). Scottsbluff points are generally wider, have more substantial shoulders, and are more triangular than Eden points. Here too we know of no substantial performance-related comments or experiments.

Eden. Eden points date to between 9400 and 8000 ^{14}C BP (Knell and Muñiz 2013a). Eden points are long and narrow stemmed points with slight shoulders; serial comedial flake scars that create a thick, diamond cross-section; short longitudinal flake scars that create a triangular pattern on the base; parallel-sided haft elements; and basal and lateral edge grinding (Bradley and Stanford 1987:207; also see Fogle-Hatch 2015; Knell and Muñiz 2013b; Wormington 1957). The serial comedial flake scars on Eden points are generally shallow and narrow. Frison (1978:337) attached an Eden point to a split foreshaft and "penetrated the rib cage of a mature female buffalo with relative ease." This experiment led Frison (1978:337) to conclude that Eden points are "the optimum design to date for killing bison using a thrusting spear," but he later moderated this sentiment by saying that Eden points were his "second choice of a projectile for its effectiveness on bison" (2004:111). No other performance review experiments are known.

MATERIALS AND METHODS

Following Hughes (1998), tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TCSP) are defined as

$$\text{TCSA} = \frac{1}{2}(\text{width})(\text{thickness})$$

and

$$\text{TCSP} = 2\sqrt{(\text{width})^2 + (\text{thickness})^2}$$

where width and thickness are measured at the widest location on the point blade ("tip" and "blade" are used interchangeably here and are differentiated from the base).

Experiments carried out by Sitton et al. (2020) showed that—at velocities reasonable for atlatl-thrown stone-tipped projectiles—a stone point's cross-sectional perimeter is a good indicator of whether a point would have penetrated a prey's body cavity and injured a vital organ. In particular, Sitton et al.'s (2020) results identify TCSP as a better predictor of penetration depth than TCSA. Yet they show that stone points with smaller values of TCSA or TCSP have greater penetration depths than stone points with larger values of TCSA or TCSP. This finding supports analytical work that shows penetration depth is inversely proportional to tip cross-sectional geometry (Ashby 2005; Hughes 1998; Kneubuehl 2011; Sperrazza and Kokinakis 1968).

Datasets

We compiled width and thickness measurements from 343 Paleoindian projectile points from sites in the northern portion of North America (Table 1). The Clovis points ($n = 46$) come from seven sites, four of which are cache locales (Buchanan et al. 2012; Kilby 2008) and comprise the majority of the points in the sample ($n = 40$). The remaining six Clovis points are from three kill/butchering sites. The Clovis sites range from Idaho (Simon and Fenn) and Montana (Anzick), across Wyoming (Colby) and Colorado (Dent and Drake), to South Dakota (Lange-Ferguson). The Folsom sample of 50 points derives from bison kill/butchery and campsites located primarily in Colorado (Lindenmeier, Linger, Mountaineer, and Barger Gulch) and Wyoming (Agate Basin, Hanson, and Hell Gap), with two samples from North Dakota (Big Black and Bobtail Wolf). The largest sample of Folsom points comes from the Lindenmeier site ($n = 34$). Most of the 52 Agate Basin points are from bison kill/butchery sites, primarily the Agate Basin site in Wyoming ($n = 33$; also the Frazier site in Colorado [$n = 6$]), and various campsite localities at Hell Gap, Wyoming ($n = 13$). The 18 Plainview points are from two sites, Mill Iron ($n = 14$) and Jim Pitts ($n = 4$) located in Montana and South Dakota, respectively. The 48 Hell Gap points are also primarily from bison kill/butchery sites, mostly the Casper site in Wyoming ($n = 41$) but also the Agate Basin ($n = 5$)

Table 1. Number of points by type and number of sites represented

Type	*N* of points	*N* of sites
Agate Basin	52	3
Alberta	18	7
Clovis	46	7
Eden	70	15
Folsom	50	9
Hell Gap	48	3
Plainview	18	2
Scottsbluff	41	12

and Hell Gap (*n* = 2) sites. The 18 Alberta points come from seven sites, primarily bison kill and butchery locales. The largest concentration of Alberta points is from the Hudson-Meng site in Nebraska (*n* = 9), with a smaller number from Canada (Fletcher, Niska, Peace River region), North Dakota (Benz), and Wyoming (Blue Point and Hell Gap). The 41 Scottsbluff points come primarily from bison kill and butchery locales that, geographically, extend from Canada (Fletcher in Alberta and Niska in Saskatchewan) south to New Mexico (Blackwater Draw) and from the Rocky Mountain states of Colorado (Claypool), Montana (MacHaffie), and Wyoming (e.g., Blue Point, Finley, Horner and Osprey Beach) east to the high plains of Nebraska (Scottsbluff and the eastern Sandhills). Horner I and Finley have the highest concentrations of Scottsbluff points (*n* = 12 and 9, respectively). Eden points are present in highest frequency among the various point types (*n* = 70) and are likewise represented primarily by kill and butchery locales, but also campsites (e.g., Hell Gap V and Osprey Beach) and a workshop (Mammoth Meadows). The distribution of Eden points is similar to that of Scottsbluff points, with sites in Canada (DjNf-8), the Rocky Mountain states of Colorado (e.g., Claypool, Frasca, Lamb Spring), Montana (Mammoth Meadows), and Wyoming (e.g., Finley, Horner, Hell Gap, and Osprey Beach), and east to the Sandhills of Nebraska. The highest concentrations of Eden points are from the Claypool (*n* = 26) and Horner I (*n* = 12) sites.

Statistics

The sample datasets of TCSA and TCSP values for the eight point types mostly conform to an underlying normal distribution, with Scottsbluff and Clovis samples being slightly skewed. We carried out a series of parametric multi-sample comparative statistical analyses to investigate differences in TCSA and TCSP measures among the eight types. Although we do not necessarily expect statistical differences in average TCSA and TCSP values (differences could be important and yet statistically indistinguishable), we used ANOVA and pairwise *t*-tests to investigate differences in the average values. Prior to the ANOVA tests we log-transformed both TCSA and TCSP to normalize the sample distributions. We conducted ANOVA and Bonferroni corrected pairwise *t*-tests in R version 4.0.3 (note that equivalent nonparametric tests yield qualitatively similar results as reported below). The data and R script for these analyses are available by contacting the authors.

RESULTS

Tip cross-sectional area varies considerably among the eight Paleoindian projectile point types in our study (Figure 2). Alberta and Clovis points have the highest mean values of TCSA and the most variation, followed by Hell Gap, Agate Basin, Scottsbluff, and Eden (Table 2). Folsom and Plainview points have the lowest TCSA average values and variation. TCSP also varies among the point types (Figure 3), with Clovis and Alberta having the highest mean values of TCSP and the most variation, followed by Hell Gap, Scottsbluff, Agate Basin, Plainview, Folsom, and Eden (Table 3).

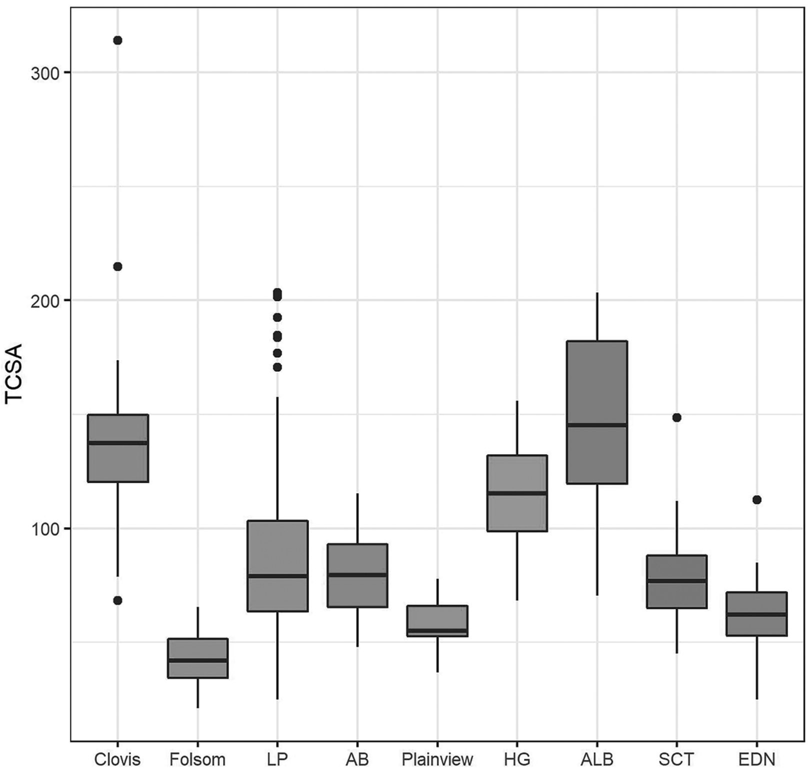

Figure 2. Boxplot of TCSA values for Plains Paleoindian projectile point types (LP=Late Paleoindian; AB=Agate Basin; HG=Hell Gap; ALB=Alberta; SCT=Scottsbluff; EDN=Eden).

Table 2. Summary statistics for TCSA values for Plains Paleoindian points by type

Type	*n*	Mean	SD	min	Q1	median	Q3	max
Agate Basin	52	79.57	17.91	47.84	65.48	79.42	93.02	115.43
Alberta	18	145.73	41.35	70.50	119.66	145.34	182.09	203.50
Clovis	46	137.79	38.39	68.41	120.45	137.50	149.77	314.05
Eden	70	62.33	14.09	25.00	52.88	62.13	72.00	112.50
Folsom	50	42.56	12.59	21.13	34.45	41.96	51.50	65.60
Hell Gap	48	114.40	22.10	68.25	98.64	115.43	132.00	156.00
Plainview	18	57.48	9.57	36.80	52.85	55.13	64.94	77.81
Scottsbluff	41	78.32	19.29	45.00	65.00	77.00	88.00	148.50

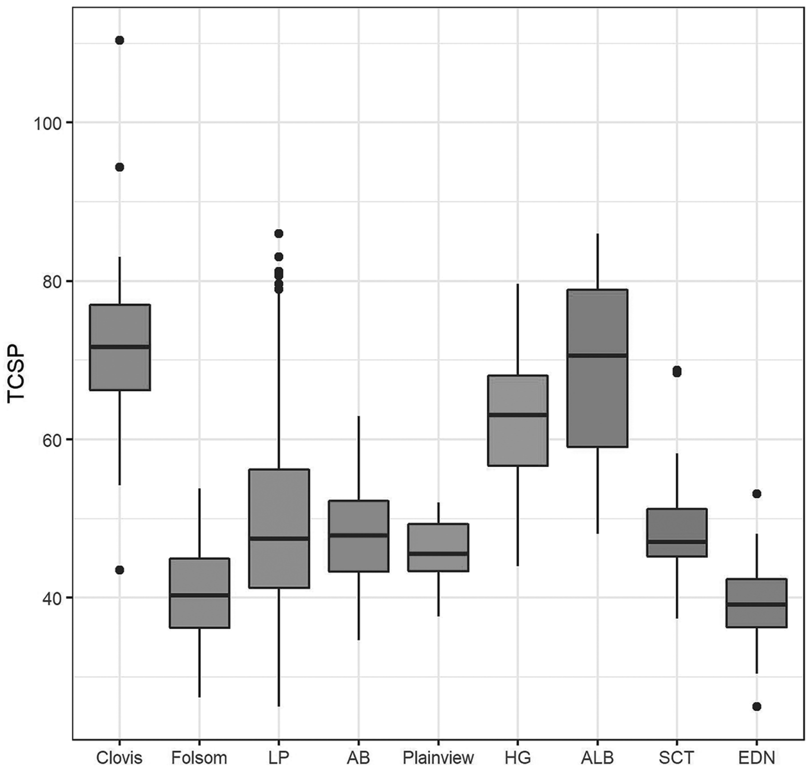

Figure 3. Boxplot of TCSP values for Plains Paleoindian projectile point types (LP=Late Paleoindian; AB=Agate Basin; HG=Hell Gap; ALB=Alberta; SCT=Scottsbluff; EDN=Eden).

Table 3. Summary statistics for TCSP values for Plains Paleoindian points by type

Type	*n*	Mean	SD	min	Q1	median	Q3	max
Agate Basin	52	47.53	6.23	34.62	43.27	47.84	52.23	62.92
Alberta	18	68.67	12.09	48.08	59.08	70.60	78.88	86.01
Clovis	46	71.71	10.47	43.51	66.19	71.68	76.99	110.40
Eden	70	39.29	4.68	26.25	36.30	39.15	42.32	53.14
Folsom	50	40.25	6.46	27.42	36.19	40.31	44.96	53.82
Hell Gap	48	62.81	8.27	43.97	56.67	63.05	68.06	79.62
Plainview	18	46.31	3.97	37.66	43.42	45.56	49.28	52.05
Scottsbluff	41	48.59	6.46	37.36	45.22	47.07	51.23	68.73

In Figures 2 and 3, the combined Late Paleoindian category includes Agate Basin, Plainview, Hell Gap, Alberta, Scottsbluff, and Eden, to provide a visual comparison of the poorly dated Late Paleoindian types to the relatively better dated Early Paleoindian Clovis and Folsom types.

The ANOVA comparing mean TCSA by point type shows an overall significant difference between types ($F = 121.9$, $df = 7$, $p < 0.0000$) as does the ANOVA comparing mean TSCP by point type ($F = 124.8$, $df = 7$, $p < 0.0000$). Subsequent multiple pairwise comparison *t*-tests using the Bonferroni correction show that most comparisons are significantly different, only Clovis and Alberta, Alberta and Hell Gap, Scottsbluff and Agate Basin, and Plainview and Eden have statistically similar TCSA values (Table 4). For TCSP values the comparisons show that only Clovis and Alberta, Alberta and Hell Gap, Scottsbluff and Agate Basin, Plainview and Agate Basin, and Plainview and Scottsbluff are statistically similar (Table 4). The comparison of TCSP values shows Folsom and Eden as well as Plainview and Agate Basin (and Scottsbluff) points to be statistically similar, yet the comparison of TCSA values indicates Folsom has a significantly smaller average TCSA than Eden and Plainview has a significantly smaller average TCSA than Agate Basin and Scottsbluff. Therefore, the ranking of TCSA values of Paleoindian point types from least to greatest, and thus penetration capability from best to worst, is (1) Folsom, (2) Plainview and Eden (these are statistically similar), (3) Scottsbluff and Agate Basin, (4) Hell Gap and Alberta, and (5) Clovis (although Alberta and Clovis are not different), whereas for TCSP values the ranking is (1) Folsom and Eden, (2) Plainview, Agate Basin, and Scottsbluff, (3) Hell Gap and Alberta, (4) and Clovis (again, Alberta and Clovis are not different). Based on recent experimental results, Sitton et al. (2020) suggest that TCSP is the better predictor of the two measures and thus we can similarly suggest that the TCSP ranking is currently the best supported ranking of penetration depth capability.

Table 4. Significance (*p*) for pairwise Bonferroni corrected *t*-tests of TCSA values (below the diagonal in the matrix) and TCSP values (above the diagonal in the matrix). Nonsignificant *p*-values are bold and italicized.

	Agate Basin	Alberta	Clovis	Eden	Folsom	Hell Gap	Plainview	Scottsbluff
Agate Basin	–	0.0000	0.0000	0.0000	0.0000	0.0000	***1***	***1***
Alberta	0.0000	–	***1***	0.0000	0.0000	***0.9174***	0.0000	0.0000
Clovis	0.0000	***1***	–	0.0000	0.0000	0.0002	0.0000	0.0000
Eden	0.0000	0.0000	0.0000	–	***1***	0.0000	0.0002	0.0000
Folsom	0.0000	0.0000	0.0000	0.0000	–	0.0000	0.0029	0.0000
Hell Gap	0.0000	***0.0487***	0.0258	0.0000	0.0000	–	0.0000	0.0000
Plainview	0.0002	0.0000	0.0000	***1***	0.0000	0.0000	–	***1***
Scottsbluff	***1***	0.0000	0.0000	0.0001	0.0000	0.0000	0.0010	–

DISCUSSION

An archaeological experiment either supports a functional hypothesis for an artifact type or trait, thereby allowing an appeal to selection, or it falsifies a functional hypothesis, thereby permitting an investigator to advance a different functional hypothesis or a nonfunctional transmission bias or drift as the predominant explanation. In recent years, numerous experiments have shown that decreasing projectile point TCSA and TCSP increases target penetration (Bebber et al. 2020; Chen 2020; Grady 2017; Howe 2017; Mika et al. 2020; Mullen et al. 2021; Salem and Churchill 2016; Sitton et al. 2020), suggesting that when TCSA or TCSP differences are documented in the archaeological record, selection for or against penetration may be considered.

Here, we assessed the TCSA and TCSP of several different Late Pleistocene and Early Holocene Paleoindian projectile point types from the northern portion of the North American Great Plains. Statistical differences among the point types suggest that different point designs allowed for increased penetration, whereas other designs did not (e.g., Newman and Moore 2013; Vierra and Heilen 2020). The discussion that follows speculates on these results, but three caveats must be kept in mind. First, we are hampered by our lack of understanding regarding which weapon system(s) was used with each point type: a hand-held spear, atlatl and dart, or, though unlikely, bow and arrow. Thus, when discussing differences in Paleoindian point penetration depth, we assume that everything else regarding the weapon system is equal. Second, the lack of robust chronometric control with respect to the Late Paleoindian point types does not permit a chronology more detailed than Clovis–Folsom–Late Paleoindian. As such, any discussion of Late Paleoindian points "emerging" from Folsom should be taken as conjecture at this time since we do not currently understand the exact relationship between Folsom and Late Paleoindian points. Third, there are several performance criteria against which points should eventually be assessed beyond penetration potential, such as aerodynamics, sharpness, wound size inflicted, durability, and perhaps multifunctionality (Buchanan and Hamilton 2020; Eren et al. 2020; Maguire et al. 2021). We mention these criteria below, but our present discussion focuses on the evolution of Paleoindian points predominately in terms of target penetration. We fully acknowledge that our interpretations of Paleoindian point evolution may change as more experiments are conducted and more experimental results are integrated into archaeological artifact interpretations.

Overall, our results suggest no single, long-term directional trend in performance as it relates to point penetration.[3] Clovis points, the earliest artifact type examined, exhibit high TCSA and TCSP values relative to most other Paleoindian point types. If Clovis foragers were in the process of colonizing and settling a largely unfamiliar landscape (Meltzer 2021), then a tool that was designed to be larger, more robust, and multifunctional may have outweighed the benefits of a smaller, more lethal tool that came with unavoidable costs of fragility. Buchanan et al. (2018) showed that Clovis points were more variable in shape than Folsom points after adjusting for size differences, suggesting that there may have been several classes of Clovis points that were intended for different functions such as cutting and sawing, a conclusion supported by microwear analysis (e.g., Bebber et al. 2017b; Eren et al. 2018a; Miller 2013, 2014; Smallwood 2015). Therefore, the size, durability, and manner of hafting of Clovis points (or at least of some subsets of Clovis points) may have permitted them to be employed as multifunctional tools and used for a wider range of tasks.

Folsom points, however, may have been designed only for hunting. Folsom foragers, more familiar with the landscape a millennium after Clovis, could perhaps more easily find resources to replace broken or worn-out tools (Buchanan et al. 2019). They could thus afford to select for increased tool specialization and lethality, as evidenced by the smallest TCSA and TCSP values of any Paleoindian point type in our analysis. These small TCSA and TCSP values are likely due to Folsom's full-face fluting, which is an important design difference between Clovis and Folsom points. Clovis points usually have flutes that extend about one third the length of the point from the base toward the tip, whereas Folsom points tend to have full-face fluting, with flutes extending the entire length of the point (Figure 4). Several hypotheses have been proposed to

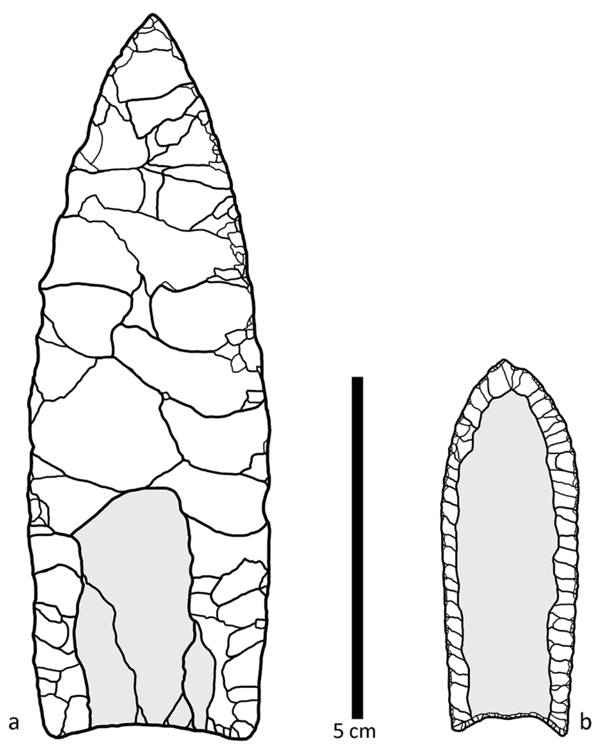

Figure 4. Schematic comparative illustration of Clovis (a) and Folsom (b) points.

explain why Folsom knappers would pursue the time-consuming and risky technique of full-faced fluting, including hafting, symbolism, or hunting advantages (Ahler and Geib 2000; Bradley 1991, 1993; MacDonald 2010; Meltzer 2021; Patten 2002, 2005; Thomas et al. 2017). Yet, one universally agreed upon attribute that full-faced fluting confers upon a stone point is significant thinness. Given the increased potential penetration ability of Folsom points relative to Clovis points, we wonder, following Hunzicker (2005), whether the reduction of tip cross-sectional attributes had been a motivating factor for the use of full-faced fluting.

In this scenario, Clovis fluting initially emerged as a risk-mitigating device that, along with the artifact size, increased the resilience of the stone points used by colonizing foragers (Story et al. 2019; Thomas et al. 2017). However, as post-Clovis Folsom foragers became more familiar with the regional landscape and its stone resources for resupply (Andrews et al. 2015; Buchanan et al. 2019; Jennings 2016; Jennings et al. 2010), they could afford to design points with the exclusive goal of maximizing killing potential as opposed to balancing lethality with durability (Thomas et al. 2017:28–29; see also Frison 2004). Thus, the short Clovis fluting could have been co-opted by Folsom knappers for a different purpose than originally intended, which resulted in the evolution of fluting ontogenetically and morphologically (Lycett and von Cramon-Taubadel 2015).

The TCSA and TCSP values of Late Paleoindian points suggest a radiation of penetration capabilities. Some point types, such as Alberta, may have functioned more often as knives, whereas others, such as Plainview, Eden, Scottsbluff, and Agate Basin, seemingly continued to function as effective penetrating projectiles (Frison 2004). Nevertheless, based on TCSA and TCSP values, Late Paleoindian point penetration was overall still not as effective as Folsom point penetration, perhaps indicating that ease of point manufacturing techniques and reduction sequences was more important to knappers than point lethality. Nearly all modern knappers agree that Folsom full-faced fluting is exceptionally difficult to master. If Paleoindian knappers experienced this difficulty as well—and the high number of archaeological fluting failures suggests this is a reasonable assumption (Lassen 2013)—then as demographic and cultural regionalization occurred from Folsom to Late Paleoindian times, perhaps a technique as complex as Folsom fluting would have ultimately been selected against. Even though North American populations were likely increasing overall during the Late Pleistocene and Early Holocene, Late Paleoindian regionalization may have led to a smaller *effective* population size, which would have resulted in the loss of complex cultural traits such as fluting (e.g., Henrich 2004; Lycett and Norton 2010).

The question for the Late Paleoindian knapper, then, became how to avoid Folsom fluting but still minimize TCSA and TCSP as much as possible. Given that Folsom, Plainview, Scottsbluff, Eden, and Agate Basin all exhibit parallel pressure flaking, we can imagine one possible scenario in which a cultural "mutation" eliminates fluting (e.g., Norris et al. 2019) from the medial portion of the point's distal-proximal axis. Once the flute (perhaps analogical to an "organ"; Norris et al. 2019) is eliminated, the two parallel-pressure-flaked lateral edges are directly combined (Figure 5). In other words, when the fluted portion is removed from a Folsom point (i.e., the cultural mutation), what is left over morphologically and technologically is a Late Paleoindian point. The slight decrease in penetration lethality (due to a slight increase in TCSA/TCSP) is counterbalanced by a decrease of required skill and manufacturing risk.

Casting aside our three caveats requisite to the above discussion, we must acknowledge that in all likelihood at least some Paleoindian points were multifunctional implements. Thus, point design may be influenced by the desire to use a single tool for multiple functions. Microwear analyses of Clovis points certainly support this hypothesis (e.g., Bebber et al. 2017b; Eren et al. 2018a; Kay 1996; Miller 2013, 2014; Miller et al. 2019; Perrone et al. 2020; Smallwood 2015; Werner et al. 2017), but more microwear analyses are needed for the later Paleoindian point types (e.g., Boulanger et al. 2021; Smallwood et al. 2020). Alternatively, potential for differential or "down-the-line" use may be influencing the design of point types. Rather than designing a tool that performs several functions simultaneously since an artifact's morphometric properties change over the course of its use-life, its primary function may serially change, perhaps starting off primarily as a knife and then ending up as a projectile (Frison 1968; Kuhn 2020).

As noted by Cheshier and Kelly (2006:362; see also Vierra and Heilen 2020), and demonstrated for Paleoindian point forms by Eren et al. (2021) and Buchanan and Hamilton (2020), "artifact design is a balance between several often conflicting desires." For example, Eren et al. (2021) experimentally show that different Clovis point forms can excel in penetration, or excel in durability, or achieve mediocrity in both factors. A Clovis point morphology cannot excel in both penetration and durability simultaneously. This finding suggests that the selection of one functional factor may automatically, though coincidentally, influence the performance of another functional factor (Eren et al. 2021). It is important to emphasize, however, that this coincidental influence need not be conflicting in all cases. Two distinct functional tasks may benefit from a particular morphology, when in reality only one of those tasks was the motivating factor for selection. As such, point penetration potential may not have been *the*, or even *a*, motivating factor in the design of Paleoindian points. It is one thing to demonstrate an artifact morphology excels or flounders at a functional task; it is another thing entirely to robustly infer that an artifact morphology was selected for increased effectiveness at that task.

The difficulty in robustly inferring the functional factor(s) that govern(s) artifact design increases when archaeologists consider non-use factors. Consider, for instance, artifact production (Lycett and von Cramon-Taubadel 2015). A transition from making points on stone nodules to making points on stone flakes may increase production economy and transport efficiency (e.g., Eren and Andrews 2013; Kuhn 1994). The production of points on flakes will likely result in smaller points on the population level, relative to a point population previously made on nodules (Eren et al. 2018b). These smaller points made from flakes will better penetrate a target given their smaller

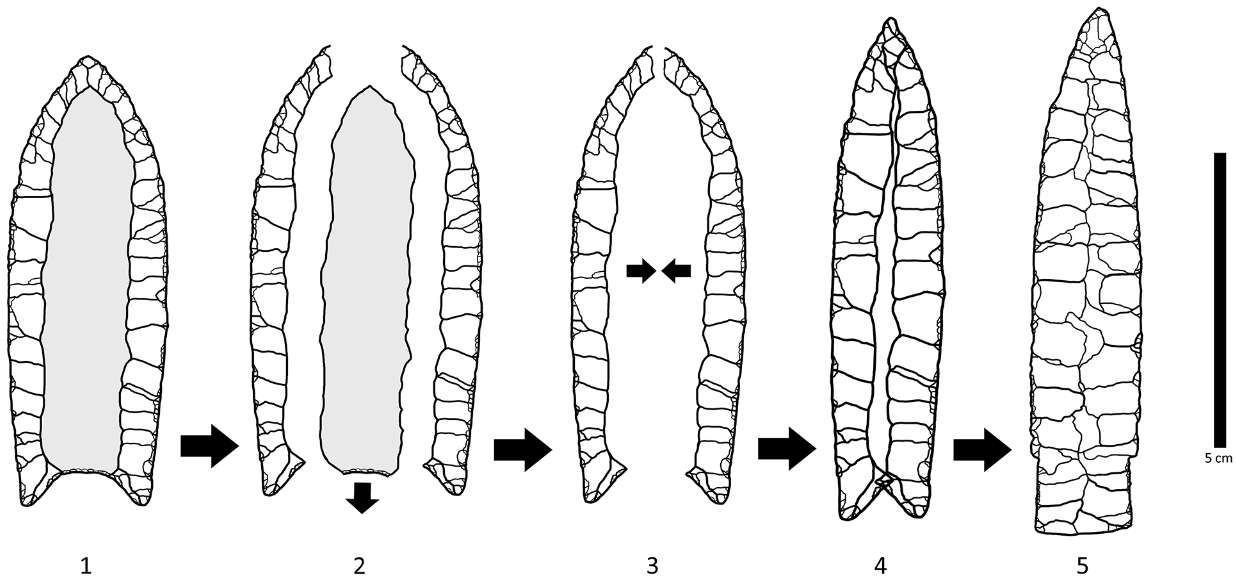

Figure 5. A hypothetical evolution of Folsom into a Late Paleoindian style point, such as an Eden. See text for full description.

TCSA/TCSP. Yet, in this scenario it is entirely possible that either (1) production economy and transport efficiency were the targets of selection and increased penetration potential was coincidental or (2) production economy and transport efficiency *and* penetration potential were targets of selection, together acting as coinciding optima in the adaptive design of the point (Brantingham and Kuhn 2001; Lycett and Eren 2013).

That seemingly beneficial artifact designs can arise through drift can further complicate archaeologists' interpretations, as can designs that appear to be nonfunctional but in fact possess functional benefits that are simply unknown or "hidden" to the archaeologist. The notion that unknown or hidden functional benefits may exist is supported by the recent work of Harris et al. (2021), who show that ethnographic foragers who regularly make and use a technology consistently expressed beliefs about design that diverge from what is known about function. Harris et al. (2021) interviewed Hadza bowyers and demonstrated that these bow makers understand some mechanical trade-offs, but not others. Thus, technological designs suggested to be functional (or nonfunctional) by the makers themselves, much less archaeologists, may not be correctly understood unless a thorough experimental and engineering approach to that technology is adopted (Stiles 1979; Wiessner 1983).

Ultimately, demonstrating that functional factors contributed to the evolution of artifact design requires a dual understanding of both artifact function and artifact context, *plus* a direct link between that function and context (Eren 2012; Meltzer 1991). Experimental archaeology can go a long way to advance our understanding of artifact function, and when the results of experiments are subsequently integrated with archaeological and paleoenvironmental data, archaeologists will be in a stronger position to make evolutionary inferences at different analytical scales. Indeed, given experimental archaeology's robustly documented relationship between TCSA/TCSP and penetration, continued assessment of TCSA/TCSP will be highly productive for studies at different analytical scales (e.g., Lombard 2020; Newman and Moore 2013; Vierra and Heilen 2020; Wood and Fitzhugh 2018). Further application of TCSA/TCSP to ethnographic projectile points beyond what has already been accomplished is likely to be highly informative (e.g., Shea 2006). For example, Wiessner's (1983) analysis of !Kung, !Xo, and G/wi projectile points established their importance in possessing and conveying nonfunctional group identity information. Calculating the mean TCSA/TCSP of each point, however, suggests that—all else being equal—these points might perform significantly differently in terms of their penetration potential (Figure 6). The !Kung, !Xo, and G/wi makers of these points may not have been consciously aware of these possible performance differences (Sackett 1985; Wiessner 1985), but Wiessner (1983: 270) suspected they could exist. A future experiment could systematically test this hypothesis, further illustrating how controlled experiments can shed light on interpretations of the ethnographic record (Eren et al. 2019; Harris et al. 2021; Pontzer et al. 2017).

Returning to the opening quote by Frison (2004), in terms of lethal penetration potential, one of his hunches was correct: Eden likely possesses excellent penetration

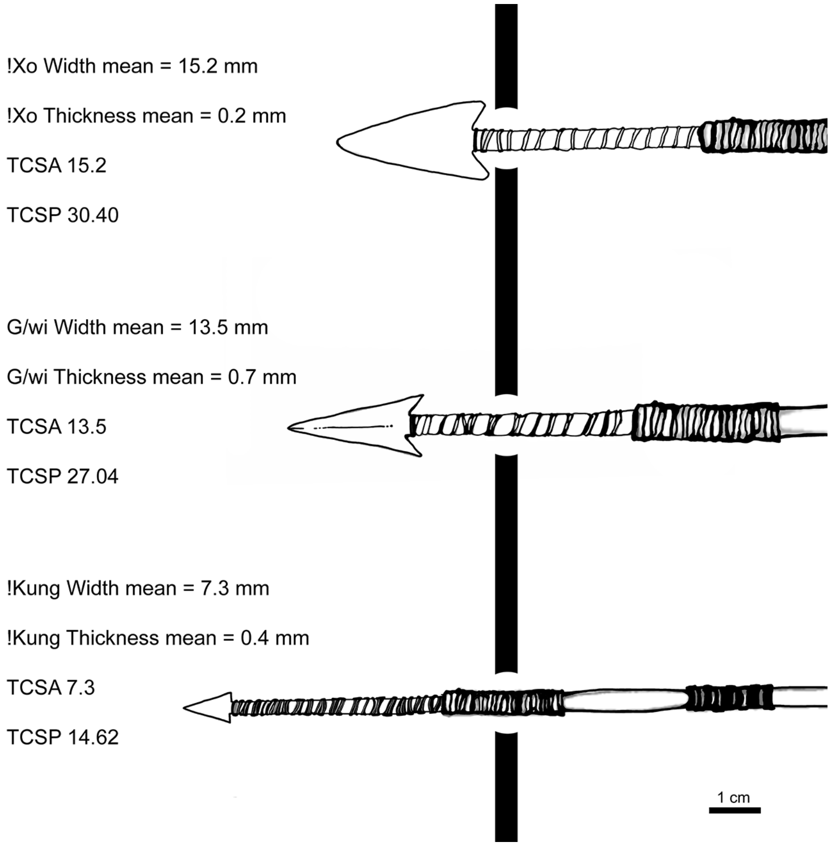

Figure 6. Based on data from Wiessner (1983), ethnographic projectile points might function differently given their distinct TCSA/TCSP values (!Kung: width mean = 7.3 mm, thickness mean = 0.4 mm, TCSA = 7.3 mm^2, TCSP = 14.62 mm; !Xo: width mean = 15.2 mm, thickness mean = 0.2 mm, TCSA = 15.2 mm^2, TCSP = 30.40 mm; G/wi: width mean = 13.5 mm, thickness mean = 0.7 mm, TCSA = 13.5 mm^2, TCSP = 27.04 mm). Future experiments can assess this hypothesis.

ability. However, when we consider the lethality of points in terms of theoretical ballistics and experimental findings, his intuitive preference for Agate Basin does not square with the evidence. Overall, our results emphasize the importance of interpreting artifact production and function in terms of quantitative, experimental findings, rather than relying on intuition (see Surovell 2009:xiv). In this regard, we see several avenues of future experimental research with respect to the study of TCSA, TCSP, and projectile point penetration that will help further explain Paleoindian technological evolution. For example, researchers note that TCSP appears to exhibit a stronger relationship with penetration depth than does TCSA (e.g., Sitton et al. 2020). Why? And does TCSP always exhibit a stronger relationship with penetration than TCSA?

One situation in which this may not be the case is Folsom points, which are concave on both faces. The Folsom point can theoretically have a TCSP value equal to that of a point with two convex faces, even though its TCSA value is substantially smaller. Another question involves where maximum TCSA/TCSP values occur along a projectile point's length, and either a distally loaded TCSA/TCSP maximum value penetrates a target better or worse than a proximally loaded TCSA/TCSP maximum value. Finally, experiments assessing the interactions of varying projectile point TCSA/TCSP values with varying kinetic energies and momentum values are needed to better understand each of these variable's relative contributions to penetration depth.

NOTES

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1. It is important to emphasize that the selection of functional traits over time and space is still a cultural process. Archaeologists will at times talk about artifacts or artifact traits in terms of function *versus* culture (e.g., Dayet et al. 2019; Hodder 1982; Thomas 2002), but this dichotomy is unhelpful in an evolutionary archaeology. Following Mesoudi (2011), who defines culture as socially transmitted information, an artifact's functional properties, transmitted between individuals or populations, are still cultural.

2. We agree with Frison (1991:290), however, who states that "ethnographic analogy is in some ways another form of experimental archaeology."

3. Seeman et al. (2020) recently wrote "A lack of correlation between lithic supply size/shape and known climatic changes in the eastern Midwest makes it difficult to explain the inferred changes in mobility due entirely to externally driven environmental forces. Instead, a social perspective that situates much of the changes we document in the constitution and reconstitution of alliance networks, individual agency, and other historical considerations may be more appropriate (Sassaman and Randall 2012:22–26). Our findings add to a growing body of data that show that hunter-gatherers in eastern North America over the long haul were involved in events and processes that speak of a more contingent, nuanced sequence than gradualist, neoevolutionary theory allows." It is important to note that in contrast to the 1950s era neoevolutionary approach Seeman et al. (2020) are criticizing, *current* cultural evolutionary theory (e.g. Lycett 2015; Lycett and von Cramon-Taubadel 2015; Mesoudi 2011, 2017) (1) does not predict unilineal patterns; (2) is not based entirely on environmental forces; (3) is not always gradualist; (4) and routinely incorporates social factors, individual agency, and historical factors.

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