PROJECTILE POINT SHAPE AND DURABILITY: THE EFFECT OF THICKNESS:LENGTH

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We describe an experiment that tests the hypothesis that projectile points with high thickness:length ratios are more durable than points with low thickness:length ratios. Fifty obsidian projectile points were manufactured to specific lengths, widths, and thicknesses. These were then fired into a deer carcass with a bow repeatedly until each point broke. None of the points were resharpened. The hardness of the material struck was a significant predictor of a point's durability. Controlling for this variable, however, we found that points with a high thickness:length ratio (> .121) were slightly albeit significantly more durable than those with a low ratio. No other attribute of size or shape was a significant predictor of durability.

Describimos un experimento diseñado para probar la hipótesis que las puntas de proyectil con cocientes altos espesor:largo son más durables que las puntas con cocientes bajos espesor:largo. Cincuenta puntas de proyectil de obsidiana fueron fabricadas con longitudes, anchos y espesores específicos. Estas fueron luego disparadas reiteradamente contra una carcasa de ciervo con un arco, hasta que cada una de las puntas se fracturó. Ninguna de estas puntas fue reafilada. La dureza del material impactado fue un indicador significativo de la durabilidad de una punta. Controlando esta variable, sin embargo, encontramos que las puntas con un cociente alto de espesor:largo (>.121) eran leve, aunque no significativamente más durables que aquellas con un cociente bajo. Ningún otro atributo de tamaño o de forma fue un indicador significativo de la durabilidad de las puntas.

Archaeologists are fascinated by projectile point shapes in large measure because of their proven utility in constructing cultural chronologies. As a result, they devote much time to constructing and revising projectile point typologies. In this task, it is not necessary to explain projectile point shape; projectile points of different shapes are different styles, different ways to accomplish the same task of killing game. But archaeologists are also concerned with the functionality of projectile points. Anyone who has turned a long, thin Eden point over in his or her hand cannot doubt that the point could penetrate even the toughest hide. But an innate sense of physics would leave that person wondering how an artisan could have worked so hard to produce an object of such beauty knowing that it would probably break on its first use.

Tools were constructed with multiple design characteristics in mind (Nelson 1991). For projectile points these include accuracy, range, killing power, and durability (Christenson 1986). These different goals can conflict with one another, and ancient hunters had to balance them. Accuracy and range are perhaps best maximized through elements of the shaft, foreshaft, and fletching. But the stone tip must not detract from the capacity of a projectile's shaft, and should preferably enhance it. Thus, the optimal size of a projectile tip depends on the size of the shaft and the presence or absence of fletching (Christenson 1986). A point's killing power comes from its ability to penetrate hide and to create a deep and lasting wound. Increasing a projectile's mass enhances its penetration, but too heavy a point reduces the projectile's velocity and its ability to penetrate. Thin, narrow points have greater penetrating power, but wide, thick points create a larger wound that bleeds more easily. For a skilled craftsmen, more effort goes into a projectile's shaft, foreshaft, and fletching than into the stone point. (Indeed, the experimental points in this study were made on average in 20 minutes.) How-

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ever, the cost of a point also includes the effort to locate, quarry, and transport the stone. Thus, durability should be a desirable attribute of a projectile point.

Stone points of any size or shape tend to break so easily that durability beyond a few uses was probably not an achievable goal. Thus, durability may have been sacrificed to meet the other needs of accuracy, range, and killing power (Christenson 1986). The question arises as to how we would know if durability was a significant concern in the design process. If an experimental program could demonstrate which attributes of a point were most closely linked to a point's durability, then we would have an empirical basis on which to argue whether a particular projectile point type was designed with durability in mind. In this paper we describe the results of such an experimental program.

Experimental archaeology, especially in regards to projectile technology, has a long history; in fact, the beginnings of experimental archaeology are often traced back to the work of Saxton Pope, who learned much about aboriginal bow and arrow technology from Ishi (Pope 1923). Others have since experimented with various facets of projectile technology (e.g., Browne 1940; Butler 1975; Christenson 1986; Flenniken and Raymond 1986; Higgins 1933; Knecht 1997; Mau 1963), including projectile point breakage (Bergman and Newcomer 1983; Fischer 1985; Flenniken and Raymond 1986; Frison 1978, 1989; Towner and Warburton 1990). However, few studies report data pertaining to durability (but see Odell and Cowan 1986; Titmus and Woods 1986). To our knowledge, this is the first experiment that focuses specifically on that projectile point characteristic.

We describe our experiment and results, comparing them to other experiments in projectile point breakage. Note that our work concerns arrow points, not dart points. Although we suspect that our conclusions are relevant to the latter, they would require substantiation through further experiments.

The current study grew out of a pilot project that was intended to test the hypothesis that short points are more durable than long points. Conducted as an undergraduate research project, the pilot study consisted of a sample of 20 obsidian points, and was conducted in a manner similar to that described below. This project was hampered by some errors, e.g., the arrow spines were not well-matched to the bow's pull, but it still supported the proposition that short points were more durable than long points. However, this experiment also suggested that a point's thickness:length ratio, rather than size, was a more critical variable in determining projectile point durability. Thus, we undertook a second study to test the hypothesis that points with a high thickness:length ratio would be more durable, as measured by the number of times they could be used before they broke, than points with a low thickness:length ratio. It is this second experiment that we report on here.

Methodology

An experienced flintknapper, Allen Denoyer, crafted the bifacial projectile points used in the experiment. The points were made of high-quality obsidian, free of the fractures and flaws that could weaken a tool and promote breakage. The reduction process included the use of hammerstones, antler billets, antler tines for pressure flaking, and thinned antler shafts for notching. The points were generic, triangular, side-notched points, biconvex along both axes. These points were not intended to replicate anything in particular from the archaeological record. We thought a more generic style would allow us to focus on the basic metric properties and their relationship to projectile point performance characteristics. However, it is possible that points of other forms, e.g., lanceolate, or points with deeper side notches than used here, might behave differently than those used in this experiment.

We asked Denoyer to manufacture 10 "short and thick" points, 10 "short and thin" points, 10 "long and thin" points, and 10 "long and thick" points (Figure 1); as it happened, he made 20 "long and thin" points, for a total of 50 points. We asked Denoyer to be as consistent as possible in regards to length, width, and thickness within each of these groups. Short points were about 2.5 cm long, and long points about 5 cm long. The goal was to represent a range of thickness:length ratios, but to provide some control of the variables of length and width. After manufacture, the points were photographed and measured, generally following Thomas (1981) but including some other variables. Table 1 shows coefficients of variation for each attribute within the five size groups. Note that

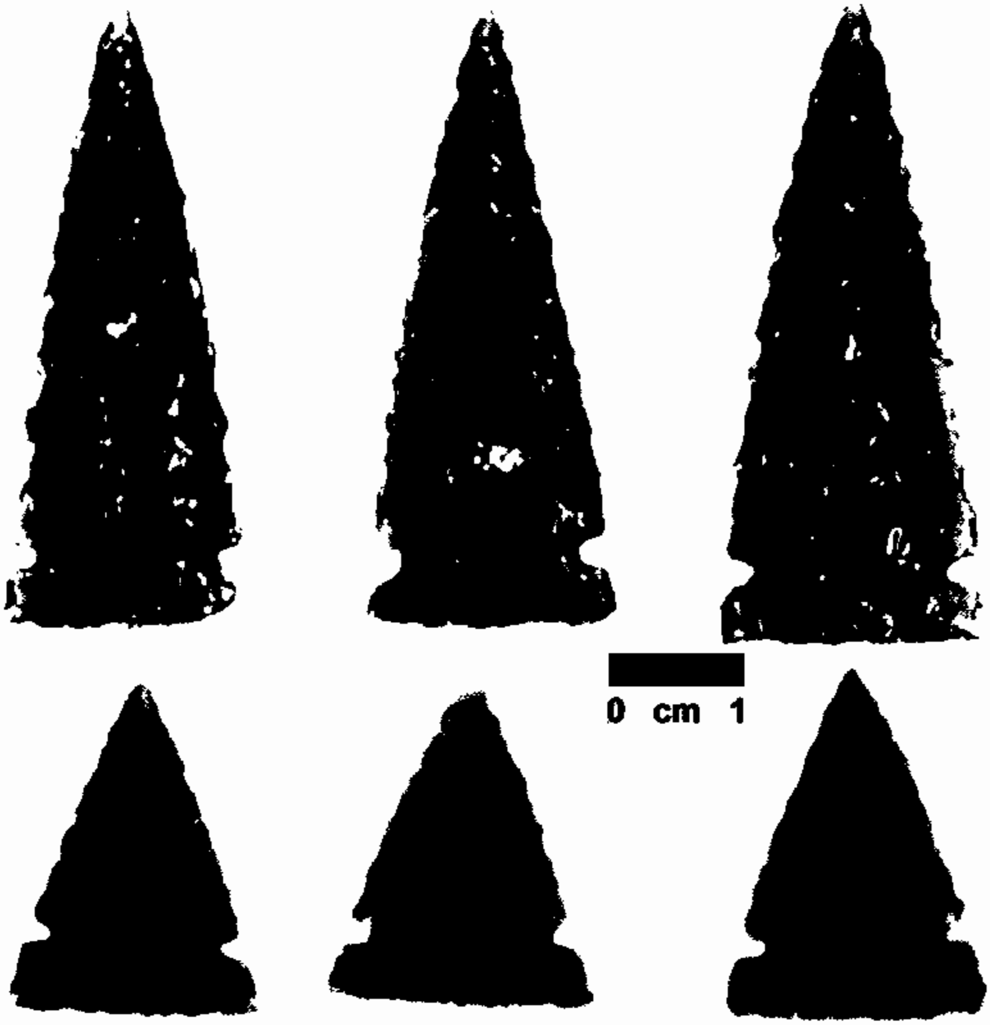

Figure 1. Six examples of the 50 points used in the experiment. Top, "long and thin" points; bottom, "short and thick" points; scale is 1 cm.

lengths and widths within each group were consistent, with coefficients of variation that are impressively close to Eerkens and Bettingers' (2001) theoretical maximum of 1.6 percent; these data also show that thickness was more difficult to control, as one might expect.

The bow used in the experiment was made by Dan Wolf, an experienced bow hunter, who was also the archer. The bow was a 66 inch (168 cm) self bow made of Arkansas hickory that pulled 32 pounds at 25 inches.

The points were mounted on foreshafts made of

Table 1. Coefficients of Variation for Basic Point Attributes, by Experimental Group.

Point Group	Length	Max.Th.	Th/L.	Max Wid.	Neck Wid.	Wt
Long, thin	.027	103	092	041	.097	.120
Long, thin	.020	.040	036	025	.054	.058
Short, thin	.027	.063	064	040	067	067
Short, thick	.022	.139	141	030	059	115
Long, thick	016	.073	.078	.032	.086	.076

Figure 2. One of the experimental points mounted to its foreshaft.

5/16 inch diameter wooden dowels, cut to 6.5 cm in length, with the proximal ends tapered. The foreshafts' distal ends were rounded so as to offer minimal resistance upon penetration. A notch was cut, to fit the specific dimensions of each individual projectile point, perpendicularly across the diameter of the distal end of the foreshaft. A mastic of pine resin and deer feces along with a sinew wrap secured the points in the foreshafts (Figure 2). After a few shots, we found that we needed to wrap the foreshaft/shaft connection with strapping tape to help hold the foreshaft in place.

The arrow shafts were a lightweight cedar. The main shafts had plastic nocks, feather fletching, and weighed about 20.5 grams each, with little variation. The flexibility (spine) of the mainshafts was correlated to the bow's draw strength.

In our first experiment, many arrows were deflected off the target. This was a problem in other experiments as well. Odell and Cowan (1986:202) observed that many of their arrows, tipped with chert points, were deflected at a higher rate than occurred in a previous experiment conducted by Flenniken (unpublished). They suggested that Flenniken's use of sharp, bifacial obsidian points could have enhanced penetrating power and worked against deflection. However, our experiments used sharp, bifacial obsidian points; and the distance between the carcass and archer was also the same. The greatest difference between our two experiments was that in the second the arrows' spines were matched to the bow's pull. Arrows that are mismatched to a bow's pull can wobble, especially early in their flight, strike the target at an angle, and ricochet. With the arrows' spines matched to the bow's pull, only four shots in the second experiment were deflected. Odell and Cowan did not match the arrows' spines to the bow's pull (Odell, personal communication, 2005) and this may account for some of the deflection. Odell and Cowan also found that unretouched points had a higher rate of deflection than retouched points. Arguing that it was difficult to haft unretouched points in such a way as to establish a "symmetrical line from the tip through the body of the stone," they (1986:203) suggest that unretouched points may have contributed to the high rate of deflection. This is not an issue in our study since we only used bifacial points.

Our experiment sought to simulate a "real world" situation as closely as possible and so the target was a female, field-dressed road kill white tail deer (*Odocoileus virginianus*). Use of a carcass rather than a live animal alters the "real world" conditions of projectile point use, since a live animal will move and possibly break a point after penetration. But a carcass provided the closest real world conditions and avoided ethical considerations. Field-dressing was necessary for the recovery of each point after it was shot. We do not think that the carcass's field-dressed condition influenced the results since it is bone, rather than internal organs, that breaks points.

The deer was hung with the left flank facing outward in front of a plywood backstop (were we to repeat the experiment we would use foam cushioning as a backstop). A line of tape on the floor at 4.5 m (15 ft) marked the spot from which the archer fired all shots. All shots were aimed at the heart/lung area. The carcass did not become so badly beat up that later shots had an easier target to penetrate than the initial shots. To avoid any "learning curve" errors that could bias the results, the experimental points were fired in a rotating order, one from each of the five groups.

Each point was fired until it broke. No points were rehafted or resharpened. In fact, when most points broke, they shattered beyond the point of repair or were too loose in the haft due to ear breakage to be reused. In total, 111 shots were fired.

With each shot we examined the wound and recorded what the point struck in terms of four categories. These categories are the "hardness score" discussed below: (1) Flesh; points that managed to find their way between ribs, (2) Glancing shots; points that did not impact bone directly, but did make contact, (3) Bone; points that hit bone directly, (4) Wall shots; points that penetrated the carcass and made contact with the plywood backstop. The depth of each arrow's penetration was also documented. All shots fired hit the target, but early in the experiment four shots bounced off as the archer accustomed himself to the arrows; these shots' hardness score was recorded as "0." The terminal hardness score (see below) recorded what the point struck on its final use.

Afterwards, we removed the deer's hide and simmered the remains for two days. We removed the large skeletal elements and sifted the remaining material through 1/16th inch screen to recover as much lithic material as possible. Only a few grams of obsidian shatter were recovered.

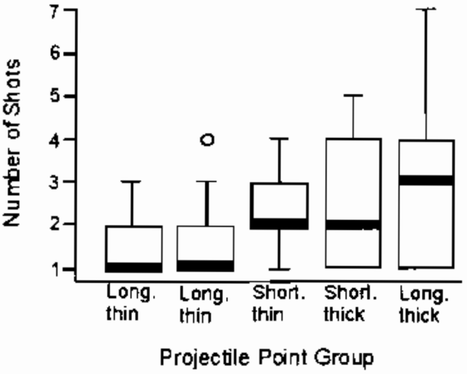

Figure 3. Box plots showing the number of shots fired for each of the five groups of projectile points.

Results

Projectile points do not last very long. Nearly half of our points ($n = 21$) broke on their first use. Twelve survived two shots, eight survived three shots, six were fired four times, and three points survived five, six, and seven shots (Figure 3). Table 2 presents the raw table on point measurements and experimental results. Table 3 summarizes the five size groups and their mean number of shots, lengths, widths, and thickness:length ratios.

We employed several statistical methods to test the hypothesis that points with greater thickness:length ratios survived more shots than points with smaller thickness:length ratios. An ANOVA test revealed a difference in the mean number of shots withstood by the points in each size group ($F = 2.17$, $df = 48$, $p = .08$). Correlation coefficients were then run between the metric variables and the number of shots. Only three variables stood out as statistically significant, the terminal hardness score and left and right ear height ($r = -.308$, $p = .029$; $r = -.371$, $p = .023$; $r = -.372$, $p = .008$, respectively).

It makes sense, of course, that the hardness of the substance that a point strikes affects its durability. And there is little that prehistoric hunters could have done about this since they did not intend to miss and strike a stone or tree, nor did they intend to strike bone when their arrow did find its mark. Thus, some elements of projectile point manufac-

Table 2. Projectile Point Basic Measurements and Experimental Results

Point Number	Total Shots	Mean material hardness	Final material hardness	Length (mm)	Base Width (mm)	Neck Width (mm)	Maximum Thickness (mm)	Mean Ear Height (mm)	Weight (grm)	Breakage
101	2	1	1	48.8	19.5	14.4	4.4	5.3	3.2	impact fracture, broke point near midsection
102	1	1	3	52.0	19.7	13.4	5.5	5.1	4.2	lateral fracture
103	2	1	2	50.7	19.8	13.4	5.3	6.1	4.1	shattered
104	1	2.5	3	51.2	19.0	12.6	4.2	6.4	3.3	broke at one ear, tip snapped/impact fracture
105	3	2.5	3	48.0	19.7	13.2	4.8	5.4	3.3	broke at both ears; tip snapped/impact fracture
106	1	2	1	48.7	19.4	12.9	4.6	5.8	3.3	broke at tip/impact fracture
107	1	3	4	50.5	18.2	13.5	4.7	5.3	3.5	broke across midsection; tip snapped/impact facture
108	2	2.66	1	48.2	20.4	13.9	4.7	5.6	3.7	broke at one ear
109	1	2	1	49.7	21.2	14.1	5.7	4.9	3.5	broke across midsection
110	1	1.5	3	49.7	19.0	13.6	4.5	6.0	4.5	broke at one ear; crack from notch propogated up and through middle of point
201	3	3	1	50.2	21.0	14.9	4.1	5.7	3.2	broke at tip/impact fracture
202	1	1	2	49.8	20.4	14.0	4.0	5.6	3.1	broke at one ear, impact fracture at tip
203	1	2	3	49.0	19.6	15.2	4.0	3.7	3.1	broke across midsection
204	1	1	3	50.9	20.8	15.0	4.4	5.0	3.6	broke at tip/impact fracture, impact fracture down one face
205	1	2	2	47.9	20.4	13.8	4.1	6.0	3.1	broke at one ear: crack from notch propogated up and through middle of point: tip missing
206	2	1.66	2	51.5	20.0	15.2	4.1	4.3	3.3	broke at one ears, crack propogated downward across base, tip snapped/impact fracture
207	1	1	4	50.7	20.2	14.4	4.5	4.9	3.5	broke at both ears
208	1	2	3	50.3	19.8	13.5	4.2	5.0	3.3	broke across midsection
209	2	2.5	3	49.7	19.4	13.7	4.0	4.3	3.1	broke at both ears
210	4	4	1	49.9	19.7	14.9	4.2	4.2	3.2	broke across midsection
301	2	2	3	25.9	20.1	13.6	3.1	4.4	1.2	broke at one ear
302	3	1	3	26.3	19.4	12.3	3.4	5.0	1.2	broke at one ear
303	2	3	3	25.6	19.8	13.2	3.1	4.6	1.2	shattered; most of point missing
304	2	0	3	25.4	20.3	14.0	3.2	4.5	1.2	broke across midsection: distal half missing
305	2	2	1	26.7	19.4	13.2	2.9	4.8	1.3	broke at both ears
306	1	3	2	25.7	20.9	13.3	3.4	4.8	1.3	broke at one ear; split down middle of point
307	3	2.5	2	24.7	18.9	13.0	2.9	4.3	1.0	broke at tip/impact fracture
308	4	1.2	4	24.7	20.4	13.9	3.4	4.6	1.2	broke at both ears
309	4	1.42	3	24.7	18.4	12.6	3.0	4.3	1.1	shattered, most of point missing
310	1	1	2	26.2	18.8	13.3	3.3	4.2	1.2	shattered: most of point missing

401	1	3	4	26.1	18.9	11.8	4.2	5.7	1.5	broke at one ear, lateral break; impact fracture broke point near midsection
402	1	1	3	26.5	20.7	13.0	5.1	5.2	1.9	broke at one ear, impact fracture at tip
403	2	3	1	25.5	20.7	13.0	4.5	5.3	1.6	broke at one ear; impact fracture broke point near midsection
404	1	2.5	1	25.4	20.2	11.9	4.9	5.9	1.6	impact fracture at tip
405	4	3	1	25.7	20.0	11.3	5.4	5.9	1.8	impact fracture at tip
406	3	2.75	2	26.5	20.6	13.8	3.5	3.4	1.6	broke at one ear, impact flake removed from one face
407	2	1	2	26.0	20.5	12.2	4.5	5.9	1.7	broke at both ears
408	5	3	1	25.8	19.5	11.6	3.7	4.4	1.3	impact fracture at tip
409	1	1	3	26.9	19.8	12.7	5.3	5.0	1.9	broke at one ear; large impact flake removed from one face
410	4	1.33	1	25.0	20.7	12.8	4.8	5.2	1.7	broke at one ear; impact fracture broke point near midsection
501	1	2	2	48.9	18.9	14.6	6.6	4.2	4.4	impact fracture at tip
502	3	0	3	48.6	19.2	13.7	6.0	3.8	4.2	lateral fracture; impact fracture at tip
503	7	2	1	49.9	20.7	15.2	6.3	4.2	4.8	lateral fracture; impact fracture at tip
504	1	2.5	1	49.6	19.9	14.8	5.5	4.0	4.4	broke one ear, impact fracture at tip propogated to nearly the base of the point
505	4	2	3	50.4	19.2	14.2	5.8	3.5	4.2	shattered
506	3	2	1	49.9	18.7	14.1	6.5	4.3	4.4	both ears broken
507	1	2	4	49.4	19.9	15.2	6.6	4.8	4.9	impact fracture at tip
508	2	1.5	1	49.7	19.8	15.0	7.1	4.4	4.9	tip broken/impact fracture at tip
509	6	1.75	1	48.8	18.8	13.3	6.1	3.4	3.9	one ear broken, crack propagated up and across point, impact fracture at tip
510	3	2	3	47.5	18.9	14.4	6.5	4.2	4.4	point missing

Table 3. Basic Size Attributes of the Five Projectile Point Groups.

Point	Shots		Length		Max. thick.		Th:L.		Max. width		Weight	
Group	mean	sd	mean	sd	Mean	sd	mean	sd	mean	sd	mean	sd
Long, thin	1.5	.71	49.74	1.35	4.84	.50	.097	.009	19.59	.81	3.66	.44
Long, thin	1.7	1.10	49.98	1.02	4.15	.17	.083	.003	2.12	.51	3.25	.19
Short, thin	2.4	1.07	25.58	.71	3.16	.20	.124	.008	19.63	.80	1.18	.08
Short, thick	2.4	1.5	25.93	.59	4.58	.64	.177	.025	2.15	.61	1.65	.19
Long, thick	3.1	2.08	49.29	.83	6.30	.46	.128	.010	19.39	.63	4.44	.34

ture may have been intended to overcome the inevitability of a point striking something hard, like bone.

The correlation coefficients suggest that ear height may be one of those elements. Ear height is the distance from the point's base to the outermost corner where the notch begins. As ear height increases, projectile point durability decreases (although this variable accounts for only a small amount of variance), even though the range in mean ear height is only 3 mm, from 3.4 to 6.4 mm. One reviewer suggested that by moving the notches closer to a point's midsection, increasing ear height increases the lever-like power of force applied to the point's tip (as the reviewer pointed out, it is easier to break a stick by applying force to its middle, rather than close to one of its ends). This explanation implies that the longer a point's ear is relative to its length, the less durable it would be. However, there is no correlation between number of shots and the ear height:length ratio (two-tailed $p = .77$, assuming unequal variance).

We might also expect that if ear height were critical, then fatal point breaks would more commonly occur at a point's neck. On the 50 points we recorded 68 breaks of 7 kinds (Table 2). Only two points (4 percent) broke cleanly at the neck. However, 17 (34 percent) suffered the loss of one ear and 7 (14 percent) lost both ears; these two categories together (48 percent) were the most common type of break, followed by impact factures that broke the point at its tip (44 percent), midsection snaps (14 percent), shattered points (14 percent), lateral breaks (8 percent; a large flake that removed one of the point's edges), and impact fractures that broke the point in midsection (8 percent). Of those points that lost one or both ears, four also broke across the point's body because of a crack propagated at the notch. The point's notch, as expected, is a weak point (even though these points were not deeply notched), but the infrequent clean breaks across the neck argue against the importance of ear height in promoting point durability.

The ear height correlation may be a red herring (in fact, by removing the two points that survived six and seven shots from the dataset, the significant correlation between ear height and number of shots disappears). And since so few points survived more than three shots, the correlation coefficients could be misleading. We therefore examined the data in another fashion. Following Odell and Cowan (1986) we divided the 50 points into two groups based on a variable's median value and tested for a significant difference between those above and below the median. Splitting the sample in half based on the median thickness:length ratio (.121), we found that points with thickness:length ratios >.121 withstood significantly more shots on average those with a thickness:length ratio < .121 (t = 2.37, two-tailed $p = .02$ assuming unequal variance, $df = 38$; average of 2.68 shots for high thickness:length points, average of 1.76 for low thickness:length points). Those few points that survived multiple shots might be biasing the results, but we get the same significant difference if the three points that survived 5 or more shots are removed from the sample ($t = -1.81$, two-tailed $p = .08$ assuming equal variance, 2.25 versus 1.69 shots).

We also found a significant difference after dividing the points into two groups based on the median of the mean ear height (averaging the left and right heights; $t = 2.85$, two-tailed, $p = .006$ assuming unequal variance). Points with "short" ears (less than 4.85 mm) withstood an average of 2.76 shots and points with "tall" ears withstood an average of 1.68 shots. However, there is no difference between points based on the median ratio of ear height:length.

Overall projectile point size does not contribute to projectile point durability in this study. We found no significant differences in durability when dividing the sample into "long" and "short," "wide" and "narrow," "thick" and "thin," "heavy" and "light" points, or "wide" and "narrow" neck widths based on median values. In fact, projectile point size may be more related to efforts to create proper arrow flexure, since an arrow's flexure is partly a function of the weight of its point. If so, point size would have more to do with an arrow's spine and be linked to the kind of material(s) used for the shaft, as well as arrow length. We cannot investigate these aspects in this study since all arrows used were of the same material, weight, and length.

Odell and Cowan (1986) also found no significant correlation between projectile point size and durability. However, they did find a significant relationship between projectile point length:width ratios and durability that is linked to the importance of the hardness score in this study. They found that short, wide points were more durable than long, narrow points. However, they did not relate this difference in durability to structural aspects of the points. Instead, they observed that short, wide points tend to bounce off the target, or not penetrate very deeply, while long, narrow points penetrate more effectively. Thus, they argued that points that penetrate deeply have a greater probability of striking bone and thus a greater chance of breaking.

Unlike Odell and Cowan (1986), we found no significant difference in durability between groups of points divided by the median length:basal width ratio (basal width is maximum width in these sets of points). We likewise found no difference between groups of points divided in terms of the median length:neck width or thickness:neck width ratios. As noted above, only two points broke cleanly across the neck, and the data suggest that neck width is not related to projectile point durability (although this could change in points that are more deeply notched than those used in this sample). We conclude that the thickness:length ratio is the primary metric variable, of those considered in this study, affecting projectile point durability. A high thickness:length ratio increases a point's lifespan.

It is also clear that whether a point struck bone plays a significant role in its durability. In fact, in a relatively small sample, it is possible that the results are biased by those points that struck bone early in their experimental use. Thus, the question arises: did those points with low thickness:length ratios, and that survived only a few shots, strike significantly harder material than those points with higher thickness:length ratios and that were shot multiple times?

We first approached this question by comparing the groups above and below the median thickness:length ratio in terms of their terminal hardness scores. A Mann-Whitney U test shows no significant difference between the groups ($z = -.16$, two-tailed $p = .87$; corrected for continuity). But the terminal hardness score is what a point impacted on its *final* shot. This may be inaccurate since multiple shots could produce micro-fractures that cumulatively take a toll on points fired more than once—leading to their breakage even if they did not strike bone on their final shot. We cannot simply average a point's hardness scores since an average assumes that the differences between the four hardness categories are equal, and we cannot make such an assumption here. For this reason, we simply considered the hardness scores of all shots (N = 111). Comparing points above and below the median thickness:length ratio we still found no significant difference between the two groups ($z = -.268$, two-tailed $p = .79$).

Conclusion

Titmus and Woods (1986) made and broke atlatl dart points by throwing them into a variety of different targets (none of which were carcasses) in order to determine if it were possible to discern the difference between use-related and manufacturing induced breakage. Of importance to our study is the fact that 70 percent of their sample of 30 points broke on first impact. Although some of their points survived 10 throws, on average, their atlatl points survived only 2.1 throws. Similarly, Odell and Cowan (1986) found that their arrow points survived an average of 2.68 shots (with no significant difference in arrow and spear point durability); as in our dataset, nearly half of Odell and Cowan's 40 arrow points (43 percent) could be fired only once. As one might expect, glassy objects that are hurled at high velocities toward hard surfaces are not exceptionally durable.

There are ways to increase durability, and increasing a point's thickness relative to its length appears to be one of them. However, this study did not achieve large increases in durability; increasing the thickness:length ratio to > .121 on average results in only one additional shot. Moreover, the coefficients of variation demonstrate that projectile point thickness, as flintknappers know, is one of the most difficult variables to control.

The possible significance of notching, its location relative to a point's length and depth may also be significant variables. Since notching is an easier variable to control than thickness, it, rather than the thickness:length ratio, may have been flintknappers' preferred means of increasing point durability. In fact, removing the notches altogether, and creating a triangular or lanceolate point may increase durability even more. Determining whether this is true will require additional experiments since there was little variability in notch placement and depth in this study.

Artifact design is a balance between several often conflicting desires. Prehistoric hunters wanted their weaponry to last a long time so as to avoid the cost of replacing parts, including projectile points. At the same time, ancient hunters wanted their weaponry to be effective, and in the case of projectiles this means, in large part, penetrating deeply into an animal so that it dies quickly. These two desires can conflict in the design of projectile points: a point that is thick relative to its length is more durable but a point that is thin relative to its length is a more effective killing implement. A point with notches is perhaps more securely seated in its haft than one that lacks notches. Prehistoric hunters had to balance their different needs. Artisans might have maximized the killing power of points that were intended to be used only as projectile tips, and made them with low thickness:length ratios. Alternatively, long, thin points might be made more durable by lengthening the haft element, binding more of the point and providing it with more support. As we had to keep the haft element constant in this experiment, we are unable to comment on how changes in the haft might improve projectile point durability.

We can also imagine that projectile point durability might have been an undesirable characteristic. Given that large gains in durability are unlikely, it may be that ancient hunters intended that their points break to encourage bleeding and hasten death. Alternatively, a point intended to break might absorb the impact's force and hence protect the more time-consuming haft elements from shock and breakage. We will note, however, that in 111 shots in this experiment, only one arrow foreshaft broke.

But in other cases artisans might have tried to maximize durability, with high thickness:length ratios. This might be especially important for those points that were intended to serve as knives as well as projectile tips, where stone tool raw material was difficult to acquire, leading to a need to conserve points, or where the points were intended to tip thrusting spears that the hunter might need to sustain several quick penetrations. When combined with additional experiments that examine the durability of other basic point styles, such as triangular and lanceolate points, and raw materials other than obsidian, the data presented here should help archaeologists determine whether variation in projectile point shape is related to changes in the relative importance of these elements of projectile point design. As such, this experiment should help us understand spatial and temporal variation in projectile point design.

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