Projectile Point Reworking: An Experimental Study of Arrowpoint Use Life

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This article summarizes the results of controlled experiments in which flaked-stone points that varied in impact strength by a factor of almost three were shot at media that were increasingly inelastic and therefore likely to break the points. Broken tips were reworked if possible, and used again under the same conditions. Our results show that all damage to low impact-strength materials, especially obsidian, was generally catastrophic, and, consequently, these points could only rarely be reworked. The fact that low-strength stones were commonly used to make small arrowpoints suggests that reworking was not a primary concern for their designers. Furthermore, in those instances when broken tips could be reworked, their performance declined. In addition, reworking broken points also resulted in shapes that are uncommon in many arrowpoint assemblages. Our results suggest that the original design attributes of arrowpoints may have been less affected by reworking, and, consequently, may more accurately suggest temporal and behavioral associations.

Keywords: projectile point reworking, use damage, design, performance, raw material constraints, controlled experiment

Este artículo resume los resultados de los experimentos controlados en los que puntas de proyectil de piedra que varían en la resistencia al impacto en un factor de casi tres se dispararon a materiales que eran cada vez más inelásticos y, por lo tanto, que podían romper las puntas. Las puntas rotas se reformaron si era posible y se volvieron a usar en las mismas condiciones. Nuestros resultados muestran que el daño a los materiales de baja resistencia al impacto, como la obsidiana, fueron generalmente catastróficos, y, en consecuencia, estas puntas rara vez se podian volver a trabajar. El hecho de que piedras de baja resistencia se usaran comúnmente para hacer pequeñas puntas de flecha sugiere que los diseñadores no pensaban en reacondicionarlas. Además, en aquellos casos en que las puntas rotas se pudieran reacondicionar, su rendimiento disminuía. En consecuencia, la reformatización de puntas rotas también dio lugar a formas que son poco comunes en muchos conjuntos de puntas de flecha. Nuestros resultados sugieren que los atributos de diseño originales de las puntas de flecha pueden haberse visto menos afectados por el retoque, y, en consecuencia, pueden sugerir con mayor precisión asociaciones temporales y de comportamiento.

Palabras clave: reformación de puntas de proyectil, daño debido al uso, diseño, rendimiento, restricciones de materia prima, experimento controlado

Researchers have identified many variables that conditioned the form of flaked-stone projectile points (Shott 1996). These varied factors can be grouped into three general lines of inquiry: design characteristics, raw material constraints, and reworking. Point design variables include both stylistic expressions (e.g., serrations) that do not substantially change point performance as well as intentional modifications (e.g., side notching of triangular points) that do significantly alter point function, and, therefore, are potentially related to differences in the intended use (Ahler 1971; Bettinger and Eerkens 1999; Bonnichsen and Keyser 1982; Buchanan et al. 2011; Christenson 1997; Ellis 1997; Hughes 1998; Knecht 1997; Loendorf

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2012; Loendorf et al. 2015a, 2015b, 2017; Lyman et al. 2009; Mason 1894; Mesoudi and O'Brien 2008; O'Brien et al. 2014; Sedig 2014; Shott 1996, 1997; Sisk and Shea 2009; Sliva 2015; Thomas 1978; Tomka 2013; VanPool 2003; Whittaker 1994, 2016; Wood and Fitzhugh 2018). The second general category includes the distribution and nature of raw materials on the landscape, which has been shown to substantially constrain lithic industries (Ahler 1971; Andrefsky 2005, 2006; Lerner et al. 2007; VanPool 2003; Whittaker 1994). Finally, wear or damage from use and subsequent rejuvenation are also widely agreed-upon factors that may have affected point form (Azevedo et al. 2014; Buchanan et al. 2015; Charlin and González-José 2012; Cheshier and Kelly 2006; Eren and Sampson 2009; Flenniken and Raymond 1986; Goodyear 1974; Frison 1968; Hoffman 1985, 1997; Lerner 2015; Rots and Plisson 2014; Shott 1989, 1993; Thomas 1978;). These three general categories are interrelated, and, in order to understand point form, it is necessary to consider all of them. This article focuses on the reworking of arrowpoints, while holding design traits constant as much as possible and controlling for material constraints by considering stones with varying impact strength (Loendorf et al. 2018).

Reworking damaged projectile points may change their shape and size, and, decades ago, archaeologists recognized that this process may alter their classification in typological systems (Flenniken and Raymond 1986; Frison 1968; Hoffman 1985, 1997). Consequently, investigators have adopted an analytical paradigm under which it is assumed that much of the apparent variation within lithic collections is a direct result of the intensity with which stone tools were used, rejuvenated, and repaired (Azevedo et al. 2014; Bettinger and Eerkens 1999; Blades 2008; Charlin and González-José 2012; Eren and Sampson 2009; Kuhn 1990, 1994; Lerner 2015; Lerner et. al. 2007; Shott 1989; Shott and Ballenger 2007; Weedman 2002). At the same time, some researchers have failed to identify patterning expected for projectile tip reworking and, instead, have suggested that rejuvenation did not always result in substantial modifications to flaked-stone points (e.g., Buchanan et al. 2015).

One way to objectively examine point reworking is to conduct controlled laboratory experiments. This article reports the results of an investigation that employed 58 flaked-stone arrow tips made from four different raw materials that vary in impact strength. The points were shot at increasingly inelastic targets until they broke, and all sufficiently large recovered fragments were reworked and reused. This process was repeated until all points were broken and could not be reworked. Results presented here demonstrate that arrowpoint breakage patterns vary substantially among raw material types, and low impact-strength materials, including obsidian and chert, could more rarely be reworked than higher impact-strength stone. Nevertheless, all of the points that struck bone targets failed catastrophically and could not be reworked (see also Odell and Cowan 1986). Data reported here also suggest that reworking points negatively impacted their performance. In addition, the process of reworking broken projectile points resulted in shapes that are rare or absent in some arrowpoint collections. In summation, physical constraints differ for spear, atlatl, and arrowpoints, which, in combination with the experimental results presented here, suggest that stone arrow tips are less likely to be reworked and reused than atlatl dart or, especially, spear tips. This possibility has implications for the interpretation of variation within projectile point assemblages, and it appears that the initial design features of arrow tips are less likely to be altered through use and reworking.

Projectile Point Performance

In order to test the performance of flaked-stone points, it is necessary to define the tasks that they were designed to perform (Knecht 1997). Extensive ethnographic and archaeological evidence suggests that flaked points were primarily made for use in large game hunting or conflict with other people, and, because of their different selection criteria, stone points were sometimes designed differently for these two tasks (Ahler 1992; Ellis 1997; Keeley 1996:52; Loendorf 2012; Loendorf et al. 2015a; Mason 1894; Stevens 1870:564; Whittaker 2016).

Large-animal hunting and human conflict differ fundamentally in that the former practice is undertaken to obtain food, while the primary intent of the latter is to kill or wound adversaries (Loendorf et al. 2015a). As a result, substantially different design constraints exist for these two tasks, and this factor should be considered when theorizing about point performance factors. Because of the effort required to track a wounded animal, as well as the increased chance it will not be recovered for consumption, hunting points were made to kill as rapidly and consistently as possible. In contrast, warfare points were designed to maximize the probability that severe injury or death resulted, regardless of the time required (Loendorf et al. 2015a). As a consequence of the differences in functional requirements between hunting and warfare, the experimental study focused only on factors that are common to both tasks, and potential distinctions between these two designs are not tested in this analysis.

Projectile Point Design Constraints

The primary performance characteristic for a projectile is the kinetic energy of the weapon, which is a function of mass and velocity (Anderson et al. 2016). Using a launching mechanism of a fixed propulsive force, heavier projectiles have greater energy because more force is transferred to heavier projectiles during launch than lighter ones (Baker 2001:107; Cotterell and Kamminga 1992:33–35; Hughes 1998; Klopsteg 1993; Kooi 1983:28; VanPool 2003:162; Whittaker et al. 2017). Not only does a heavier projectile have more kinetic energy when launched, it also decelerates at a slower rate (Kooi 1983:69; VanPool 2003:122). Therefore, a heavier projectile begins with more kinetic energy, and it retains a higher percentage of its impact force downrange. On the other hand, because they have lower inertia, lighter projectiles will generally leave the launching mechanism at higher velocities than heavier ones (Baker 2001:107; Cotterell and Kamminga 1992; Hughes 1998:353; Kooi 1983:28; VanPool 2003:122). Increasing projectile velocity has important performance advantages (Whittaker et al. 2017). First, higher velocities allow greater range (Klopsteg 1993; VanPool 2003:119). Second, higher velocities allow increased accuracy, because the lower the velocity the greater the necessity to aim above a target at a given range (Cotterell and Kamminga 1992; Hughes 1998:348; Klopsteg 1993:14; Kooi 1983:24). For the same reason, low-velocity projectiles also require greater accuracy in target-distance estimation and control over projectile speed in order to determine precisely how far above the target to aim. Third, the higher the velocity, the less time will elapse between launching the projectile and its impact with the target. This makes hitting moving targets easier and allows less time for an intended target to avoid the projectile.

As a result of these physical constraints, effective projectile design is a tradeoff between projectile mass and velocity. Because potential velocity is constrained by the launching mechanism technology (e.g., arm, atlatl, bow, firearm), projectiles theoretically were designed to have only sufficient mass for the level of kinetic energy necessary to effectively penetrate the large game or human targets for which they were intended (Loendorf 2012). It is possible to improve the performance of launching mechanisms such as the atlatl by altering their length, flexibility, and weight distribution; however, more dramatic improvements are possible with different designs like the bow and arrow. Developments of the former type should result in incremental modifications to point designs, while changes of the latter variety must be associated with more substantial alterations. In theory, these changes are expected to produce a kind of "punctuated equilibrium" in point design, where long periods of gradual change are interspersed by comparatively short periods of more dramatic differences (see Lyman et al. 2009).

The method of propulsion also constrains the design of projectile tips. For example, when throwing both spears and atlatl darts, it is possible to alter the rate of acceleration until the moment of release. This allows the thrower to compensate for differences in the mass of projectiles during launch. In contrast, acceleration occurs after the release of an arrow, and it is therefore impossible to compensate for projectile mass during acceleration, which more tightly constrains the acceptable range of variation in arrow design. Because arrows of varying mass will have different points of impact, accuracy is impossible without careful standardization of their weight (Klopsteg 1993:11–22; Mason 1894:660). Consequently, reworking broken points is less likely to have occurred for arrow tips but may more commonly have happened with atlatl dart and, especially, spear points.

Furthermore, in order to efficiently transfer the energy stored in the bow to an arrow, it also must be the correct length and stiffness. This limits the extent to which arrow dimensions and materials can be adjusted to standardize mass. Another factor is that both atlatl darts and arrows are accelerated from the distal end, while spears are held closer to their center of mass (i.e., balance point) during launch, which creates different constraints on their distribution of mass. Because the end of the arrow is accelerated before the tip, it necessarily moves at a greater velocity; when this is combined with the inertia of a tip of higher density than the shaft and on its opposite end, the force tends to spin the distal portion of the projectile forward (Ratzat 1999:201). Heavy points also increase stresses that occur in the shaft during rapid acceleration from the opposite end, which can result in severe oscillation of the projectile or even shatter it (Hughes 1998:348; Klopsteg 1993:22; Ratzat 1999:200). Fletching (e.g., feathers) near the nock slows this end of the shaft and helps counteract these forces (Ratzat 1999:201), but fletching is also the primary source of drag that slows projectiles after launch (Klopsteg 1993:23). These factors further constrain the design of arrow tips.

Finally, it is also important to recognize that, after manufacture, arrowpoints were hafted to projectiles and stored for use in quivers or by other means. Consequently, most of the use-life of points is expected to have been a period of time in which the points are more likely to be accidentally damaged, for example, by slipping and falling upon a quiver with arrows inside. This could simultaneously damage multiple tips, thus forcing repairs. Because of the effort involved in hafting the point, tips that were accidentally broken while attached to arrows may have been more commonly reworked, especially if the damage occurred away from the resources necessary to replace the point. There are many other circumstances in which points may have broken during handling, and accidental damage may account for certain instances in which evidence for reworking of arrowpoints is identified.

Arrowpoint Reworking Experiment Methods

To test the effects of reworking on the performance of flaked-stone arrow tips, we conducted laboratory experiments in which shot distance, point of aim, bow strength, point morphology, arrow characteristics, and target type were all controlled. During experiential trials, any points that broke were reworked if fragments larger than approximately 40% of the original point were recovered. Broken points were retouched with the goals of producing a symmetrical and pointed tip, while retaining the largest mass possible. This strategy minimized the amount of time spent reducing broken points and maximized their size. All points were shot until they were broken and could not be reworked, including those that had already been reworked. At the end of the experimental trials, all points were too fragmentary to be reworked. The performance of the initial points was reported in a previous publication (Loendorf et al. 2018), and, because the same methods were employed to test the reworked points, they are summarized again here.

The raw materials employed in the projectile experiments included two obsidian varieties (Government Mountain and Mule Creek), two chert types (Whetstone and Tolchaco), a black fine-grained volcanic stone, and a metamorphosed fine-grained sedimentary stone. For convenience, hereafter the latter two materials are respectively referred to as "basalt" and "siltstone." All of the raw materials are from Arizona sources, and they were selected to reflect a wide range of variation in impact strength. The impact strength of the materials was independently assessed using a falling weight method, and they were found to vary by a factor of approximately 2.6 to 2.8 (Loendorf et al. 2018).

To minimize variation, data were collected in 28 trials during which the target type and distance were fixed. A total of 35 commercially

Figure 1. Basalt arrow tips, archaeological example (left) and experimental point example (right), photograph by Chris Loendorf.

prepared wooden arrows was employed. Arrows were matched based on morphological similarity into groups of four and, having thus been grouped together, were fired sequentially during trials. Three arrows that lacked stone points were used as controls during the trials. At the start of each trial, all points were socket-hafted and secured with 30 cm of 1 mm wide artificial sinew and commercially prepared pine pitch adhesive. The points were tightly wrapped with the sinew in a figure-8 pattern. Obsidian, chert, siltstone, and basalt points were secured to one arrow in each matched group. The original points were all morphologically similar isosceles triangular shapes that matched the average size of arrow tips recovered from surface contexts in the Gila River Indian Community (GRIC; Loendorf and Rice 2004; Figure 1). Side notches were present in the lower one-third of the blade, and all points had straight blade margins and straight bases prior to being reworked (Loendorf et al. 2018).

The Mule Creek obsidian, Whetstone chert, siltstone, and basalt armatures were produced by Allen Denoyer. Because of damage to the obsidian and chert points, it was necessary to also include Government Mountain obsidian points made by the lead author and Tolchaco chert points produced by William Bryce. The lead author also reworked all of the sufficiently large fragments that were recovered from broken points.

In order to minimize shot-to-shot variability, all projectiles were fired using a fixed stand that maintained a constant draw length and point of aim. A modern recurve bow with a draw weight of 17 kg at a draw length of 66 cm was employed. Arrow velocities were measured with a Caldwell Ballistic Precision™ chronograph, and they averaged 43 meters per second. This velocity is at the lower end of the data summarized by Tomka (2013) for Native American archery equipment in general and is consistent with results reported by Parks (2017) for his reconstruction of Southwestern US bows, as well as those of Whittaker and colleagues (2017), who extensively review the available data.

Arrows were fired indoors in order to minimize variances caused by wind and other factors. The first arrow shot into a given test media lacked a stone point. This arrow was employed to establish the point of aim for the launching mechanism. These control arrows had sharpened tips but were otherwise the same as arrows with points. Breakage patterns, velocity, depth of penetration, and other data were collected. To maintain consistent conditions, arrows with obsidian, chert, basalt, and siltstone were alternately fired into the test media. Approximately every thirteenth arrow shot into a given target lacked a stone point. This was done to control for possible shot-to-shot sources of variation and to check the point of aim.

Trials were undertaken using increasingly inelastic targets (foam blocks, ballistics gelatin, rawhide of different thicknesses, and bovine scapulae covered with ballistic gelatin). Thus, the experiments began with materials that were unlikely to break the points and proceeded through media that were increasingly likely to cause damage. Although no artificial target can perfectly replicate the effects of a projectile on a living organism, the materials employed have the advantage that they are widely available and comparatively uniform (Rots and Plisson 2014).

Points were first fired into foam block targets, consisting of five layers of 70 mm thick polystyrene covered with a layer of 5 mm thick foam core poster board and two layers of 0.15 mm thick plastic. These targets are analogous to humans and other animals in the sense that the exterior consists of elastic materials (i.e., plastic and poster board), which covered a more inelastic material (i.e., foam) as is the case with skin and muscle. Following the foam-block trials, points were fired into commercially prepared synthetic ballistic gelatin that was made by Clear Ballistics™. These targets were more than 15 cm thick and match the density of human tissue. They are also more stable at a wider range of temperatures than organic gelatin. Next, in order to examine impacts with less elastic materials, rawhide with thicknesses between 2.6 mm and 3.0 mm was placed in front of the ballistics gelatin. Finally, points were fired at a block of approximately 5 cm thick ballistic gelatin covering two bovine scapulae.

Reworking Experiment Results

The following analyses present data for 1,257 arrow impacts to the four target types that were employed. Within the foam-block targets, arrows were fired ($n = 809$) until the points detached, but this was not logistically possible for the ballistics gelatin targets ($n = 311$). With the rawhide targets, most points broke on the first or second impact ($n = 115$), and all points broke on the first shot for bone targets ($n = 23$). Consequently, sample sizes vary by raw material type for the foam targets (siltstone $n = 180$, basalt $n = 309$, chert $n = 122$, obsidian $n = 71$, and wood $n = 127$), and comparatively few impacts were recorded for the inelastic materials ($n = 138$).

Point Breakage

Fragments were recovered from 52 of the 58 arrow tips that were employed in the experiments. The remaining six artifacts were either lost within targets or were too fragmentary to be collected. Despite the tightly controlled conditions, it was difficult to collect large pieces from all points that impacted inelastic materials, especially bone. This was, in part, because these points tended to shatter, and frequently only small fragments remained within the haft after removal of the arrow from the target (Figure 2).

Figure 2. Arrow shafts with the remaining in situ point fragments after bone target impacts, photograph by Brian Huttick.

Table 1 shows breakage patterns for all targets by material type and portion of the point that was damaged. Siltstone, basalt, and chert arrow tips all tended to break in similar ways. For these materials, damage to the blade was most common, accounting for roughly half of the overall total (see also Odell and Cowan 1986). The average total weight of recovered broken portions was also similar for these three material types, although chert point fragments were slightly lighter on average. Obsidian points, on the other hand, tended to suffer severe damage more often than the other three material types, and the total weight of recovered point fragments was also substantially lighter. Over 58% of the broken obsidian points either had damage to both the blade and haft elements, or they suffered catastrophic failures in which only small fragments were recovered, usually from the haft element.

Not surprisingly, projectile points did not generally break within the elastic targets, although one obsidian point did fail in the foam, and another broke in the ballistic gelatin. In contrast, all of the points that struck the bone target broke catastrophically, and none of them

Table 1. Breakage Patterns for All Target Types by Point Material and Broken Portion.

Damage location	Siltstone		Basalt		Chert		Obsidian	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Blade	4	50%	5	50%	8	53%	6	32%
Haft	2	25%	2	20%	4	27%	2	11%
Both Blade and Haft	1	13%	0	0%	0	0%	2	11%
Shattered	1	13%	3	30%	3	20%	9	47%
Average Weight (g)	0.41		0.42		0.38		0.28	

could be reworked. These data suggest that any arrowpoints that strike bone are likely to irreparably break, and the probability of hitting one or more bones when impacting an animal or human target is high (Bill 1882; Odell and Cowan 1986:206). Similarly, points that struck rawhide generally broke, but high impact-strength materials were substantially more durable, and siltstone, which had the highest measured strength, averaged more than two shots for the rawhide impacts (Table 2).

In summary, these data show that it was possible to rework high impact strength points most often, and the percentage of points that could be reworked decreases with impact strength. This suggests that if reworking was a primary concern for the people who made and used the points, then low impact strength stones like obsidian would not have been employed to manufacture arrowpoints, unless no other higher-strength materials were available.

Reworked Point Performance (Wound Size)

This section evaluates the performance of reworked points by examining wound size, which is a fundamental factor for successful projectile design (Christenson 1997; Cotterell and Kamminga 1992; Loendorf 2012; Odell and Cowan 1986; Rots and Plisson 2014; Shott 1993; Sisk and Shea 2009; Sliva 2015; Tomka 2013). Heavier arrows have more momentum and kinetic energy than lighter arrows shot from the same bow, and the potential energy of the bow was held constant. Therefore, arrow weight was used to standardize the arrow penetration data (Loendorf et al. 2018).

Figure 3 presents boxplots of standardized penetration data for points before and after reworking, and Table 3 summarizes these results. Data for reworked obsidian points are not available because only two obsidian tips could be reworked, and the sample size for the chert points ($n = 6$) is small. But these observations are presented because they have similar patterning to the siltstone and basalt points, which have substantially larger sample sizes. These data show that the reworked points performed significantly worse than the original tips for each of the tested material types. Furthermore, as would be expected, the reworked points also have significantly smaller cross-sectional areas (T-test for equality of means $t = 2.51$; $df = 42$; $p = 0.01$), and the reworked tips consequently produced both shallower and narrower wound channels within the target media.

Although it is impossible to rule out that the performance of the reworked tips would differ under other conditions, these data clearly show a performance decrease. This is not surprising, because if substantially smaller arrowheads performed identically to larger points, then simply consistently producing small tips would save potentially difficult-to-acquire raw materials

Table 2. Percentage of Reworked Points by Raw Material Type.

	Impact strength (μJ/mm)	Rawhide shots per point	Number reworked	Initial total	Reworked percent
Siltstone	11558	2.3	5 (1 twice)	8	62%
Basalt	10882	1.8	4 (2 twice)	10	40%
Chert	5774	1.2	5 (1 twice)	18	28%
Obsidian	4337	1.1	2	20	10%

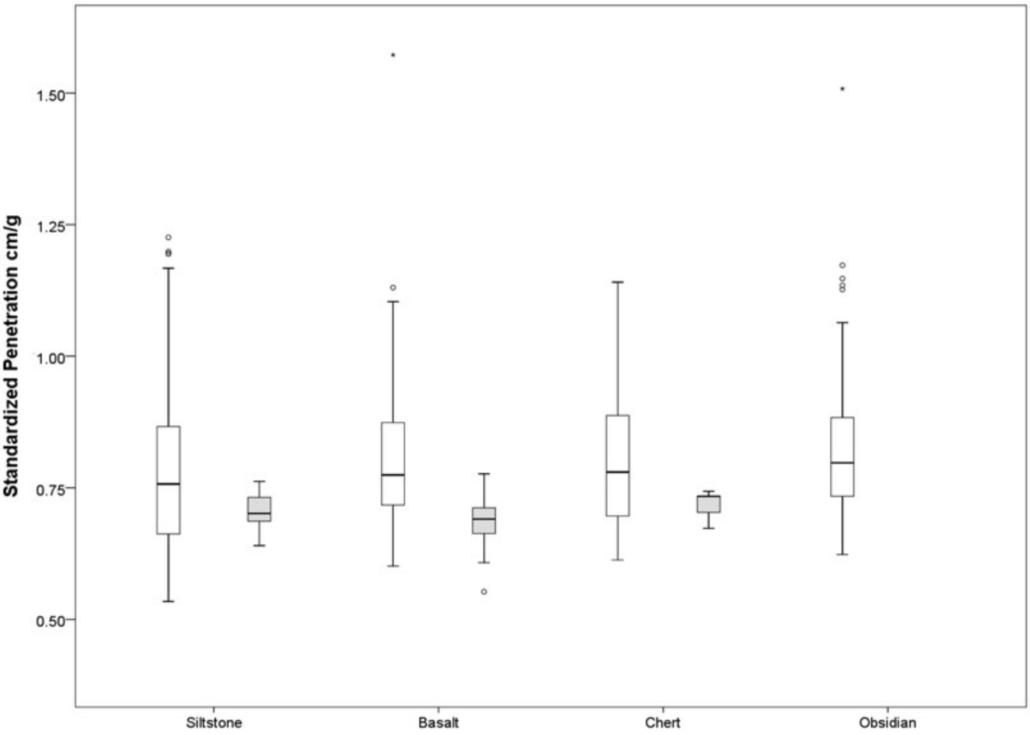

Figure 3. Standardized penetration data for foam targets at 2.3 m by reworking.

and manufacturing time, because smaller points are both faster and easier to produce than larger ones. Finally, the significantly poorer performance of the reworked projectile tips is expected to have limited the extent to which even relatively complete broken arrowpoints would have been reworked.

Reworked Projectile Point Morphology Changes

Reworking of broken experimental points resulted in morphological forms that differ from the original point designs, and the process of rejuvenation resulted in stemmed and corner-notched forms (Figure 4). This patterning is similar to what Flenniken and Raymond (1986) observed in their experiments with atlatl dart tips; however, stemmed and corner-notched shapes are generally rare or absent in small-point assemblages. For example, in the large surface collection from the GRIC for those 148 complete arrow points that weigh less than 0.6 grams (the initial size of points used in the experiments), less than 1% are corner notched and only 1.4% are stemmed (Loendorf and Rice 2004). A more specific example can be seen at the Historic period Sacate site, where there is no ethnographic or ethnohistorical evidence for the use of atlatl darts during the time the site was occupied, while extensive evidence exists for stone point use on arrows used in warfare (Loendorf 2012). Consequently, it is highly improbable that any of the projectile points from the site are atlatl dart tips. The site collection of nearly 100 arrowpoints only included triangular points that lack side or corner notches, as well as stems (Loendorf et al. 2013). This surprisingly strong pattern would not be expected if arrowpoints were commonly reworked. For example, Lerner (2015) posits that, in the course of reworking, triangular points should be reduced into drills, incipiently notched points, and then finally notched points. This possibility is not supported by the Sacate data, because no examples of these posited reduction products were present, and the retouched tool collection consists entirely of projectile points or preforms that all lack notches (Loendorf et al. 2013). This low diversity in arrowpoint form has been documented elsewhere (e.g., Lyman et al. 2009).

Table 3. Summary Statistics for Standardized Penetration Data before and after Reworking, for Foam Targets at 2.3 m.

Material	Summary Statistic	Original	Reworked	Probability
Siltstone	*N*=	93	43	
	Mean	0.79 (cm/g)	0.7 (cm/g)	T-test; $t = 5.2$; $p < 0.01$
	Median	0.76 (cm/g)	0.7 (cm/g)	Mann-Whitney; U = 1661; $p < 0.01$
	Std. Deviation	0.16 (cm/g)	0.03 (cm/g)	
	Interquartile Range	0.69 (cm/g)	0.12 (cm/g)	
Basalt	*N*=	124	57	
	Mean	0.81 (cm/g)	0.68 (cm/g)	T-test; $t = 9.4$; $p < 0.01$
	Median	0.77 (cm/g)	0.69 (cm/g)	Mann-Whitney; U = 4122; $p < 0.01$
	Std. Deviation	0.13 (cm/g)	0.05 (cm/g)	
	Interquartile Range	0.97 (cm/g)	0.22 (cm/g)	
Chert	*N*=	74	6	
	Mean	0.79 (cm/g)	0.72 (cm/g)	T-test; $t = 4.45$; $p < 0.01$
	Median	0.78 (cm/g)	0.74 (cm/g)	Mann-Whitney; U = 211; $p < 0.01$
	Std. Deviation	0.11 (cm/g)	0.03 (cm/g)	
	Interquartile Range	0.53 (cm/g)	0.07 (cm/g)	
Obsidian	*N*=	95	0	
	Mean	0.82 (cm/g)	N/A	
	Median	0.79 (cm/g)	N/A	
	Std. Deviation	0.14 (cm/g)	N/A	
	Interquartile Range	0.88 (cm/g)	N/A	

Finally, obsidian source data for Sacate projectile points suggests that the Akimel O'Odham were not commonly collecting and reworking broken points or flakes from very large and immediately adjacent prehistoric sites (e.g., Snaketown), despite the fact that obsidian was a rare commodity that had to be imported (Loendorf et al. 2013).

Discussion

Although the targets employed in the experiments were artificial, they are comparatively homogeneous and varied in elasticity, as do skin, muscle, and bone. We suggest that homogeneous artificial targets have analytical advantages over more realistic heterogeneous media, such as animal carcasses. First, because stone points are likely to rapidly break, it is more difficult to achieve the large sample sizes that are necessary to identify slight variations in performance (Wood and Fitzhugh 2018). Second, although more similar, animal carcasses do not replicate many important characteristics of living organisms, especially vascular pressure and muscle contractions (Odell and Cowan 1986:202). Thus, neither artificial targets nor carcasses replicate live organisms, and even if ethical issues were ignored and animals were killed, achieving the over 1,200 target impacts that were completed in this study would be nearly impossible. Third, elasticity varies with temperature, and, if carcasses are tested at body temperatures, they will rapidly decay and desiccate, thus requiring frequent replacement. If animal remains are kept at the cooler temperatures that are necessary to preserve them longer, then their elasticity will substantially differ, and the results will not represent the actual conditions of use. Third, heterogeneous targets increase stochastic variation

Figure 4. Reworked points: basalt (left), obsidian (center), and siltstone (right), photograph by Brian Huttick.

that may mask patterning, and this problem is compounded by the small sample sizes that are generally achieved. In contrast, homogeneous materials with consistent elasticity reduce shot-to-shot variation, and comparison across homogeneous targets improves the identification of performance differences. Fourth, the use of uniform medium that are widely available facilitates the replication of experimental protocols, and thus the testing of previously reported patterning. Finally, animal remains can also be used in conjunction with artificial targets in order to compare results (e.g., Wood and Fitzhugh 2018).

It could be the case that other impact media in the environment (e.g., trees, grass, rock, soil, etc.) would produce different results, but additional testing is necessary to evaluate this possibility, and it is improbable that low impact-strength materials would be more durable than higher strength stone in most circumstances. Similarly, although the points employed in the experiments were initially the average size of arrow tips in a large archaeological collection, they are small compared to some arrowpoints. Therefore, it is possible that larger points could perform differently, especially with respect to durability, and additional experimentation is necessary to test this possibility (Odell and Cowan 1986). Nevertheless, it is improbable that the differences observed between the raw materials with varying impact strength would change, and it is unlikely that low impact-strength stones would be durable under any actual conditions of use.

Conclusions

Although this analysis has focused on point reworking for heuristic reasons, in order to examine variability within archaeological flaked-stone collections it is necessary to consider multiple variables, including design factors, reworking effects, and limitations imposed by the available raw materials. For example, data presented here show that it was possible to rework high impact-strength materials substantially more often than low impact-strength stones, and, if durability was the only relevant factor, then low impact-strength stones such as obsidian or chert would not have preferentially been selected for point manufacture. Low impact-strength materials like chert, however, were commonly employed to make arrowpoints, and fine-grained stones have slightly better performance when penetrating elastic materials. In addition to raw material availability, this factor may help explain why these materials were selected over more durable stone types (Loendorf et al. 2018). In addition, when it was possible to rework experimental points made from high impact-strength stone, performance suffered. Again, in addition to material availability, this may also explain why more durable stone types were not always preferred for arrowpoint manufacture. In contrast, physical constraints differ for spear and atlatl dart tips, which both experimental and archaeological data suggest were reworked more commonly than arrowpoints, and high impact strength stones were more frequently employed for atlatl tip production (Loendorf et al. 2018).

Our results show that the elasticity of the target has a major effect on the chance that an arrowpoint will survive an impact, and contact with inelastic materials tended to cause extensive damage. For example, under the moderately high-impact energies employed in the experimental design, all of the points that hit the bone target irreparably broke, and the high probability of impacting bone when hitting an animal or human suggests that a substantial portion of successfully used arrowpoints may not have been recovered or reused. Most of the use-life of points is a period in which they are more likely to be accidentally damaged under lower-energy conditions that may not produce catastrophic damage, for example, by being dropped. The tips of arrows that missed targets and impacted more elastic materials may also have been less damaged. Because of the effort involved in attaching the point to the arrow, tips that were accidentally broken may have been more commonly reworked especially if, as is likely, the damage occurred away from the resources necessary to replace the point.

Finally, our experimental results have implications for stone point analysis. First, if arrowpoints that were used successfully were often shattered in the process, then it would be expected that a disproportionate number of points in archaeological collections should lack residues that resulted from impacting an animal or human target. In addition, because of their greater durability points made from high impact-strength stone that may have more commonly survived impacts are better candidates for residue analyses. Second, if arrowpoints were not always extensively reworked and reused, then their original design attributes are expected to be less often altered during their use-life. This possibility has implications for typological classification analysis, and point variation though time may have been more patterned than expected based on point reworking and raw material expectations alone.

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