Parts and Wholes: Reduction Allometry and Modularity in Experimental Folsom Points

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Projectile points are a common subject of archaeological study. In the past decade, landmark-based geometric morphometrics (LGM) has increasingly been used to analyze points as whole objects. LGM and other studies document allometric changes in points—change in shape with change in size—as a product of resharpening. Allometry registers in part because different segments or modules *of points are subject to different degrees of resharpening, with blades often experiencing more reduction than stems. Different modules retain varying degrees of morphological integrity as points move through their use lives. Most previous LGM studies involved two-dimensional point models, and few tested directly for modularity. We apply LGM methods to three-dimensional models of Folsom point replicas whose degree and pattern of reduction are known, finding evidence for both allometry and modularity, with modest integration. Complementary non-LGM data reveal similar results, indicating a robust pattern and ways to approximate LGM results in other data. Moreover, our dataset's experimental control clearly identifies the results as a function of the progressive reduction in use experienced by points.*

Keywords: Folsom points, allometry, modularity, geometric morphometrics, reduction

Cabezales líticos son sujetos populares en análises arqueológicos. Recientemente, la geometría morfométrica basada en hitos (LGM en inglés) se ve aumentanda en el análisis de cabezales como objetos enteros. La LGM y otros estudios documentan cambios alométricos —cambio de forma con cambio en tamaño— entre los cabezales como producto de la reactivación. En parte, se registre la alometría porque segmentos distintos, es decir módulos*, de los cabezales se sujetan a grados diferentes de la reactivación, los limbos a menudo soportando mas reducción que las pedúnculas. Módulos distintos conservan grados diferentes de la integridad morfológica como pasan los cabezales a lo largo de sus vidas útiles. La mayoría de estudios anteriores de la LGM involucran modelos 2-dimensionales de los cabezales, y pocos investigaron directamente la modularidad. Aplicamos métodos de la LGM a modelos 3-dimensionales de réplicas cabezales del tipo Folsom, entre quienes se conocen grado y patrón de la reactivación. Encontramos prueba de ambas de la alometría y la modularidad, con integración intermedia. Medidas complementarias no-LGM revelan resultados semejantes, indicando un patrón bien fuerte, y tambien maneras a aproximar los datos y resultados de la LGM en otros fuentes o tipos de datos. Más bien, los controles experimentales que residen en nuestros datos identifiquen claramente los resultados como función de la reducción en uso secuencial a que los cabezales se sujetaron.*

Palabras clavas: puntas de tipa Folsom, alometría, modularidad, morfométrica geométrica, reactivación

Projectile points are important for many reasons. Types mark intervals of past time, register activity by their gross form and use wear, and may distinguish social or cultural groups. For these and other markers of human behavior, points long have been popular subjects of study.

Some tools were handheld in use, but points usually were components of larger, composite tools. Most archaeologists regard points as

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integral wholes, but even the smallest hafted point is made up of parts. To its users, the different segments or "modules" of a point served different purposes and were treated differently. From the perspective of hunters, minimally, tip modules initiated wounds in animal prey, blade modules deepened them, and stems articulated the exposed blade to the composite tool. Modularity may be resolved even more finely: stem modules are defined by overall size and shape, whereas fluted points have more specific functions related to adhesion to mastics in the haft. Understanding how blade and stems, or their own parts, worked as modules and together to propel a point or provide mass to aid thrust was probably critical to hunting success.

People likely perceived point modules in accordance with their function. For example, by their acuity, length, and plan form, edges could comprise modules (e.g., during beveling) or perhaps components of larger modules of the tip (if edge properties assisted penetration) or of the blade (if they aided wound expansion). If points also functioned as knives or other tools, different modules may have had joint or dual purposes (for example, blades deepen wounds, while their edges also are useful in filleting or scraping) that forced compromises in their design. Point segments may have comprised modules of a particular size and configuration for some purposes like use as weapon tips, as well as modules of different sizes and configurations for other purposes. Depending on the analytical purpose, points can be treated as wholes or as things of sometimes complexly organized parts.

Obviously, points cannot grow, but they can shrink because damage or dulling necessitates repair by resharpening. Therefore, points can change in size and shape during their use lives, a quality that recommends modular approaches to their study because some modules may change more and some less in the process and proportions between them may change greatly. Changeability as an integral property of points may seem paradoxical, but specimens may experience varying degrees and patterns of reduction in use that any comprehensive treatment of their variation must consider.

Traditionally, archaeology treated points mostly as wholes, often simply by classifying them as Type X or Y based on their overall form (e.g., Justice 2002). Even advanced studies usually treat points as wholes, not only in analysis of the attributes that all modules share (e.g., tool stone) or those that measure their collective magnitude (e.g., mass) but also in measurement. Usually, we define and measure whole-object dimensions (e.g., length) that crosscut modules and whose variation among specimens or over any point's use life may differ between modules. Of course, dimensions may be measured separately for any modules defined. But measuring *the* length or width of points treats them as undifferentiated wholes and obscures the segmentation—modularity—that may inhere in them.

To illuminate the problem of parts and wholes, this study considers a holistic approach to point morphology. We use three-dimensional (3D) models of points from a controlled experiment and their 3D morphometrics to assess the effects of resharpening on the variation and covariation between point wholes and their parts as modules. Our broader contribution to lithic analyses is to suggest that signals of modularity coupled with allometry may indicate that curation could have played a role in generating such patterning.

Morphometric Analysis of Points

The application of landmark-based geometric morphometrics (LGM) to point analysis has quietly revolutionized the field (Shott 2014). LGM characterizes whole-object form much more comprehensively than do traditionally reported dimensions, and associated software permits more thorough analysis of point size and shape than is possible otherwise. But detail in characterization is only one of LGM's virtues. From its origins in biology, LGM has acquired a set of concepts and associated analytical methods that facilitate a modular view equally relevant to points and to organisms.

LGM originated to characterize the size and shape not only of whole organisms but also of their anatomical modules (e.g., limbs, organs)

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and their geometric configurations. During individuals' growth or over evolutionary time, modules' size and shape can vary, and they can covary with one another in strong or weak degrees. The strength of covariation between modules describes their degree of integration.

In LGM studies, *modules* are sets of contiguous landmarks (2D or 3D coordinates of locations on larger wholes) whose covariation is greater within the module than they are with landmarks outside the module. Thus, they are "tightly integrated internally but relatively independent from other . . . modules" (Klingenberg 2008:116). Modules thus are entities, components of large wholes. *Integration* is the degree of covariation among the modules that comprise the whole: the "coordinated movement of the [modules] of the structure relative to one another" (Klingenberg 2008:117). Of course, some covariation integrates all parts of larger wholes; sets of objects do not vary by kaleidoscopic randomness. Modularity measures the degree to which covariation patterns geometrically within the whole, integration the degree to which separate modules covary strongly or weakly. Modules of any size, shape, and location may be defined for any analytical purpose. Defining modules is a statement of hypothesis that requires testing in the variation found among study specimens.

For various reasons, what applies to organisms' modules like limbs and organs applies equally to points: whole objects are divisible into modules. Modularity and integration can be studied at levels from individual growth to evolutionary change—developmental/ontogenetic to evolutionary, respectively, in Klingenberg's (2008:117–119) terms. Our study concerns allometric variation in points, which is analogous to ontogenetic allometry in biology. Allometry—the change in shape with a change in size—may characterize variation not only between point types but also among specimens *within* types, as a function of the reduction for maintenance that points may experience from first to last use. Because "types of modularity and integration closely parallel . . . types of allometry" (Klingenberg 2008:120), they engage allometric variation and its analysis.

Allometry and Reduction

During use, curated stone tools were damaged or dulled and then resharpened. Unless all tool modules were resharpened in proportion to their sizes, some must have experienced disproportionate resharpening and therefore reduction. Archaeologists sometimes refer to this disproportion as the "Frison effect" (Frison 1968). It also is allometry: a change in proportions among modules (and therefore shape) with a change in size. Hoffman (1985) extended this effect to the study of points, arguing that reduction concentrated changes on blade modules more than on stems.

If modularity occurs, then different modules require separate treatment for some analytical purposes. Research can test modularity by comparing the covariation of traits within modules to their covariation with traits in other segments. Most studies to date document allometric reduction effects, usually in 2D models of archaeological specimens. Investigations of modularity are uncommon (but see González-José and Charlin 2012). The reduction thesis argues that both allometry's cause—damage repair by resharpening—and its effects on size and shape characterize the life history of tools (Iovita 2010; Shott 2005). However, not all stone tools were necessarily resharpened throughout their life history; reduction allometry was probably common but not universal.

Archaeologists have documented allometry from many times and places in many tool types, including unifacial scrapers and flake tools (e.g., Ahler and Geib 2000; Blades 2003; Dibble 1987; Goldstein 2014; Hiscock and Attenbrow 2005; Iovita 2010, 2011; Morales 2016; Sahnouni et al. 1997; Shott and Weedman 2007). The reduction thesis is particularly well documented in bifaces (e.g., Andrefsky 1997, 2006; de Azevedo et al. 2014; Bement 2002:136; Buchanan 2006; Charlin and Cardillo 2018; Charlin and González-José 2018; Ellis 2004; Flegenheimer and Weitzel 2017:150; González-José and Charlin 2012; Hashizume 2009; Iovita 2011; Iovita and McPherron 2011; Iriarte 1995; Lerner 2015; Li et al. 2015; Loyola et al 2017:21–22, Figure 14; Miller 2018:93–99; Peterson 1978:141, Fig. 2; Prentiss et al. 2016;

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Serwatka 2015; Shott and Ballenger 2007; Shott et al. 2007; Skinner 2018; Smallwood et al. 2018; Suárez 2011:179–183, 2017; Wheat 1975; Wilmsen and Roberts 1978:108–120), even in relatively crude Middle Paleolithic bifaces (e.g., Presnyakova et al. 2018: Table S4). Reduction is also reported in ethnographic sources, mostly in flake tools and unifaces, because bifaces are rare in such accounts (e.g., Hayden 1977; Sahle and Negash 2016; Shott and Sillitoe 2005; Tindale 1965; Weedman 2000).

Buchanan's (2006) analysis of archaeological Folsom points from the North American plains is particularly relevant to our study. He defined a set of "inter-landmark distances" (ILDs) between locations that included the tip, base corners, and midpoint and points of maximum width (Buchanan 2006:Figure 2, Table 3). This scheme provided a different, somewhat more detailed 2D description of point form than standard dimensions. Buchanan measured point size as 2D plan area size and regressed the log-transformed ILDs individually on log-area. He found allometric variation with size in several ILDs (Buchanan 2006:195, Table 6) indicated. Corroborating Buchanan, others reported similar results for linear dimensions, along with mass and allometric measures (Miller 2018:90–93; Shott 2020; Shott et al. 2007:212, Table 5): length and all ratios were positively allometric, whereas width and thickness were negatively allometric. Buchanan's approach represented an advance, suggesting that many ILDs likely vary with the degree of reduction that points experienced. However, it is essential not to treat some dimensions (e.g., "BW," width at one-third of total length above base corners) as design attributes. The location of these dimensions changes with reduction because the total length from which they are calculated declines with reduction.

The reduction thesis and the allometry and modularity it engenders have important implications. One is typological. Changes in specimens of a single original type's size and shape resulting from resharpening can cause them to be confused with different types of points (e.g., Hoffman 1985) and flake tools (e.g., Dibble 1987; Hiscock and Attenbrow 2005). Understanding allometry's effects on points requires distinguishing at least blade and stem modules. Stems may change in use less than blades, both because blades usually are bigger ceteris paribus and they can experience more damage than stems, thereby requiring more resharpening (Flegenheimer and Weitzel 2017:150; Loendorf et al. 2019:358; Odell and Cowan 1986:204). Resharpening decreases blade length substantially; blade (less likely stem) width may decline, but thickness changes little, if at all (e.g., Andrefsky 1997; Ellis 2004; Hashizume 2009:279; Hoffman 1985; Peterson 1978; Shott and Ballenger 2007; Shott et al. 2007:Table 1). Depending on the degree and pattern of reduction, those changes can produce sufficient variation in size and form at discard to make specimens of the same original type appear to be different types (Hoffman 1985). For instance, "San Jon" points may be merely a reduced version of Firstview points (Wheat 1975). Reduction also can make specimens in different types look similar. Among Patagonian stemmed-point types, "reduction constraints impose some limitations in phenotypic variability, leading to shape convergence among different types of . . . points" (Charlin and Cardillo 2018:123). Valid typological judgments of stone tools must take reduction effects into account.

The reduction thesis has implications beyond typology, certainly for points. Reduction patterns suggest kinds of use by identifying the edges or segments of tools that were retouched. In addition, the degree of reduction is a measure of curation, an important theoretical concept (Binford 1973; Shott 1996). Tools vary in their curation rates. Just as plotting the distribution of metric dimensions like length or width is informative for some purposes, plotting the distribution of reduction measures among specimens indicates assemblage accumulation rates and type composition (Dibble 1987; Surovell 2009). Reduction distributions calibrate discard rates of tool types to common scales and implicate causes of discard (Shott 2016). Fitted to the Weibull model, for instance, distributions indicating a constant discard rate, regardless of the degree of curation, identify chance as a cause of discard, whereas those indicating that the discard rate increases with curation implicate attrition. Moreover, different ranges of the Weibull shape parameter

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β implicate different failure scenarios. When $1 < \beta < 2$, failure rate increases at a decreasing rate consistent with early wear-out failure, when $\beta = 2$ failure increases at a constant rate, and when $\beta > 2$ failure increases at increasing rate (e.g., Douglass et al. 2018; Morales 2016; Shott and Seeman 2017:732). Similarly, reduction distributions can distinguish between, for instance, competing scenarios of Folsom hunting practices by linking the duration of point use—and, by extension, distributions themselves—to different assumptions about group size and hunting rates (Hunzicker 2005:55–60). Reduction patterns within or between tool types comprise an integral characteristic of type specimens just like their metric dimensions (Iovita 2010:236).

Beck's (1995:234–237) selectionist study revealed that longevity and the related quality of impact resistance and, by extension, curation rate distinguished Great Basin dart types. Side-notched points were selected against partly due to their lower impact resistance and resulting shorter use lives. Degrees of curation and the form of their reduction distributions can test theoretical models of tool use and wider adaptive practices. Miller (2018:55–63) used the marginal-value theorem to model points as resource patches, relating their degree of utility extracted—therefore reduction—to varying hunting-return rates. This treatment makes reduction a behavioral variable to be explained by, and thereby tracking, long-term adaptive processes leading in Miller's study to the origins of agriculture. In the process, the argument both invokes the utility concept (Shott 1996) and makes the form of point types' reduction distributions (Miller 2018:Figure 3.1) relevant to sophisticated behavioral modeling. The use of multiple reduction measures and their multifactorial reconciliation establish comparability between measures and studies (Shott and Seeman 2017), quantifying the degree of curation and grounding behavioral models in data.

On balance, "reduction is an important source of variation on size and shape differentiation between point assemblages" (Charlin and González-José 2018:169). Because reduction is not necessarily proportional, "major distinctions between groups of points, when measured using blade characteristics, are likely the result of differential resharpening activities" (Prentiss et al. 2016:127). Precisely because of such differential patterns, analysis should avoid freely combining characters from blades and stems that might comprise separate modules. The work of Prentiss and colleagues (2016:124, Figures 10–12), for instance, yielded phylogenetic inferences from separate analyses of point stems and blades that were obscured by treatment that combined those modules.

Some researchers, however, disagree on the effects of resharpening. Although Buchanan (2006) found considerable evidence for allometry in Folsom-point variation using 2D outline methods applied to a sample of midcontinental Clovis points, Buchanan and Collard (2010; see also Buchanan et al. 2015) argued that Clovis points either experienced little resharpening reduction in use or little allometric shape change. In their view, any resharpening that occurred was proportional among all dimensions and modules, with only a possible reduction in size that did not involve significant shape change. Inferring that Folsom points at Lindenmeier regularly were resharpened, mostly on blades, and that the resulting reduction altered points' forms disproportionately (i.e., a reduction thesis stated decades before the question acquired salience), Wilmsen and Roberts concluded that it "must be tested before its validity can be ascertained" (1978:111). Following from Buchanan (2006), our study is designed to test Wilmsen and Roberts's view and the broader reduction thesis, in part in an attempt to resolve uncertainties. In addition to archaeological specimens, our study includes experimental specimens that provide independent control over resharpening and other effects that can resolve the question.

Approaches to Point Reduction

As mentioned, point reduction is observed in many contexts. There is no reason to doubt that Folsom points might be subject to reduction allometry. In fact, damage and repair are central to models of Folsom design and use (Ahler and Geib 2000; Hofman 1992:212–213), and empirical evidence of resharpening is common (Bement 1999:113; Titmus and Woods 1991:127;

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Wilmsen and Roberts 1978:108–111). Previous studies of point reduction used geometric or allometric measures. Geometric ones included retouch invasiveness (Andrefsky 2006), plots of blade edge-angle against length (Hoffman 1985:581–583), and sharpness indexes approximating the geometry of point form by a set of detailed measurements near the specimen tips (Lerner 2015; Quinn et al. 2008). Allometric measures included simple ratios of length-to-thickness (L/T) and mass-to-thickness (M/T; Iriarte 1995:143–144, Figure 3) validated in earlier analysis of the current dataset (Shott et al. 2007) and the ratio of shoulder angle to blade length (Suárez 2011:182). Reduction allometry also is documented using Fourier methods (Iovita 2010, 2011).

Particularly valuable, however, are studies that use LGM methods (e.g., de Azevedo et al 2014; González-José and Charlin 2012), because compared to traditional analytical approaches, LGM methods at once are richer and more detailed in data capture and more amenable to analysis using more powerful methods. That is, they approximate the fullness of 2D and especially 3D form better than do orthogonal dimensions or ILDs. (Most studies cited earlier analyzed 2D outlines or other characterizations of points.) LGM also can define modules, which is not easily accomplished in ILD studies. As a result, LGM analysis can test explicitly for modular integrity and allometry. (MacLeod's [2019] pixel-based method also deserves consideration in future research.) Biological analysis often uses LGM to study modularity and allometry characterizing not only physical growth and development but also possibly phylogenetic relationships between taxa (e.g., Adams and Otárola-Castillo 2013).

Yet few of the stone-tool reduction measures noted earlier have been tested and validated in experimental data, and even fewer use LGM methods. Whatever ambiguities may inhere in the interpretation of LGM analysis of archaeological specimens are controlled for in experimental studies that furnish independent evidence for the causes invoked, such as allometry. Goodyear's (1974:Figure 12) classic example of the progressive reduction of a single Dalton-point replica documented the changing proportion among orthogonal dimensions. He made, used, and resharpened the point over four cycles, from original size and shape to unworkable remnant (Goodyear 1974:28). Resharpening occurred on the blade only, the stem experiencing no reduction. Essentially, this made Goodyear's experiment a null case of reduction confined strictly to the blade (Shott 2020:Figure 2a). The experiment suggested a disproportionate reduction in width on the blade, not stem, and at varying rates, with more width reduction occurring in the first than in successive resharpenings, compared to length; of course, there was patterned variation in the ratios of both blade area to stem area and blade length to stem length, because only the former changed during the experiment. Trivially, the Dalton replica was reduced by resharpening. Nontrivially, that reduction was attended by systematic variation in ratios between dimensions and in the relative size of the blade and stem modules. Skinner (2018:37–49) documented similar effects in Western Stemmed Tradition experimental replicas. Analytical approaches that fail to distinguish stem and blade modules risk obscuring informative variation in resharpened points.

Materials and Methods

We report analysis of reduction effects in experimental replicas of Paleoindian Folsom points (Hunzicker 2005, 2008). Earlier analysis of this dataset used dimensions and other measures of specimen size (length, area, mass [of chert originals as reported by Hunzicker, not resin casts]) and simple ratios computed by dividing each of them by near-constant thickness (Shott et al. 2007) or ILDs (Shott 2020). In our study, LGM methods test for the effects of allometry and modularity. In Klingenberg's (2008) terms, our focus is on developmental or ontogentic modularity and the resulting allometry. In contrast to most previous studies that analyzed 2D point models, ours involves 3D models.

Data

Hunzicker studied 25 Folsom points made by Bob Patten, an accomplished knapper (Patten 2005). Using several hafting and propulsion methods, Hunzicker fired spears tipped with the points into the rib cages of slaughtered cows.

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The experiment's chief goal was to gauge the durability and performance of combinations of hafting and propulsion (Hunzicker 2005:32–47). After each cycle of use and damage, points were removed from hafts and examined for type and the pattern and extent of damage. Except when damage was catastrophic, with the point shattering into too many pieces to salvage, Patten repaired the points by careful resharpening in "a complex process involving simultaneous efforts to restore symmetry, reduce tip thickness, [and] improve alignment" (Hunzicker 2005:28). Most resharpening occurred, as Wilmsen and Roberts (1978:108–111) expected, on the exposed blade and tip (see also Ahler and Geib 2000; Flegenheimer and Weitzel 2017; Odell and Cowan 1986). Figure 1 illustrates this pattern of damage location. Yet stems wrapped in sinew and covered with mastic also could and did suffer damage in use. Even when stems were not damaged, repair and resharpening of the blades, when they were removed from the hafts, could impinge on stems and thereby reduce them (Hunzicker 2005:27–29). That is, reduction by resharpening occurred mostly on blades but somewhat on stems as well. The effect was to shorten the points (and, of course, reduce their mass) but to alter other dimensions little if at all, thereby changing the shape and the proportions among dimensions (Figure 2). Allometry that may attend this process resides mostly, not entirely, on blades.

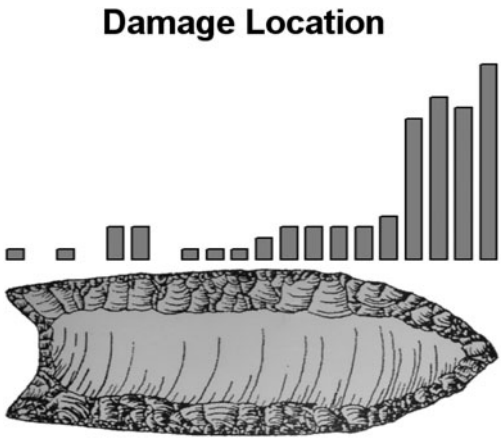


Figure 1. Major patterns of damage location in Hunzicker Folsom replicas, showing concentration on tip and blade (from Hunzicker 2005:Figure 7).

Most experimental points survived the first cycle of damage and repair, and 22 of 25 experienced two or more cycles. Hunzicker made resin casts of specimens before their first use and after each repair cycle, yielding a total of 82 versions of the 25 originals. Overall, points survived an average of about 3.3 cycles (82 cycles for 25 points). Therefore, we know how long each replica was used and how much it was reduced in each of as many as five cycles encompassing first use and subsequent repair and reuse. For most original specimens and their repaired and reduced versions, successive use-and-repair intervals were numbered successively 1, 3, 5, 7, and 9, limited, of course, by the number of cycles that each survived. For instance, specimen B22 experienced four cycles of repair after first use. Accordingly, its first use was as B22.1, then progressed through B22.3, B22.5, and B22.7 before culminating in B22.9. (Intervening even numbers usually were reserved for damaged but not yet repaired versions of each specimen in each repair interval. Although Hunzicker also made casts of these damaged versions, they are not considered in this study.)

Mean length ranged from 60.0 mm before first use to 31.4 mm by final reuse stage, with mean maximum width ranging from 22.5 to 20.7 mm and mean thickness from 4.8 to 4.5 mm over the same range of uses (Shott et al. 2007: Table 1). This range of values resembles mean dimensions of finished and used Folsom points reported by Lassen (2016:Tables S1–4) across the Plains, Ahler and colleagues (2002: Table 5.7) for the northern Plains, Asher (2015: Table 11) for the central Plains, and Collins (1999:26) and LeTorneau and Baker (2002: Table 3.4) for the southern Plains. At the type site, the sole intact Folsom specimen (AMNH 20.2.5865) measured 56 mm in length, 24.2 mm in maximum width, and 3.9 mm in maximum thickness, and two intact specimens described as "reworked" (Sn23/CAVO-116 and Sn24/B.Burchard; Meltzer 2006:Table 8.2) measured between 32 and 35 mm in length, 19 and 22 in maximum width, and 4.0 and 4.6 in maximum thickness (Meltzer 2006: Table 8.4). At Lindenmeier, weighted means were 35.7 mm for length, 18.6 mm for maximum width, and 3.8 mm for maximum thickness,

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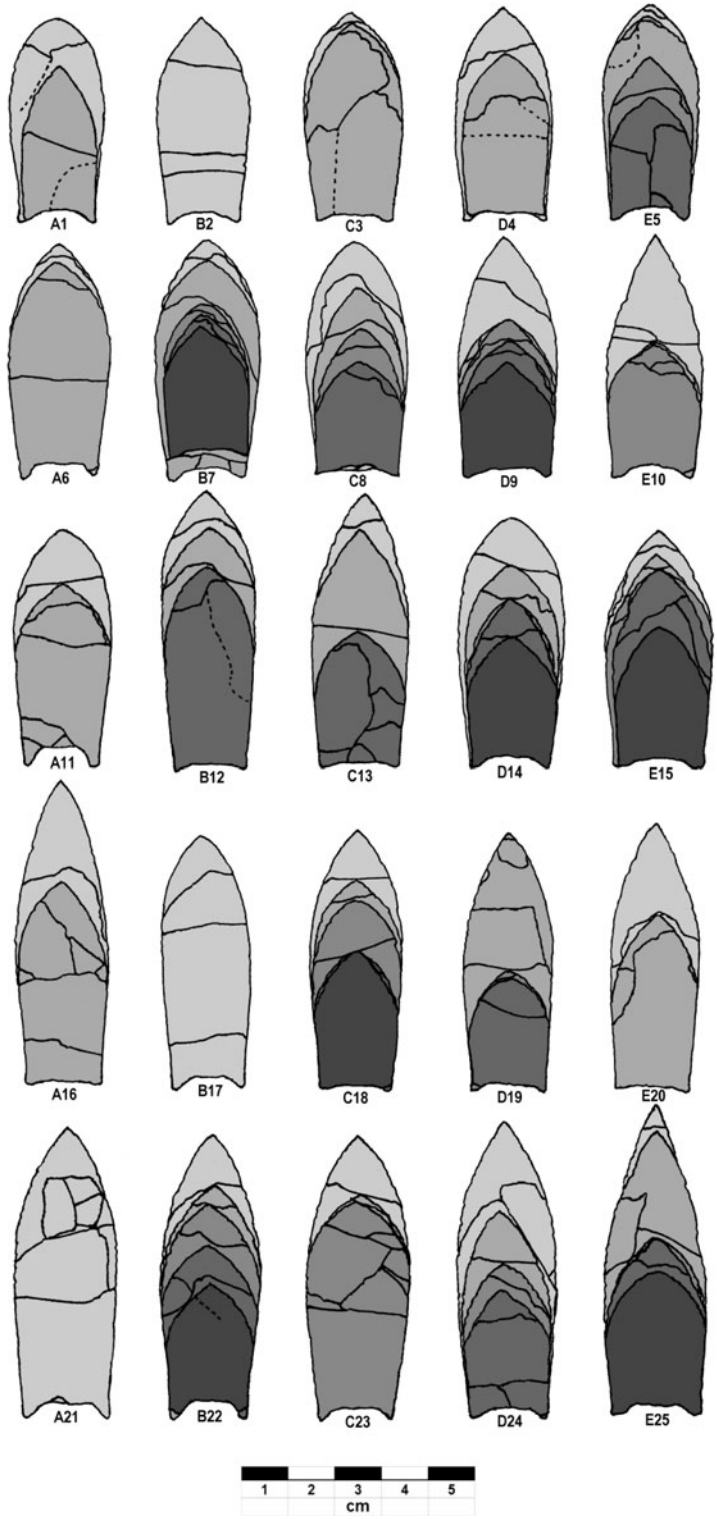


Figure 2. Hunzicker Folsom replicas showing pattern and range of reduction by breakage and repair. Progessively reduced versions of each original specimen shown in darker shading. Dashed lines indicate visible fractures that did not detach (from Hunzicker 2008:Figure 6).

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although these measurements referred to "whole points (including fragments)" (Wilmsen and Roberts 1978:Table 43; see also Ahler and Geib 2000:808), so may not be strictly comparable to those cited earlier. Ahler and Geib (2000:813; see also Collins 1999:26) considered the maximum length of unused Folsom points to be approximately 75 mm and the length of depleted specimens to be roughly half that (although according to Collins, resharpened Folsom points "as short as ca. 25 mm are not uncommon" [1999:26]). Hunzicker (2005:44) considered 30 mm a minimum value for the length of Folsom points. Consistent with these expectations, mean dimensions in the highly reduced Cooper assemblage are 33.7 mm for length, 19.3 mm for maximum width, and 3.5 mm for maximum thickness (Bement 1999: Table 1). In contrast, Lassen's (2016) dataset ranges widely in length from less than 20 mm to 75 mm, although specimens more than 50 mm in length form a relatively small right tail.

On balance, Folsom replicas seem reasonably faithful in major orthogonal dimensions to archaeological specimens documented over a wide geographic range. Yet judging by these studies, they may be somewhat shorter at first use and slightly thicker on average than archaeological specimens, even though their thickness falls squarely in the range reported by Asher (2015:Table 11). Assuming these differences, their effects on point longevity and pattern and degree of reduction are unknown.

Here and elsewhere (e.g., González-José and Charlin 2012), the tip angle formed by the converging blade margins is considered an original design attribute but one also subject to change as reduction progresses. For instance, Ahler and Geib observed a pattern "in which the longest whole points or most lengthy distal tip fragments . . . have the most acute front [tip] angles" (2000:809). Consistent with this observation, tip angles of Folsom replicas not only tended to increase—become more obtuse—with resharpening but also regularly exceeded 90°. Overall, the tip angle was roughly normal in distribution, with its mean about 82° and its range 45°–115°. Although such wide tip angles may seem dysfunctional, Ahler and Geib's (2000:809, 813) reported tip angles in Lindenmeier and other Folsom assemblages that often exceeded 90° and even 100°. Similarly, South American fluted points ranged from 60° to 140°, with one outlier at 170° (Suárez 2017:289; see also Hermo et al. 2015:109–110). Overall, about 15% of Suárez's sample exceeded tip angles of 130°; whether specimens bearing such obtuse tips remained points or took on other functions (Suárez 2017:289) is less important than the fact that they continued in use.

Hunzicker's dataset is useful for several purposes. The average number of shots and the distribution of values across specimens are well suited to use-life and survivorship analysis (e.g., Shott 2016). Our current interest, however, lies in the progressive reduction of Folsom points at each interval of use and repair and whether signals of allometry, modularity, and integration reside in their patterns of variation.

Analysis

In earlier analyses of these data, ratios of length: thickness (L/T) and mass:thickness (M/T) correlated strongly with reduction and the number of use-repair cycles (Shott et al. 2007), as did ILDs identified mostly with blade modules (Shott 2020). These correlations were attributed to allometry. Biological allometry acts with growth, but the allometry of finished stone tools acts with their reduction by combinations of resharpening and repair, as discussed earlier. Allometry in repair of damaged points acts similarly in some respects—for example, in earlier analyses, by reducing L/T as reduction proceeds because length was progressively reduced in repair, whereas thickness remained virtually unchanged—but differently in others (e.g., in rate, by occurring more sporadically and producing abrupt, relatively large-scale change in both point shape and size; Ellis 2004; Peterson 1978). We used LGM analysis to investigate allometry and, following Hoffman's distinction between blade and stem, the modularity that may exist in the data.

Workflow

Hunzicker's Folsom replicas include both the 25 original specimens and the 57 resharpened and reduced versions through which most of the

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originals transited; seven could not be processed, yielding a total of 75 analyzed models, which were scanned and postprocessed in NextEngine™ to produce 3D models. We then exported them as .ply files to place six Type-I landmarks at the tip, distal extent of lateral-edge grinding (to distinguish stem and blade, demarcated by a line perpendicular to the axial length at the most proximal of the two points) and at base corners, and center in Landmark (IDAV 2007) along with mesh landmarks on blade and stem modules.

We then imported these to geomorph (Adams and Otárola-Castillo 2013) using custom programs in R. Each artifact model's point cloud was downsampled to 1,000 sliding semi-landmarks using Template Correspondence (TempCorr) to a randomly chosen model as in Dines and colleagues (2014). Combined with the fixed and mesh landmarks noted earlier, this step yielded $\Sigma n = 1{,}143$ total landmarks and semi-landmarks. For modularity analysis we distinguished blade and stem modules at the distal terminus of edge abrasion to facilitate hafting. TempCorr ensures correspondence of sliding surface semi-landmarks among specimens, efficiently reducing the size of each model's mesh while retaining sufficient corresponding points to ensure the adequate quantification of morphological variation (e.g., Otárola-Castillo et al. 2018). LGM analysis computed centroid size (CS; natural-log-transformed as lnCS) as the square root of the sum of squared distances from each landmark point to the centroid.

We then used Generalized Procrustes Analysis (GPA) superimposition, fixing Type I landmarks and sliding along tangents in one direction for edge and two directions for surface semi-landmarks (Otárola-Castillo et al. 2018; Supplemental Table 1). Geomorph GPA obtains shape variables from landmarks by translation, scaling to unit-centroid size, and rotation. GPA-aligned landmarks often are interpreted as size-free shape data; strictly, GPA minimizes differences between subjects' landmark configurations, yet scaling of each one's landmark coordinates to its centroid size rescales, but does not eliminate, shape variation that correlates with size. Principal-component analysis (PCA) of aligned landmarks identifies major dimensions of shape variation. The common allometric component (CAC), "estimated by a pooled regression of the shape variables . . . on [centroid] size" (Mitteroecker et al. 2004:684), is computed by geomorph's procD.allometry, here using 999 iterations.

Testing for Modularity and Integration

To gauge modularity between the blade and stem landmarks, we used the covariance ratio (CR; Adams 2016), the ratio of between-to-within module covariation. The higher its value, the greater the between-module covariation; lower values indicate greater within-module covariation. CR values are between 0 and 1 when the degree of covariation between modules is less than within modules, a pattern that characterizes modular structures. When the associated p value is significant, greater than expected independence among modules occurs under a null model of neither a modular nor an integrated structure. By contrast, CR values larger than 1 describe greater covariation between modules than within modules. If the p value is significant, there is significantly greater dependence among modules than expected under the null model.

We evaluated the degree of integration using a two-block partial least squares analysis (2B-PLS). This technique identifies the major axes of covariation between the two "blocks" of shape data, in this case the stem and blade modules (Rohlf and Corti 2000). Significance was assessed by permutation, following details in geomorph's two.b.pls function.

Complementary Measures

There are numerous geometric measures for unifacial tools (e.g., Shott and Seeman 2017:729–731). For points, Hoffman proposed an allometric measure: a ratio of point length to blade edge-angle that captures "a *dimension* or scale of variability that can be used . . . to measure the use-life of a point" (1985:581; emphasis in original). Lerner (2015) applied this measure to eastern North American triangular arrow points, documenting an inverse relationship between point length and tip angle. Earlier (e.g., Ahler and Geib 2000:809; Iovita and McPherron 2011:67; Odell and Cowan 1986:204) and later (Charlin and González-José

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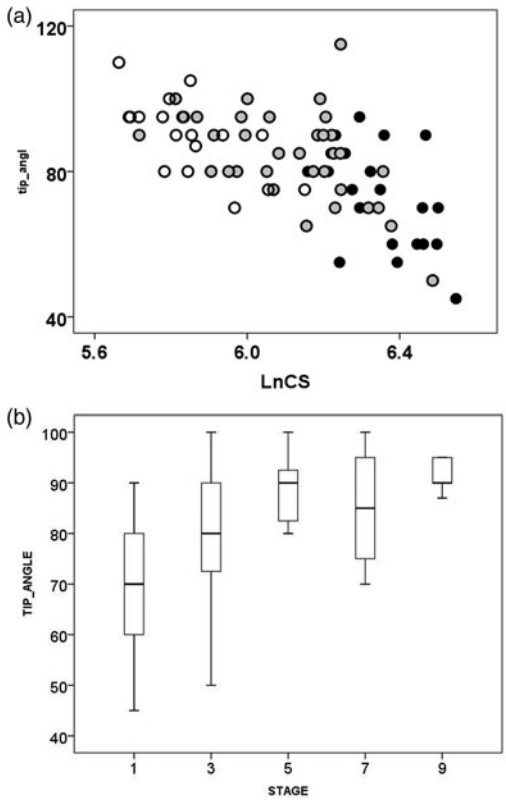


Figure 3. Tip angle against lnCS: (a) By grouped reduction stages (solid circles = Stage 1, shaded circles = Stages 3 and 5, open circles = Stages 7 and 9); (b). boxplot by reduction stage.

2018:163; Suárez 2017:288–289) studies also showed tip angle increasing as reduction progressed. In Folsom replicas, tip angle generally but not always increases with resharpening (Figure 3). For instance, specimen C18's tip angle fluctuated from 85° as C18.5 to 105° as C18.7 and then back to 95° as C18.9. We also calculated the ratio of blade length to stem length (González-José and Charlin's [2012] IBR) validated as an allometry measure, along with tip angle, L/T, and M/T (Supplemental Table 2). In earlier analysis L/T and M/T patterned strongly with the extent of reduction as allometric measures, determined on independent grounds in these controlled experimental data: both numerator quantities were reduced at each use-and-repair cycle, whereas the denominator was substantially unchanged (Shott et al. 2007). These measures were retained for additional analysis that followed Procrustes superimposition and LGM analysis.

Results

Modularity and Integration

Results from 2B-PLS analysis of 500 permutations show that stem and blade modules covary significantly. However, CR results also show that within-module covariation is stronger than between modules, as in earlier studies (González-José and Charlin 2012:3–5). Results indicate both strong stem-blade modularity (i.e., CR < 1; Adams 2016) and weak integration (Table 1).

This is not the paradox it may seem. As in archaeological cases (e.g., Bement 2002), Hunzicker (2005) sometimes removed damaged points from hafts, and stems sometimes were shortened as blades were resharpened. Therefore, both modules could be reduced but to different degrees that register in both allometry and modular integration (i.e., the shape changed with its size not because stems were not reduced at all but because the modules were reduced disproportionately). In Folsom assemblages, stem length can vary between 21 and 50 mm as a function of resharpening (Bement 2002:137), suggesting similar effects. Stem and blade modules exist, and landmark covariation within each is stronger than between them. As points were used, damaged, resharpened, and therefore reduced, blade modules experienced greater proportional reduction than did stems. Yet both modules decreased in size, reflecting some integration between them.

Allometry

The geomorph PCA of GPA-aligned landmarks is summarized in Table 2, where PC1–4 account

Table 1. Modularity and Integration Analysis.

	Modularity		Integration	
Stage	CR	p	2block PLS r	p
1	0.818	0.002	0.886	0.034
3	0.925	0.002	0.938	0.001
5	0.942	0.002	0.960	0.001
7 & 9	0.898	0.002	0.933	0.001

Notes: CR = covariance ratio; PLS = partial least squares.

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Table 2. geomorph PCA Results.

Component	Eigenvalue	%variance
1	0.013	62.3
2	0.003	14.9
3	0.002	7.5
4	0.001	3.7

for 88.4% of variance. The first component extracted ("shapePC1" here) typically is interpreted as the major dimension of size-free shape (e.g., González-José and Charlin 2012). Plotted with PC2 (Figure 4), shapePC1 shows clear patterning by grouped reduction stage: Stage 1 specimens tend to have negative shapePC1 values, with later-stage ones having mostly positive values. If size patterns with stage, then shapePC1 preserves both size and shape variation. The plot also shows that PC2 scores for later-stage specimens converge toward 0; among recorded variables, PC2 correlates only with IBR ($r = -0.76$ $p < 0.01$).

Again, lnCS is a size measure. As elsewhere (e.g., Charlin and González-José 2018:165), shapePC1 and lnCS clearly covary, indicating allometry (Figure 5). To explore the relationship further, original use-repair stages 1, 3, 5, 7, 9 were pooled (to reduce clutter in graphic output) into 1, 3, 7 (representing 1, 3 + 5, 7 + 9). Specimens sort by pooled stage in Figure 5 (and subsequent figures), with Stage1 versions

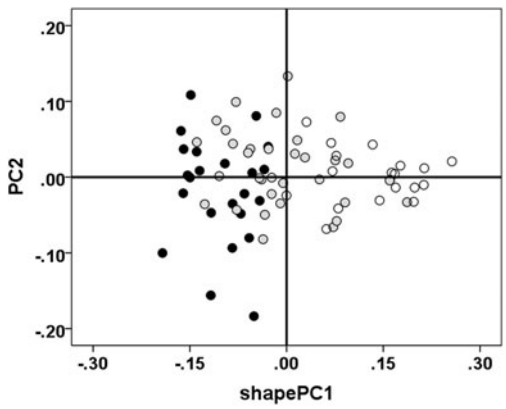


Figure 4. Cross-plot of PC1 ("shapePC1") and PC2 scores from PCA analysis of Procrustes-aligned landmarks (symbols as in Figure 3a).

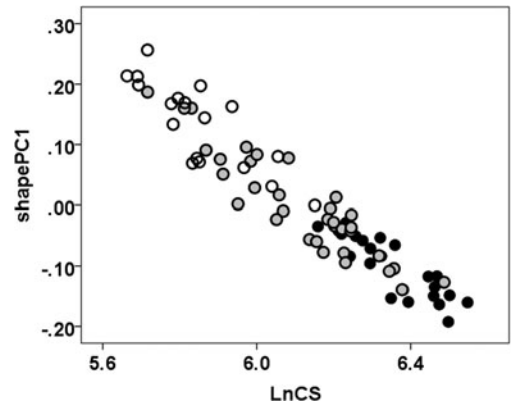


Figure 5. shapePC1 against lnCS, by grouped reduction stage (symbols as in Figure 3a).

possessing high lnCS (i.e., size) values and Stage 7 versions having low lnCS values. Correspondingly, large Stage 1 specimens occupy the negative range on shapePC1; small Stages 7 + 9 versions have positive values on shapePC1. In regression of the common allometric component on lnCS by stage, the blade module's slope coefficient consistently exceeds that of the stem module (Figure 6; Supplemental Table 3), supporting the earlier inference to modularity.

Complementary Measures

Tip angle, IBR, L/T, and M/T may track allometry separately from LGM data. Here, tip angle but not IBR patterns with lnCS and reuse stage ($r = -0.64$, $p < 0.01$), but diffusely near the maximum value from Stage 5 onward (Figure 3). L/T and M/T also pattern with lnCS ($r = 0.94$, $p < 0.01$, and $r = 0.98$, $p < 0.01$, respectively). Because shapePC1 also patterned with lnCS, it is no surprise that shapePC1 also patterns with these allometric ratios ($r = -0.93$ $p < 0.01$ and $r = 0.89$ $p < 0.01$, respectively), corroborating Shott and colleagues' (2007) observations. Figure 7 plots shapePC1 against L/T.

To define a dimension of geometric variation largely independent of LGM data and analysis, we entered tip angle, lnCS (admittedly, an LGM variable), L/T, and M/T into PCA. Extraction was via the correlation matrix because input variables are measured on different scales. Results identified a single component (eigenvalue = 3.36; %variance explained = 84.1) on

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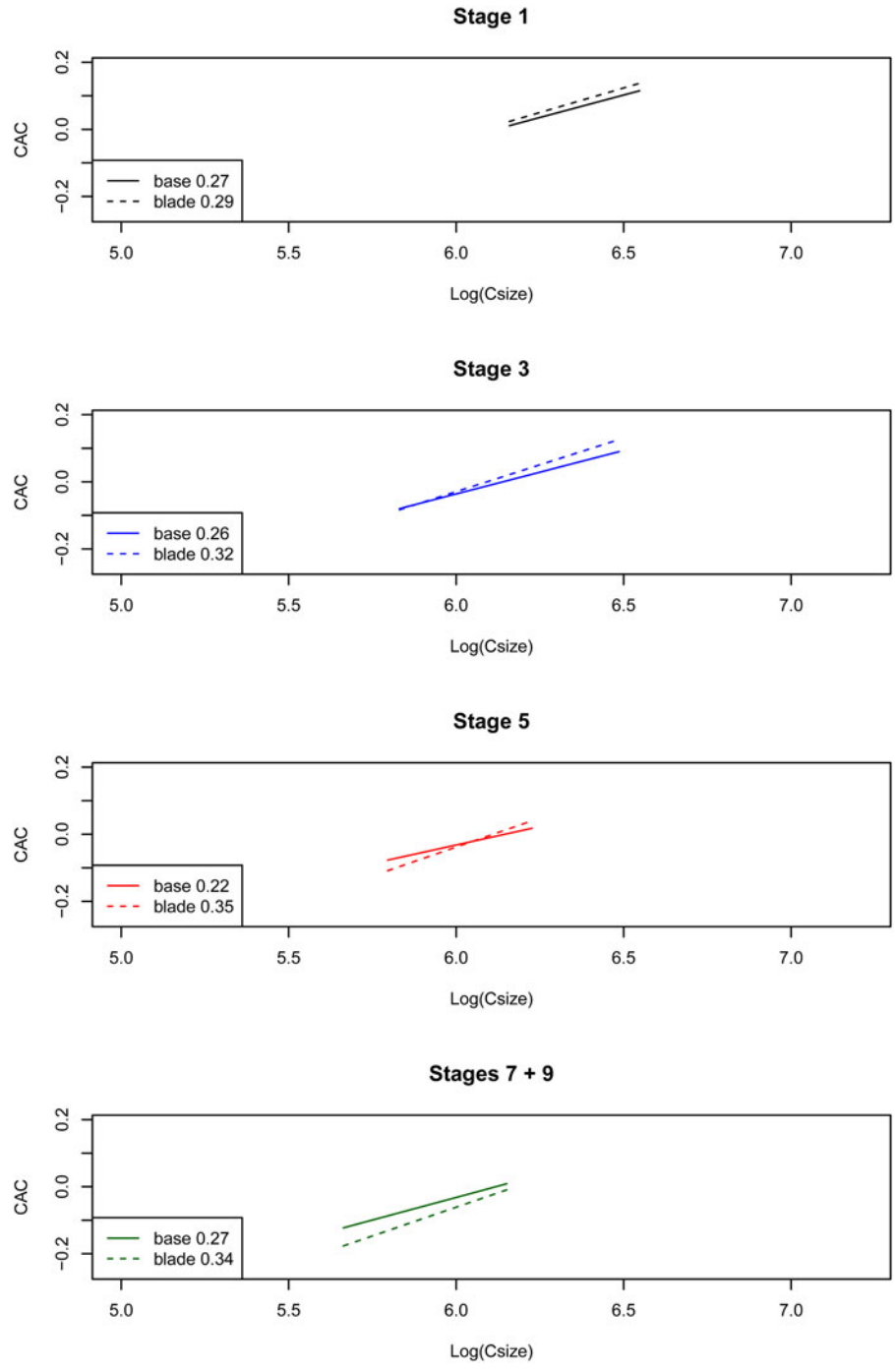


Figure 6. Regression of stem and blade common allometric component (CAC) on lnCS by stage.

which all entered variables exhibited high loadings; all other extracted components had eigenvalues less than 0.55 and %variance explained < 14 (Table 3). PC1 loadings were positive for lnCS, L/T, and M/T and negative for tip angle. (The directionality of loadings varies with

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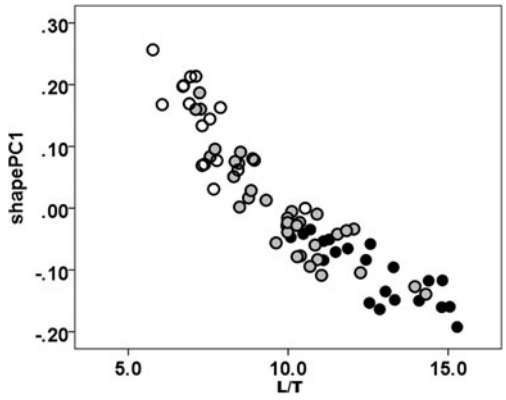


Figure 7. shapePC1 against L/T, by grouped reduction stage (symbols as in Figure 3a).

analytical method. Here, high positive values correlated inversely with the degree of reduction.) We interpret this as a general reduction/allometry PCA dimension, in which high positive values indicate relatively long, heavy, and large specimens with relatively acute tip angles (i.e., points that had experienced little reduction). We labeled the resulting PC1 "rednPC1" (a separate PCA that omitted lnCS yielded very similar results). Positive values of rednPC1 are associated with larger size and, by extension, lesser allometry.[1]

rednPC1 covaries positively with CAC ($r = 0.94$, $p < 0.01$; Figure 8a) and inversely with shapePC1 ($r = -0.94$, $p < 0.01$; Figure 8b; see also Charlin and Cardillo 2018:Figure 7.7). Again, specimens sort fairly clearly by pooled use-repair cycle along the single axis of variation visible there. They also pattern as expected by size, Stage 1 versions having high positive rednPC1 values and correspondingly low, negative shapePC1 values. LGM-based shapePC1 and (mostly) geometric rednPC1 apparently track the same axis of variation but in opposite directions. As use-repair cycles increase and reduction advances and hence rednPC1 falls, LGM shapePC1 rises. Point shape and size are related; they are not independent.

We repeated PCA seeking independent geometric or size dimensions that are common in other studies. First we replaced lnCS with mass (g), easily measured in archaeological specimens, and entered it with tip angle, L/T, and M/T. Results were similar, again yielding a single significant component (eigenvalue = 3.27; %variance explained = 81.8) on which mass, L/T, and M/T showed very high positive loadings and tip angle had correspondingly high negative loadings (Table 3). We labeled this dimension redn2PC1. It also patterned strongly and positively with CAC ($r = 0.93$, $p < 0.01$; Figures 9a) and inversely with shapePC1 ($r = -0.92$, $p < 0.01$; Figure 9b). Finally we conducted PCA using area (mm^2), measured in ScanStudio, in place of either lnCS or mass. In this analysis, specimen B22.7 was omitted because of its erroneous area measurement. Results closely resembled the two PCAs reported earlier.

LGM analysis using geomorph yields CAC as a measure of degree and pattern of allometry. Combinations of the tip angle, ratios of orthogonal dimensions (L/T, M/T), and size variables (lnCS, mass) yield a single major dimension of variation that clearly is allometric as well and that correlates strongly with CAC. What is more, although LGM analysis is necessary to compute lnCS, most other variables are more

Table 3. Summary of PCA of Complementary Allometric Measures.

Component	Eigenvalue	%variance	Variable	PC1 Loading
1	3.49	87.2	lnCS	0.974
2	0.42	10.6	L/T	0.975
3	0.07	1.8	M/T	0.948
			tip angle	−0.828
Component	Eigenvalue	%variance	Variable	PC1 Loading
1	3.27	81.8	mass	0.943
2	0.56	13.9	L/T	0.943
3	0.17	4.1	M/T	0.969
			tip angle	−0.745

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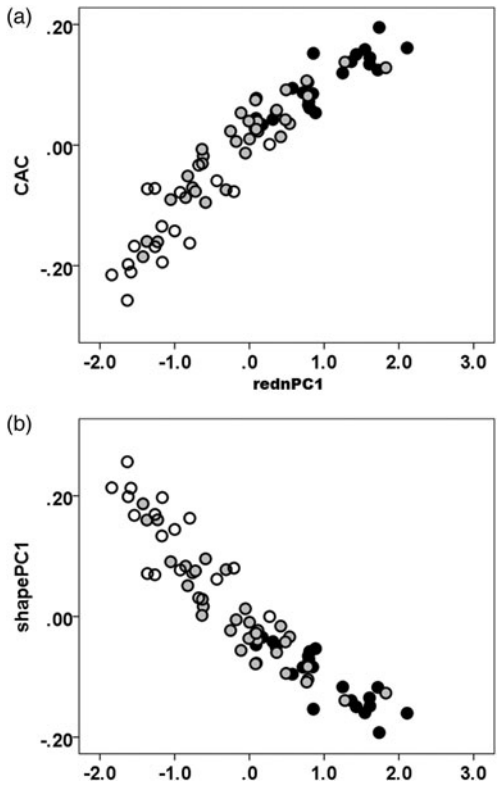


Figure 8. CAC (a) and shapePC1 (b) against rednPC1 (symbols as in Figure 3a).

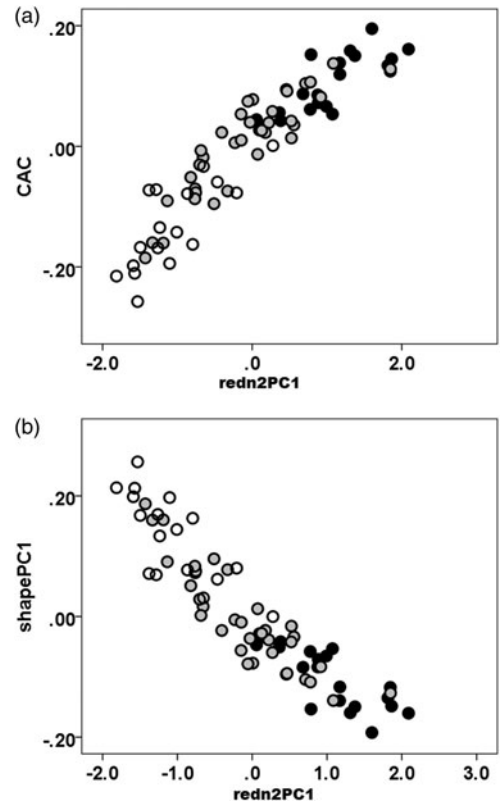


Figure 9. CAC (a) and shapePC1 (b) against redn2PC1 (symbols as in Figure 3a).

easily obtained. An allometric component can be extracted not only from LGM data but also from other analytical approaches using easily obtained geometric, size, and ratio variables.

Discussion

This study involved Folsom replicas; similar earlier studies involved Clovis or similar points. Obviously, Folsom and Clovis points shared fluting and chronological proximity but differed in salient technological and organizational respects (Collins 1999; Sellet 2017) that complicate comparisons. If, compared to Folsom points, "Clovis points . . . sustain many more episodes of resharpening" (Sellet 2017:271), then allometric resharpening effects in Folsom replicas suggest at least their equal probability in Clovis technology. Broadly, the generally larger size and lower launch velocity of hand-thrown spears and atlatl-launched darts extend their use life or survivorship; although such points suffer damage and edge dulling, damage is less likely catastrophic, so spear or dart points are more often subjects of resharpening than are late prehistoric arrow points that tend to fail catastrophically (Loendorf et al. 2019:354; cf. Lerner 2015).

Allometry must be sought either using LGM data or ILDs, as in our study, or the allometric ratios used in earlier work (e.g., Andrefsky 2006; Lerner 2015; Shott et al. 2007). As earlier, IBR as an allometric measure did not pattern with reduction stage nearly as well as did tip angle, L/T, and M/T, perhaps because both stem and blade modules usually were reduced (if disproportionately). Reduction of both modules has been invoked to explain what is considered the absence of allometry in other fluted-point samples (Buchanan and Collard 2010). However modules were defined and in whatever way degree of reduction was gauged there, our analysis included explicit modularity

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tests. Hunzicker's experimental design also provided independent control over the degree of reduction. Results suggest strongly that allometry registers even when both stem and blade modules are subject to resharpening. The key issue is testing: if allometry and especially modularity do *not* characterize datasets, that negative conclusion will emerge in valid tests for their effects. If the one is not considered and if neither is measured directly, negative conclusions remain ambiguous. Practically, testing must start from the hypothetical definition of at least two modules, blade and stem, and perhaps additional ones, such as tip area, per results of González-José and Charlin's (2012) study. At least some modules, like stem versus blade, are easily enough defined in stemmed or notched points but possibly also in lanceolates by, for instance, the distal extent of edge grinding.

In these data, size and shape are not separated easily. As results showed, shapePC1 patterns clearly with size. In resharpened stone tools, a change in shape occurs in significant part because of a change in size, as it does in growth trajectories in many biological taxa. If "size-related shape effects are inextricably mixed up with almost every biological feature of organisms" (Oxnard 1978:233), no less seems true of the morphometric features of stone tools. When allometry occurs, separating shape from size is complicated by their integral covariation. Size–shape correlation is a legitimate dimension of patterning in reduced stone tools, not necessarily an artifact of analysis.

LGM analysis of the size and shape of adults and juveniles of many animal species reveals similar patterns, with allometric change occurring as a function of growth. Conducting LGM analysis of any single species that omitted juveniles would reveal more legitimate size-free shape variation. Yet many biological LGM studies of size and shape involve sets of often related animal species and are designed to reveal and quantify differences in adult size and shape. Presumably, such studies take care to omit juveniles, because their inclusion could confuse intraspecific growth allometry with interspecific evolutionary allometry. Again, stone-tool reduction allometry works in the opposite direction of biological growth allometry; analysis seeking it must include specimens distributed along the full range of joint size–shape variation. Similarly, any analysis that distinguishes point types must control for reduction allometry within the types so as not to confuse it with design variation between types. This can be accomplished by confining LGM analysis to stems only (e.g., Prentiss et al. 2016), even if results suggest that stems themselves are subject to some allometric variation because progressive use and resharpening cause bases to intrude on them or by extracting CACs from each type before comparing types.

Finally, modularity and integration may pertain to more than the allometric trajectories that individual points take in their use lives. In the longer term, they may help explain the morphological transitions by which some types emerge over time from earlier ones (i.e., Klingenberg's evolutionary allometry). For instance, changes in the range of target species, in hunting methods (e.g., ambush versus stalking), or in the econometrics of hunting (e.g., the relationship between search and pursuit time as animal communities change) could prompt adjustments to the size and shape of stems and other modules to accommodate the changing demands of weapons range, accuracy, or thrust. Over time, such adjustments may gradually transform notched points, for instance, into stemmed ones as bases progressively narrow, necks widen, and stem margins converge toward points' longitudinal axes. This is not to argue that all point types morphed into other types, but morphing is a possibility—a hypothesis—that LGM analysis is well suited to test.

Conclusion

Our study applied LGM methods to 3D models of 25 Folsom replicas from Hunzicker's (2005) work. The experimental design furnished an independent control that enabled us to identify allometry with reduction. After defining separate blade and stem modules, analysis in geomorph indicated modularity; separate stem and blade modules are somewhat decomposable yet remain partially integrated. Results also indicate allometry: a change in shape with the change in size. The controlled nature of the experiment—we

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know how and why points underwent reduction and to what degree—conclusively identifies reduction allometry as the explanation. 3D Folsom models register both allometry and modularity in the reduction of points. With cycles of use, repair, and reuse, points change in shape as their size declines, partly because stem and blade modules experience different rates and patterns of reduction.

But ours is a controlled experimental dataset. However useful it may be in documenting both modularity and allometry and in explaining their expression, it does not provide the explanation for those features that may be observed in archaeological data. Further tests are required in a range of point types that include but are not confined to lanceolates. Archaeological datasets vary not only in typology but also in other ways (e.g., knapper, tool stone, circumstance, time) controlled for in this experimental study; the strong signals found here may be complicated elsewhere. Our study's chief value is to document the clear modularity, limited integration, and strong allometric signal that reside in these experimental data. If archaeological data pattern similarly, their parsimonious interpretation implicates resharpening as the source of the patterning.

Whether in 2D models of point outlines or 3D models of their fuller form, we should not treat all points as integral wholes. If they are indeed such wholes, valid analysis will reach that conclusion. If they display modularity and if variation among them can be attributed to reduction allometry, then valid analysis will reach that conclusion instead. Whatever the case, we must seek and test for allometry, modularity, and integration directly, rather than approaching them indirectly. At least for some purposes, points are not irreducible wholes but things of modular parts. Our analyses must recognize and exploit this modular quality.

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Data Availability Statement. Supplemental Tables 1 and 2 and the R Code to create Figure 6 in the text are available at the Open Science Framework (OSF) site, https://osf.io/acbs5/?view_only=2c0f225ed93d4751ad9415054d88 37d0.

Note

1. Dimensions like length and width are not necessarily shape-free; in LGM, only CS is "a size variable uncorrelated with all shape coordinates" (Bookstein 1991:172). Accordingly, their use engages the risk of false allometry. We acknowledge but discount that risk in this dataset. rednPC1 correlates well with lnCS from landmark data, thereby corroborating patterning revealed by LGM analysis to which allometry is integral.

References Cited

Adams, Dean
2016 Evaluating Modularity in Morphometric Data: Challenges with the RV Coefficient and a New Test Measure. *Methods in Ecology & Evolution* 7:565–572.

Adams, Dean, and Erik Otárola-Castillo
2013 geomorph: An R Package for Collection and Analysis of Geometric Morphometric Shape Data. *Methods in Ecology & Evolution* 4:393–399.

Ahler, Stanley A., George C. Frison, and Michael McGonigal
2002 Folsom and Other Paleoindian Artifacts in the Missouri River Valley, North Dakota. In *Folsom Technology and Lifeways*, edited by John E. Clark and Michael B. Collins, pp. 69–112. Lithic Technology Special Publication No. 4. Routledge, New York.

Ahler, Stanley A. and Phil R. Geib
2000 Why Flute? Folsom Point Design and Adaptation. *Journal of Archaeological Science* 27:799–820.

Andrefsky, William
1997 Thoughts on Stone Tool Shape and Inferred Function. *Journal of Middle Atlantic Archaeology* 13:125–144.
2006 Experimental and Archaeological Verification of an Index of Retouch for Hafted Bifaces. *American Antiquity* 71:743–757.

Asher, Brendon P.
2015 From the Continental Divide to the Plains-Woodland Border: Clovis and Folsom/Midland Land Use and Lithic Procurement. PhD dissertation, Department of Anthropology, University of Kansas, Lawrence.

Beck, Charlotte
1995 Functional Attributes and the Differential Persistence of Great Basin Dart Forms. *Journal of California and Great Basin Anthropology* 17:222–243.

Bement, Leland
1999 View from a Kill: The Cooper Site Folsom Lithic Assemblage. In *Folsom Lithic Technology: Explorations in Structure and Variation*, edited by Daniel S. Amick, pp. 111–121. International Monographs in Prehistory. University of Michigan, Ann Arbor.
2002 Pickin' up the Pieces: Folsom Projectile Point Resharpening. In *Folsom Technology and Lifeways*, edited by John E. Clark and Michael B. Collins, pp. 135–140. Lithic Technology Special Publication No. 4. Routledge, New York.

Binford, Lewis R.
1973 Interassemblage Variability: The Mousterian and the 'Functional' Argument. In *The Explanation of Culture Change: Models in Prehistory*, edited by Colin Renfrew, pp. 227–254. Duckworth, London.

Blades, Brook S.
2003 End Scraper Reduction and Hunter-Gatherer Mobility. *American Antiquity* 68:141–156.

https://doi.org/10.1017/aaq.2021.62 Published online by Cambridge University Press

Bookstein, Fred L.
1991 *Morphometric Tools for Landmark Data: Geometry and Biology*. Cambridge University Press, Cambridge.
Buchanan, Briggs
2006 Analysis of Folsom Projectile Point Resharpening Using Quantitative Comparisons of Form and Allometry. *Journal of Archaeological Science* 33:185–199.
Buchanan, Briggs, J., and Mark Collard
2010 A Geometric Morphometrics-Based Assessment of Blade Shape Differences among Paleoindian Projectile Point Types from Western North America. *Journal of Archaeological Science* 37:350–359.
Buchanan, Briggs, J. David Kilby, Bruce B. Huckell, Michael J. O'Brien, and Mark Collard
2015 Size, Shape, Scars, and Spatial Patterning: A Quantitative Assessment of Late Pleistocene (Clovis) Point Resharpening. *Journal of Archaeological Science: Reports* 3:11–21.
Charlin, Judith, and Marcelo Cardillo
2018 Reduction Constraints and Shape Convergence along Tool Ontogenetic Trajectories: An Example from Late Holocene Projectile Points of Southern Patagonia. In *Convergent Evolution and Stone-Tool Technology*, edited by Briggs Buchanan, Metin Eren, and Michael J. O'Brien, pp. 109–129. MIT Press, London.
Charlin, Judith, and Rolando González-José
2018 Testing an Ethnographic Analogy through Geometric Morphometrics: A Comparison between Ethnographic Arrows and Archaeological Projectile Points from Late Holocene Fuego-Patagonia. *Journal of Anthropological Archaeology* 51:159–172.
Collins, Michael B.
1999 Clovis and Folsom Lithic Technology on and Near the Southern Plains: Similar Ends, Different Means. In *Folsom Lithic Technology: Explorations in Structure and Variation*, edited by Daniel S. Amick, pp. 12–38. International Monographs in Prehistory. University of Michigan, Ann Arbor.
de Azevedo, Soledad, Judith Charlin, and Rolando González-José
2014 Identifying Design and Reduction Effects on Lithic Projectile Point Shapes. *Journal of Archaeological Science* 41:297–307.
Dibble, Harold
1987 The Interpretation of Middle Paleolithic Scraper Morphology. *American Antiquity* 52:109–117.
Dines, James P., Erik Otárola-Castillo, Peter Ralph, Jesse Alas, Timothy Daley, Andrew D. Smith, and Matthew D. Dean
2014 Sexual Selection Targets Cetacean Pelvic Bones. *Evolution* 68:3296–3306.
Douglass, Matthew J., Sam C. Lin, David R. Braun, and Thomas W. Plummer
2018 Core Use-Life Distributions in Lithic Assemblages as a Means for Reconstructing Behavioral Patterns. *Journal of Archaeological Method and Theory* 25:254–288.
Ellis, Christopher
2004 Understanding "Clovis" Fluted Point Variability in the Northeast: A Perspective from the Debert Site. *Canadian Journal of Archaeology* 28:205–253.
Flegenheimer, Nora, and Celeste Weitzel
2017 Fishtail Points from the Pampas of South America: Their Variability and Life Histories. *Journal of Anthropological Archaeology* 45:142–156.
Frison, George C.
1968 A Functional Analysis of Certain Chipped Stone Tools. *American Antiquity* 33:149–155.
Goldstein, Stephen
2014 Quantifying Endscraper Reduction in the Context of Obsidian Exchange among Early Pastoralists in Southwestern Kenya. *Lithic Technology* 39:3–19.
González-José, Rolando, and Judith Charlin
2012 Relative Importance of Modularity and Other Morphological Attributes on Different Types of Lithic Point Weapons: Assessing Functional Variation. *PLoS ONE* 7(10):e48009.
Goodyear, Albert C.
1974 *The Brand Site: A Techno-Functional Study of a Dalton Site in Northeast Arkansas*. Research Series No. 7. Arkansas Archeological Survey, Fayetteville.
Hashizume, Jun
2009 Paleoindian Projectile Point Breakage and Reshaping. In *Hell Gap: A Stratified Paleoindian Campsite at the Edge of the Rockies*, edited by Mary Lou Larson, Marcel Kornfeld, and George C. Frison, pp. 274–284. University of Utah Press, Salt Lake City.
Hayden, Brian
1977 Stone Tool Functions in the Western Desert. In *Stone Tools as Cultural Markers*, edited by R. V. S. Wright, pp. 178–188. Australian Institute of Aboriginal Studies, Canberra.
Hermo, Darío, Enrique Terrannova, and Laura Miotti
2015 Tecnología y uso de materias primas en puntas cola de pescado de la Meseta de Somuncará (Provincia de Rio Negro, Argentina). *Chungara* 47:101–115.
Hiscock, Peter, and Val Attenbrow
2005 *Australia's Eastern Regional Sequence Revisited: Technology and Change at Capertee 3*. BAR International Series 1397. British Archaeological Reports, Oxford.
Hoffman, C. Marshall
1985 Projectile Point Maintenance and Typology: Assessment with Factor Analysis and Canonical Correlation. In *Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory*, edited by Christopher Carr, pp. 566–611. Westport Press, Kansas City.
Hofman, Jack L.
1992 Recognition and Interpretation of Folsom Technological Variability on the Southern Plains. In *Ice Age Hunters of the Rockies*, edited by Dennis J. Stanford and Jane S. Day, pp. 193–224. University Press of Colorado, Boulder.
Hunzicker, David A.
2005 Folsom Hafting Technology: An Experimental Archaeological Investigation into the Design, Effectiveness, Efficiency and Interpretation of Prehistoric Weaponry. Master's thesis, Department of Museum and Field Studies, University of Colorado, Boulder.
2008 Folsom Projectile Technology: An Experiment in Design, Effectiveness, and Efficiency. *Plains Anthropologist* 53:291–311.
Institute for Data Analysis and Visualization (IDAV)
2007 *Landmark User Guide 3.6*. IDAV, University of California, Davis.
Iovita, Radu
2010 Comparing Stone Tool Resharpening Trajectories with the Aid of Elliptical Fourier Methods. In *New Perspectives on Old Stones: Analytical Approaches to Paleolithic Technologies*, edited by Stephen Lycett and Parth Chauhan, pp. 235–253. Springer, New York.
2011 Shape Variation in Aterian Tanged Tools and the Origins of Projectile Technology: A Morphometric

https://doi.org/10.1017/aaq.2021.62 Published online by Cambridge University Press

Perspective on Stone Tool Function. *PLoS ONE* 6(12): e29029.

Iovita, Radu, and Shannon P. McPherron
2011 The Handaxe Reloaded: A Morphometric Reassessment of Acheulian and Middle Paleolithic Handaxes. *Journal of Human Evolution* 61:61–74.

Iriarte, José
1995 Afinando la puntería: Tamaño, forma y rejuvenecimiento en las puntas de proyectil pedúnculadas del Uruguay. In *Arqueología en Uruguay: 120 años despues*, edited by Mario Consens, José Maria López Mazz, and Maria del Carmen Curbelo, pp. 142–151. VIII Congreso de Arqueología Nacional Uruguaya, Montevideo, Uruguay.

Justice, Noel D.
2002 *Stone Age Spear and Arrow Points of the Southwestern United States*. Indiana University Press, Bloomington.

Klingenberg, Christian P.
2008 Morphological Integration and Developmental Modularity. *Annual Review of Ecology, Evolution and Systematics* 39:115–132.

Lassen, Robert D.
2016 The Spectrum of Variation in Folsom-Era Projectile Point Technology. *Paleoamerica* 2:150–158.

Lerner, Harry
2015 Dynamic Variables and the Use-Related Reduction of Southern Huron Projectile Points. In *Works in Stone: Contemporary Perspectives on Lithic Analysis*, edited by Michael Shott, pp. 143–161. University of Utah Press, Salt Lake City.

LeTorneau, Philippe D., and Tony Baker
2002 The Role of Obsidian in Folsom Lithic Technology. In *Folsom Technology and Lifeways*, edited by John E. Clark and Michael B. Collins, pp. 31–45. Lithic Technology Special Publication No. 4. Routledge, New York.

Li, Hau, Kathleen Kuman, and Chaorong Li
2015 Quantifying the Reduction Intensity of Handaxes with 3D Technology: A Pilot Study on Handaxes in the Danjiangkou Reservoir Region, Central China. *PLoS ONE* 10(9):e0135613.

Loendorf, Chris, Thatcher Rogers, Theodore J. Oliver, Brian R. Huttick, Allen Denoyer, and M. Kyle Woodson
2019 Projectile Point Reworking: An Experimental Study of Arrowpoint Use Life. *American Antiquity* 84:353–365.

Loyola, Rodrigo, Lautaro Núñez, Carlos Aschero, and Isabel Cartajena
2017 Tecnología lítica del Pleistoceno final y la colonización del Salar de Punta Negra (24,5° S), Desierto de Atacama. *Estudios Atacameños* 55:5–34.

MacLeod, Norman
2019 The Quantitative Assessment of Archaeological Artifact Groups: Beyond Geometric Morphometrics. *Quaternary Science Reviews* 201:319–348.

Meltzer, David J.
2006 *Folsom: New Archaeological Investigations of a Classic Paleoindian Bison Kill*. University of California Press, Berkeley.

Miller, D. Shane
2018 *From Colonization to Domestication: Population, Environment, and the Origins of Agriculture in Eastern North America*. University of Utah Press, Salt Lake City.

Mitteroecker, Philip, P. Gunz, M. Bernhard, K. Schaefer, and Fred L. Bookstein
2004 Comparison of Cranial Ontogenetic Trajectories among Great Apes and Humans. *Journal of Human Evolution* 46:679–698.

Morales, Juan I.
2016 Distribution Patterns of Stone-Tool Reduction: Establishing Frames of Reference to Approximate Occupational Features and Formation Processes in Paleolithic Societies. *Journal of Anthropological Archaeology* 41:231–245.

Odell, George H., and Frank Cowan
1986 Experiments with Spears and Arrows on Animal Targets. *Journal of Field Archaeology* 13:195–212.

Otárola-Castillo, Erik, Melissa G. Torquato, Hannah C. Hawkins, Emma James, Jacob A. Harris, Curtis W. Marean, Shannon P. McPherron, and Jessica C. Thompson
2018 Differentiating between Cutting Actions on Bone Using 3D Geometric Morphometrics and Bayesian Analyses with Implications to Human Evolution. *Journal of Archaeological Science* 89:56–67.

Oxnard, Charles E.
1978 One Biologist's View of Morphometrics. *Annual Review of Ecology and Systematics* 9:219–241.

Patten, Bob
2005 *Peoples of the Flute: A Study in Anthropolithic Forensics*. Stone Dagger Press, Denver.

Peterson, Robert R.
1978 Projectile Point Re-Utilization Patterns at the Agate Basin Site. *Wyoming Contributions to Anthropology* 1:139–147.

Prentiss, Anna M., Matthew J. Walsh, Randall R. Skelton, and Matt Markes
2016 Mosaic Evolution in Cultural Frameworks: Skateboard Decks and Projectile Points. In *Cultural Phylogenetics: Concepts and Applications*, edited by Larissa M.Straffen, pp. 113–130. Springer, Basel, Switzerland.

Presnyakova, Darya, David R. Braun, Nicholas J. Conard, Craig Feibel, John W. Harris, Cornel M. Pop, Stefan Schlager, and Will Archer
2018 Site Fragmentation, Hominin Mobility and LCT Variability Reflected in the Early Acheulean Record of the Okote Member, at Koobi Fora, Kenya. *Journal of Human Evolution* 125:159–180.

Quinn, Colin P., William Andrefsky, Ian Kuijt, and Bill Finlayson
2008 Perforation with Stone Tools and Retouch Intensity: A Neolithic Case Study. In *Lithic Technology: Measures of Production, Use, and Curation*, edited by William Andrefsky, pp. 150–174. Cambridge University Press, Cambridge.

Rohlf, F. James, and Marco Corti
2000 The Use of Partial Least-Squares to Study Covariation in Shape. *Systematic Biology* 49:740–753.

Sahle, Yonatan, and Agazi Negash
2016 An Ethnographic Experiment of Endscraper Curation Rate among Hadiya Hideworkers, Ethiopia. *Lithic Technology* 40.

Sahnouni, Mohamed, Kathy Schick, and Nicholas Toth
1997 An Experimental Investigation into the Nature of Faceted Limestone "Spheroids" in the Early Palaeolithic. *Journal of Archaeological Science* 24:701–713.

Sellet, Frédéric
2017 My Flute Is Bigger than Yours: Nature and Causes of Technological Changes on the American Great Plains at the End of the Pleistocene. In *Lithic Technological*

https://doi.org/10.1017/aaq.2021.62 Published online by Cambridge University Press

Organization and Paleoenvironmental Change: Global and Diachronic Persectives, edited by Erich Robinson and Frédéric Sellet, pp. 263–269. Springer, Cham, Switzerland.

Serwatka, K.
2015 Bifaces in Plain Sight: Testing Elliptical Fourier Analysis in Identifying Reduction Effects on Late Middle Palaeolithic Bifacial Tools. *Litikum* 3:13–25.

Shott, Michael J.
1996 An Exegesis of the Curation Concept. *Journal of Anthropological Research* 52:259–280.
2005 The Reduction Thesis and Its Discontents: Review of Australian Approaches. In *Lithics 'Down Under': Australian Perspectives on Lithic Reduction, Use and Classification*, edited by Christopher Clarkson and Lara Lamb, pp. 109–125. BAR International Series 1408. British Archaeological Reports, Oxford.
2014 Digitising Archaeology: A Subtle Revolution in Analysis. *World Archaeology* 46:1–9.
2016 Survivorship Distributions in Experimental Spear Points: Implications for Tool Design and Assemblage Formation. In *Multidisciplinary Approaches to the Study of Stone Age Weaponry*, edited by Radu Iovita and Katsuhiro Sano, pp. 245–258. Springer, Dordrecht, Netherlands.
2020 Allometry and Resharpening in Experimental Folsom-Point Replicas: Analysis Using Inter-Landmark Distances. *Journal of Archaeological Method and Theory* 27:360–380.

Shott, Michael J., and Jesse Ballenger
2007 Biface Reduction and the Measurement of Dalton Curation: A Southeastern Case Study. *American Antiquity* 72:153–175.

Shott, Michael J., David A. Hunzicker, and Bob Patten
2007 Patterns and Allometric Measurement of Reduction in Experimental Folsom Bifaces. *Lithic Technology* 32:203–217.

Shott, Michael J., and Mark F. Seeman
2017 Use and Multifactorial Reconciliation of Uniface Reduction Measures: A Pilot Study at the Nobles Pond Paleoindian Site. *American Antiquity* 82:723–741.

Shott, Michael J., and Paul Sillitoe
2005 Use Life and Curation in New Guinea Experimental Used Flakes. *Journal of Archaeological Science* 32:653–663.

Shott, Michael J. and Kathryn J. Weedman
2007 Measuring Reduction in Stone Tools: An Ethnoarchaeological Study of Gamo Hidescraper Blades from Ethiopia. *Journal of Archaeological Science* 34:1016–1035.

Skinner, Sarah M.
2018 A Geometric Morphometric Analysis of Projectile Point Maintenance Using Experimental Resharpening Techniques: An Examination of PFP1 Curation, Cooper's Ferry Site, Idaho. Master's thesis, Department of Anthropology, Oregon State University, Corvallis.

Smallwood, Ashley M., Thomas A. Jennings, and Charlotte D. Pevny
2018 Expressions of Ritual in the Paleoindian Record of the Eastern Woodlands: Exploring the Uniqueness of the Dalton Cemetery at Sloan, Arkansas. *Journal of Anthropological Archaeology* 49:184–198.

Suárez, Rafael
2011 *Arqueología durante la Transición Pleistoceno-Holoceno en Uruguay: Componentes Paleoindios, Organización de la Tecnología Lítica, y Movilidad de los Primeros Americanos*. BAR International Series 2220. British Archaeological Report, Oxford.
2017 The Peopling of Southeastern South America: Cultural Diversity, Paleoenvironmental Conditions, and Lithic Technological Organization during the Late Pleistocene and Early Holocene. In *Lithic Technological Organization and Paleoenvironmental Change: Global and Diachronic Perspectives*, edited by Erich Robinson and Frédéric Sellet, pp. 281–300. Springer, Cham, Switzerland.

Surovell, Todd A.
2009 *Toward a Behavioral Ecology of Lithic Technology: Cases from Paleoindian Archaeology*. University of Arizona Press, Tucson.

Tindale, Norman
1965 Stone Implement Making among the Nakako, Ngadadjara and Pitjandjara of the Great Western Desert. *Records of the South Australian Museum* 15:131–164.

Titmus, Gene L., and James C. Woods
1991 Fluted Points from the Snake River Plain. In *Clovis: Origins and Adaptations*, edited by Robsen Bonnichsen and Karen Turnmire, pp. 119–131. Oregon State University Press, Corvallis.

Weedman, Kathryn J.
2000 An Ethnoarchaeological Study of Stone Scrapers among the Gamo People of Southern Ethiopia. PhD dissertation, Department of Anthropology, University of Florida, Gainesville.

Wheat, Joe Ben
1975 Artifact Life Histories: Cultural Templates, Typology, Evidence and Inference. In *Primitive Art and Technology*, edited by J. Raymond, B. Loveseth, C. Arnold, and G. Reardon, pp. 7–15. University of Calgary Department of Archaeology, Calgary.

Wilmsen, Edwin N., and Frank H. H. Roberts
1978 *Lindenmeier, 1934–1974: Concluding Report on Investigations*. Contributions to Anthropology No. 24. Smithsonian Institution, Washington, DC.

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