Imposed form in the Early Acheulean? Evidence from Gona, Afar, Ethiopia

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2023-08-06

Abstract

TBD.

Keywords: Gona; TBD; TBD; TBD; TBD; TBD; TBD

Contents

1 Introduction

The imposition of intended form on artifacts has long been viewed as a watershed in human cognitive and cultural evolution and is most commonly associated with the emergence of "Large Cutting Tools" (LCTs) in the Early Acheulean (Holloway, 1969; Isaac, 1976; Kuhn, 2020). However,

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this interpretation of Acheulean LCTs as intentionally designed artifacts remains controversial. Alternative proposals range from the possibility that LCTs were unintended by-products of flake production (Moore & Perston, 2016; Noble & Davidson, 1996) to the suggestion that their form was "at least partly under genetic control" (Corbey et al., 2016). Even accepting that LCT form was to some extent intended, there is substantial disagreement over the specificity of design. Some analyses have indicated that shape variation in Acheulean handaxes is largely a result of resharpening (Iovita & McPherron, 2011; McPherron, 2000) whereas others find form to be unrelated to reduction intensity and more likely to reflect normative expectations of what handaxes should look like (García-Medrano et al., 2019; Shipton & Clarkson, 2015b; Shipton & White, 2020). Such debates about shape of Acheulean LCTs may appear narrowly technical but have broad relevance for evolutionary questions including the origins of human culture (Corbey et al., 2016; Shipton & Clarkson, 2015b; Tennie et al., 2017), language (Stout & Chaminade, 2012), teaching (Gärdenfors & Högberg, 2017), brain structure (Hecht et al., 2015), and cognition (Stout et al., 2015; Wynn & Coolidge, 2016). To examine these questions, we studied the complete collection of Early Acheulean flaked pieces from 5 sites at Gona Project Area and compared them with Oldowan cores form 2 published sites at Gona. By comparing shape variation to measures of flaking intensity and patterning, we sought to identify technological patterns that might reveal intent.

1.1 Identifying design

There is a broad consensus that refined handaxes and cleavers from the later Acheulean resulted from procedurally elaborate, skill intensive, and socially learned production strategies (Caruana, 2020; García-Medrano et al., 2019; Moore, 2020; Sharon, 2009; Shipton, 2019; Stout et al., 2014) although debate over the presence of explicit, culturally transmitted shape preferences continues (Iovita & McPherron, 2011; Moore, 2020; Shipton & White, 2020; Wynn & Gowlett, 2018). There is much less agreement regarding the less heavily worked and formally standardized LCTs typical of the earliest Acheulean (Beyene et al., 2013; Diez-Martín et al., 2015; Lepre et al., 2011; Semaw et al., 2018; Torre & Mora, 2018). Such forms continue to occur with variable frequency in later time periods (McNabb & Cole, 2015), and may be especially prevalent in eastern Asia (Li et al., 2021). Although formal types have been recognized in the Early Acheulean and are commonly used to describe assemblages, many workers now see a continuum of morphological variation (Duke et al., 2021; Kuhn, 2020; Presnyakova et al., 2018)including the possibility that simple flake production remained an important (Shea, 2010) or even primary (Moore & Perston, 2016) purpose of Early Acheulean large core reduction.

Typologically, LCTs are differentiated from Mode 1 pebble cores on the basis of size (>10cm) and shape (elongation and flattening) (e.g., Isaac, 1977). This consistent production of large, flat, and elongated cores in the Achuelean has long been thought to reflect the pursuit of desired functional and ergonomic properties for hand-held cutting tools (Wynn & Gowlett, 2018). Unplanned flaking can sometimes produce cores that fall into the LCT shape range (Moore & Perston, 2016) and this is one possible explanation of the relatively small "protobifaces" that occur in low frequencies in Oldowan assemblages (Isaac & Isaac, 1997). However, the Early Acheulean is clearly distinguished from the Oldowan by the production of larger artifacts necessitating the procurement and exploitation of larger raw material clasts. Although studies of handaxe variation often focus on shape rather than size, this shift is an important aspect of artifact design with relevance to both production and function.

Production of larger tools was accomplished either through a novel process of detaching and working Large Flake Blanks (LFBs) from boulder cores or simply by using larger cobble and slab cores (Isaac, 1969; Semaw et al., 2018; Torre & Mora, 2018). Both may involve similar flaking "strategies" (e.g., bifacial or multifacial exploitation) to those present in the Oldowan (Duke et al., 2021) but require more forceful percussion to detach larger flakes. This increases the perceptual motor difficulty of the task (Stout, 2002) and in many cases may have been accomplished using different percussive techniques and supports (Semaw et al., 2009). These new challenges would have increased raw material procurement (Shea, 2010) and learning costs (Pargeter et al., 2019) as well as the risk of serious injury (Gala et al., 2023) associated with tool production. This strongly implies intentional pursuit of offsetting functional benefits related to size increase. These likely included tool ergonomics and performance (Key & Lycett, 2017) as well as flake generation, resharpening, and reuse potential (Shea, 2010). Early Acheulean LCT production is thus widely seen as a part of shifting hominin behavioral ecological strategies including novel resources and mobility patterns (Linares Matás & Yravedra, 2021; Rogers et al., 1994).

The degree of intentional design reflected in the shape of Early Acheulean LCTs is more difficult to determine. For example, LFB production using a simple "least effort" bifacial/discoidal strategy will tend to generate predominantly elongated (side or end struck) flakes (Toth, 1982) whether or not this is an intentional design target. Similarly, the difficulty of flaking relatively spherical cobbles (Toth, 1982) might bias initial clast selection and subsequent reduction toward flat and elongated shapes even in the absence of explicit design targets. On the other hand, it has been argued that the shape of Early Acheulean LFBs was intentionally predetermined using core preparation techniques (Torre & Mora, 2018) and many researchers perceive efforts at intentional shaping in the organization of flake scars on Early Acheulean handaxes and picks (Beyene et al., 2013; Diez-Martín et al., 2015; Duke et al., 2021; Lepre et al., 2011; Semaw et al., 2009; Torre & Mora, 2018). To date, however, the identification of Early Acheulean shaping has generally relied on qualitative assessment by lithic analysts. Such assessment may in fact be reliable, but is subject to concerns about potential selectivity, bias, and/or overinterpretation (Davidson, 2002; Moore & Perston, 2016). Notably, a 3-dimensional morphometric (3DGM) study by Presnyakova, et al. (2018) concluded that LCT shape variation in the Okote Member (~1.4 mya) at Koobi Fora was largely driven by reduction intensity rather than different knapping strategies. However, this study did not directly address the presence/absence of design targets constraining the observed range of variation.

In later Acheulean contexts, reduction intensity effects are commonly equated with resharpening and seen as an alternative to intentional form imposition (McPherron, 2000). Across heavily-worked and relatively standardized LCT assemblages (e.g., Shipton & White, 2020), a *lack* of association between morphology and reduction intensity has be used as an argument-by-elimination for the presence of imposed morphological norms or "mental templates" (García-Medrano et al., 2019; Shipton et al., 2023; Shipton & Clarkson, 2015c). However, in the less heavily-worked and more heterogeneous assemblages typical of the early Acheulean (Kuhn, 2020), it is equally plausible that increasing reduction intensity would reflect degree of primary reduction rather than subsequent resharpening (Archer & Braun, 2010). In this case, reduction intensity effects on morphology would have the opposite interpretation: more reduction should result in closer approximation of a desired form if such were present. For example, Beyene, et al. (2013) found that increasing flake scar counts were associated with increasing handaxe refinement through time at Konso, Ethiopia, which may reflect a more general trend in the African Acheulean (Shipton, 2018).

Interpretive approaches address this quandary by "reading" the organization of scars on individual pieces to infer intent, but an adequate method to objectively quantify these insights has yet to be developed. Current measures of reduction intensity, such as the scar density index (SDI)

(Clarkson, 2013), are designed to estimate total mass removed from a core and are reasonably effective (Lombao et al., 2023). However, mass removal was not the objective of Paleolithic flaking. Indeed, knapping efficiency is usually conceived as generating an outcome while *minimizing* required mass removal. This is true whether the desired outcome is a useful flake, a rejuvenated edge, or a particular core morphology. In simple flake production, mass removed is probably a good reflection of the completeness of exploitation ("exhaustion") of cores and may have implications for required skill (Pargeter et al., 2023; Toth, 1982) as well as raw material economy (Reeves et al., 2021; Shick, 1987). However, in core shaping and resharpening, mass removal would typically represent an energetic and raw material cost to be minimized, and might even interfere with function (Key, 2019). Without further information, relationships between artifact shape and reduction intensity are thus open to conflicting interpretations as evidence of intentional design or its absence.

Li, et al. (2015) proposed a Flaked Area Index (FAI) as an alternative to SDI as a measure of reduction intensity, arguing that its validity is supported by an observed correlation (r=0.424) with SDI. However, they also explain that "flaked area does not necessarily relate to the number of flake scars…a small number of large scars can produce a large area of scar coverage, and conversely, a large number of small scars can produce a small area of scar coverage." (p. 6). We suggest that what FAI actually captures is the spatial extent modifications to the surface of a core. It is thus complementary to the measure of volume reduction provided by SDI and provides additional information to inform technological interpretations. For example, a correlation between FAI and artifact form without any effect of SDI would suggest a focus on "least-effort" shape imposition whereas the opposite pattern would be consistent with relatively intense resharpening of spatially restricted areas on the core. A lack of shape correlation with either measure would be expected for simple debitage with no morphological targets whereas a strong correlation with both would indicate a highly "designed" form achieved through extensive morphological and volumetric transformation. In the current study we thus considered SDI and FAI together in order to evaluate evidence of intentional shaping in the early Acheulean of Gona.

1.2 Measuring artifact form and modification

Three-dimensional scanning and geometric morphometric (3DGM) methods are increasingly common in the study of LCT form and reduction intensity (Archer & Braun, 2010; Caruana, 2020;

Li et al., 2015, 2021; Lycett et al., 2006; Presnyakova et al., 2018; Shipton & Clarkson, 2015c). These methods provide high-resolution, coordinate-based descriptions of artifact form including detailed information about whole object geometric relations that is not captured by conventional linear measures (Shott & Trail, 2010). This includes measures of surface area used to compute both SDI and FAI measures (Clarkson, 2013; Li et al., 2015). At the time of writing, however, 3D scans are available for only a small number of Gona artifacts, including 33 of the Oldowan and Acheulean flaked pieces used in this study (**Figure** 1). Despite continuing improvements, 3DGM methods still impose additional costs in terms of data collection and processing time as well as required equipment, software, and training. Importantly, 3DGM methods cannot be applied to pre-existing photographic and metric data sets (e.g., Marshall et al., 2002), including available data from Gona. For this reason, and to better understand the relative costs and benefits of 3DGM more generally, we sought to test the degree to which conventional measurements can approximate 3DGM methods and produce reliable results by directly comparing our conventional measures with 3DGM analysis of the 33 available scans.

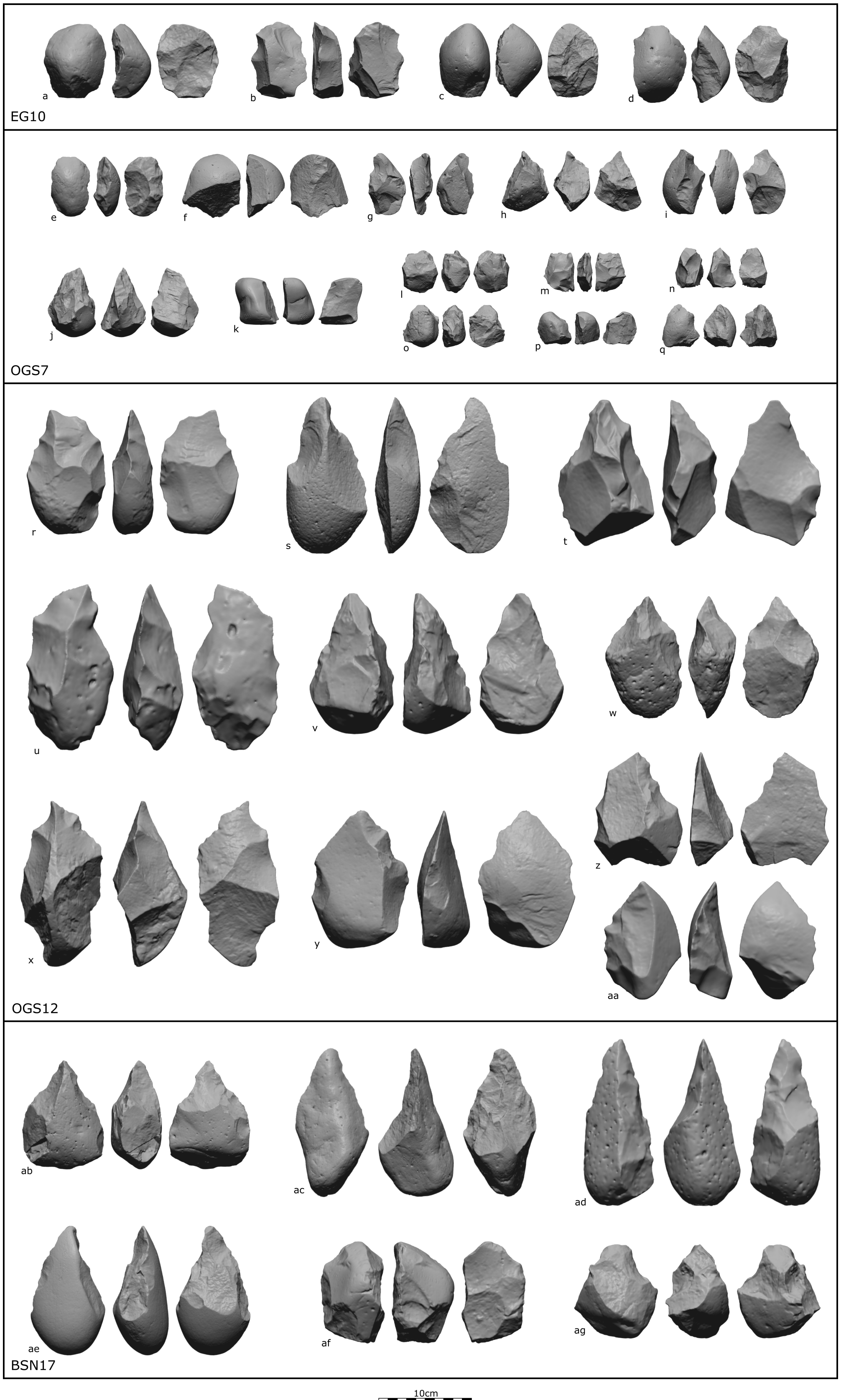

Figure 1: 3D Artifact scans from Gona used in this study.

For our study, we are specifically concerned with the accurate description of morphological variation and estimation of artifact surface and flaked areas. With respect to morphology, we were encouraged by the fact that aspects of form variation relevant to our research question (i.e., core elongation, flattening, and pointedness) are relatively simple to describe using sparse data. 3DGM studies of LCTs collect vast amounts of shape data but may discard upward of 50% of the observed variation in order to focus on two or three interpretable principal components. Across studies, these PCs consistently correspond to basic features like elongation, relative thickness, pointedness, and position of maximum thickness that also emerge from lower-resolution spatial data (Archer & Braun, 2010; García-Medrano et al., 2019; Lycett et al., 2006) and studies employing linear measures rather than spatial coordinates (Crompton & Gowlett, 1993; Pargeter et al., 2019). There is less evidence that conventional methods can accurately estimate artifact surface and flaked areas. Clarkson (2013) advocated the use of 3D surface area measures as more accurate than estimation from linear measures (e.g., surface area of a rectangular prism defined by artifact dimensions). However, he also found that the error introduced by the linear approach was a highly systematic, isometric overestimation of surface area and that results correlated with direct 3D measures with an impressive $r^2 = 0.944$ and no effect of variation in core shape. Insofar as it is variation in the relationship between surface area and flaking intensity that is of interest, rather than absolute artifact size, such systematic overestimation may not be problematic. Similar concerns apply to the estimation of flaked area. Traditionally, such estimates have been done "by eye" as a percentage of the total artifact surface (e.g., Dibble et al., 2005). Such estimations have been found to be reasonably accurate when compared to 3D methods, but with the potential for substantial error on individual artifacts (Lin et al., 2010). The accuracy of by-eye estimation has yet to be systematically studied in Early Stone Age cores like those from Gona.

1.3 The Early Acheulean at Gona

Early Acheulean sites in the Gona Project area are distributed over a wide area within the Dana Aoule North (DAN), Ounda Gona South (OGS), and Busidima North (BSN) drainages in the Busidima Formation (Quade et al., 2004) and range in age from approximately 1.7 to 1.2 mya (Semaw et al., 2018). The specific sites included in the current analysis are DAN-5, OGS-5, OGS-12, and BSN-17, all estimated to ca. 1.7 – 1.4 mya by stratigraphic position in the Gona sequence (Quade et al., 2008; Semaw et al., 2020). The Busidima Formation accumulated through fluvial deposition by the ancestral Awash River (Type I context) and its smaller tributary channels (Type

II context) (Quade et al., 2004, 2008). Oldowan sites at Gona all occur in Type I sediments, indicating channel bank/margin (OGS-7) or proximal floodplain (EG-10, EG-12) contexts close to the large, hetero-lithic clasts available from point bars in the axial river channel (Quade et al., 2004; Stout et al., 2005). Acheulean sites continue to occur in Type I contexts (BSN-17, DAN-5) but are also found in Type II sediments (OGS-5, OGS-12,) reflecting increased utilization of large perennial tributaries to the ancestral Awash River (Quade et al., 2008). Clasts locally available in these tributaries were relatively small, implying that the large flakes and cobbles used to produce Acheulean artifacts were initially sourced from the axial river. A similar pattern of habitat diversification and increasing lithic transport distances has been described at other sites and may be typical of the early Acheulean (Hay, 1976; Linares Matás & Yravedra, 2021; Rogers et al., 1994). As with other early (i.e. >1.0 mya (Presnyakova et al., 2018; Stout, 2011)) Acheulean assemblages, the Gona collections include numerous "crudely made" handaxes and picks on large flake blanks and cobbles, as well as large (> 10cm) unmodified flakes, flaked pieces interpreted typo-technologically as Mode 1 cores (see Figure 1af), and smaller debitage (Semaw et al., 2018; Semaw et al., 2020).

2 Materials and Methods

2.1 Materials

2.1.1 Archaeological Sample

Artifact collections analyzed here include *in situ* pieces excavated from intact stratigraphic contexts and surface pieces systematically collected from the sediments eroding from these layers. Surface pieces are included because the current technological analysis does not require more precise spatial association, stratigraphic, and chronological control. Our sample comprises the total collection of flaked pieces (Isaac & Isaac, 1997) and large (>10 cm) detached pieces from each site, regardless of typo-technological interpretation.

2.2 Methods

2.2.1 Artifact Classification

Artifacts were classified according to initial form (pebble/cobble, detached piece, or indeterminate), presence/absence of retouch, technological interpretation ("Mode 1" core vs. "Mode 2"

LCT), and archaeological context (Oldowan vs. Early Acheulean sites). LCTs were additionally classified as handaxes, knives, or picks following definitions from Kleindienst (1962). The validity of technological interpretations and typological classifications was assessed through cluster analysis based on artifact shape and reduction intensity variables.

2.2.2 Artifact Measurement

Conventional linear measures capture the direction (e.g., length > breadth) but not the location of geometric relations (e.g., position of maximum breadth). We address this by collecting linear measures defined by homologous semi-landmarks. All artifacts were oriented along their maximum dimension, which was measured and defined as "length." The next largest dimension orthogonal to length was used to define the plane of "breadth," with the dimension orthogonal to this plane defined as "thickness" Width (W_1, W_2, W_3) and thickness (T_1, T_2, T_3) measures were then collected at 25%, 50%, and 75% of length, oriented so that 25% Width > 75% Width. To partition variation in shape from variation in size, we divided all linear measures by the geometric mean (Lycett et al., 2006). GM-transformed variables were then submitted to a Principal Components Analysis (covariance matrix) to identify the main dimensions of shape variation.

Our semi-landmark measurement system allowed us to improve on the prism-based surface area formula (2LW + 2LT + 2 WT) by using our 7 recorded dimensions to more tightly fit three prisms around the artifact: $SA = W_1T_1 + 2(.33L * W_1) + 2(.33L * T_1) + 2(.33L * W_2) + 2(.33L * T_2) + 2(.33L * W_3) + 2(.33L * T_3) + W_3T_3$. Surface area calculated in this way correlates with mass$^{2/3}$ at $r^2 = 0.947$ in our sample. Calculated surface area was then used to derive the Scar Density Index: SDI = number of flake scars > 1cm per unit surface area (Clarkson, 2013; Shipton & Clarkson, 2015a). The Flaked Area Index (FAI: flaked area divided by total surface area)(Li et al., 2015) was estimated directly "by eye" as a percentage of the total artifact surface.

2.2.3 3D Methods

Artifact scans (N=33) were cleaned, smoothed, and re-meshed using MeshLab. The 3D triangular mesh of each scan was computed using Kazhdan and Hoppe's (2013) method of screened Poisson surface reconstruction in MeshLab. 3DGM analysis was conducted using the *AGMT3-D* program of Herzlinger and Grosman (2018). Artifacts were automatically oriented according to the axis of least asymmetry, then manually oriented in the interests of standardization with the length, width, and thickness dimensions defined by the longest axis, followed by the next two longest axes perpendicular to the first. The wider end of the artifacts was positioned as the proximal end (base), and more protruding surfaces were oriented towards the user in the first orthogonal view. Then, a grid of 200 homologous semi-landmarks were overlain on each artifact's surface. Generalized Procrustes and Principal Component analyses were then undertaken to explore the shape variability of the sample. The surface area of each artifact was calculated using the *Artifact3-D* program of Grosman et al. (2022). *Artifact3-D* was also used to automatically identify the flake scar boundaries and compute each scar's surface area, using the scar analysis functions of Richardson et al. (2014).

2.2.4 Analyses

Measurement Validation: To assess the adequacy of shape descriptions based on our linear measures, we directly compared these with shape as quantified by 3D methods on the 33 artifacts for which scans are available. GM-transformed linear measures from these 33 artifacts were submitted to a variance-covariance matrix PCA. PCs with an eigenvalue greater than the mean were retained for analysis and the results compared qualitatively (morphological interpretation of PCs) and quantitatively (correlation of artifact factor scores) to 3D results. Accuracy of surface area and flaked area estimates was also assessed by correlation with 3D results.

Three-dimensional scanning and geometric morphometric (3DGM) methods are becoming increasingly common in the study of LCT form (Archer & Braun, 2010; Caruana, 2020; Li et al., 2021; Lycett et al., 2006; Presnyakova et al., 2018; Shipton & Clarkson, 2015b). These methods can provide high-resolution, coordinate-based descriptions of artifact form including detailed information about whole object geometric relations that is not captured by conventional linear measures (Shott & Trail, 2010). However, they also impose additional costs in terms of data collection and processing time as well as required equipment, software, and training. Insofar as these costs might present an obstacle to participation by some researchers and/or draw resources away from other activities, they must be balanced against benefits. In particular, it is not clear that these powerful methods are required in order to describe relevant variation in Acheulean LCT shape. Unlike hominin crania or even projectile points, Acheulean handaxes, cleavers, and picks are not complex shapes. Individual LCTs exhibit complex morphologies defined by idiosyncratic scar patterns, but these details are largely noise at the level of comparative analyses. Laser-scanning 3DGM studies of LCTs collect vast amounts of shape data, but typically discard upward of 50% of the observed variation in order to focus on two or three interpretable principal components. Across studies, these PCs consistently corresponding to basic features like elongation, relative thickness, pointedness, and position of maximum thickness that also emerge from lower-resolution spatial data (Archer & Braun, 2010; García-Medrano et al., 2019; Lycett et al., 2006) and studies employing linear measures rather than spatial coordinates (Crompton & Gowlett, 1993; Pargeter et al., 2019). Thus, while the level of detail enabled by 3DGM is arguably useful for building artifact phylogenies (Okumura & Araujo, 2019), it is of questionable behavioral/technological relevance for the study of LCTs. For these reasons, we favored the use of simple caliper-based linear measures to quantify shape in our study. Nevertheless, Shott and Trail (2010) do identify three potential shortcomings of linear measurements compared to 3DGM. We considered each in the context of our particular materials and research questions. First, conventional linear measures capture the direction (e.g., length > breadth) but not the location of geometric relations (e.g., position of maximum breadth). We address this by collecting linear measures defined by homologous semi-landmarks. All artifacts were oriented along their maximum dimension, which was measured and defined as "length." The next largest dimension orthogonal to length was used to define the plane of "breadth," with the dimension orthogonal to this plane defined as "thickness." Breath and thickness measures were then collected at 25%, 50%, and 75% of length, oriented so that 25% Breadth > 75% Breath. To partition variation in shape from variation in size, we divided all linear measures by the geometric mean (Lycett et al., 2006).

Second, linear measures risk reducing complex forms to overly simplistic "stick figure caricatures" (Shott & Trail, 2010). However, whether or not this risk actually presents a problem depends on the particular artifacts and research questions involved. We have already noted that 3DGM LCT studies typically evaluate only a small portion of the measured variation. To better evaluate the measurement density required for our study, we reanalyzed a data set of 128 experimental handaxes previously published by Pargeter et al. (2019). These data comprise 19 linear measures (length plus breadth and thickness at 10% increments of length) collected from digital photos using the same orientation protocol described above. We conducted a PCA on the full set of 19 measures and again on a reduced set of 7 (length plus breadth and thickness at 30%, 50%, and 70% length). Despite this reduction, the first two components from each analysis displayed strikingly similar component loading matrices (PC1 positive on length and tip breadth, negative on thickness; PC2 positive on base breadth, negative on length and thickness) almost perfectly correlated component scores for individual pieces (PC1 r=0.919, PC2 r=0.913). As a further check, we performed the same comparison on a subset of the current archaeological sample from Gona for which photos were available for measurement (n = 50). This produced two PCs that were not only similar with each other, but also matched the PCs extracted from the experimental handaxe sample. Individual piece component scores were again highly correlated (r=0.975 and 0.927 respectively). Seven linear measures thus appear sufficient to explain technologically/behaviorally relevant shape variation in our sample. Third, linear measures may struggle to capture attributes such as cross-sectional area and shape (e.g., Caruana, 2020) more easily assessed using 3DGM. Particularly relevant here are measures of surface area used to calculate indices of reduction intensity (Clarkson, 2013; Shipton & Clarkson, 2015b) and surface modification (Li et al., 2015) used in our study. Clarkson (2013) advocates the use of 3D surface area measures as more accurate than estimation from linear measures (e.g., surface area of a rectangular prism defined by artifact dimensions). However, he also found that the error introduced by the linear approach was a highly systematic, isometric overestimation of surface area and that results correlated with direct 3D measures with an impressive r2 = 0.944 and no effect of variation in core shape. Insofar as it is variation in the relationship between surface area and flaking intensity that is of interest, rather than the absolute size of artifacts, such consistent overestimation is not problematic. Here we improved on the prism-based surface area formula (2LW + 2LT + 2 WT) by using our 7 recorded dimensions to more tightly fit three prisms (Figure 1) around the artifact: SA = W1T1 + 2(.33L * W1) + 2(.33L * T1) + 2(.33L * W2) + 2(.33L * T2) + 2(.33L * W3) + 2(.33L * T3) + W3T3. Surface area calculated in this way correlates with mass2/3 at r2 = 0.947 in our sample.

PCA on GM-transformed caliper measures (length, 3 breadth, 3 thickness). Length is maximum dimension, piece oriented so that Br1>Br3

Typological and technological attributions considered unreliable. Data grouped according to context (~2.5 mya Oldowan sites vs. ~1.5 mya Acheulean sites) and blank form (cobble, flake, indeterminant).

Associations between form and reduction intensity are considered as an indicator of “imposed form.” Such form could reflect mental templates and/or biased flaking patterns due to functional or technological constraints

2.2.5 Reduction Indices

Research by Clarkson and Shipton has established the Scar Density Index (SDI = number of flake scars > 1cm per unit surface area) as a reliable indicator of mass removed from a core across technologies (Clarkson, 2013) and for handaxes specifically (Shipton & Clarkson, 2015a). We thus use SDI as an indicator of reduction intensity (mass removed) in our study. However, reduction intensity does not constitute a full description of core modification. Mass removal is the aim during flake production and extent of shaping are not necessarily the same thing. For example, imposition of a desired form

3 Results

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