**Evaluating the Suitability of Lithic Illustrations in Morphometric Analyses**

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**Abstract**

Illustrations of lithic artefacts are an abundant source of morphological and technological information for those interested in our human past. As a typical part of archaeological reports and publications, lithic drawings are - or have to be – trusted as faithful reproductions of the selected artefacts. Despite the considerable epistemic work lithic illustrations (and illustrators) are expected to do, usually little information is available regarding the illustrator’s technical skill; thus, it remains unknown whether drawings produced by illustrators of differing technical skill are comparable or produce images of equal analytical potential to other media, e.g. photographs. The issue of lithic illustration accuracy is brought to the fore by the recent emergence of geometric morphometric approaches as innovative and powerful ways of describing and analysing complex shapes, as lithic illustrations provide one of the key sources for such analyses. Motivated by these issues, we present an experiment investigating the degree of error observed in illustrations of differing technical illustrative skill. Analyses suggest that lithic illustrations produced by individuals with a variety of experience in drawing lithics create, in the majority of instances, equally faithful representations (in outline shape) of chipped stone artefacts. With error observed in a small number of instances, archaeologists are still urged to be critical of an illustration’s source prior to lineal and geometric morphometric methodologies. Despite this, archaeologists can be confident in their exactitude and we remain strong advocates in favour of lithic illustrations as a readily available legacy resource for morphometric analyses.

**Keywords**: LITHICS; ILLUSTRATION; GEOMETRIC MORPHOMETRIC; STONE TOOLS

**Introduction**

Lithic illustrations testify how archaeologists have, for over a century, visually described and documented the morphological and technological characteristics of this omnipresent material culture. From the commissioned wood-engravings by Fairholt and Swain (Evans 1872), to early twentieth century drawings by Waterhouse (Smith 1926, 1931; Oakley 1949) and Gurd (Curwen 1939), and through to the development of professional technical guides (Dauvois 1976; Martingell 1980, 1981, 1982, 1983; Addington 1986; Bryant 1986; Martingell and Saville 1988; Inizan et al. 1999; Raczynski-Henk 2017), a common language for describing and discussing chipped-stone artefacts has become prescribed. Despite these efforts to standardise lithic illustration, substantial variability persists (cf Martingell and Saville 1988; Saville 2009). To this day, lithic illustrations are central to the archaeological process, continuing to have a central place in conference oral and poster presentations, articles, teaching materials and excavation reports. As highlighted by Pastoors and Weniger (2011: 9), the ability to produce and understand lithic illustrations is commonplace among researchers and taught at university level education; postgraduate and further education courses specific to archaeological illustration (in which lithic drawings are a central component) have also been offered over the last decade. While contrary to most scientific disciplines, acknowledging that photographs and other recording processes are more appropriate (Lopes 2009), the lithic drawing, and act of putting pencil/pen to paper is still the main means for communicating artefact forms to this day.

While lithic illustrations are formal documentation detailing technological aspects of an individual artefact, they can also be ‘read’ and thus communicate specific interpretations (Adkins and Adkins 1989). Lithic illustrations therefore represent the interplay of objectivity and subjectivity, providing “… much more relevant and comparable information […] edited more easily than a photograph” (Adkins and Adkins 1989: 6). Lopes (2009:14) describes this mixture of faithful realty and intended emphasis as a “concourse between detail, realism, visuality and selectivity”, comparable to both a piece of art and a scientific technical document (Hahn 1992; Inizan et al. 1999).

While many articles highlight the merits of three-dimensional recording for the extraction of technological and morphological information (Lycett et al. 2006; Grosman et al. 2008; Clarkson 2010; Lin et al. 2010; Bretzke and Conard 2012; Sholts et al. 2012; Shott 2014; Chacón et al. 2016; Shott and Trail 2016; Herzlinger et al. 2017; Herzlinger and Grosman 2018; Herzlinger and Goren-Inbar 2019), several studies continue to extract morphological data from lithic illustrations. Over the last decade, geometric morphometric (GMM) methodologies have been routinely employed for the analysis of two-dimensional shape, and given their abundance and perceived accuracy, lithic illustrations have served as a means for extracting and investigating lithic shape data. This is particularly relevant for artefacts that are generally flat, e.g. bifacial- and blade-based tool classes (Buchanan et al. 2015; Costa 2010; Charlin et al. 2014; Serwatka 2015, 2018; Cardillo et al. 2016; O'Brien et al. 2016; Serwatka and Riede 2016; Charlin and González-José 2018; Riede and Pedersen 2018). This too is true for the analysis of other artefact morphologies, including ceramic and metal material culture (Forel et al. 2009; Martínez-Carrillo et al. 2010; Monna et al. 2013; Wilczek et al. 2014, 2015; Birch and Martinón-Torres 2019). Lineal measurements, and indices resulting from these measurements, have also been extracted and recommended from lithic illustrations, for example in research quantifying handaxe symmetry (Hardaker and Dunn 2005; White and Foulds 2018).

The extraction of two-dimensional data sourced from lithic illustrations, in comparison to three-dimensional procedures, boasts a number of advantages. Firstly, two-dimensional data (in photograph format) has been assessed as equally valid for GMM analyses in comparison to three-dimensional techniques (e.g. Courtenay et al. 2018). Secondly, less technical knowledge is required to extract two-dimensional data; illustrations and images are easier to clean than a three-dimensional mesh, and through photo-editing software measurement data can be extracted. Perhaps the greatest advantage is in the ability to amass large datasets with relative ease, with the inclusion of archival and legacy data gleaned from old collections of illustrations and photographs. Thus, a trade-off between the loss of morphological coverage is offset, in comparison to three-dimensional data, by the gain in statistical power.

However, as hinted above, while standardisation is emphasised in illustration guides and by lithic analysts (Chase 1985; Addington 1986; Martingell and Saville 1988), illustrations can vary depending on the skill set of the illustrator, and as noted by Pastoors and Weniger (2011: 10), “the graphical transformation of the same lithic artefact can differ from researcher to researcher… which may lead to variations in the scientific analysis of the same prehistoric object”. More importantly, illustrations in articles often lack enough metadata to demonstrate the skill base of the illustrator, whether this be the number of previously published examples, their training and background in lithic illustration, or the number of hours an illustrator has roughly drawn for. The hiring of graphical artists who do not specialise in stone tool technology is also widely known to be commonplace (Adkins and Adkins 1988). While this may seem a superficial footnote in the representation of the artefact, and how we comprehend past material culture, if illustrations are both objective and subjective, and vary in their quality from illustrator to illustrator, then it is unknown if published lithic illustrations are the a faithful representation of artefact shape, or a suitable form of data for understanding our human past.

This article addresses for the first time this fundamental yet overlooked precondition in the extraction of measurement and shape data from lithic illustrations: specifically, does the extracted morphological data differ in shape and dimensions depending on the level of technical illustrator skill? This paper does not seek to test the strengths and weaknesses of either two- or three-dimensional recording strategies, nor their curatorial importance (Abel et al. 2011), but purely the methodological protocol undertaken by lithic analysts interested in morphology. In this article, two research questions are addressed:

1. Do illustrators of differing technical (lithic) illustrative skill produce different shapes?
2. Do illustrators of differing technical (lithic) illustrative skill produce different measurements?

In examining these two research questions, it is possible to determine whether illustrations produced by illustrators of differing technical knowledge provide equally valid results for studies examining artefact morphology. Such an analysis would evaluate pre-existing practices in researchers utilising lithic illustrations to record morphological data, and examines the notion of whether archaeologists need to be more critical of archaeological illustrations in data extraction procedures

**Methodology**

In order to examine the presence and extent of morphological error associated with differing illustrator technical skill, the following workflow was produced. A total of 15 artefacts from three different artefact types were selected: five elongated artefact forms (including Danish axe-head rough-outs and Grand Pressigny *livres de beurres*), five handaxes and five tanged points. These three different artefact groups were chosen given their varying shape complexity and morphology (with five different examples demonstrating a degree of variation within each artefact class), and their use in GMM in recent years (see references above). These artefacts were sourced and loaned from collections at Moesgaard Museum (Aarhus, Denmark)

*Illustrator recruitment and skill-level*

While there are different criteria for defining skill and determining skill-levels, for this paper we are focusing our definition on distinguishing between the lay-illustrator (with little-to-no experience), the mid-level illustrator (with experience approved by peers), and the professional illustrator (with qualifications or equivalent experience, and who illustrates as a main or secondary occupation). A three-fold categorisation was created in liaison with the UK-based Chartered Institute for Archaeologists Graphics Archaeology Group (<https://www.archaeologists.net/groups/graphics>), formerly the Association of Archaeological Illustrators and Surveyors (AAI&S), incorporating three criteria: 1) knowledge-base (lithic drawing conventions and protocol), 2) experience (in time spent drawing lithic illustrations), and 3) commercial, professional and/or academic output.

For this article, professional technical illustrators are defined as having experience greater than 40 hours (including tuition) of producing lithic illustrations, using pre-referenced and established illustrative and technical conventions, and examples in a number of publications in commercial (published or grey literature), professional or research-based projects. Intermediate technical illustrators are defined as being able to demonstrate a suite of agreed conventions in lithic illustrations, with limited or no academic, commercial or professional output and experience totalling between 20-40 hours (including tuition). Novice technical illustrators are here defined as individuals who cannot demonstrate an understanding of agreed conventions in lithic illustration, do not have experience or minor experience in lithic illustration (c. less than 10 hours including tuition), and cannot demonstrate any academic, commercial or professional output.

Following a general recruitment scheme, a total of 17 individuals were recruited for the drawing experiment, totalling 270 lithic illustrations from 13 novice illustrators (195 illustrations: 76.5%), three intermediate illustrators (45 illustrations: 17.6%) and one professional illustrator (15 illustrations: 5.9%). Many of the novice illustrators were first-year undergraduates from the Department of Archaeology and Heritage Studies at Aarhus University, of which four students had complete a module with four hours of lithic illustration (and tuition) included. Intermediate illustrators included individuals who had produced lithic illustrations for their studies, in addition to internal departmental research projects, and were of postgraduate level with a specialism in prehistoric archaeology. A professional illustrator from Moesgaard Museum (Louise Hilmar) was recruited for the experiment; Louise Hilmar has over a decade of experience in lithic illustration, with illustrations in a number of archaeological publications (XXX)..

A greater number of intermediate and professional illustrators would have been desirable; however, with a large number of artefacts, and the use of artefact classes, the small number of intermediate and professional illustrators are offset by the quality (255 illustrations and a further 15 photographs) of the data produced. Furthermore, in capturing a true sense of representation among novice illustrators (where the greatest amount of variation was assumed to occur), a greater number of novice illustrators were necessary. However, any further study should incorporate a greater number of intermediate and professional illustrators (see the discussion for more information).

*Illustration exercise*

All participants produced illustrations on the same white graph and tracing paper, using conventional illustrator drawing tools (0.2mm Artline water-resistant fine-liner pens and Faber Castell 0.35mm mechanical retractable drawing pencils), and had access to equipment typical to the illustrative process, including callipers, rulers, set-squares and a kneadable rubber (for artefact orientation and steadying). A number of other stationary aids were provided. Participants were told to refrain from researching lithic illustration conventions and were not told which equipment was necessary. Upon arrival, participants were instructed to produce one perspective for each artefact (as indicated with a detachable label), and to produce their finish inked illustrations on tracing paper to a 1:1 scale. Importantly, this exercise was blind in that participants were unaware of why the illustrations were necessary, and that only the shape outline was required; this resulted in illustrations including scar drawings and minute details. No time limit was imposed, and all participants ensured that no other commitments were planned, as to reduce the production of hurried drawings. All students performed their illustrations independently without communication as to avoid external illustrative influences from other individuals. Students were compensated for their time following the experiment. For photographs of the lithic illustration exercise, please refer to Figure 1.

**Fig 1** Photographs from the lithic illustration exercise. Left: participants drawing lithic illustrations. Right: the experiment, with the three artefact classes and finished illustrations. Photographs: CSH

*Post-illustration digitisation*

Following the experiment, all illustrations were scanned as a TIFF file with a resolution of 600 dots-per-inch (dpi), following guidelines by Raczynski-Henk (2017). All images, scanned to 1:1 scale, were cleaned through a binary transformation function in Photoshop CS6. Following this, a .psd file 10mm scale was then placed onto each image. For examples of the artefacts illustrated, refer to Figure 2 and Figure 3.

**Fig 2** Examples of illustrations drawn by the professional illustrator (Louise Hilmar, Moesgaard Museum, Denmark). Top: handaxe artefacts; Middle: elongated artefacts; Bottom: large tanged point artefacts. Scale: 10mm

**Fig 3** Examples of the same illustrations in Figure 2 drawn by novice and intermediate illustrators. Top: handaxe artefacts; Middle: elongated artefacts; Bottom: large tanged point artefacts. Scale: 10mm

As photographs are also a common method of two-dimensional GMM and measurement extraction (Buchanan and Collard 2010; Iovita and McPherron 2011; Okumura and Araujo 2014, 2016; Iovita et al. 2017; MacLeod 2018; Hoggard et al. 2019), all artefacts were photographed and compared to the drawn technical illustrations. A photographic rig set-up and a 50MP Canon EOS 5DS DSLR camera were used throughout this process. A 50mm lens was used in order to avoid photograph distortion or ‘fish-eye’ (Mullin and Taylor 2002). In addition, to avoid scaling issues associated with the collection of measurement data, the scale, used in all photographs, was elevated to the height of all artefacts (as large artefacts may result in a scaling and distortion issue). Following this, all photographs were saved a raw image file, exported in a TIFF format with the scale replaced by the same 10mm .psd file scale used previously.

In order to extract measurement and shape data from the illustrations and photographs, the following data collection procedure was created: Once all images were catalogued and ordered, the images were rotated along their axis of symmetry, with a one-pixel thick line created along this axis. All illustrations and photographs were then inspected, with scales double-checked, before being converted into a thin-plate spline (.tps) file in the open-source program tpsUtil v.1.69 (Rohlf 2017a). In tpsDig2 v.2.31 (Rohlf 2019) each image was scaled using the ‘image tools’ function. Using the ‘Make Linear Measurements’ function in tpsDig2 the maximum length and width measurements for each artefact were calculated. Following this exercise, twenty landmarks – two geometrically determined landmarks and 18 sliding semilandmarks – were digitised along the right portion of each artefact. As these artefacts are largely symmetrical, an analysis of a cross-section would capture a sufficient level of artefact shape, and a similar level of shape information as the total shape, as to address the first research question. Landmarks (two-dimensional Cartesian coordinates) provide the shape-based information for each artefact at their extremities while sliding semilandmarks (Gunz and Mitteroecker 2013) provide optimal coverage for curves (lithic edges) where homologous points are problematic or difficult to position. For further information on the analytical framework underpinning GMM, and the above practice, refer to the following publications: Rohlf (1986), Bookstein (1989, 1991, 1997), MacLeod (1999, 2017, 2018), MacLeod et al. (2010), O’Higgins (2000), Adams et al. (2004), Zelditch et al. (2004), Slice (2007), and Gunz et al. (2005). For GMM review articles specific to archaeological material culture, refer to the following publications: Lycett et al. (2006), Cardillo and Reyment (2010), Buchanan et al. (2015), Hirst et al. (2018) and Okumura and Araujo (2019).

*Calculating digitisation and measurement error*

Measurement error (ME) and digitisation error (DE) can occur from a number of sources. These include: 1) the measurement device or software used, 2) the definition of the measure in question, 3) the measurer, 4) methodological protocol, 5) landmark placing and 6) the number of observers (Hildebolt and Vannier 1988; Barker et al. 1994; Choi et al. 2002; Arbour and Brown 2014). As this article is addressing error in illustrator skill then the ability to quantify (and minimise) ME and DE is essential. Through the above protocol many sources of error are mitigated; however, some imprecision error is still expected. For error associated with scale calibration and measurement extraction, fractional uncertainty was calculated. This as calculated as the ratio (in percentage format) of the standard error (standard deviation of the mean) divided by the average value for ten repeated length, width and scale calibration measurements. These 30 measurements were taken over the course of ten days (one of each measurement a day), performed in tpsDig2, and recorded by one of the authors (CSH). Fractional uncertainty MEs of 0.11%, 0.23% and 0.12% were calculated for length, width and scale calibration respectively. A further experiment, replicating the process from image scanning to measurement calibration (five times), was performed to test for error in the digitisation process; a fractional uncertainty of 0.9% was recorded.

In calculating landmark DE, the same TIFF file of a randomly selected artefact was examined five times (over the course of five days). Following this, the landmark data was transformed through a generalised Procrustes analysis (GPA) (Gower 1975; Rohlf and Slice 1990; Bookstein 1991; Adams et al. 2004). Through a GPA, all specimens are translated to a common origin (0,0 for a two-dimensional space), scaled to unit centroid size, and through a least-squares criterion, optimally rotated until all corresponding coordinates align as close as possible. For the optimal placement of sliding semilandmarks, during the GPA, the minimising of Procrustes distance between target and reference specimens was calculated (Rohlf and Slice 1990). For this procedure three GPA iterations were necessary for maximum convergence. To investigate the error associated with these Procrustes coordinates, a Procrustes ANOVA (Goodall 1991) was performed to test for statistical significance (with a null hypothesis of same populations). Subsequently, the digitisation error calculated as the ratio of sum of squares (SS) for within and between groups (individuals) was calculated and expressed as a percentage. The Procrustes ANOVA highlighted that the null hypothesis of same populations could not be rejected (F: 0.282, Z: -2.366, p: 0.991), with a digitisation error of 8.59% calculated.

*Analytical and exploratory framework*

To investigate if different illustrators of differing technical knowledge produce different shapes, Procrustes coordinates for the three artefact classes were first obtained through the same procedure outline above: individual .tps files for each artefact class were normalised through a GPA prior to exploratory and analytical examination. Changes in artefact shape within each artefact class, and between the different technical skill levels, were then investigated through a principal component analysis (PCA), with shape variance analysed through the first few principal components and the respective scree plot for each analysis. Second, differences in illustrator skill were assessed through individual Procrustes ANOVAs for each artefact, allowing a detailed examination of where difference in skill level is best exemplified. Post-hoc testing through discriminant analyses, while problematic given issues of sample size (Kovarovic et al. 2011), provides an additional means of understanding whether illustrator skill levels can be separated, and was also employed. With issues in sample size, classification scores – sourced from discriminant analysis – are not explored here.

To investigate if different illustrators of differing technical knowledge produced different measurements, all metric data was first examined through bivariate analyses and an assessment of respective coefficient of variation (CV – see Eerkens and Lipo 2005) values for each artefact measurement were explored. These are accompanied by the mean length and width values for each artefact and skill level to exemplify the degree of between-group difference between each artefact. Normality testing (through a Shapiro-Wilk test) was then employed before multivariate testing through a MANOVA. In instances where the null hypothesis (where the sample originates from a normally distributed population) was rejected, then a permutated MANOVA using distance matrices (Anderson 2001) was employed (Anderson 2001). For a workflow of the analytical procedure adopted in this article please refer to Figure 4.

Figure 4. Analytical workflow for this article. Orange: measures of inter-observer error.

In all instances, a null hypothesis of same populations was assumed with an alpha level of 0.01 deemed appropriate given the context of the experiment, dataset size and the sensitivity of the project’s aims (in detecting change in the artefact illustrations); all significance values are never-the-less reported, with the analysis and framework designed to test the robustness of the produced significance or their lack of. In performing the above procedure, geomorph (Adams and Otárola-Castillo 2013), MASS (Venables and Ripley 2002), psych (Revelle 2017), tidyverse (Wickham 2016) and vegan (Oksanen 2017) packages in the R Environment (R Development Core Team 2017) were used. A number of other dependent attached packages were also used: please refer to the R Script for further information. All data created and used throughout this experiment, and an R Markdown (with .html report) accompanies this article. Furthermore, all supplementary information can also be found on the Open Science Framework (OSF): <https://osf.io/xtghn/>.

**Analysis**

In all three PCA bivariate graphs (Figures 5-7), greater than 70% cumulative shape variance can be accounted for in the first two principal components, with elongated, tanged and handaxe artefact classes accounting for 70.1%, 84.7% and 91.8% cumulative shape variance respectively. In all three instances, the five different artefacts for each class appear distinguishable within the first two principal components, irrespective of technical illustrative skill or method. Within the first two principal components, variation among the novice and intermediate illustrators are demonstrated, and in the majority of instances the professional and photograph shapes closely align. With respect to within-group variation, among the scatterplots, a greater degree of clustering (suggestive of lower within-group variance) can be observed for tanged point forms, with observable or looser clustering (suggestive of higher within-group variance) for elongated and handaxe forms. While elongated and tanged artefacts are spatially exclusive among the first two principal components, several handaxes (artefacts 1 and 2, and 4 and 5) overlap due to novice illustrations, an important point noted in the discussion.

**Fig 5** PCA axes 1 and 2 for elongated artefacts (totalling 70.1% shape variance). For individual XY shape transformations please refer to the R Script

**Fig 6** PCA axes 1 and 2 for tanged artefacts (totalling 84.7% shape variance). For individual XY shape transformations please refer to the R Script

**Fig 7** PCA axes 1 and 2 for handaxe artefacts (totalling 91.8% shape variance). For individual XY shape transformations please refer to the R Script

Post-hoc testing through individual discriminant analyses for each artefact (summarised in Figure 8) reveal how in the majority of instances (n = 10) photographs cannot be differentiated from illustrations drawn by novice illustrators among the first two discriminant axes. Discriminant analyses demonstrate close alignment between professional and photograph artefact shapes, in addition to minor clustering between novice and intermediate illustrations. For further details on the discriminant analysis, please refer to the R Script

**Fig 8** Discriminant analysis for individual artefacts according to illustration skill. Each class represented in this graph is in artefact order. Square: novice; triangle: intermediate; circle: professional; cross: photograph

Procrustes ANOVAs (with residual randomisation) for individual artefacts (Table 1) demonstrate that no statistical significance (to the proposed 0.01 alpha level) exists for observed shapes of differing individual artefacts recorded, and thus the null hypothesis of no difference in technical illustrative skill has to be accepted. This supports the above exploratory ordination methods and post-hoc testing.

**Tab 1** Procrustes ANOVA (Goodall 1991) for illustrative technical skill and photographs for each artefact class. Residual randomisation method: ordinary least squares (OLS)

With regard to the calculated length and width measurements, bivariate analyses (Figure 9) highlight a similar pattern to the above GMM analyses, specifically: 1) observed clustering between the photograph and professional artefact measurements, 2) deviations in both the measurements of intermediate and novice illustrations when compared to photograph and professional illustrations, and 3) increased within-group variation for handaxe illustrations.

**Fig 9** Length and width bivariate graphics in millimetres (units not displayed) for elongated (a), handaxe (b) and tanged point (c) artefact illustrations. Shapes correspond to illustration skill (Square: novice; triangle: intermediate; circle: professional; cross: photograph)

Further analysis through an assessment of central tendency (Table 2) highlight that length and width measurements calculated from the professional illustrations generally mirror measurements extracted from photographs. For width measurements, greater variation can be observed with seven of the 15 novice and intermediate sets of illustrations nearest to values calculated from the photographs. An examination of their dispersion, through an assessment of CV values, demonstrates a general trend in increasing standardisation with increasing skill level, with novice illustrators on average producing a mean CV value of 1.8% for length measurements and 1.5% for intermediate illustrations. Greater variation, corresponding with the bivariate and central tendency analyses, is observed; however, increasing standardisation is again noted with a mean CV of 3.3% and 2.8% for novice and intermediate illustrators accordingly. It is possible that the drawing of larger artefacts is prone to a greater degree of error, however post-hoc testing through regression analyses suggests no statistical relationship between size and standardisation (length permutated p: 0.741; width permutated p: 0.135). Ever mindful of the relatively low sample size, these analyses in sum suggest increasing standardisation in shape (in terms of length and width) with increasing skill.

**Tab 2** Measures of central tendency and dispersion for length and width measurements calculated for each artefact. N: novice; I: intermediate; Pr: professional; Ph: photograph. Bold: values closest to the values observed for the photograph

Finally, multivariate analyses of variance (Table 3) indicate that statistical significance to the 0.01 value can be observed for one artefact (elongated artefact #5), with significant responses for the length measurements of two artefacts (elongated artefact #3 and #5). As other examples do not demonstrate the required significance level the null hypothesis has to be rejected. However, as a number of other artefacts demonstrate noticeably low statistical responses, and as the previous analyses have suggested, it would be incorrect to disclaim wholly that illustration skill does not affect artefact shape (in lineal measurements).

**Tab 3** MANOVA and response values for illustration skill and method for individual artefacts. Bold: significant to the 0.01 alpha level. Asterisk: significant to the 0.05 alpha level. Note: one artefact (handaxe artefact #3) was examined through a permutated MANOVA (perMANOVA) due to violated assumptions in multivariate normality

**Discussion**

Collectively, these results demonstrate the suitability of illustrations, irrespective of technical drawing skill, and irrespective of shape complexity, for the collection of accurate metric and outline data, when compared alongside photographs. The analyses, as faithful reproductions of a variety of artefact shapes, confirm the merit of studies which have utilised lithic illustrations in understanding aspects of our human past (e.g. Costa 2010; Serwatka 2015, 2018; Cardillo et al. 2016; Serwatka and Riede 2016; Charlin and González-José 2018; Riede and Pedersen 2018). Despite the trade-off in comparison to other forms of higher-resolution two- and three-dimensional data, the potential of legacy and archival data can continue to be seen as of great merit to any archaeologist interested in understanding artefact morphological change. Interestingly, the documented CV values observed for the length and width measurements for novice and intermediate illustrators (c. 1-6%) demonstrate a relatively high strength of conformance in replicating the two-dimensional shape from an artefact, and a copy error range that is highly-standardised and deemed imperceptible as suggested through models from psychophysics (e.g. Weber’s Law) and cultural transmission studies on artefact morphology (Eerkens and Lipo 2005; Kempe et al. 2012).

While so, the exploratory and analytical procedure for both the measurement and shape data, specifically the spatial overlap of handaxe shapes by novice illustrators, and low *p* values observed for the length and width responses, highlight the need for caution in the use of illustrations in analyses of morphology. Such concerns echo similar data collection procedures (Evin et al. 2016; Shott and Trail 2016), with illustrations by professional illustrators or photographs always favoured. In the spirit of methodological transparency, we encourage all researchers who use illustrations to formally acknowledge a drawing’s provenance, if known, the illustrator’s background, and respect possible sources of error in their use. With the above analyses suggesting that errors in illustrations of differing technical illustrative skill may arise in a small number of instances, best practice and a critical mindset of the illustrations sourced for analysis, should be paramount.

As this study was designed to investigate illustration error, and the ramifications for their use in analyses of morphology, four future lines of work are desirable in building on from the hypotheses generated above. First, future studies should first consider the role of scaling (i.e. whether this is performed during illustration or post-illustration), specifically how illustrators of different skill scale down an artefact to a variety of ratios commonly adopted by archaeologists and archaeological illustrators (e.g. 1:2, 2:3, 3:4) and how (and if) error akin to the above CV values is introduced throughout this process. Next, studies should include strictly published examples of lithic illustrations, rather than comparing illustrations to drawings. While archival drawings do provide a means for detailing artefact shape, published examples provide an accepted form of artefact shape. Such a method which examines published drawings would complement an experimental approach, as detailed here, and provide further justification and/or caution for the use of lithic illustrations in GMM procedures. In addition, future studies should investigate potential error introduced in the abstraction of measurements from photograph data, and explicitly the positioning of the scale relative to the plane of the artefact. Future studies should investigate how the above methods compare to three-dimensional models for each artefact. As methods such as photogrammetry and structured-light 3D scanners are becoming increasingly portable, cheaper, simpler to use, with standardised and explicit protocols for data acquisition (Bates et al. 2010; Falkingham 2012; Katz and Friess 2014; Porter et al. 2019), such an investigation would provide a useful framework for understanding the accuracy of illustrative methods. Finally, and perhaps most importantly, there is a need to upscale the experiment in order to allow for further explorative and analytical methodologies at a higher analytical level. These future studies should prioritise the inclusion of a large number of intermediate and expert illustrators. This too could include the analysis of illustrations from other artefact classes of both greater shape complexity and more variable sizes (cf. Forel et al. 2009; Monna et al. 2013; Wilczek et al. 2014, 2015), given that drawing inaccuracy may become substantially aggravated as objects become increasingly more complex or reduce in size. That said, our study does not indicate that more complex forms – here the tanged points – lead to greater error, but instead that objects of larger size may be more difficult to accurately reproduce independently of shape complexity, perhaps due to psychophysical limitations in visual accuracy.

**Conclusion**

Encouragingly, our analyses demonstrate that lithic illustrations produced by illustrators of differing technical skill and knowledge of lithic artefacts offer comparably accurate results to photographs and professional illustrators. Through the replication of three different artefact classes, and a range of artefacts within each class, this article highlights their analytical power and suitability for lineal and two-dimensional GMM methodologies, thus strengthening the methodological frameworks of past publications utilising such data, and lending confidence to future studies that laudably seek to integrate such legacy data - the plentiful drawings of lithic artefacts contained in archaeological reports, monographs and syntheses – into digitally and computationally enabled approaches. Yet, while the corpus of illustrations at disposal to archaeologists provide a means to understand artefact change, our analyses do reinforce the need for the analyst to be cautious. In a minority of examples outlined here, minimal differences in particular shapes may produce unfaithful reproductions of stone artefacts, lending strength to the necessity for care to be adhered. Nonetheless, our study provides support and legitimacy for utilising legacy and archival lithic illustrations as data in computational methods for quantifying and understanding morphological change.

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