Detecting skill level and mental template in biface morphology: Archaeological and experimental insights

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Abstract

Stone tools provide key evidence of human cognitive evolution but remain challenging to interpret.

Keywords: Late Acheulean; Biface production; Boxgrove; Experimental archaeology; Skill level; Mental template

Contents

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1 Introduction

Handaxe is a well-studied and well-published topic, but some aspects of it still remain elusive. More specifically, the sources of variation of handaxe morphology can be very complex, but skill level and mental template are two major factors.

Skill level: short literature review

Mental template: short literature review

Here we have two interconnected research questions based on a reference sample generated from our 90-hour handaxe skill acquisition experiment: 1) Can skill level and mental template (or "aesthetic preference") be effeciently detected from biface morphometric data? 2) What is the effect of training on these two aspects?

2 Materials and methods

2.1 Boxgrove biface collection

The archaeological site of Boxgrove is located in the former Eartham quarry, Boxgrove, West Sussex, featuring a long sequence of Middle Pleistocene deposit (Pope et al., 2020; Roberts & Parfitt, 1998). This 500-ka-old site has documented exceedingly rich details of Lower Paleolithic hominins' subsistence behaviors (Smith, 2013, 2012) and their paleoenvironmental contexts (Holmes et al., 2010). In addition to the presence of one of the earliest hominin fossil (*Homo heidelbergensis*, Hillson et al., 2010) and bone assemblages with anthropogenic modifications in northern Europe (Bello et al., 2009), Boxgrove is mostly known for its large sample size of Late Acheulean-style flint handaxes and the high knapping skill level reflected in this manufacture of these handaxes. As such, it has received wide research attention in the past two decades regarding the relationships between technology, cognition, and skills (García-Medrano et al., 2019; Iovita et al., 2017; Iovita & McPherron, 2011; Shipton & Clarkson, 2015; Stout et al., 2014). To identify the morphological manifestation of knappers' dexterity in our study, we selected a complete handaxe assemblage (n=326) previously analyzed and reported in digital formats by Iovita and McPherron (Iovita & McPherron, 2011), which is currently curated at the Franks House of the British Museum (Iovita et al., 2017).

2.2 Experimental biface collection

The biface experimental replicas used in this study comprised two sub-collection. The first sub-collection includes 10 bifaces knapped by three expert knappers, including Bruce Bradley (n=4), John Lord (n=3), and Dietrich Stout (n=3) (Stout et al., 2014). The second sub-collection is produced from a 90-hour handaxe knapping skill acquisition experiment (Bayani et al., 2021; Pargeter et al., 2020; Pargeter et al., 2019), where 30 adults with no previous experience in knapping were recruited from Emory University and its surrounding communities and requested to make 132 bifaces in total. Among these 30 adult participants, 17 have gone through multiple one-to-one or group training sessions that amounted to 89 hours in maximum, while the remaining 13 were assigned to the controlled group, where no formal training is given.

In this experiment, all research participants participated in the initial assessment (assessment 1 in our data set) before formal training, where they each produced a handaxe after watching three 15-minute videos of Late Acheulean style handaxes demonstrated by expert knappers and examining four Late Acheulean style handaxe replicas. Subsequently, the 17 participants in the experimental group were assessed after every ten hours of the cumulative learning period, where each of them was requested to produce a handaxe for expert knapper's review, leading to the compilation of a data set composing 9 assessements in total. It should be also noted that 6 out of 17 participants dropped out of the research before the final assessment due to personal reasons. To detect the effect of training on skill level and mental template, we reorganized our assessment classification scheme and combined it into three broader categories, namely pre-training (assessment 1), early training (assessment 2-5), and late training (assessment 6-9), which helps increase the sample size of the measured intervals. A more detailed experimental protocol can be assessed in one of our published papers (Pargeter et al., 2019).

2.3 Lithic analysis

To better understand the morphological variation of Boxgrove biface collection, we adopted a standardized analytical procedure to extract the morphometric information from 752 photos of the studied samples prepared by R. I. (Iovita & McPherron, 2011), which include both the front and lateral views of a given specimen. First, we used Adobe Photoshop to conduct a batch transformation of the samples' pixel scale into a real-world measurement scale based on the fixed photographic setting. This is then followed by the batch conversion of color photographs to a black-and-white binary format. Subsequently, we cropped the silhouettes of bifaces one by one using the Quick Selection Tool in Adobe Photoshop. The metric measurements were conducted in ImageJ (Rueden et al., 2017), where we employed a custom script (Pargeter et al., 2019) to measure the maximum length, width, and thickness of a given silhouette. The width and thickness measurements are taken at 10% increments of length starting at the tip of each biface (**Figure** 1), which eventually leads to 19 morphometric variables in total (1 length measurement, 9 width measurements, and 9 thickness measurements). Finally, we calculated the geometric means of all 19 linear measurements to create a scale-free data set that preserves the individual morphological variation at the same time (Lycett et al., 2006). The same procedure was also applied to the morphometric analyses of the experimental biface collection, which was partially published in Pargeter et al. (2019).

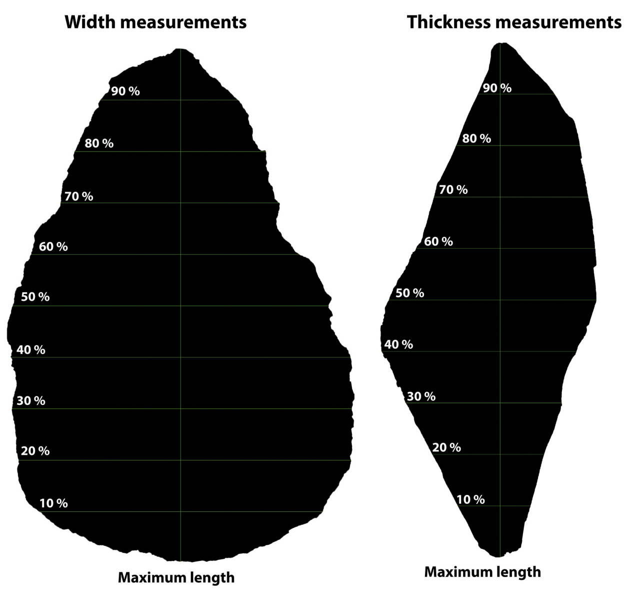

Figure 1: A visual demonstration of the biface measurement protocal using Image J (after Pargeter et al. 2019: Figure 5).

2.4 Statistical analyses

Given the number of variables involved in this study, we used the principal component analysis (PCA) to reduce the dimension and identify the possible patterns in this morphometric data set, which is one of the most commonly used techniques in similar studies (García-Medrano, Maldonado-Garrido, et al., 2020; García-Medrano, Ashton, et al., 2020; Iovita & McPherron, 2011; Shipton & Clarkson, 2015; Stout et al., 2014). To detect the effect of training on novices' performance as compared with archaeological samples and biface made by experts, we also compare the corresponding metrics built on PCA across different training periods and across all groups using the Games-Howell nonparametric post-hoc test, which does not rely on the assumptions of equal sample sizes and equal variance. This study adheres to the principles of reproducibility and data transparency of archaeological research by depositing all the codes and data sets involved in an open-access online repository (Marwick, 2017), which can be accessed through the author's Github (https://github.com/Raylc/PaST-pilot).

3 Results

3.1 Principal component analysis

Our analysis suggested that the first two components already explain 77.2% of the variation for the entire morphometric data set composed of 19 variables (**Figure** 2), which is a rather decent explained variance ratio to avoid overfitting. We then decided to focus on and further interpreted the implications of these first two components based on their relationships between variables (**Table** 1). The first principal component (PC1) indicates the overall biface thickness as it is positively correlated with all thickness measurements while negatively correlated with all other measurements. That being said, a higher PC1 value indicates a thicker biface, and vice versa. The second principal component (PC2) tracks the elongation and pointedness based on its positive relationship with maximum length and bottom width/thickness. As PC2 increases, a biface will be generally longer and more pointed since its bottom part will be bulkier.

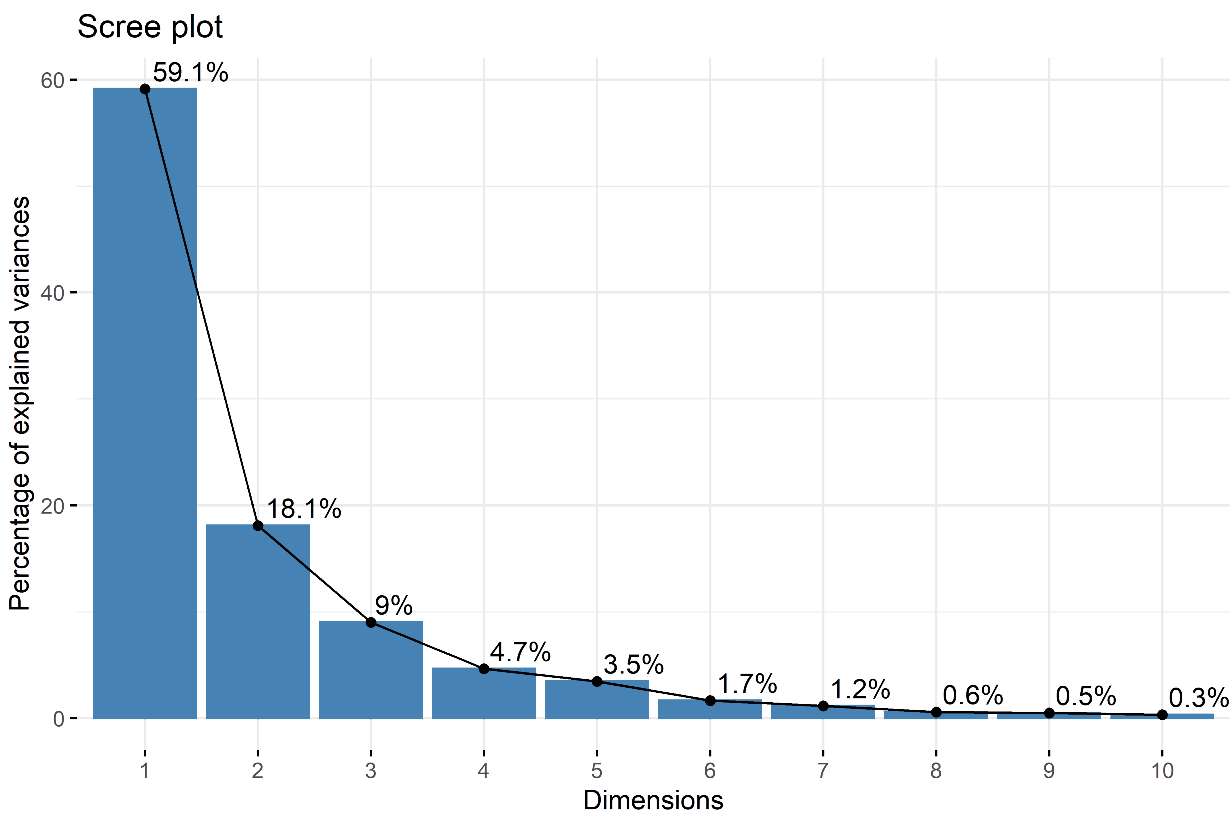

Figure 2: A scree plot showing the percentage of explained variances of the first 10 principal components.

Table 1: Variable loadings for the first two principal components

X	Dim.1	Dim.2
width_0.1	-0.1131312	-0.1256408
width_0.2	-0.1419554	-0.1326946
width_0.3	-0.1684170	-0.1232328
width_0.4	-0.1867226	-0.0966578
width_0.5	-0.2037483	-0.0651505
width_0.6	-0.2121330	-0.0197136
width_0.7	-0.2083163	0.0232790
width_0.8	-0.1885821	0.0661257
width_0.9	-0.1447319	0.0805702
thickness_0.1	0.0142639	-0.0240388
thickness_0.2	0.0247137	-0.0227114
thickness_0.3	0.0435524	-0.0093580
thickness_0.4	0.0667936	0.0047643
thickness_0.5	0.0893523	0.0261202
thickness_0.6	0.1083112	0.0484852
thickness_0.7	0.1288346	0.0628567
thickness_0.8	0.1444047	0.0659257
thickness_0.9	0.1308949	0.0487419
max_length	-0.3626265	0.2507234

A closer look at the principal component scatter plot (**Figure** 3) yields the clustering of different groups of bifaces. The majority of Boxgrove bifaces occupy an area featuring negative values of both PC1 and PC2. The expert group is similar to the Boxgrove group in PC1, while the former has a relatively higher PC2 value than the latter on average. The group of novice displays the highest level of variability, however, it is rather pronounced that most bifaces made by novices have a positive PC1 value that is different from both the groups of Boxgrove and experts.

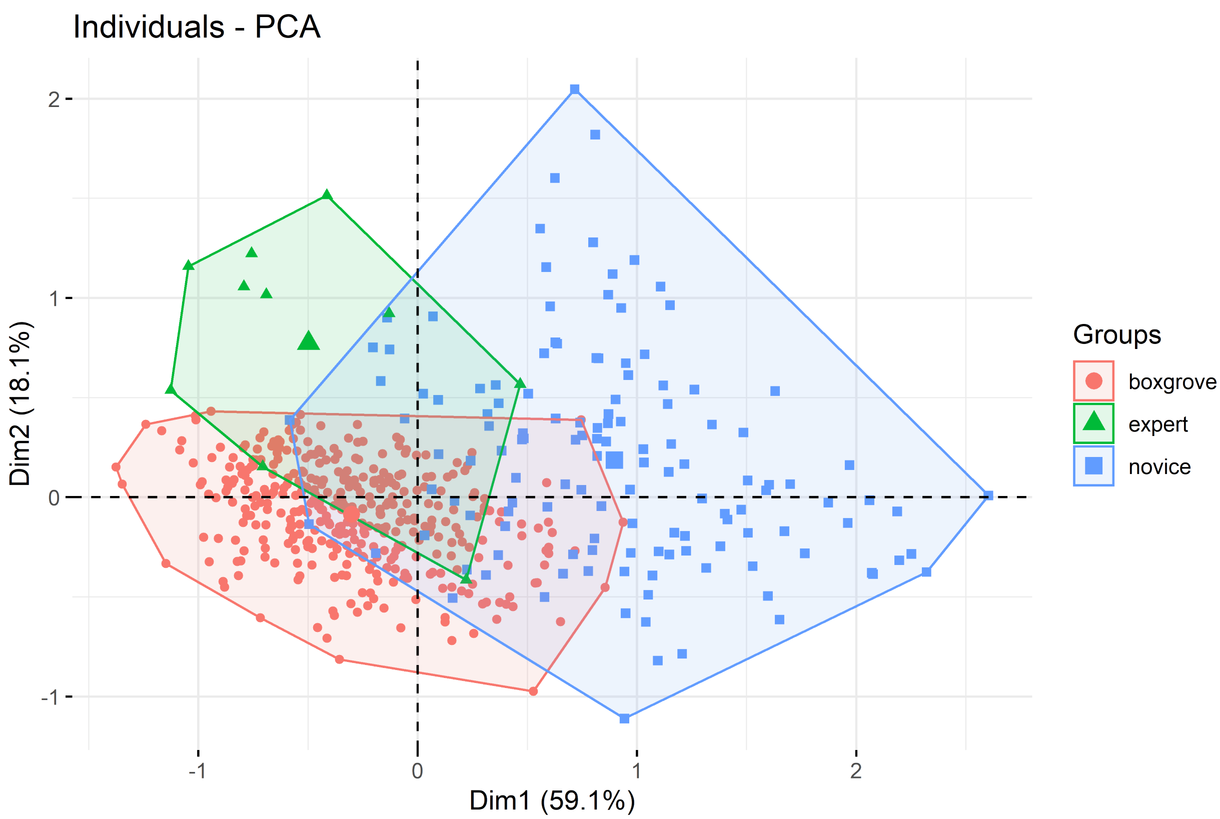

Figure 3: A principal component scatter plot of bifaces from the groups of Boxgrove (red, n=326), expert (green, n=10), and novice (blue, n=132).

3.2 Effects of training

We extracted the PC1 and PC2 values of individual bifaces and compared them between different groups. More specifically, the novice group was divided into three sub-groups based on their training stages as specified in the method section. As such, we found that for PC1 values (**Figure** 4), the only two group comparisons that are **not** statistically significant are the one between Boxgrove and Expert and the one between Early training and Late training stages, which at least partially confirms our visual observation of the general PCA scatter plot. Likewise, for PC2 values (**Figure** 5), the group comparison between the Early training and Late stages again is **not** statistically significant. However, a rather surprising result here is that the mean PC2 value difference between the Pre-training group and Boxgrove is also **not** statistically significant.

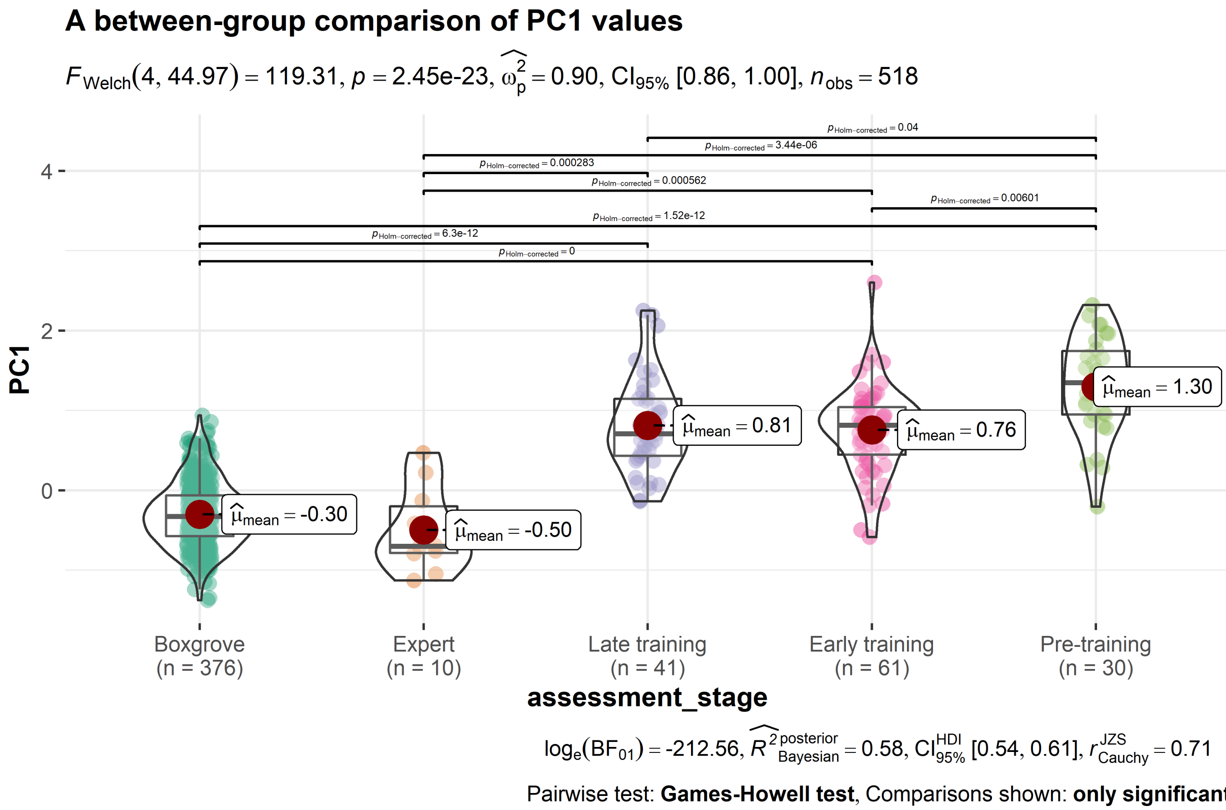

Figure 4: A between-group comparison of PC1 values.

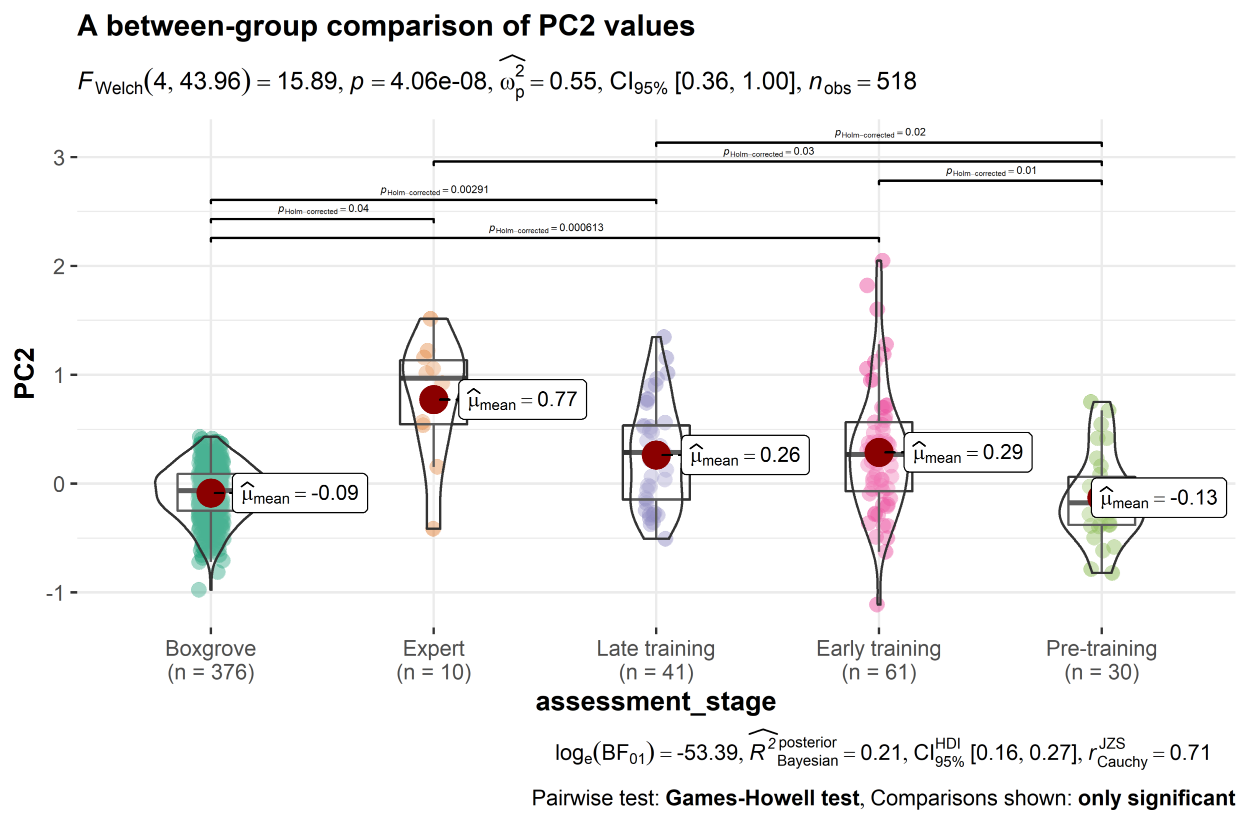

Figure 5: A between-group comparison of PC2 values.

4 Discussion

PC1 (thickness) is a robust indicator of skill level as it is shared by modern expert knapper and boxgrove foragers, while PC2 (elongation and pointedness) reflects more of personal/community-level aesthetic choices. However, we do not intend to construct a false binary framework and put these two factors as disconnected and opposite concepts.

Training is important in terms of its immediate effects (pre-training vs. post-training) in both skill level and mental template, however, 90 hours of training is still not enough for novice to reach the reach the skill level as reflected in expert knappers or Late Acheulean toolmaker.

The pre-training group is similar to the Boxgrove group in PC2 because these novices lack the ability to effectively reduce the nodules, which are typically flat pre-prepared cortical flakes, to a desired form (**Figure** 6). That being said, if the given nodules already possess a oval morphology like those presented in the Boxgrove assemblage, it is likely the form of end products knapped by novices in the pre-training group will remain roughly unchanged. This explanation is also supported by the comparison of average delta weight, defined as the difference between the weight of handaxe and the weight of nodule, among four groups, where the pre-training group display the lowest value (**Figure** 7). On the other hand, the refitting analyses of the Boxgrove handaxe assemblage have suggested that the nodules exploited by foragers inhabiting this site are somewhat bulky and amorphous (Roberts & Parfitt, 1998: 339, 360). These characteristics have been clearly displayed in a recent attempt of slow motion refitting of a handaxe specimen from Boxgrove GTP17 (https://www.youtube.com/watch?v=iS58MUJ1ZEo). As such, behind the resemblance of the pre-training group and the Boxgrove assemblage in PC2 are two types of mechanisms that are fundamentally different from each other, where the latter group exhibits a complex suite of cognitive and motor execution processes to transform the shapeless raw materials to a delicate end product in a given shape.

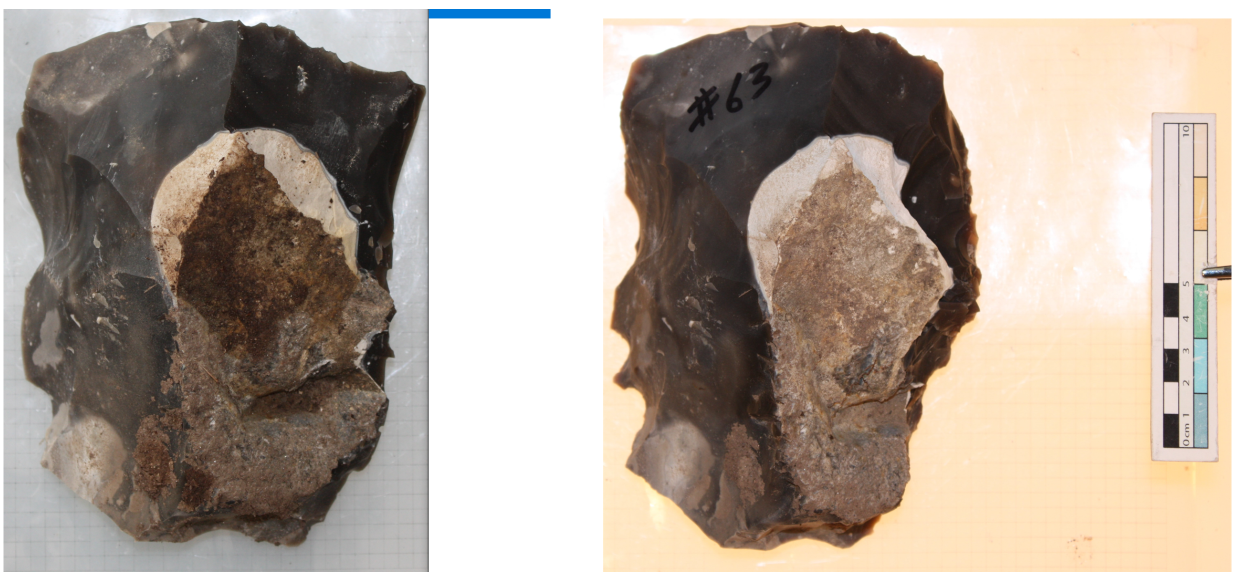

Figure 6: Core 63 before (left) and after knapping(right), showing the minimal morphological change during the process

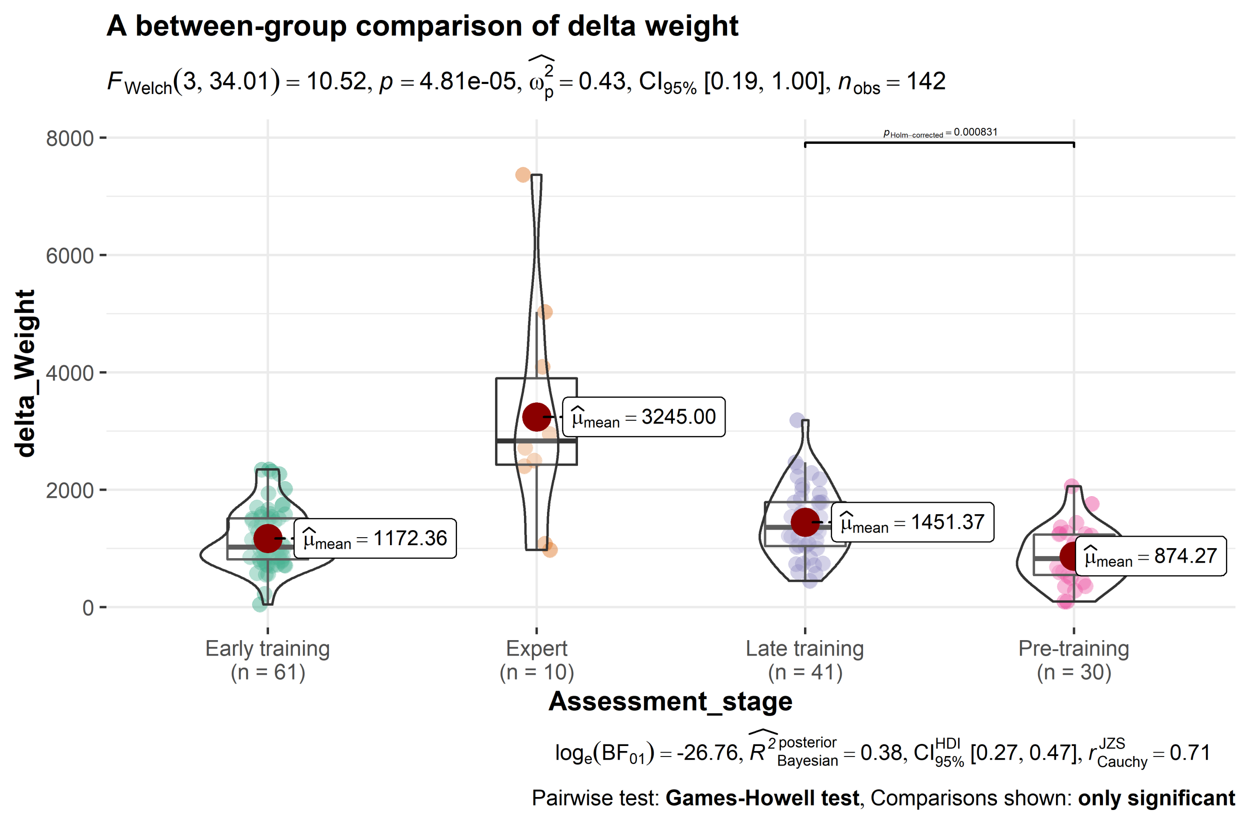

Figure 7: A comparison of the delta weight between the pre-training, early training, late training, and the expert group.

Experimental archaeology has a huge potential in similar topics.

Maybe also something about how this study demonstrate the potential of archaeological data reuse and its contempoary relevance [information age+pandemic+ethical research]?

5 Conclusions

Regarding the two research questions we proposed in the beginning, our case study suggested that 1) we can delineate the effects of skill level and mental template through the multivariate analysis of morphometric data, where the former is associated with thickness while the latter is reflected in elongation and pointedness; 2) Training has an effect, but 90 hours of training is still not enough for novice to reach the level of expertise.

6 CRediT authorship contribution statement

Cheng Liu: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Nada Khreisheh**: Investigation, Writing – review & editing. **Radu Iovita**: Resources, Writing – review & editing. **Dietrich Stout**: Conceptualization, Investigation, Resources, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing. **Justin Pargeter**: Conceptualization, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

7 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8 Acknowledgements

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References

Bayani, K. Y. T., Natraj, N., Khresdish, N., Pargeter, J., Stout, D., & Wheaton, L. A. (2021). Emergence of perceptuomotor relationships during paleolithic stone toolmaking learning: intersections of observation and practice. *Communications Biology*, *4*(1), 1–12. https://doi.org/10.1038/s42003-021-02768-w

Bello, S. M., Parfitt, S. A., & Stringer, C. (2009). Quantitative micromorphological analyses of cut marks produced by ancient and modern handaxes. *Journal of Archaeological Science*, *36*(9), 1869–1880. https://doi.org/10.1016/j.jas.2009.04.014

García-Medrano, P., Ashton, N., Moncel, M.-H., & Ollé, A. (2020). The WEAP method: A new age in the analysis of the Acheulean handaxess. *Journal of Paleolithic Archaeology*, *3*(4).

https://doi.org/10.1007/s41982-020-00054-5

García-Medrano, P., Maldonado-Garrido, E., Ashton, N., & Ollé, A. (2020). Objectifying processes: The use of geometric morphometrics and multivariate analyses on Acheulean tools. *Journal of Lithic Studies*, *7*(1). https://doi.org/10.2218/jls.4327

García-Medrano, P., Ollé, A., Ashton, N., & Roberts, M. B. (2019). The Mental Template in Handaxe Manufacture: New Insights into Acheulean Lithic Technological Behavior at Boxgrove, Sussex, UK. *Journal of Archaeological Method and Theory*, *26*(1), 396–422. https://doi.org/10.1007/s10816-018-9376-0

Hillson, S. W., Parfitt, S. A., Bello, S. M., Roberts, M. B., & Stringer, C. B. (2010). Two hominin incisor teeth from the middle Pleistocene site of Boxgrove, Sussex, England. *Journal of Human Evolution*, *59*(5), 493–503. https://doi.org/10.1016/j.jhevol.2010.06.004

Holmes, J. A., Atkinson, T., Fiona Darbyshire, D. P., Horne, D. J., Joordens, J., Roberts, M. B., Sinka, K. J., & Whittaker, J. E. (2010). Middle Pleistocene climate and hydrological environment at the Boxgrove hominin site (West Sussex, UK) from ostracod records. *Quaternary Science Reviews*, *29*(13), 1515–1527. https://doi.org/10.1016/j.quascirev.2009.02.024

Iovita, R., & McPherron, S. P. (2011). The handaxe reloaded: A morphometric reassessment of Acheulian and Middle Paleolithic handaxes. *Journal of Human Evolution*, *61*(1), 61–74. https://doi.org/10.1016/j.jhevol.2011.02.007

Iovita, R., Tuvi-Arad, I., Moncel, M.-H., Despriée, J., Voinchet, P., & Bahain, J.-J. (2017). High handaxe symmetry at the beginning of the European Acheulian: The data from la Noira (France) in context. *PLOS ONE*, *12*(5), e0177063. https://doi.org/10.1371/journal.pone.0177063

Lycett, S. J., von Cramon-Taubadel, N., & Foley, R. A. (2006). A crossbeam co-ordinate caliper for the morphometric analysis of lithic nuclei: a description, test and empirical examples of application. *Journal of Archaeological Science*, *33*(6), 847–861. https://doi.org/10.1016/j.jas.2005.10.014

Marwick, B. (2017). Computational Reproducibility in Archaeological Research: Basic Principles and a Case Study of Their Implementation. *Journal of Archaeological Method and Theory*, *24*(2), 424–450. https://doi.org/10.1007/s10816-015-9272-9

Pargeter, J., Khreisheh, N., Shea, J. J., & Stout, D. (2020). Knowledge vs. know-how? Dissecting the foundations of stone knapping skill. *Journal of Human Evolution*, *145*, 102807. https://doi.org/10.1016/j.jhevol.2020.102807

Pargeter, J., Khreisheh, N., & Stout, D. (2019). Understanding stone tool-making skill acquisition: Experimental methods and evolutionary implications. *Journal of Human Evolution*, *133*, 146–166. https://doi.org/10.1016/j.jhevol.2019.05.010

Pope, M., Parfitt, S., & Roberts, M. (2020). *The horse butchery site 2020: A high-resolution record of lower palaeolithic hominin behviour at boxgrove, UK*. SpoilHeap Publications.

Roberts, M. B., & Parfitt, S. A. (1998). *Boxgrove: A middle pleistocene hominid site at eartham quarry, boxgrove, west sussex*. English Heritage.

Rueden, C. T., Schindelin, J., Hiner, M. C., DeZonia, B. E., Walter, A. E., Arena, E. T., & Eliceiri, K. W. (2017). ImageJ2: ImageJ for the next generation of scientific image data. *BMC Bioinformatics*, *18*(1), 529. https://doi.org/10.1186/s12859-017-1934-z

Shipton, C., & Clarkson, C. (2015). Handaxe reduction and its influence on shape: An experimental test and archaeological case study. *Journal of Archaeological Science: Reports*, *3*, 408–419. https://doi.org/10.1016/j.jasrep.2015.06.029

Smith, G. M. (2013). Taphonomic resolution and hominin subsistence behaviour in the Lower Palaeolithic: differing data scales and interpretive frameworks at Boxgrove and Swanscombe (UK). *Journal of Archaeological Science*, *40*(10), 3754–3767. https://doi.org/10.1016/j.jas.2013.05.002

Smith, G. M. (2012). Hominin-carnivore interaction at the Lower Palaeolithic site of Boxgrove, UK. *Journal of taphonomy*, *10*(3-4), 373–394. https://dialnet.unirioja.es/servlet/articulo?codigo=5002455

Stout, D., Apel, J., Commander, J., & Roberts, M. (2014). Late Acheulean technology and cognition at Boxgrove, UK. *Journal of Archaeological Science*, *41*, 576–590. https://doi.org/10.1016/j.jas.2013.10.001