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Standardization of Nubian Levallois Technology in Dhofar, Southern Arabia

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ABSTRACT
The characteristics and distribution of "Nubian" Levallois technology have been prominent in recent discussions of Middle Palaeolithic/Middle Stone Age technological variability and its implications. Here we explore Nubian Levallois technology by focusing on the relative "standardization" of the TH.69 assemblage from western Dhofar, one of the most "Nubian" of all "Nubian" assemblages. Aspects evaluated include the shape of cores and the dorsal surface preparation patterns. We found that in some ways – such as the overall reduction method, and coefficients of variation for various features of core shape – the assemblage does demonstrate standardization. Yet, in others, such as the precise way in which dorsal surface convexity was prepared, the assemblage is rather less standardized. Our findings highlight the complexity of defining and operationalizing the concept of standardization. On balance, we argue that TH.69 does demonstrate relatively standardized reduction, yet the wider meaning of this is not clear.

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Introduction

The trend in lithic analysis in recent decades to more dynamic perspectives, focusing on reconstructing processes rather than on describing static objects – has, perhaps, a downside that it often has a strongly essentializing character, and frequently lacks clear data to support its claims. This paper calls for more attention to variation *within* technological categories, as well as to provoke thought and questions on the notion of standardization in lithic technology in general, and specifically in relation to a pertinent area where this topic is raised: debates on Nubian Levallois technology. Should we think about standardization of the form of the products, or of the process to produce them? What counts as standardized and what not? A long history of research explores lithic standardization, and particularly its implications in terms of cognition (e.g. Byers, 1994; Wurz, 1999). Others have cautioned against interpreting cognitive aspects directly from lithic standardization (e.g. Chase, 1991; Dibble, 1989; Monnier, 2006). The perspectives emphasized here build on previous arguments such as the importance of quantitative analysis and the need to cross-cut analyses of reduction methods with measures of reduction intensity (e.g. Groucutt et al., 2015a, 2015b, 2017; Scerri et al., 2014). Our focus is not on cognition as such, but relative standardization of lithic assemblages in the context of debates on hominin dispersal and adaptation – as cultural markers. A key point to emphasize is the lack of clarity on what lithic analysts exactly mean by standardization. This is not a debate we attempt to resolve here. Rather, we wish to consider a particular case study in the light of debates on standardization.

To proponents of the "Nubian Complex" as a taxonomic unit – that is to say, assemblages where the Nubian Levallois is reduction strategy is prominent – this "technocomplex" represent a spatially and temporally restricted phenomenon that offers a direct proxy for a human population (e.g. Rose et al., 2011; Rose & Marks, 2014; Usik et al., 2013). Following the discovery of Nubian Levallois technology in distant areas such as South Africa (Will et al., 2015), well outside the geographic distribution of "Nubian Complex" sites, an alternative perspective is that Nubian Levallois technology merely represents a subtle variation from other forms of Levallois reduction, and this is why it appears to have been repeatedly independently invented and used (e.g. Groucutt, 2020; Will et al., 2015). As such, this debate raises an important question as to how similar or different (i.e. how standardized) the

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technological features being discussed really are. Regardless of how one interprets the presence of Nubian Levallois technology, it is necessary to move from discussions of essentialised characteristics to comparisons of real characteristics.

The notion of "standardization" in lithic technology is often mentioned, yet rarely clearly defined or meaningfully operationalized. The Nubian Levallois method, which is primarily distinguished from other Levallois strategies by the creation of a median distal ridge, is often cited as being highly standardized, yet formal analysis of this remains limited. Guichard and Guichard (1965, p. 99), for instance, describe Nubian cores being ""mass produced" from an elaborate archetype". More recently, Rose et al. (2011, p. 11) observe Nubian Levallois technology in both Africa and Arabia as displaying a "high degree of standardisation" and being "virtually identical" on either side of the Red Sea. Likewise, Usik et al. (2013, p. 248) argue that Nubian Levallois cores in Dhofar are "highly standardised".

While Nubian Levallois technology is often regarded as highly standardized, there are, arguably, hints of regional variation in this technology, and therefore a need for further description and comparative study. In the case of Arabia, abundant Nubian Levallois technology has been found concentrated in western Dhofar, Oman (Rose et al., 2011; Usik et al., 2013). While absent from many Arabian Middle Palaeolithic sites (e.g. Armitage et al., 2011; Delagnes et al., 2012; Bretzke et al., 2014; Groucutt et al., 2015a, 2018, 2021), it has also been found elsewhere in Arabia, such as in both central (Crassard & Hilbert, 2013; Hilbert et al., 2016) and northern (Hilbert et al., 2017) Arabia. The excavated material from Umm al'Sha'al in central Arabia does not seem to have any specifically Nubian Levallois technology, but is argued to share some general affinities (Crassard et al., 2019).

Reports on Nubian Levallois technology in Arabia have noted various forms of variability. For instance, Hilbert et al. (2016) classify around twice as many of the Nubian Levallois cores from AK-40 as "Type 1" Nubian versus AK-43. In terms of shape, AK-43 Nubian Levallois cores are larger and more elongate than the others. Similarly, in Dhofar, multiple dimensions of variation have been documented. For instance, the frequency of Nubian Levallois cores varies considerably, from 56.5% at TH.383c to 90.1% for TH.69. Triangular shaped Nubian Levallois cores are much higher frequency in TH.377 (51.5%) compared to just 29.4% at TH.69. For median distal ridge angle, almost half the percentage of cores at TH.69 (30.4%) have steep angles compared to TH.383c (57.1%). To name just a few of the variations in Nubian Levallois core attributes found in Dhofar. Yet, what does this variability mean?

This paper aims to extend these debates by examining the TH.69 assemblage (Usik et al., 2013). TH.69 is a lithic surface scatter found at the headwaters of Wadi Aybut on the western Nejd plateau, in the Dhofar region of southern Arabia. TH.69 is of particular interest for its exceptional prevalence of Nubian Levallois technology, and for the large size of the assemblage (particularly in terms of the number of cores). The site was briefly described by Usik et al. (2013), who noted the relatively small size of lithics at TH.69, which they speculate could either represent a difference in age compared to other sites they studied, or, more probably, because it is the only site they studied not immediately on a raw material outcrop, and was therefore more intensely reduced. That material has been taken to the site for knapping may explain the unusually high frequency of Nubian Levallois technology, and the small size of cores compared to most other sites with Nubian Levallois technology in the area. As outlined below, a variety of features of the assemblage were studied in an effort to assess the assemblage's degree of standardization, as well as the implications of this in terms of analytical methodology in general, and the significance of Nubian Levallois technology specifically.

In this study we focus on the core assemblage from TH.69. This is in part because the character of cores has been central to discussions of Nubian Levallois technology. Indeed, many studies in lithic analysis have focused on cores (e.g. Jones, 2016; Lycett & von Cramon-Taubadel, 2013). It also reflects an analytical choice as the TH.69 assemblage features many more Levallois cores than it does Levallois products. Given that every lithic assemblage offers a particular window into spatially and temporally fragmented reduction processes, after evaluating the TH.69 assemblage from the perspective of standardization, we explore ways in which assemblages with different characteristics can be compared.

While one aim of this paper is to highlight and explore the various ways in which "standardization" can be understood in terms of lithic technology, we emphasize the utility of the coefficient of variation (CV) as a simple and effective quantitative measure in this regard (see e.g. Eerkens & Bettinger, 2001). Various lithic studies have used the CV to explore lithic standardization (e.g. Blessing et al., 2022; Key & Gowlett, 2022; Marks et al., 2001; Monnier, 2006; Muller & Clarkson, 2022; Wurz, 1999). We discuss in the Methods section our expectations of what standardization means in terms of the CV values. Finally, we consider how our assessment of the TH.69 lithic assemblage, including CV measures for various aspects of it, influences our understanding of lithic standardization and how future studies can improve understanding of this topic.

Methods

There were two parts to this study: firstly a detailed analysis of the TH.69 assemblage, and secondly comparative analyses with other sites from Arabia and adjacent regions. The detailed analysis of the TH.69 assemblage was conducted in 2012 and focused on the cores from the site. A brief examination of flakes and retouched flakes was conducted to contextualize the core analyses, and selected examples chosen for illustration. 178 cores were tabulated from the site. Of this, removing some broken and non-Nubian forms, a total of 171 Nubian Levallois cores were analyzed in detail. This is slightly more than the 155 Nubian Levallois cores classified by Usik et al. (2013). The difference may lay in different classification of cores interpreted as "preforms".

To clarify variation within the core assemblage, we tabulated the proportion of cores in the categories defined below. This is not intended as a complex typological scheme, but rather as a basic way to divide the assemblage in order to illuminate some of its fundamental characteristics. By Nubian Levallois preform, we mean cores which have a median distal ridge and some Levallois-like core features, but on which preparation has not been completed and no Levallois product has been removed. "Type 1" and "Type 2" Nubian Levallois cores, representing polar ends of a single reduction continuum, reflect the division between cores emphasizing preparation of the medial distal ridge from the distal end of the core (Type 1) versus from the lateral edges along the distal end of the core (Type 2). Note here that our use is focussed on the median distal ridge, rather than the debitage surface as a whole. Indeterminate Nubian Levallois is where the core cannot easily be assigned to either Types 1 or 2, such as where the Levallois removal has overshot and removed the distal end of the core (a common occurrence in Nubian Levallois reduction), including the median distal ridge that is the key defining feature of Nubian Levallois cores. Finally, "Levallois other" refers to non-Nubian Levallois cores. Further to this, we distinguish between cores which are: (1) unstruck (i.e. where preparation has seemingly been completed but a Levallois flake not removed); (2) struck (i.e. a Levallois flake has been removed, and the core has then not been evidently further reduced), and (3) reprepared, where further flaking of the debitage surface has taken place after the removal of a Levallois flake, thus potentially changing the size and shape of the negative scar of the Levallois removal.

For all cores, a variety of metric measurements and attribute states were recorded, following the method outlined in Scerri et al. (2014) and Groucutt et al. (2015a, 2015b, 2018). This aims to record aspects that allow for the quantification of the size and shape of the core, as well as features such as dorsal scar patterns. In addition to direct measurements, values were calculated for volume (length x width x thickness), elongation (length/width), and flattening (width/thickness). The angle of the medial distal ridge was measured as close to the distal edge as possible using a goniometer. Diacritical illustrations of many cores were made, focusing on the cores that had not been reprepared after the removal of the Levallois flake, as these give the clearest view of the character of preparation. This was achieved by recording the sequence of removals on the core debitage surfaces, seeing which scars superimpose others. The illustrations were later digitized using GIMP and color shading used to show the sequence of removals (lighter = earlier, darker = later). Indices such as volume and scar density index (a measure of reduction intensity) were calculated, as outlined in earlier studies by the first author (Groucutt et al., 2015b). Statistical analyses were conducted with PAST4 software, which was used to calculate basic descriptive statistics and visual forms such as histograms and violin plots.

For the inter-regional analysis, the characteristics and variability of TH.69 cores were compared to core assemblages from selected other Middle Palaeolithic sites in Arabia (TH.123b, MDF-61), Jordan (Tor Faraj), and Ethiopia (BNS, Omo Kibish). All data were collected by the first author. The aim is not a comprehensive regional study, but more an illustrative comparison based on some "typical" sites, such as Tor Faraj for the Levantine Late Middle Palaeolithic (Henry, 2003) and BNS for the East African MSA (Shea, 2008). The assemblages were examined in terms of scar density index and mass (g) in order to compare the basic characteristics of the cores. Only complete cores were studied. In some cases, refits were glued together to cores, which were not included in the present study. It should also be noted that the small "Nahr Ibrahim" pieces often interpreted as cores-on-flakes from Tor Faraj were not included in this study, to aid comparability between assemblages.

Secondly, a comparison of the shape of Levallois products was made. At TH.69, where cores massively outnumber Levallois products that were presumably carried away from the site, measurements on the final Levallois removal on cores were taken, whereas for other sites the dimensions of Levallois flakes themselves were measured. This was done both as the best way to elucidate Levallois products at TH.69, but also as a case study in how we can compare assemblages when those assemblages have different characteristics and reflect different stages of reduction.

While giving a variety of descriptive statistics, in terms of a quantifiable measure of standardization, we focus on building upon previous studies in terms of the meaning of coefficient of variation results. The CV is calculated by dividing the standard deviation in a sample by the mean, and then multiplying by 100 to give the results as a percentage. This gives a simple and scale free way to measure standardization.

Some general expectations from the literature can guide our broad understanding of the meaning of CV values. Eerkens and Bettinger (2001) seminal paper on the topic, for instance, highlights that a CV of over 57.7% indicates random variation, while emphasizing that humans cannot distinguish less than 1.7% CV (the Weber Fraction), although 5% may be a more realistic lower bounds (Eerkens, 2000). In other words, low CV values indicate high standardization, while high CV values indicate low standardization. CV values for other craft activities can give some insights. For instance, highly specialized pottery production can lead to CV values of around 5–10% (Roux, 2003), while the examples of stone tools such Mesolithic microliths, which we might expect to be standardsised, have CVs of around 20% (Eerkens & Bettinger, 2001).

Many lithic studies have employed the CV measure. For instance, Wurz (1999) argued that CV values for backed lithics from Klasies River in the 20–30% range indicated standardization (and pointed out that backed artefacts from LSA "Wilton" sites have a similar range of CV values). Muller and Clarkson (2022) explored CV on experimentally produced stone tools, using different core reduction methods, highlighting different CV values for flake length and width with different core reduction methods from 43.9% an 44.4% for length and width respectively for the bipolar method, to 21.6% and 27.8% respectively for pressure prismatic blade reduction. Blessing et al. (2022) present CV values for southern African MSA assemblages. For basic features such as flake length and width, they found values of around 20-30%. Interestingly, for some measures the CV was rather higher; for instance, blade thickness is typically more like 30-40%, but reached nearly 50% in one Howiesons Poort assemblage.

CV values were calculated for most handaxe measurements reported by Key and Gowlett (2022), although they found that some measures (such as weight) and some sites (such as their Kapthurin sample) had higher CVs than most. Measurements on handaxes from Boxgrove, for instance, often discussed showing a standardized handaxe shape, gave results in the 21–24% range, while other handaxe assemblages included in their study gave broadly similar measures, mostly in the 15–30% range. Given these indications of relatively standardized handaxe morphology in some aspects, fundamental considerations of the character of standardization in the long-term lithic record remains an important aspect for future discussion.

Looking specifically at Levallois technology – both archaeologically (Dibble, 1989) and experimentally produced (Eren & Lycett, 2012; Muller & Clarkson, 2022) – found that basic measurements of Levallois flakes had CVs of around 20-30%. Those are the typical values for measures such as length and width, while others such as thickness often have higher CVs.

From the body of literature on the topic, we propose the following thresholds as guides for evaluating standardization in the TH.69 assemblage. CV values of less than 20% indicate very high standardization, 20–30% indicate fairly high standardization, 30-40% indicates moderate standardization, while more than 40–50% indicates little standardization. In what follows, we aim to both consider the overall character of lithic reduction at TH.69 as well as an evaluation of CV to explore the relative standardization of the assemblage.

Results

Assemblage Description and Typology

Prior to focussing on the cores, a general overview of the assemblage was made. This indicates the homogeneity of the lithics, in terms of both weathering and technology. Given the relatively uniform surface weathering on the assemblage, it does not appear to (significantly) represent a palimpsest. Compared to other Nubian Levallois sites in Dhofar, the cores and debitage are significantly smaller (Usik et al., 2013) and exhibit greater intensity of scarring on the underside, indicating they have undergone more reduction than at other sites. As TH.69 is the only studied Nubian Levallois site in Dhofar not located directly on a raw material outcrop, the assemblage may represent a later stage of core reduction, supported by the comparatively large number of tools. A selection of general core preparation flakes are shown in Figure 1. The high frequency of cortical flakes (25.9%) suggests short reduction processes, rather than multiple phases of re-preparation.

The number of Levallois products in the assemblage ($n = 39$) is the highest of Nubian Levallois sites in Dhofar (Usik et al., 2013), yet miniscule considering the number of cores. Levallois products at TH.69 are typically rather diminutive (compared to other Dhofar sites with Nubian Levallois technology) pointed Levallois flakes (Figure 2).

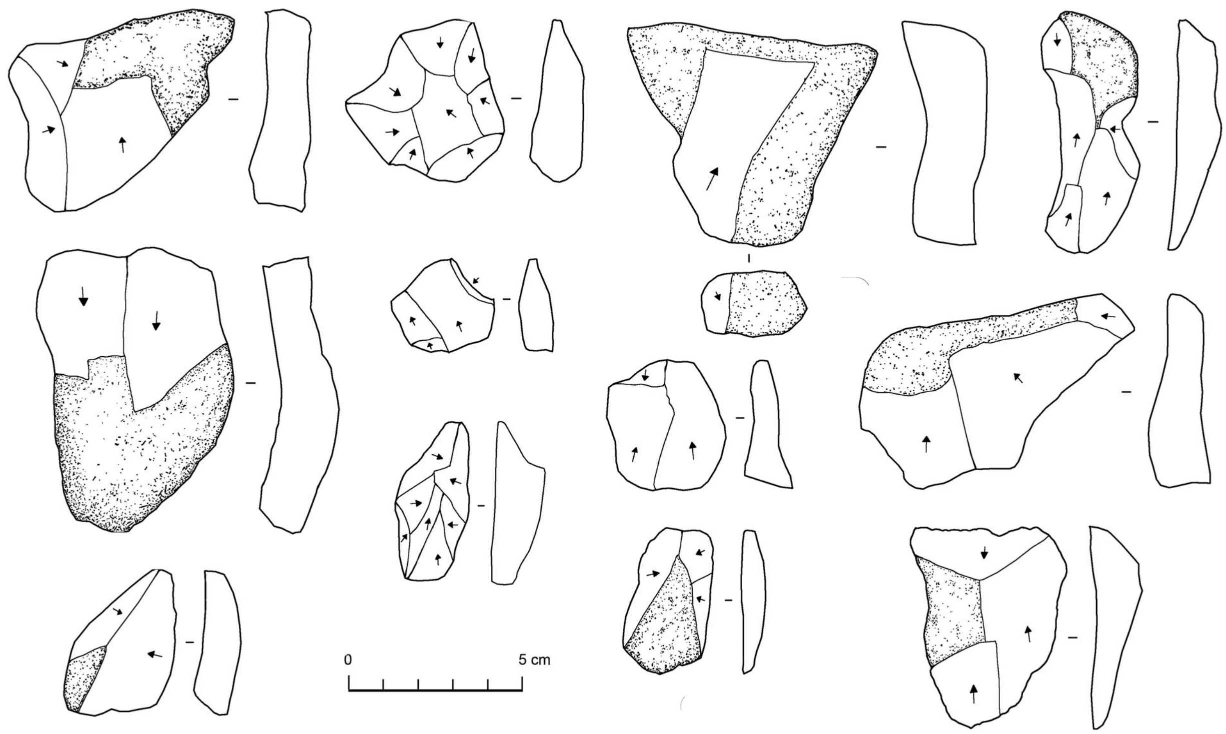

Figure 1. Selected non-Levallois flakes from TH.69 to show character of preparatory debitage.

When it comes to the TH.69 core assemblage, several technological aspects were noted. The main striking platforms on the cores appear to be relatively homogenous, and are mostly the "dihedral chapeau" form which are a distinctive feature of Dhofar assemblages (Usik et al., 2013). In this approach, the main shaping of the platform involves two main removals, the interface being the point where the blow for the preferential removal was subsequently made. In some cases, additional fine faceting of the platform was performed after the initial dihedral shaping. In terms of core shaping, the preparatory removals to create the median distal ridge and shape the lateral and distal convexity of the core surface occupy a broad spectrum between those described as Type 1 and Type 2 preparation (i.e. with removals from both the lateral and distal areas). The angle of the preparatory removals appears rather steep by typical Levallois standards. Most cores retain at least some cortex on the underside, but considerably less than other Nubian Levallois sites in Dhofar. Occasionally, a second Levallois removal per preparation cycle was made, but this is unusual and typically debitage surfaces show a single Levallois negative. The cores show few hinge and step terminations, indicating that knapping was well controlled, but overshot terminations are quite common.

In the typological scheme presented here, excluding a few fragments and non-Levallois cores (Usik et al., 2013), the cores are classified as Nubian Levallois preforms ($n = 7$), Nubian Levallois Type 1 ($n = 140$), Nubian Levallois type 2 ($n = 2$), Nubian Levallois indeterminate ($n = 18$), and Levallois other ($n = 4$).

Looking in more detail at the Nubian Levallois cores, with the 167 examples making up 95% of the site's total core assemblage (which itself shows a level of standardization), the Nubian Levallois cores can be classified according to the character of their preparation and exploitation ("struck" meaning that no repreparation was evident after the removal of the Levallois product). Divided in this way, the cores are classified as Nubian Levallois preforms ($n = 7$), Nubian Levallois Type 1 unstruck ($n = 1$), Nubian Levallois Type 1 struck ($n = 101$), Nubian Levallois Type 1 reprepared ($n = 38$), Nubian Levallois 2 struck ($n = 1$), Nubian Type 2 reprepared ($n = 1$), Nubian Levallois Indeterminate struck ($n = 9$), Nubian Levallois reprepared ($n = 9$). The meaning of this typology should not be taken too far; as indicated above, most cores in reality fall somewhere between those traditionally described as Type 1 and Type 2, referred to by some as Type 1/2 (Chiotti et al., 2009; Olszewski et al., 2010; Usik et al., 2013). Indeed, a consensus of researchers working on a variety of assemblages with Nubian technology in Africa and Southwest Asia have agreed to eschew these terms completely in favor of describing the pattern of distal ridge

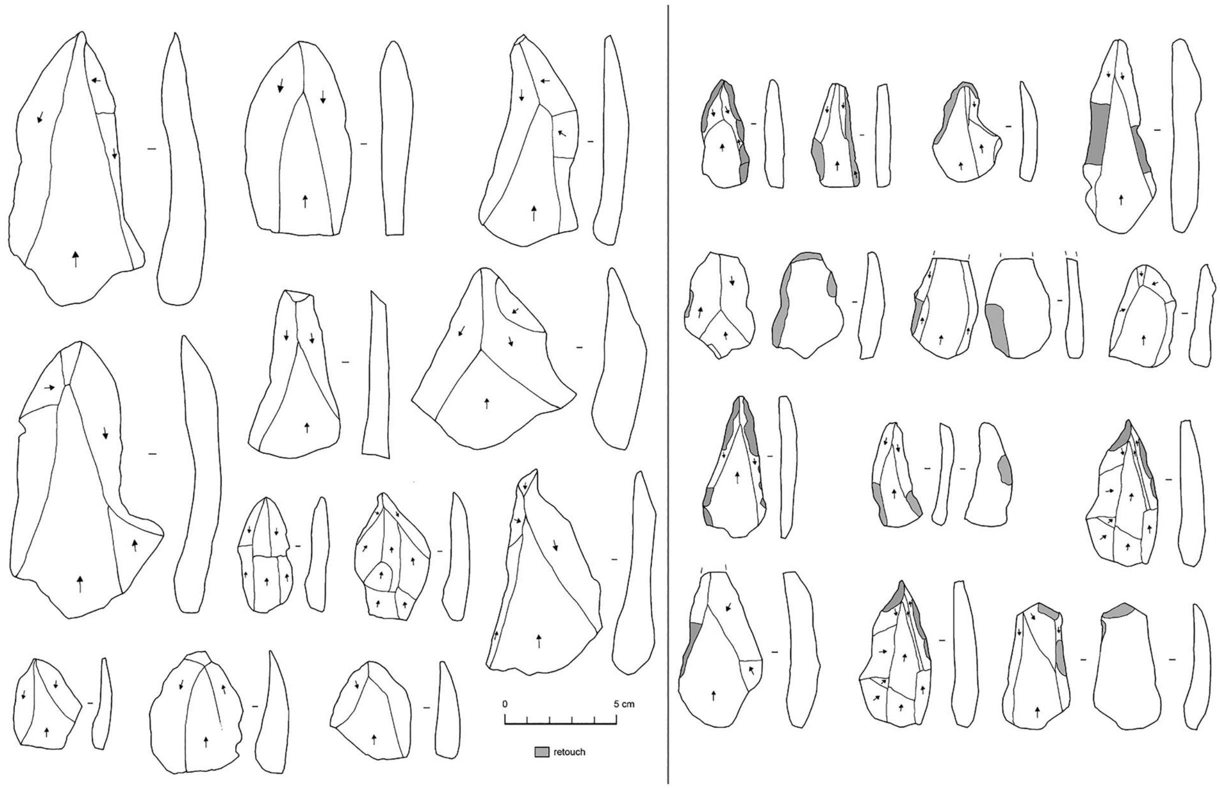

Figure 2. Levallois products from TH.123b (left) and TH.69 (right). Showing small size of TH.69 Levallois products compared to typical Middle Palaeolithic sites in Dhofar.

preparation; thereby reflecting more fully the spectrum of Nubian Levallois reduction (Hallinan et al., 2022). In overview, the typical TH.69 core (around 2/3 of the cores) shows Type 1 preparation, preferential exploitation, and no subsequent removals. Other forms represent either earlier stages of reduction, subtle variations, or were reprepared. This emphasis on preferential Levallois reduction can itself be seen as indicating a standardization of method (Figure 3).

Studying the chronological sequence of removals reveals a rather more varied picture than might be suggested by the static perspective of shapes and scar patterns. While previous accounts of Nubian Levallois have often suggested different forms of standardization of the core reduction process, albeit varying in whether median distal ridge shaping preceded or followed general debitage surface shaping (Guichard & Guichard, 1965; Usik et al., 2013), the present analysis found considerable variation in the shaping of core surfaces, as theorized by Beshkani's (2020) study of geometric "folding" of Nubian cores. In many cases, weathering of the cores made reading the chronology of removals difficult, as did horizontally invasive removals (such as "Type 1" debordant removals from the distal platform) which left small lateral scars isolated from each other and therefore hard to situate in time relative to each other. Likewise, the relatively high frequency of overshot preferential removals ($n = 14$), removed the median distal ridge and prevented a thorough reconstruction of chronology. Never the less, in many cases the majority, or even entirety, of the chronology of debitage surface preparation could be elucidated. Where the chronology was most clear, 16 cases showed median distal ridge preparation prior to general debitage surface shaping (e.g. Figure 4i), while in nine cases the opposite sequence was followed (e.g. Figure 4j). Various combinations of flaking were applied within these categories. Figure 4(m) shows an example where it cannot be determined whether the debitage surface was prepared before or after the rest of the core surface. Even where the entirety of the chronology of removals for the debitage surface cannot be reconstructed, there is clearly relatively high diversity in the directionality and chronology of removals. Summarising these data, the TH.69 cores show a general tendency to prepare the median distal ridge early in the core shaping process, but by no means exclusively.

Metric and Attribute Variation

Taking into account the size and shape of Nubian Levallois cores from TH.69, objects such as preforms have

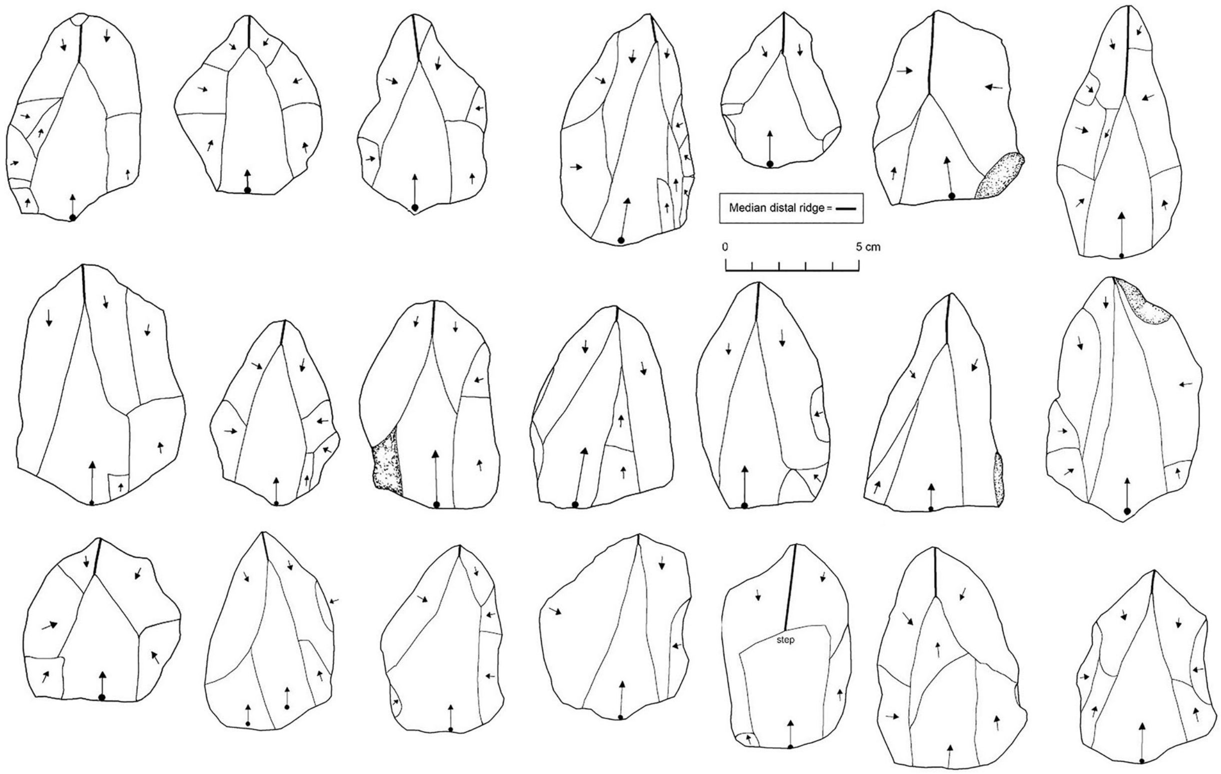

Figure 3. The debitage surfaces of selected Nubian Levallois cores from TH-69. The arrows with circles represent Levallois removals.

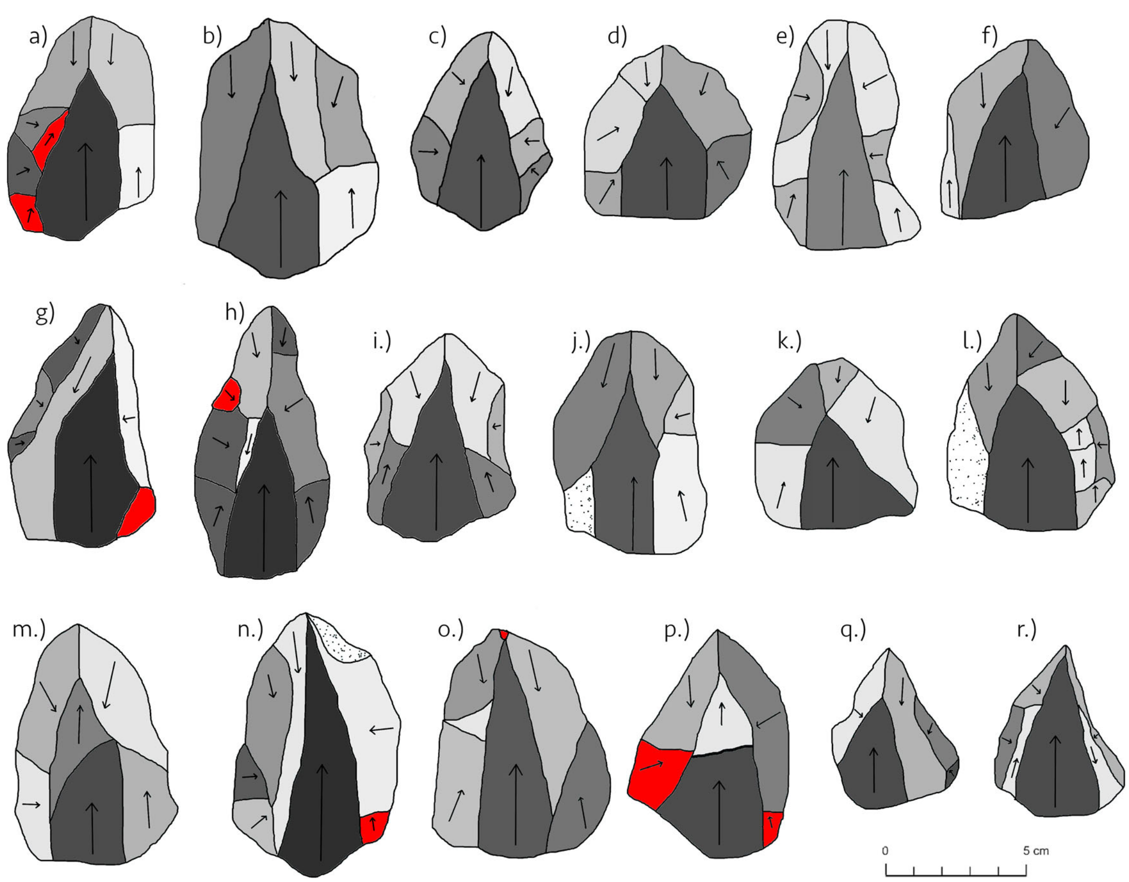

Figure 4. Diacritical illustrations of TH-69 Nubian Levallois cores, light colors are earlier in reduction and dark colors later. Red shows removals of unclear chronology.

been removed, so we consider only cores from which a Levallois flake has been removed; with the core then abandoned in some cases and further flaked in others. These cores can be regarded as "finished" forms in some sense, as they have produced at least one preferential Levallois flake. Variation of basic features of size and shape as well as the percentage cortex are summarized in Table 1, and shown visually in Figure 5.

Measures of size and shape all show a similar basic pattern of distribution, with a dominant central tendency, rapidly tailing off in either direction. For instance, for the basic size features of length, width, and thickness, more than half of all cores are within 1.6 cm of each other's length, 0.8 cm of each other's width, and 0.7 cm thickness. In all cases, though, there are some cores with larger or smaller values, but even at the extremes of minimum and maximum, the range is relatively limited. These data therefore, arguably, indicate a highly standardized character to the TH.69 Nubian Levallois cores. This might in part be driven by factors such as raw material properties/selection, as opposed to, or perhaps more realistically in addition to, flaked shape. While this is a topic that needs further investigation, such as through investigating the influence of the size and shape of raw material clasts used, the simplest explanation is arguably that the core shape primarily reflects human choice in flaking them in such a way. While some measures relating to size show rather high CV values, the values for more shape related aspects (length, width, thickness, elongation and flattening) have relatively low CV values between ca. 15 and 20%.

TH.69 Technological Standardization – The Number of Scars and Median Distal Ridge Angle

Next, we looked at features that specifically reflect knapping choices, and therefore clearly can be related to standardization in an imposed sense. Two examples are pertinent here. Firstly, in a very broad sense, the total number of scars on the core offers a simple and easily quantified measure of how standardized the flaking process is. As an experiment in distinguishing initial preparation from repreparation, here we can look specifically at cores that have been struck for a Levallois removal but have not been reprepared. These arguably give us the most direct insights into the shaping of cores. As can be seen in Table 2 and Figure 6, most cores fall within a narrow range of variability. Half of the cores have between 10 and 13 scars. More than three quarters have between 9 and 14. Limited comparative data exists in the literature on what is "typical" in terms of the number of scars involved in preparing a Levallois core.

Secondly, the other deliberate choice here is the angle of the median distal ridge as the primary distinguishing technological feature of the Nubian Levallois method. This ridge was flaked into shape, and the angle therefore indicates an aspect of the standardization of the reduction process in a more continuous, quantifiable sense, beyond simply qualitative attribution to a particular preparation method. As with the previous features investigated, this has a central peak in its distribution, with a more or less normal distribution on either side of this (Table 3 and Figure 7). The challenge, at present, is a lack of published comparative data; how do these TH.69 values compare to those from other sites with Nubian Levallois technology, and how do we compare such values to technological variation in other Levallois methods which do not involve the shaping of a median distal ridge?

Comparative Reduction Intensity and Shape

Having described some aspects of the TH.69 Nubian Levallois cores, some brief points on comparative analysis will be discussed. The present study highlights some of the difficulties in comparing lithic assemblages. As well as featuring different kinds of technologies, there are different "types" of sites which produce lithic assemblages with different characteristics. The differences between intensely occupied cave/rockshelter sites versus raw material procurement/workshop localities is just one example. This is because reduction processes are fragmented across space and time, which poses some challenges to comparative analyses. If we compare TH.69 with the site of Tor Faraj in Jordan, for

Table 1. Descriptive statistics for features of size, shape, and percentage cortex for TH.69 Nubian Levallois cores.

	Weight	Length	Width	Thickness	Vol.	Elong.	Flat.	% cortex
n.	159	159	159	159	159	159	159	155
Min.	31.9	40.5	31.4	16.7	33,090.9	0.9	1.0	0
Max.	412.9	111.7	79.4	54.0	452,125.1	2.6	3.1	40
25%	68.3	59.4	44.7	26.2	68,592.4	1.3	1.5	5
75%	120.7	75.1	52.5	32.3	118,982.6	1.5	1.9	30
Mean	100.8	68.1	48.9	28.9	100,743.0	1.4	1.8	17.1
SD	49.0	11.9	7.2	6.2	50,596.2	0.3	0.4	12.0
CV	48.6	17.4	14.9	21.4	50.2	17.9	20.0	70.1

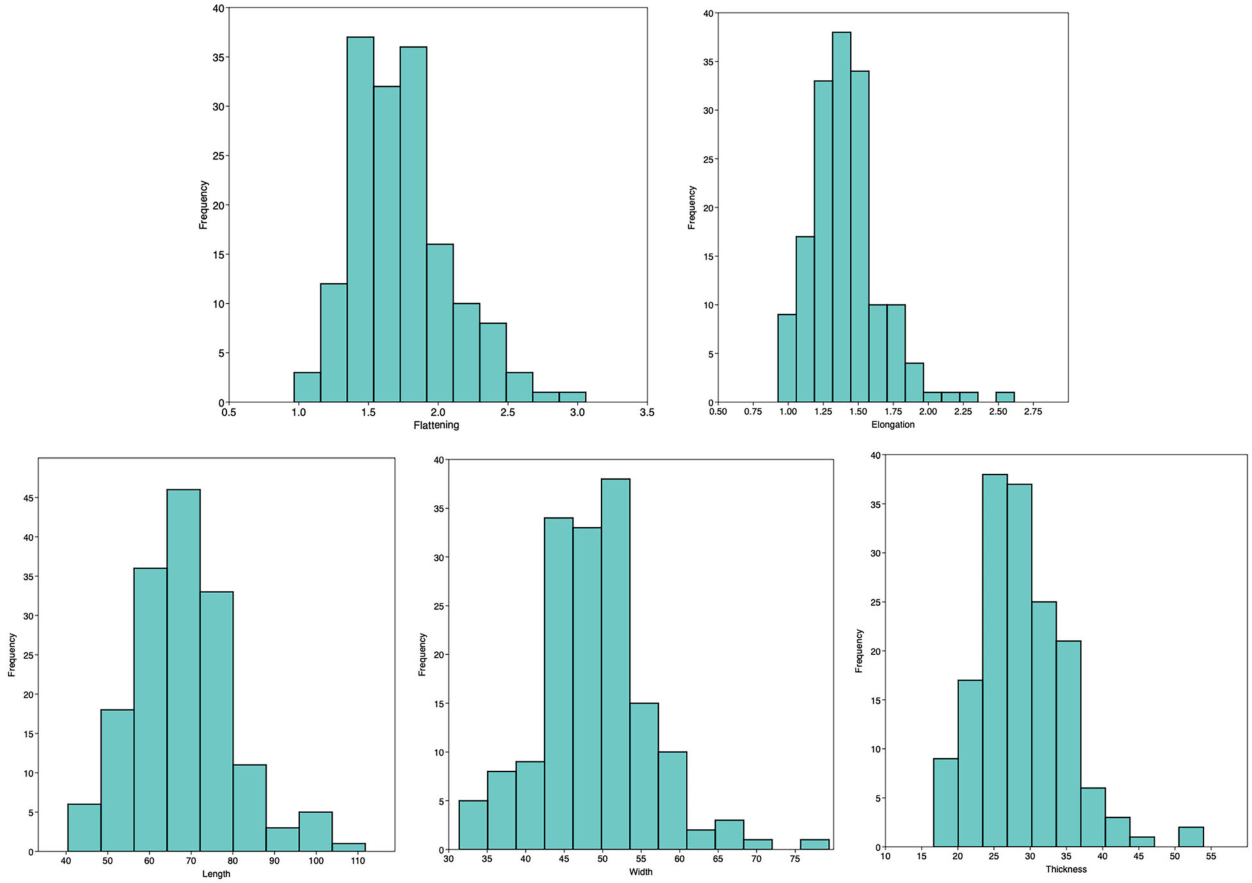

Figure 5. Histograms for selected aspects of size and shape of Nubian Levallois cores from TH.69.

Table 2. Number of scars (>5mm) on struck but not-reprepared Nubian Levallois cores.

	TH-69
n.	111
Min.	7
Max.	18
25%	10
75%	13
Mean	11.7
SD	2.3
CV	19.3

instance, some of these difficulties become clear. While TH.69 has few Levallois products and lots of cores, Tor Faraj has many Levallois flakes and relatively few cores. Of the cores present at Tor Faraj, many are intensively reduced and with a non-Levallois character to their final phases of reduction, while others are "cores-on-flakes", or secondary cores shaped on larger flakes produced during reduction. This example highlights the difficulty in comparing the character and standardization of technology within two assemblages that show a focus on producing Levallois points.

The aim here is to highlight the essential characteristics of TH.69 compared to other assemblages from East Africa (BNS; Shea, 2008), the Levant (Tor Faraj; Groucutt, 2014; Henry, 2003), Saudi Arabia (MDF-61; Groucutt et al., 2015a), and another Dhofar site dominated by Nubian Levallois technology (TH.123b; Rose et al., 2011). As shown in Figure 8 and Tables 4 and 5, the TH.69 assemblage is characterized by cores that are large relative to the other MP/MSA assemblages outside of Dhofar and non-intensively reduced (low SDI scores). They are not the most extreme in these regards, with TH.123b, a nearby site located directly on a raw material source, having larger and less intensively flaked cores. A point might be made here that assemblages with heavily reduced cores will have a somewhat blurred signal of preparation, exploitation, and repreparation, whereas sites like TH.69 may occupy an analytical sweet spot at being reduced enough to clearly demonstrate technological patterns, but not so reduced as for them to be concealed.

One way in which we might navigate issues of the spatial and temporal fragmentation of reduction cycles described at the start of this section is to compare the shape of Levallois products, both by measuring the shapes of flakes in some assemblages and the negatives of those flakes in others. TH.69 is well situated in this regard, having many cores where the negative of the

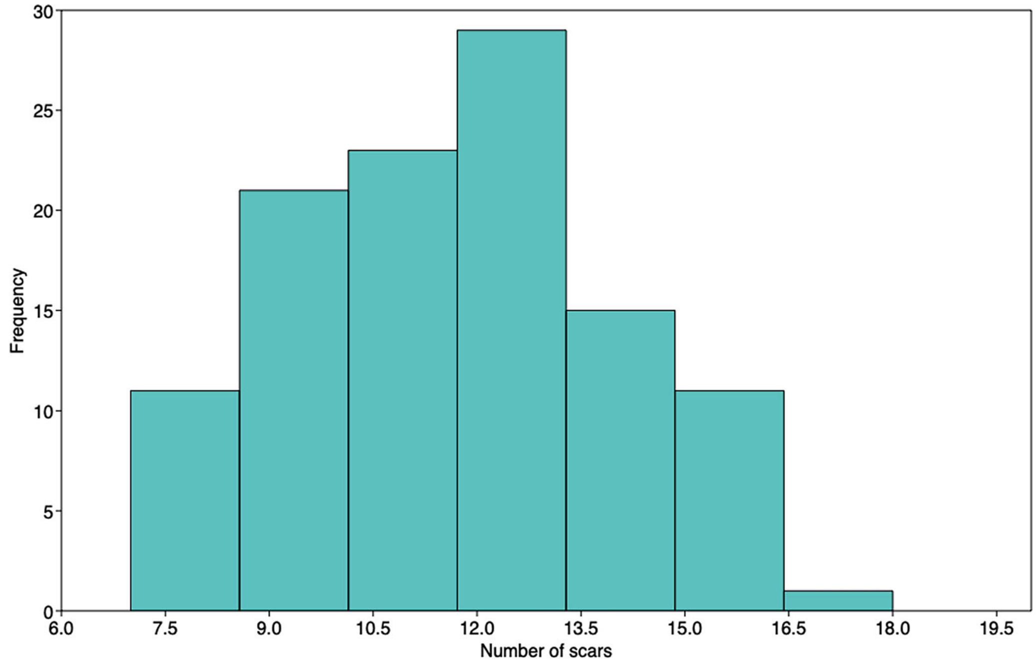

Figure 6. The number of scars (>5mm) on struck but unreprepared TH.69 Nubian Levallois cores.

Table 3. Median distal ridge angle for TH.69 Nubian Levallois cores.

	TH-69
n.	121
Min.	20
Max.	105
25%	50
75%	75
Mean	62.9
SD	17.3
CV	27.6

Levallois removal is not altered by subsequent repreparation. A simple measure of elongation (length/width) was selected here, with the aim of comparing the morphology and standardization of TH.69 Levallois flake length and elongation in relation to other assemblages. In terms of flake length, we found a similar (23–30%) range of CV values as reported in previous studies (see introduction). TH.69 appears typical in terms of Levallois flake CV in relation to the comparative sites. It is possible that variable sample sizes play a role here, and the sample size for TH.69 is considerably larger than the other comparative samples. We found that the CV for TH.69 was lower when we explored a random sample of 20 (23.8%) compared to the whole sample (28.3%). This suggests that one avenue to consider in future studies is the impacts of sample size on CV. (Table 6)

As demonstrated in Figure 9 and Table 7, while TH.69 Levallois removals are more elongate than Levallois flakes in the comparative assemblage, they are also the most varied. While there might be some impact here such as the variable recognition of Levallois removals from negatives on cores versus struck flakes, the effect of different distal termination types (some squat TH.69 removals are because of aberrant terminations; however, removing these still gives a mean elongation of 1.9), and variable sample sizes, the results appear relatively robust. A random sub-sample of 20 cores from TH.69 was included, and this still produced similar results to the total group. In terms of the simple measure of Levallois flake shape (elongation), TH.69 then does not appear particular standardized.

In sum, TH.69 Levallois removals are more varied than those from the comparative sites. Does this mean less standardization? In terms of elongation, yes. To explore whether this could partly be driven by differences in sample size, a random sub-sample of 20 cores was calculated. This reduced the variability somewhat, but it remains high relative to the comparative sites. It would be interesting in future studies to compare shape variation in a more nuanced way. For instance, perhaps standardization of shape in terms of convergence was more important for toolmakers than simple elongation? Our point here is that different measures of standardization for the TH.69 cores and products give rather different results.

Discussion and Conclusion

The TH.69 assemblage arguably occupies a “sweet spot” for the kinds of analyses conducted here, as it is shows

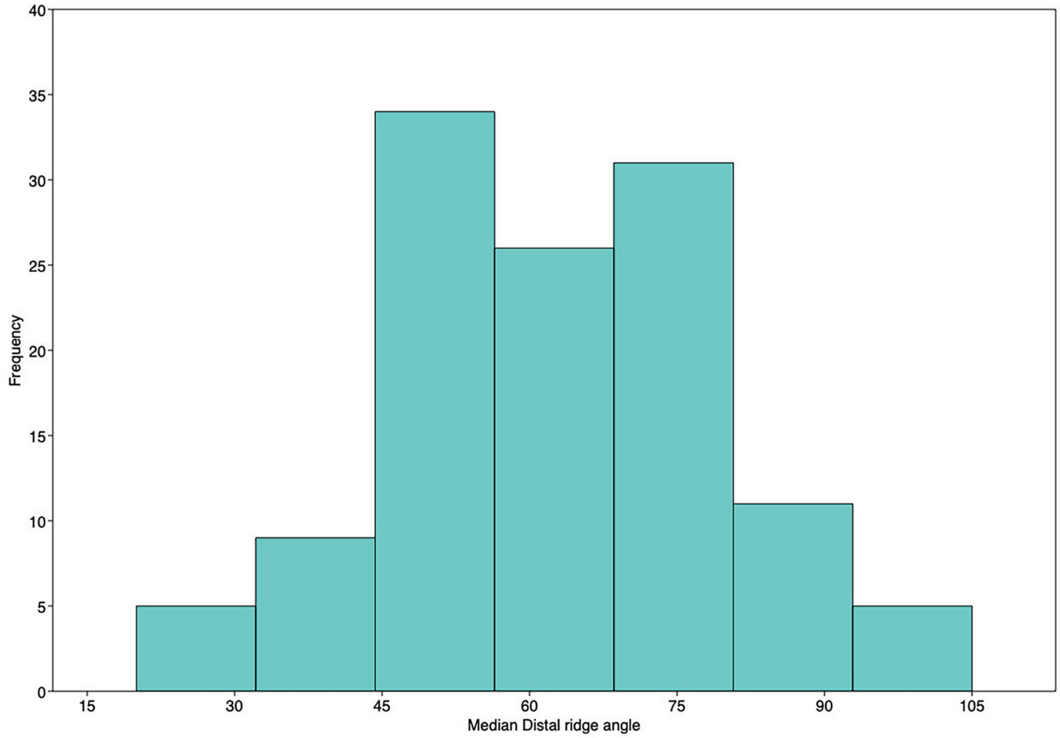

Figure 7. The median distal ridge angle for TH.69 Nubian Levallois cores.

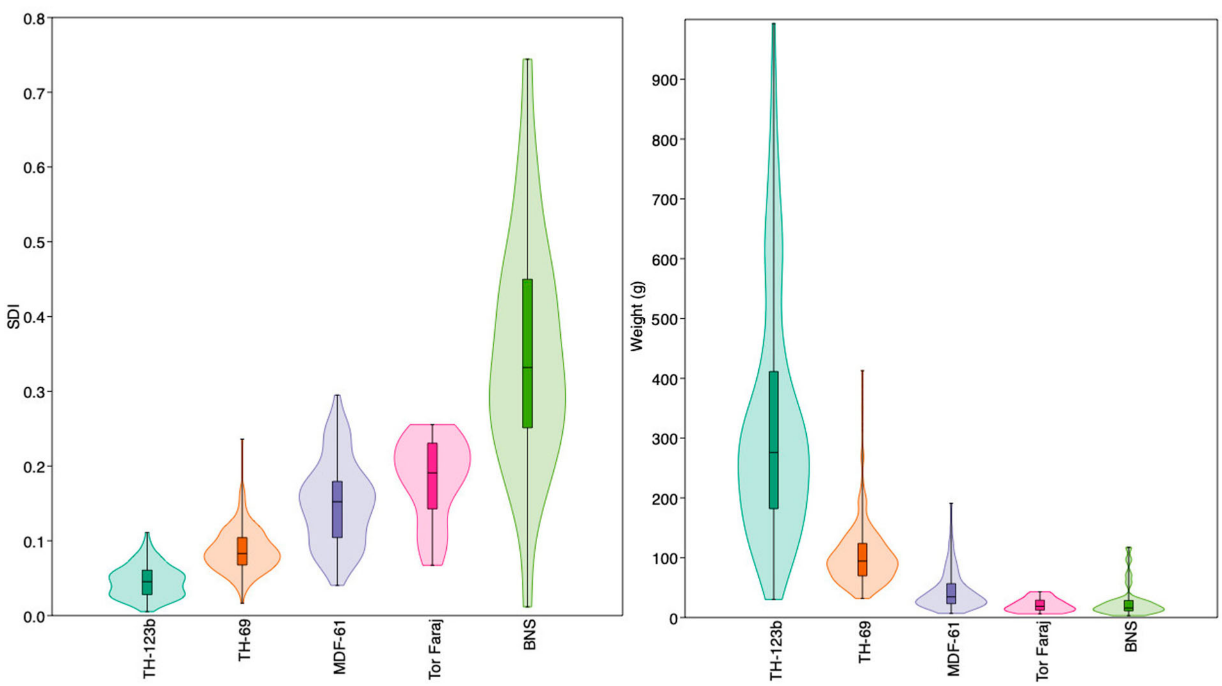

Figure 8. Scar Density Index (SDI) and weight (g) of TH-69 and selective comparative sites. Note – in graph of SDI and weight comparisons. Three large (>1 kg) cores from TH-123b removed from graphs just for visual clarity.

enough reduction intensity to be highly informative (i.e. complete cycles of preparation and preferential exploitation) but then cores were typically abandoned before being extensively reduced and the early stages concealed. What the analyses reported here emphasize is that there is a tension between standardization of process and of particular objects that were made by those processes. While the utility of dynamic, technological, approaches are clear, how to operationalize these approaches so they are data-driven and replicable

Table 4. Scar density index.

	TH-123b	TH-69	MDF-61	Tor Faraj	BNS
n.	104	167	99	26	26
Min.	0.05	0.02	0.04	0.07	0.01
Max.	0.1	0.2	0.3	0.3	0.7
25%	0.03	0.07	0.1	0.1	0.3
75%	0.06	0.1	0.2	0.2	0.4
Mean	0.05	0.09	0.2	0.2	0.4
SD	0.02	0.03	0.06	0.06	0.2
CV	46.7	33.9	37.9	30.4	45.5

Table 5. Weight (g) of complete cores.

	TH-123b	TH-69	MDF-61	Tor Faraj	BNS
n.	104	167	99	26	26
Min.	30.2	31.9	6.9	6.2	3.1
Max.	1791.0	412.9	191.0	43.1	117.3
25%	183.2	69.8	23.2	12.6	11.3
75%	438.3	123.8	56.6	29.0	28.3
Mean	363.5	104.1	44.7	20.8	27.1
SD	290.1	52.2	33.1	10.9	28.1
CV	79.8	50.1	74.1	52.3	103.6

Table 6. Comparing the length of Levallois removals; core negatives from TH.69 and Levallois flakes from other assemblages.

	TH.69	TH.69 sampled	123b	Tor Faraj	MDF-61	BNS
n.	110	20	19	79	87	32
Min.	15.6	31.3	39.9	25.8	26.8	18.6
Max.	77.7	73.8	121.2	81.6	104.4	52.4
25%	37.9	40.6	54.2	41.8	47.8	26.2
75%	58.2	58.7	96.8	58.9	62.1	42.7
Mean	48.0	49.6	78.2	50.5	56.1	34.2
SD	13.6	11.8	24.9	12.3	13.1	10.3
CV	28.3	23.8	31.9	24.3	23.3	30.0

Table 7. Comparing the elongation of Levallois removals; core negatives from TH.69 and Levallois flakes from other assemblages.

	TH.69	TH.69 sampled	123b	Tor Faraj	MDF-61	BNS
n.	111	20	19	79	87	32
Min.	0.5	1.2	1.1	0.9	0.9	0.7
Max.	4.2	3.0	2.2	4.2	2.2	1.7
25%	1.4	1.4	1.4	1.3	1.0	0.9
75%	2.4	2.0	1.9	2.0	1.4	1.3
Mean	1.9	1.8	1.6	1.6	1.3	1.2
SD	0.7	0.5	0.2	0.5	0.3	0.3
CV	35.6	26.8	20.0	31.6	24.0	24.0

remains a challenge. While there is some variation, taking into account factors such as some cores seemingly being unstruck "preforms", the assemblage clearly demonstrates a focus on producing pointed shaped Levallois flakes using a preferential Levallois method, with the debitage surface characterized by a median distal ridge and the cores having a roughly triangular shape in plan. This in itself can be interpreted as indicating a level of standardization to the assemblage.

The task is how to take the positives of both dynamic and static approaches; for all the utility of the former, you cannot measure or otherwise quantitively study an *inferred* process. Something inferred (such as a reduction "method", which is at root an essentialist concept) is, ultimately, something fictional; even if that fiction very closely parallels what actually happened. The archaeological record provides us with static objects. Robust analyses of processes must be underlain by quantitative analyses of the actual objects we find. There are also

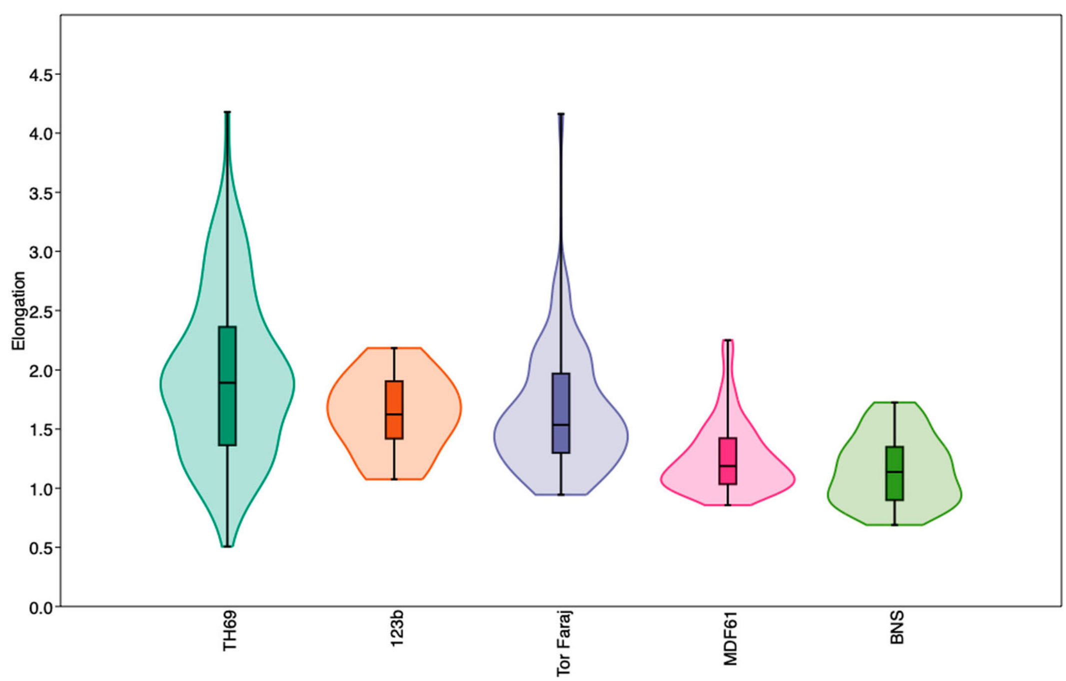

Figure 9. Elongation on final removals on un-reprepared Nubian Levallois cores from TH-69 compared to Levallois flake elongation from selected comparative sites.

analytical ambiguities flowing from the spatial and temporal fragmentation of reduction processes across landscapes and different types of sites. This is particularly clear at a site like TH.69 where, given the disparity between cores and preferential products, we can infer that the vast majority of Levallois products have evidently been removed from the site and taken elsewhere. Developing methods to compare assemblages that reflect different stages of reduction processes, and how to distinguish deliberate "design" from the impacts of variable reduction intensity, remain a key challenge. While the Frison Effect (Jelinek, 1976) remains pertinent, the problem is actually wider in that it is not simply about individual lithics changing morphology over their lifespan, but that there are fundamentally different types of sites, and that to compare, say, a raw material source and a densely occupied cave or rockshelter, where lithics were intensely reduced and recycled, requires careful consideration.

In terms of basic features of size and shape (e.g. Table 1), the TH.69 Nubian Levallois cores appear to be relatively, or perhaps even highly, standardized. One simple perspective on standardization here is that it is indicated by a limited spread of the data and a strong central clustering. Taking the benchmark of 20–30% CV as indicating a relatively standardized assemblage, as discussed in methods, this shows that for length, width, thickness, elongation and flattening TH.69 is indeed rather highly standardized, with values between 15 and 20%. While this may in part reflect factors such as raw material clast size, the simplest interpretation is that these values reflect the outcome of hominin knapping choices.

Looking at the number of scars, telling us about how cores were prepared, and the median distal ridge angle (i.e. a quantitative perspective on the key defining feature of Nubian Levallois cores), again both arguably indicate standardization. The CV values for these features of 19.3% and 27.6% do again indicate a relatively high level of standardization to the TH.69 assemblage. Ultimately, though, without benchmarks or specific comparisons, saying something is standardized or non-standardized risks being a non-specific generalization (Clarke, 1968; Eren et al., 2014; Lycett & Eren, 2013).

In other regards, particularly the way in which the cores' debitage surfaces were prepared, our analysis indicates rather diverse approaches, and perhaps therefore somewhat less standardization. Given the ultimately similar aims of giving the debitage surfaces a particular shape, what significance do we give to a relatively non-standardized chronology of removals, representing variation in the particular ways in which relatively standardized lateral and distal convexity was achieved? All we can surmise for now is that toolmakers employed a fluid approach to Nubian Levallois core preparation with the aim of creating a median distal ridge via an adaptable sequence of removals.

In terms of the comparative analysis, we show that TH.69 is relatively consistent (low CV) in terms of the reduction intensity of its cores compared to other MP and MSA assemblages in the comparitive sample. Likewise, in terms of weight it is rather varied (CV of 50.1%), but it was less than all the other assemblages in the sample. We compare the Levallois product length and elongation of the TH.69 assemblage (as determined by the negative scars on the cores) with Levallois flake dimensions from comparative assemblages. We find a similar (23-30%) range of CV values for Levallois flake length as reported in previous studies (see introduction). TH.69 appears relatively typical in terms of Levallois flake CV compared to the study sites. Variable sample sizes might play a role here, and that a lower CV (23.8%) was found for TH.69 as compared to the whole sample (28.3), given that the sample size was much bigger than for the comparative assemblages. This suggests that one avenue to consider in future studies is about the impacts of sample size on CV. Conversely, in terms of Levallois flake elongation, TH.69 does not seem particularly standardized relative to the comparative sample, although again we show that sample size may be influencing this as a random sample of 20 does reduce the CV from 35.6 –26.8. More detailed analyses of outline shape are needed to cast further light on this topic.

This analysis suggests that at least some assemblages with a focus on Nubian Levallois technology do show a standardization to the reduction process, which is evident both in terms of general considerations of the reduction methods employed and specifically in terms of the CV values for many features of the assemblage. In the case of TH.69, we conclude that the assemblage demonstrates standardization in terms of overall method, as other Levallois reduction strategies are essentially absent. There was, however, flexibility in how this standardization was achieved. In this particular assemblage, the Nubian Levallois method is not one Levallois method among others, nor is it a function of a particular phase of a reduction process; rather, the Nubian Levallois method was exclusively and intentionally being used in a way that was standardized in its principle, but flexible in its application. But what is the meaning of this? Given that in many assemblages outside Dhofar in which Nubian Levallois technology has been identified, it makes up a minor proportion of the assemblage, the general picture is very different from that given by sites in Dhofar, where it is always dominant. The problem is that there is considerable equifinality in why hominin groups would have used standardized technology. Developing more robust ways to measure and understand standardization are important for both issues like cognitive evolution, but also in debates such as the significance of Nubian Levallois technology. The manufacturers of the TH.69 assemblage employed a rather standardized method to produce Levallois products, yet *why* they did this (i.e. cultural inheritance versus local adaptation) remains debatable. Part of addressing such questions rests on the more widespread reporting of quantitative data for lithic assemblages and establishing benchmarks for the meaning of standardization in different settings.

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No potential conflict of interest was reported by the author(s).

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