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Was culture cumulative in the Palaeolithic?

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Abstract
This paper assesses the evidence for cumulative culture in the Palaeolithic through the lens of the most widely available line of evidence: knapped stone. Two types of cumulative culture are defined: additive traits in an individual's repertoire, versus a population wide stock of skills. Complexity may both *cumulate* within a single realm of expertise such as stone knapping, or may *accumulate* with multiple realms of expertise, such as the conjunction of stone knapping and bead technology. The Palaeolithic emergence of the social transmission and innovation traits that underpin cumulativity are described and assessed in relation to the evidence for cumulative culture. Examples of local population continuity are assessed for inter-generational increases in complexity as predicted by cumulative culture models. At an individual level, all cultures can be considered cumulative; at a population level cumulative culture may be entirely absent from the Palaeolithic.

Keywords Cumulative culture · Lithic technology · Acheulean · Cultural transmission · Innovation

1 Two types of cumulative culture and two ways of growing cultural complexity

Cumulative culture is frequently regarded as the *sine qua non* of human uniqueness; the idea that modern cultures are able to reach great heights of technological complexity because they are 'standing on the shoulders' of multiple generations before them (Andersson & Tennie, 2023; Boyd & Richerson, 1996; Sterelny & Hiscock, 2024). While cumulative culture may be critical to modern technological complexity, it has been suggested that we lack good evidence for it being a universal human

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trait, evident in hunter-gatherers as it is in industrialized societies (Vaesen & Houkes, 2021; Shipton, 2021)

One of the issues with cumulative culture is that definitions are so divergent that the concept lacks coherence. Two categories may be distinguished: individual and population level cumulative culture (Sterelny, 2021). In the former any additive traits acquired by an individual that build on existing cultural knowledge are considered cumulative (Buskell & Tennie, 2021; van Schaik et al., 2019). In contrast, other definitions emphasize that cumulative culture should go beyond what a "single human individual could invent on their own" (Boyd & Richerson, 1996: 80), or be outside the 'Zone of species typical Latent Solutions' (Sterelny, 2021). Legare (2017: 7877) offers the following: "a process by which innovations are progressively incorporated into a population's stock of skills and knowledge, generating a more complex repertoire". In this definition of cumulative culture we should expect material manifestations of culture (products) to exceed the knowledge that a single individual can acquire in a lifetime (Reindl et al., 2020), with the accumulated complexity distributed through the population or on external storage devices. Population level cumulative culture is clearly evident in very complex machinery such as space rockets, but even something as mundane as a mass-produced pencil is supposedly beyond the capacity of single individual (Read, 1958) and therefore dependent on cumulative culture. Central to both individual and population level conceptions of cumulative culture is progressive increases in cultural complexity over inter-generational timescales, see for example modelled trajectories in Enquist et al. (2011), Lewis and Laland (2012), Acerbi and Tennie (2016), and van Schaik et al. (2019).

High fidelity social reproduction has been identified as the key ingredient of cumulative culture, as any useful innovations that occur are reliably passed on to future generations and only rarely if ever lost, in what is known as the ratchet effect of cultural complexity (Tomasello, 1999, 2001). The primacy of social transmission is supported by both experimental and modelling studies of cumulative culture (Dean et al., 2012; Lewis & Laland, 2012). Three dimensions to high fidelity social transmission are highlighted: process copying (imitation), active teaching, and cultural norms of behaviour (Tennie et al., 2009). Other work stresses that high fidelity social reproduction is only one ingredient in cumulative culture, with innovation capacities important in generating novel behaviours in the first place (Charbonneau, 2015; Legare & Nielsen, 2015; Shipton & Nielsen, 2015; van Schaik et al., 2019).

Increasing complexity within a single realm of expertise is defined as *cumulation*, while combining different realms of expertise is defined as *accumulation* (Buskell, 2022; Dean et al., 2012). In the following, the deep-time record of the Palaeolithic is used to assess the evidence for cumulation within a single technological category for which we have evidence across that period: stone tools. For later periods of the Palaeolithic, the accumulation of stone tools alongside other traits is also considered.

Knapped stone tools (or lithics) are the most durable artefact type in prehistory and therefore provide the most complete record of human culture, with the earliest such artefacts suggested to be around 3 million years old (Harmand et al., 2015; Plummer et al., 2023). There is a widely perceived trend for increasing complexity in stone tool technology over the course of the Palaeolithic (Stout, 2011), whether this is measured in procedural units (Perreault et al., 2013) or hierarchical organisation (Muller et al., 2017). By reviewing the record of Palaeolithic technology, we may determine if such increases in complexity reflect cumulative culture (Paige & Perreault, 2024), or are the outcomes of other factors that affect knapping. For this tracking of cumulativity through lithic technology to work, there must be ample room for complexity to grow into, as opposed to rapidly reaching a ceiling beyond which more complex knapping is not possible. In the Neolithic and Metal Ages, stone tool technology reaches new heights of complexity beyond that of Palaeolithic technologies; examples include the Varna long pressure blades (Pelegrin, 2006), Egyptian ripple-flake knives (Lajs, 2019; Midant-Reynes, 1987), Polynesian adzes (Clarkson et al., 2015; Shipton et al., 2016), Mayan eccentrics (Joyce, 1932), and Danish daggers (Fig. 1).

2 Early freehand percussion

The earliest documented knapping in the world, perhaps 3.3 ma, at the site of Lomekwi in east Africa, uses a distinctive technique called passive hammer - where the core from which sharp flakes are to be removed is struck against a large stationary stone (Harmand et al., 2015). This technique is reminiscent of that invented by the bonobo Kanzi during efforts to teach him to knap, where he would throw the core against a hard floor (Savage-Rumbaugh & Fields, 2006). However, the dominant mode of stone tool production throughout prehistory is freehand percussion, in which a stone core is held in the non-dominant hand and flakes are removed from it by striking with a hammerstone held in the dominant hand. The two earliest sites in which freehand percussion is evident (>2.6 ma) (Braun et al., 2019; Plummer et al., 2023) are distinguished from later sites by high levels of battering (i.e. ineffectual blows with the hammerstone) and less than half a dozen flake removals on the cores. These sites additionally feature a high proportion of bipolar knapping (also used at Lome-

Fig. 1 Two flint daggers from Bronze Age Denmark. The blades are bifacially flaked while the handles are quadrangularly flaked. The small fine regular flake scars are achieved through pressure flaking. The zig-zag effect in the centre of the handles is achieved through punch-percussion stitching. The letter G denotes patches in the centre of the piece on the right which have been ground. Scale is 5 cm

kwi) – a conceptually simpler and lower skill technique than freehand percussion (Gurtov & Eren, 2014; Muller et al., 2017), in which stones are cracked between a hammer and an anvil. Soon after 2.6 ma in Gona, Ethiopia, local freehand percussion variants are evident at two pairs of sites 3 km apart with similar rocks available, suggesting social influence on knapping choice (Stout et al., 2010, 2019). Notably, there are no archaeological sites after the appearance of freehand percussion in which passive-hammer technology is evident as a dominant strategy, suggesting the invention of knapping itself was a rare event.

The site of Lokalalei 2C in northern Kenya shows that 2.3 ma some basic freehand percussion skills had been mastered; with the maintenance of appropriate edge angles for the removal of flakes and some cores yielding more than 50 flakes (Delagnes & Roche, 2005). Freehand percussion might have culturally cumulated in complexity over the period 2.6–2.3 ma. However, the neighbouring site of Lokalalei 1A which is only around 0.1 ma older than its namesake, shows poor quality knapping with high levels of battering and few flake removals (Kibunjia, 1994), even in comparison to the older Gona sites (Toth et al., 2006). One possibility is that freehand percussion was in the Zone of Latent Solutions of Plio-Pleistocene hominins (Tennie et al., 2016), such that these techniques would have been independently invented on multiple occasions and improved upon over separate social transmission chains. The morphological diversity of hominins associated with early freehand percussion might support independent invention (Heinzelin et al., 1999; Kimbel et al., 1996; Semaw et al., 2020). However, this diversity also speaks to another explanation of improvements in knapping capacity: the evolution of the hominin hand, which underwent important changes in the period 3 – 2 ma such as increased thumb robusticity, the ability to curl the little finger around an object, and increased size of the digit pads (Richmond et al., 2016), perhaps all partly under a selection pressure for freehand percussion knapping (Domalain et al., 2017; Key & Dunmore, 2015; Williams-Hatala et al., 2018).

When it comes to one of the next major developments in hominin knapping, anatomical changes are a likely explanation: The larger body size and the styloid process on the wrist of *Homo erectus* giving that species the power to strike flakes larger than 10 cm (Ward et al., 2014). Although there are undoubtedly improvements across the first million or so years of freehand percussion, it is unclear if these are anything other than the result of anatomical changes to the hand and wrist which are known to affect knapping.

3 Acheulean imitation

The ability to strike large flakes and to shape tools underpinned the Acheulean archaeological culture (Roche, 2005; Shipton, 2020; Shipton & Nielsen, 2018). This culture features symmetrical tools that are shaped bifacially by removing flakes from either surface of a disc, which itself sometimes initially begins as a large flake. There are two principal types of tool: The tear-drop shaped *handaxe* with a long cutting edge extending around much of its perimeter (Fig. 2); and the axe-like *cleaver* with its principal cutting edge the transverse bit at the end of the tool.

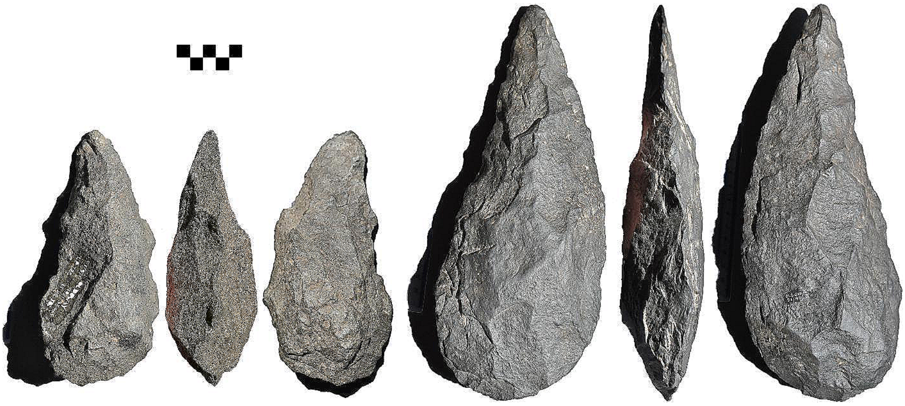

Fig. 2 Two lava handaxes from Olduvai Gorge. The piece on the left is from Bed II and the piece on the right is hundreds of thousands of years younger from Bed IV. Note that while both pieces have a bent planform the piece on the right is thinner, more symmetrical, has a more regular outline, and a straighter edge. Scale is 5 cm

Acheulean handaxes and cleavers are sometimes made according to conceptually distinct multi-stage production sequences, depending on the available rock forms. For example, at Isampur Quarry in India, thinner limestone slabs were shaped by removing flakes until the handaxe form was achieved with the two surfaces of the tool parallel to the original slab bedding plane; by contrast thicker slabs were turned into cores from which large flakes were struck obliquely to the bedding plane, and these then underwent further flaking to achieve the cleaver form (Shipton et al., 2009). This correspondence between distinctive techniques and goals indicates process copying or imitation. Such multi-stage canalized production methods for tool production are evident from the early Acheulean at sites like Olduvai Gorge EF-HR (de la Torre & Mora, 2018). A similar propensity for imitation among Acheulean hominins as our own species may have given rise to the unprecedented geographical and temporal span of this culture (Shipton, 2010): From its origin in east Africa 1.9 ma the Acheulean spread across much of the hominin occupied world from South Africa to North Wales and from Morocco to Nepal (Key, 2022; Shipton, 2020), with these artefacts continuing to be produced into the last 0.2 ma in some parts of the world (Haslam et al., 2011; Méndez-Quintas et al., 2019).

If the Acheulean is characterized by the robust social transmission mechanism of imitation we might expect it to evince cumulative culture. Bifacial shaping and striking large flakes are additive elements of knapping technology that build upon basic freehand percussion, therefore the Acheulean might be said to fulfil the requirements of individual cumulative culture. Indeed, at the earliest Acheulean sites in east Africa, Melka Kunture (locality Garba IV) and Olduvai Gorge (locality FLK West), basic freehand percussion without these traits is evident in the preceding layers (Diez-Martín et al., 2014; Mussi et al., 2023).

Such individual cumulative culture may be a low bar. It has been suggested that, working within an animal's cognitive capacities, once social transmission is reliable enough to create culture then it is necessarily reliable enough to add additional elements to it (Haidle & Schlaudt, 2020). As a hypothetical example we might consider chimpanzee termite fishing, with those groups who use the additional step of chewing the end of the stick to create a brush (Sanz et al., 2009), potentially having acquired it through the cumulative addition of brush chewing on to a pre-existing culture of using sticks for termite fishing. Indeed there are ethologically documented cases of cumulative culture increasing the complexity of individuals' behavioural repertoires in bird and whale song (Garland et al., 2022; Williams et al., 2022), in Japanese macaque food-washing (Schofield et al., 2018), and experimentally in chimpanzee tool-use (Davis et al., 2016; Yamamoto et al., 2013).

Might the Acheulean be regarded as dependent on cumulative culture in that it lies so far outside of the typical capacities for *Homo erectus* it would have been unlikely to recur along a different social transmission chain? The evidence from east Asia suggests not. Here there are independent, morphologically distinct, traditions of biface shaping, notably at the site of Baise Basin (Li et al., 2021; Shipton, 2020). Another case comes from the site of High Lodge in Britain, where there was a culture which made large handheld cutting tools that can sometimes resemble refined handaxes on one face, but in contrast to the Acheulean tools they were not flaked on the opposing face (Stileman et al., 2024).

4 Acheulean overimitation

One of the most complex Acheulean knapping techniques is the southern African Victoria West method, known from around 1 ma (Li et al., 2017). In this technique a large core is shaped bifacially with one flatter and one more domed surface, before a strong blow is delivered to one side to remove a large flake from the flatter surface. This large flake was then typically turned into a symmetrical cleaver with further removals, but one lateral edge of the flake was left untouched as the cleaver bit. Curiously, the Victoria West cores are invariably struck from the same side. This does not appear to be related to handedness as the core is symmetrical about its long axis before the large flake is struck, so it could be turned 180° and struck from the other side (Shipton et al., 2021a). Indeed, there is a similar method used in the north African Acheulean, called Tabelbala-Tachengit, which has the flakes struck from the opposite side of the core (Shipton, 2019). The standardization in strike direction appears arbitrary and is evidence of not just imitation, but overimitation in the Acheulean, whereby process copying is taken beyond what is immediately necessary to achieve the goal (Shipton & Nielsen, 2015).

Modelled transmission sequences show that the redundancy in overimitation can lead to both greater accuracy and complexity in cultural behaviours (Acerbi & Tennie, 2016). Overimitation in the Acheulean seems to be associated with more complex knapping sequences, so perhaps this extreme high fidelity social transmission mechanism allowed Acheulean knappers to cumulate cultural complexity. Examining temporal trends in the Acheulean, there do appear to be increases in knapping skill (Shipton, 2013), perhaps as a result of cumulative additions of new knapping techniques. For example comparing the early Acheulean in Bed II (~1.5 ma) of Olduvai Gorge versus the classic Acheulean in Bed IV (~0.8 ma), there are improvements in the thinness of the handaxes, their symmetry, and the straightness of their cutting edges (Fig. 2) (Shipton, 2018). However, such differences are only apparent over large timescales > 0.1 ma; when we consider penecontemporaneous assemblages, there is wide variation in skill. This suggests improvements in knapping were not occurring on inter-generational cultural timescales, but may instead have been underpinned slower paced biological change (Tennie et al., 2016), such as the massive increase in hominin brain size, that occurs during the Acheulean (Shipton, 2013, 2018).

A lack of innovation was not precluding cumulative culture in the Acheulean. Acheulean hominins were able to adapt to different biomes across the broad distribution of the culture. And they were able to make their characteristic tools on a broad variety of rock types and clast forms, altering their knapping methods in diverse ways to do so.

Perhaps the best test of cumulative culture in the classic Acheulean is at the site of Gesher Benot Ya'aqov in the Levant, where there is remarkable continuity of occupation preserved in a series of 14 layers spanning at least 50,000 years (Feibel, 2004). Technological analysis of handaxe and cleaver production through the Gesher Benot Ya'aqov sequence shows that these tools were being produced in the same way throughout, with no apparent improvements in knapping (Sharon et al., 2011). The evidence from the earlier part of the Acheulean thus suggests process copying is not in itself enough to engender cumulative culture.

5 Normativity and teaching in the later Acheulean

A development in social transmission hypothesised to enhance cumulative culture may have emerged in the later Acheulean: social norms. Norms are those behavioural variants which are socially and morally approved of by the group, thereby enhancing conformity, and, through increasing social transmission fidelity, are in turn suggested to enhance cumulative culture (Tennie et al., 2009). At the 0.5 ma site of Boxgrove in southern Britain, handaxes were made using the unusual tranchet technique, whereby the tip of the tool was removed in a single large blow, sometimes on both of its surfaces (García-Medrano et al., 2018). Initially understood to be a resharpening method, flake removal order analysis has shown that this technique was in fact often employed before initial shaping of the tool had been completed and was integral to the design of the tool (Leroyer, 2016, 2018). It is evident on a majority of Boxgrove handaxes, however it is an extremely unusual technique across the Acheulean more generally, as the handaxe is highly liable to break when attempting it. One of the few other sites where it was frequently employed is High Lodge (in a different layer to the one discussed above with large unifacial tools), also located in southern Britain and thought to date to a similar time (Ashton et al., 1992), suggesting the technique was a signature of a broader sub-facies of the Acheulean. Tranchet flaked handaxes at Boxgrove and High Lodge are the first in a series of specific handaxe sub-types that characterize the later Acheulean in Britain, including pieces with twisted profiles (Fig. 3), pieces with one very flat and one very domed surface, tapering triangular forms, and pieces with an elongated tip (White et al., 2018). These forms are difficult to make and are not determined by the starting form of the rock, the mode of flaking,

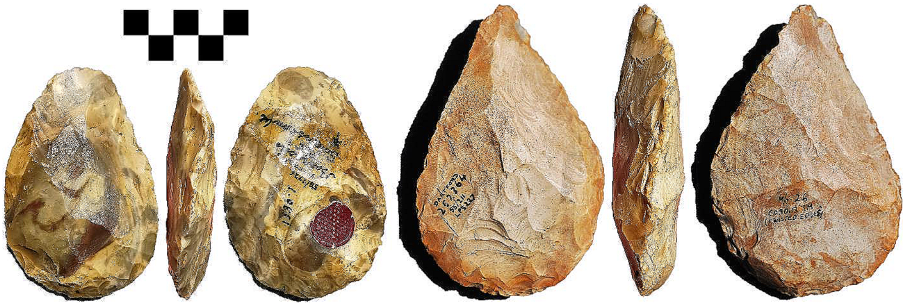

Fig. 3 Two twisted profile flint handaxes from the neighbouring sites of Swanscombe and Dartford in southern Britain. Note the twist is in the same orientation in both pieces (z as opposed to s), as it is in all such pieces from this particular interglacial period in Britain. Scale is 5 cm

or its degree (Shipton & White, 2020), nor do they confer distinct functional benefits to the tools (Key & Lycett, 2017). Instead they are patterned by interglacial occupation windows in Britain and appear to represent societally prescribed norms of what handaxes should look like (Shipton & White, 2020).

Another feature of the Boxgrove handaxes and later Acheulean handaxes more generally, is the use of a technique called 'turning-the-edge' (Shipton, 2019). This involves raising the plane of intersection between the two surfaces of the handaxe through a series of small removals to create a suitable striking platform, before turning it over and detaching a long flake across the opposite surface to remove mass from the centre thereby thinning the piece. Since you begin by flaking the opposite surface to your goal, the technique is hierarchically complex and counter intuitive, such that is has been characterized as 'mis-direction' (Lycett & Eren, 2019). Both the causal and visual opacity of the small flake removals (<4 mm long) to initiate the technique, has led to the suggestion that it would require verbal teaching to transmit (Gärdenfors & Högberg, 2017; Shipton, 2019). Indeed a learning-to-knap handaxes experiment found that only those novice subjects who were verbally instructed attempted such ambitious platform preparation (Putt et al., 2014).

With the conjunction of social norms and teaching in the later Acheulean, we might have the necessary traits for cumulations in knapping skills beyond individual capacities (van Schaik et al., 2019). The Boxgrove handaxes are incredibly skilfully made, and can only be replicated by the most expert modern knappers (Stout et al., 2014). Aside from 'turning-the-edge', this is also the earliest site where soft-hammers (those made of antler or bone) have been recovered, an important tool in making a thin handaxe, suggesting perhaps a cumulative addition of techniques. However, rather than Boxgrove representing the beginning of a clear trajectory of cumulatively increasing skill, it is actually the pinnacle of Acheulean knapping. The Boxgrove handaxes are the thinnest handaxes of any Acheulean assemblage, with thinning being the most challenging aspect of handaxe manufacture (Shipton, 2013, 2018). Over the next 200,000 years different normative handaxe types come and go from Britain as populations expand and contract from more continuously occupied regions to the south, but none exceed the skill levels seen at Boxgrove. Comparing Figs. 1

and 3, we can see this is not because the limits of hand-held flint bifacial cutting tool complexity had been reached in late Acheulean Britain.

6 Middle Palaeolithic innovation

The suite of traits that underpin high fidelity social transmission appear to be present by the late Lower Palaeolithic but they did not lead to an inexorable increase in cultural complexity. Perhaps the missing ingredient was the type of innovation providing the fuel of advantageous traits to add to cultural repertoires (Shipton & Nielsen, 2015; van Schaik et al., 2019)? The subsequent Middle Palaeolithic period is characterized by Levallois stone flaking technology, a hierarchically complex technique in which flakes of predetermined shape are produced from cores. Levallois appears to have arisen via a hominin capacity for combinatorial innovation, in which multiple existing concepts of later Acheulean knapping (including shaping a surface, striking large flakes relative to the size of the core, and 'turning the edge') were recombined into a single schema (Shipton, 2023b; Shipton et al., 2013). Since this combinatorial innovation produces more complex things from an existing behavioural repertoire, it is a good candidate for engendering cumulative culture.

Growing up in an environment with more cultural elements allows for greater possibilities in recombining those elements, therefore recombination as a process of innovation is not independent of cumulative culture (Tennie et al., 2020). In the case of Levallois, this technology might have arisen through the cumulative addition of traits rather than a new threshold in innovation capacity. The Movius-Schick hypothesis pertaining to the Lower to Middle Palaeolithic transition is a prime candidate for such a manifestation of cumulative culture. This hypothesis points out that it is only in the regions of the hominin occupied world where there was previously Acheulean technology that you subsequently have Middle Palaeolithic Levallois (Schick, 1994). More specifically Levallois shares many of its key features with Victoria West technology, including hierarchical organisation of core surfaces, with the flatter surface carefully shaped so as to guide the form of the large flake that was the primary product; indeed for a long time the technology was described as proto-Levallois (Breuil, 1930; Goodwin, 1933; Van Lowe, 1927). Boxgrove also presents some other early manifestations of elements of knapping technology that later comprise Levallois, including platform faceting and striking long invasive flakes. If it was merely a matter of cumulating the right combination of traits we should expect Levallois to have emerged in southern Africa following the appearance of Victoria West ~ 1000 ka, or perhaps in the generations following Boxgrove in northwestern Europe ~ 500 ka, instead it first appears in east Africa ~ 400 ka (Blegen et al., 2018; Shipton, 2022; Tryon et al., 2005). Levallois appears to be the manifestation of a new level of recombinatorial innovation rather than merely the gradual cumulation of the necessary technological components. In its subsequent manifestations Levallois recombination and hierarchical complexity are taken to new heights, with Levallois flakes sometimes hafted onto wooden shafts in the Middle Palaeolithic (Lombard & Haidle, 2012).

If cumulative culture was a feature of the Middle Palaeolithic from its inception, then we should expect to see new developments in cultural complexity over the course of that period. When we consider the African record this is indeed the case, with a progressive accumulation of novel behaviours (McBrearty & Brooks, 2000; Wadley, 2015). These include long distance stone transport (166 km) 200 ka in the east African Rift Valley (Blegen, 2017); the habitual use of red pigment from 164 ka in coastal South Africa (Marean, 2010); the use of shell beads from 142 ka in coastal Morocco (Sehasseh et al., 2021); controlled heating of stone to improve its knapping qualities from 130 ka in coastal southern Africa (Schmidt et al., 2020); burial with grave goods perhaps from 120 ka in the Levant (Grün et al., 2005); and flaking stone through pressure (rather than percussion) with fine bone points before 77 ka in coastal southern Africa (Rots et al., 2017). However, looking more closely at regional records, these behaviours often do not accumulate together in a single population or cultural entity. They may instead be explained by particular demographic circumstances prompting increased interaction and innovation (Powell et al., 2009; Scerri & Will, 2023) – it is perhaps no coincidence that most of these occur in coastal regions which can act as refugia in human evolution (Marean, 2011).

One culture which does appear to incorporate most of these traits together is the Still Bay of late Middle Palaeolithic southern Africa around 75 – 70 ka (Jacobs et al., 2013). Here habitual red pigment use, wearing shell beads, bone carving, heat treatment of flaking stone, and pressure flaking occur in a single culture (Henshilwood, 2012). The Still Bay is succeeded by another complex culture, the Howiesons Poort, in a potential example of cumulative culture. However, rather than Howiesons Poort cultural complexity building on that of the Still Bay, it appears to reinvent it: Marine shell beads are replaced by engraved ostrich eggshell as the dominant decorative element; and heat treated and pressure flaked bifacial spearheads are replaced by small standardized unifacially worked arrowheads made on elongate stone blades as the dominant projectile tips (Henshilwood, 2012). If this were cumulative culture we might expect to see Howiesons Poort arrowheads being miniaturized versions of the Still Bay spearheads, along the lines of the bifacial pressure flaked arrowheads of the Neolithic Levant. Following the Howiesons Poort, after about 59 ka, much of this complex material culture is abandoned altogether for thousands of years without widespread depopulation of the region (de la Peña & Wadley, 2017; Dusseldorp, 2014). A cumulative inter-generational accrual of complexity in the African Middle Palaeolithic does not accord with the spatially and temporally asynchronous presence of complex cultural traits, with frequent reversals as well as additions in complexity (Scerri & Will, 2023).

7 Long duree later Palaeolithic sequences

Bows and arrows are difficult to invent in that intermediate stages from a simple weapon such as a throwing spear are not functional. Rather than incremental outgrowths and recombinations of existing technologies therefore, much of the innovation necessary to make them must take place through mental simulation (Dennett, 2003; Shipton, 2023a). The appearance of bows and arrows in the Howiesons Poort culture (Lombard & Phillipson, 2010) heralds a new type of innovation in the last 70,000 years: abstraction, or having ideas about ideas (Lombard & Haidle, 2012; Shipton, 2023a). Abstractive innovation is similarly manifested in the advent of remote capture snares, which are complex enough that they need to operate in theory before it is worth investing in prototypes in practice. The circumstantial evidence of non-selective capture of small prey in the Howiesons Poort suggests snares were also a feature of this culture (Wadley, 2010). Abstractive innovation may have been the missing ingredient in cumulative culture, with new technology incorporated into a cultural repertoire through imagination as well as experimentation (Wadley, 2021). To test this hypothesis, we may consider archaeological sequences from the last 70 ka from maritime equatorial regions where environments have been less affected by the large swings in global climate over that period, and therefore have had more population continuity to allow cultural complexity to accumulate.

The site of Panga ya Saidi in coastal Kenya has the most continuous Late Pleistocene archaeological sequence in Africa, with occupation over the last 78,000 years, including in each of the last five major climatic phases, across a 3 m deep sequence (Shipton et al., 2018). The site includes the oldest *Homo sapiens* burial in Africa 75 ka (Martinón-Torres et al., 2021) and the earliest switch to a miniaturized Later Stone Age mode of knapping 67 ka (Shipton et al., 2021b). Magnetic susceptibility evidence suggests there was a gradual increase in occupation intensity from 67 ka to the last few hundred years (Shipton et al., 2018). The sequence is replete with innovations in material culture, including small geometric shaped stone tools (like the Howiesons Poort arrowheads), systematic flaking of long stone blades, notched bones, bone arrow points, and different varieties of both marine shell and ostrich eggshell beads (d'Errico et al., 2020; Shipton et al., 2021a). However, these innovations do not accumulate throughout the sequence, they are invented then abandoned and sometimes reinvented again several thousand years later. For example, the earliest *Conus* shell bead is from 67 ka, followed by a gap and their reappearance 47 ka. Likewise, the small geometric stone tools are known from 48 ka, they then drop out of the record before reappearing 14 ka; Levallois is evident prior to 67 ka, before dropping out and reappearing 48 ka, and then dropping out again and reappearing 1 ka.

The Asitau Kuru rockshelter on the eastern tip of the island of Timor has an occupation sequence beginning 44 ka. Despite some hiatuses in the sequence, stone tools are made using the same range of techniques and comprise the same range of products throughout, while red pigment crayons and *Oliva* shell beads also occur across the entire sequence (Langley & O'Connor, 2016; Shipton et al., 2019). The same is true for the site of Matja Kuru 2 some 17 km to the west of Asitau Kuru, with continuity in the use of red pigment crayons and the techniques used to produce stone tools across the 40,000-year span of human occupations at the site (Clarkson et al., 2023; Langley & O'Connor, 2019). The early prehistory of Timor is thus characterized by the most complex items of material culture being present from the outset, with long-term continuity in human behaviour rather than a gradual accumulation of complexity. Contrary to a model of progressive inter-generational accrual of complexity, it may be those regions of the world where there were greater environmental disruptions to cultural continuity that give rise to the most complex material cultures in the later Palaeolithic (Fogarty, 2018; Hoffecker, 2005).

8 Epipalaeolithic intensification

The last 24 ka sees intensifications in Palaeolithic material culture in most regions of the world. Even in a place with broad continuity such as Timor, there are a suite of novel behaviours that appear in the Terminal Pleistocene (O'Connor et al., 2022). These include an inter-island network of obsidian movement, new shell bead types and burial rites, shell fishhooks, and shell adzes. These traits appear to reflect a new way of life featuring regular inter-island voyaging; with the shell adzes used to make dugout canoes for reliable sea crossings, the shell fishhooks used for fishing from the canoes, the shell beads used to display group identity, burial rites perhaps to denote site ownership, and the obsidian exchanged between groups on different islands (Langley, Kealy et al., 2023; Langley et al., 2023; Shipton et al., 2021c). Perhaps they are evidence of cumulative culture underway? However, rather than accumulating gradually over the previous twenty thousand years that the region was occupied, these novel traits seem to emerge rapidly as a package. The site of Here Sorot Entapa on Kisar represents the first settlement on an island < 100 km^2 in the region and was inhabited from 16 – 9 ka (O'Connor et al., 2019). In the early phases of occupation, Here Sorot Entapa includes some of the earliest regional records of the exotic obsidian that was being moved between islands, as well as shell fishhooks and a new type of double-holed *Nautilus* shell bead (O'Connor et al., 2022). Likewise the earliest burial rites in the region occur contemporaneously on Kisar at the site of Ratu Mali (Hawkins et al., 2024). To the extent that these traits accumulated, they did so very rapidly seemingly in direct response to sea-level rise, increased connectivity, and/or increased population density on the reduced-size islands, rather than gradually over tens of millennia as an outcome of background levels of innovation and accumulation.

The most significant episodes of Palaeolithic intensification took place in the Levant, as it was here that Epipalaeolithic cultures were the forebears of the earliest agro-pastoral societies in the world (Maher et al., 2012). The site of Ohalo II on the shores of the Sea of Galilee preserves half a dozen hut structures belonging to the Kebaran culture (Nadel, 2003). These date to 23 ka, the height of the Last Glacial Maximum, the most extreme episode of global climate change in the last 400 ka. At Ohalo II there is precociously early evidence for sickle harvesting, cereal grinding, stone bowls, and perhaps even cultivation (Groman-Yaroslavski et al., 2016).

A few thousand years later, the sites of Kharaneh IV and Wadi Jilat 6 in the Azraq basin of Jordan were occupied at the end of the Kebaran culture and the beginning of the succeeding Geometric Kebaran culture, from 19 to 18 ka (Richter et al., 2013). These are the first examples of mega-sites where a very high density of cultural material was deposited in just over a millennium (Macdonald et al., 2018), indicating unprecedented population aggregations. Shell beads made from Mediterranean, Red Sea, and Indian Ocean species suggests the inhabitants of these sites were highly connected (Richter et al., 2011). The shift from the Kebaran technology of elongate microlithic tools often made through the distinctive microburin technique, to the crescentic and trapezoidal tools of the Geometric Kebaran, is abrupt (Macdonald et al., 2018). This therefore represents the abandonment of some tool types and production techniques in favour of others, rather than the cumulative elaboration of pre-existing technology, or the accumulation of new technology alongside the maintenance of old.

Like the changes between cultures within the Epipalaeolithic, the transition from the Epipalaeolithic to the Neolithic in the region from 12 to 10 ka is characterized by the abandonment of geometric tool forms and the adoption of pressure-flaked symmetrical arrowheads, not the addition of one on the other or their combination in a single tool (Belfer-Cohen & Goring-Morris, 1996). Rather than a cumulation or an accumulation of cultural traits, the succession of Epipalaeolithic and early Neolithic cultural entities in the Levant represents unique suites of traits replacing one another (Belfer-Cohen & Goring-Morris, 2020). Adaptation to climatic fluctuations (Langgut et al., 2021), population growth (Stutz et al., 2009), and population connectivity (Richter et al., 2011) seem to have been key drivers of the cultural changes that eventually gave rise to the Neolithic, not an endogenous process progressively increasing complexity.

9 Conclusions

A broad trajectory of increasing complexity in knapped stone artefacts from the early Lower Palaeolithic approximately 3 million years ago to the Bronze Age around 4 thousand years ago is undeniable. The question asked here is whether that trajectory is explained by a unitary process of cumulation and accumulation (Paige & Perreault, 2024); or if it is step-wise and explained by crossing multiple distinct thresholds in hominin behaviour.

The causes of early improvements in knapping technology in the first million or so years of the Lower Palaeolithic are difficult to distil, in part because there are many candidate fossils representing the knappers. Certainly, evolutionary changes in the hominin hand during this period would have improved knapping capacity, giving hominins the ability to strike large flakes and perhaps shape stones. With the advent of the Acheulean culture ~ 1.9 ma, increasingly robust social transmission is evident with firstly imitation, then overimitation from ~ 1 ma, and perhaps cultural norms and active teaching from 0.5 ma. During the Acheulean there are improvements in knapping skill within a single tool type including the use of new techniques like soft-hammers and 'turning the edge'. However, such improvements are only evident on biological evolutionary timescales of hundreds of thousands of years, with the site of Boxgrove representing the pinnacle of Acheulean knapping skill being over a million years younger than the earliest Acheulean sites. Temporal trajectories of increasing skill are not evident under finer-grained examinations of regional records. Given the knapping innovation capacities of Acheulean hominins, inter-generational cultural cumulation of knapping skills is too rapid a process to explain the skill trajectory. Increased knapping skill may instead be explained by the massive increase in hominin brain size that occurs during the Acheulean.

Middle Palaeolithic innovation through recombination from ~ 300 ka might be the missing ingredient in cumulative culture, with increases in knapping complexity evident during this period such as hafting modifications, heat-treatment of stone, and pressure flaking. In the Still Bay 75 ka in southern Africa, these and other innovations coalesce as part of a single culture. But even then there is a turnover of traits rather than a progressive increase into the succeeding Howiesons Poort culture. The bow-and-arrow and snaring technology of the Howiesons Poort represent pinnacles of Palaeolithic cultural complexity and are indicative of a new type of innovation through imagination or abstraction. Together with recombination and high-fidelity social transmission this innovation may have given our species the capacity for cumulative culture. However, the southern African record shows that following the Howiesons Poort there is a reversion to a simpler version of the Middle Palaeolithic. A possible explanation for this is that environmental change increased the availability of larger prey, which may have reduced the need for high mobility and investment in reliable armatures (de la Peña & Wadley, 2017; Dusseldorp, 2014). There are many such examples of the loss of that most complex of hunter-gatherer technologies in our species, the bow-and-arrow, despite our proclivities for social transmission, suggesting the loss was adaptive and deliberate (Lombard, 2016). Conversely there are many examples of independent reinvention of the bow-and-arrow in different (Carignani, 2016), as well as their principal archaeological correlate - the backed crescent (Clarkson et al., 2018). Making a bow-and-arrow may thus be described as a species typical behaviour for *Homo sapiens,* not dependent on population level cumulative culture.

Those sequences of the last 70 ka where equatorial and maritime effects combine to give stable environments might be expected to provide the ideal conditions for the accumulation of cultural complexity. However, the case study of Panga ya Saidi in coastal east Africa shows cycles of invention, loss, and reinvention, while that of Asitau Kuru on Timor shows long-term continuity. To the extent that these sequences do accumulate complexity after 25 ka, this appears to be in response to the extreme climatic episode of the Last Glacial Maximum and the subsequent warming and sea-level rise. Both in these cases and the Epipalaeolithic cultures of the Levant, increases in population density and connectivity are also implicated in the generation of cultural complexity. On Timor, Epipalaeolithic intensification does not lead inexorably to a Neolithic, this is eventually externally introduced in the last 4000 years (O'Connor, 2015). In the Levant, there is not a continuous trajectory of increasing complexity from the early Epipalaeolithic to the Neolithic, instead the Epipalaeolithic and early Neolithic feature repeated phases of distinct reinvention, perhaps in response to regional environmental cycles (Rosen & Rivera-Collazo, 2012).

The Levantine Neolithic features complex knapping technology such as pressure-flaked arrowheads and groundstone axes. The Neolithic here is the earliest in the world and the source for this period in other regions such as Europe. However, new heights of complexity in knapping technology remain to be reached in the late Neolithic and Bronze Age, with for example the Danish daggers shown in Fig. 1. These artefacts combine a diverse array of the most complex knapping techniques, including bifacial pressure flaking, grinding, quadrangular flaking, and stitching – whereby an indirect punch hammer is placed in the negative initiation of one flake removal to be the platform for the next removal on the adjacent surface (Callahan, 2003). To be able to replicate such artefacts requires decades of knapping practice, and it has been suggested that craft specialization in large internally differentiated societies may have been integral to their creation (Apel, 2008; Earle, 2004).

In the sense that more than one trait cultural trait can be combined in the behavioural repertoire of an individual, all culture may be said to be cumulative (Haidle & Schlaudt, 2020), rendering the cumulative appellation superfluous. In the sense of going beyond what a single individual could acquire in a lifetime, population level cumulative culture does seem to be describing something meaningful about human cultures today. However, the pattern of the Palaeolithic is not of a cumulative increase in complexity where there is population and cultural continuity. There was no process requiring only inter-generational time to cumulate innovations to get from the early Acheulean bifacially shaped handheld cutting tools shown in Fig. 2 to the refined versions of these same tool types shown in Fig. 3, let alone the Bronze Age examples of bifacially shaped handheld cutting tools shown in Fig. 1. An alternative suggestion to the ratchet model of increasing complexity for cumulative culture, is mountaineering, in which there are diverse peaks of cultural complexity, anchors may be placed that allow for the maintenance of complexity when some peaks are abandoned, and complexity can deliberately and rapidly be both reduced and increased (Lombard, 2016). One anchor we can be confident about in the Palaeolithic is freehand percussion, which all Palaeolithic stone knapping cultures feature aside from the earliest documented at Lomekwi. Rather than continually ratcheting up complexity, culture change in the Palaeolithic is better conceived as dropping down established complexity to an anchor and then climbing a different peak (Lombard, 2016).

Models of inter-generational accrual obscure distinct processes in the generation of cultural complexity (Stout, 2024). In the case of stone knapping discussed here, these include the biological evolution of upper limb anatomy, brain size, social transmission, and innovation capacity, as well as the cultural evolution of societal scale, connectivity, and interdependence. Cumulative culture was not a specific cognitive adaption or breakthrough in human evolution (Sterelny, 2021). By 70,000 years ago our ancestors may have had the requisite transmission and innovation capacities for population level cumulative culture, but it is not clear that the process gets in train until after the Palaeolithic. Perhaps with the larger, more interdependent societies of the Neolithic; but maybe not until the advent, or even the mass use, of the external storage mechanism *par excellence*: writing.

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