Cambridge Archaeological Journal (2025), **35**, 633–647
doi:10.1017/S0959774325100073

CAMBRIDGE UNIVERSITY PRESS

Research Article

Evolutionary Cognitive Archaeology and Acheulean Technology. A Historiographic Review

Carmen Martín-Ramos[1,2]

[1]School of Archaeology and Ancient History, University of Leicester, University Road, Leicester LE1 7RH, UK; [2]McDonald Institute for Archaeological Research, Department of Archaeology, University of Cambridge, Downing Street, Cambridge CB2 3ER, UK

Abstract

Cognitive archaeology focuses on the mental processes behind human material culture, exploring the human mind for patterns of behavioural strategies and their corresponding material expression in artefacts. Sharing some of the aims and perspectives of cultural anthropology, cognitive archaeology has also been called 'Evolutionary Cognitive Archaeology' (ECA) when it refers to hominin evolution. However, despite the abundance of publications and research projects that focus on ECA, this is a relatively new discipline, in which the earliest analyses were principally oriented to the appearance and evolution of language and symbolism. As there is no standardized method for investigating cognitive evolution, ECA researchers use multidisciplinary and wider theoretical models and methodological approaches. In this sense, partially because it is not unique to the genus *Homo*, stone toolmaking has been, and still is, an essential criterion for inferring hominids' cognitive capacities. Aiming to contribute to ongoing discussions, this paper addresses and reviews some of the more relevant evolutionary cognitive approaches related to stone-tool manufacture in general and Acheulean technology in particular, aimed at building a synthesized chronological review of the discipline.

(Received 28 March 2025; revised 28 March 2025; accepted 12 April 2025)

Introduction

Understanding the cognitive abilities of extinct hominins is a highly ambitious and complex objective. To achieve this goal, researchers need to incorporate methods and techniques from various scientific disciplines, including but not limited to biology, palaeoanthropology and psychology. Traditionally, studies on hominin cognition have been grouped into four main approaches: Palaeoneurology (studies the evolution of the brain from fossil remains), Evolutionary Psychology (explores different cognitive components and seeks to understand their evolution), Primatology (establishes social and behavioural comparisons between modern primates and extinct hominins), and Cognitive Archaeology (reconstructs hominins' cognitive capabilities from material remains) (Nowell 2000; Renfrew 1994; 2016; Wynn 2017). Researchers in Cognitive Archaeology, also called Evolutionary Cognitive Archaeology (ECA) when it refers to hominin evolution (Coolidge & Wynn 2016; Putt 2016), use multidisciplinary (Pain *et al.* 2023) and wider approaches to the subject, normally categorized according to the cognitive psychology models on which they are based: Neuroarchaeology, Cognitive Neuroscience, Developmental Psychology, Information Processing, Social Cognition, Symbolic approaches and Non-Cartesian approaches (Wynn 2009; 2017). Essentially, ECA combines multidisciplinary approaches to explore the minds and mental capacities of toolmakers, as well as their associated biological, social and behavioural traits.

The early years: linguistic and developmental psychology models

ECA is a relatively new discipline in which the earliest analyses principally focused on the appearance and evolution of language and symbolism (Bounak 1958; Leroi-Gourhan 1964; Steele *et al.* 1995). The first ECA models were originally based on psychological and linguistic theories, such as those by Chomsky and Lieberman (but see Nowell 2000 and Wynn 1991 for a review). These models were employed to draw analogies between language origin and cognitive evolution, normally through the analysis of archaeological material. Linguistic models are based on the assumption that the operational steps employed in tool manufacture and use reflect the same neural functions as the syntax of language (Atran 1982; Leroi-Gourhan 1964; Wynn 1993a). In terms of

Corresponding author: Carmen Martín-Ramos; Email: martinramos.cmr@gmail.com

Cite this article: Martín-Ramos, C. 2025. Evolutionary Cognitive Archaeology and Acheulean Technology. A Historiographic Review. *Cambridge Archaeological Journal* 35, 633–647. https://doi.org/10.1017/S0959774325100073

lithic technology, such parallels are based on the fact that both processes, language and stone toolmaking, are sequential, hierarchical and goal-directed (Greenfield 1991; Wynn 1993a).

One of the earliest linguistic models was presented by Ralph Holloway (1969). He correlated patterns of stone-tool production with those of syntactical communication, arguing that tool manufacture and language were similar cognitive processes, emphasizing, in particular, the imposition of an arbitrary form ('symbolisation') and the hierarchical organization of rules. Holloway (1969) also suggested the spatial and temporal distance between a stimulus and its consequent action as a way of measuring intelligence, although he clearly established that the lithic or fossil record could not be taken as direct evidence of the existence of language.

Similarly, later on, Glynn Isaac (1976) proposed the analysis of material culture systems, economic behaviour and adaptive patterns of early hominins to understand the evolution of language. Not only did Isaac propose using artefact complexity as an indicator of cognitive capabilities, but he also suggested a methodology based on different variables: number and variability of artefact classes, number of steps involved in artefact manufacture, use of compound artefacts and appearance of regionalism. He proposed that the increase seen in lithic technological complexity might have affected the enhancement of communication and information exchange systems, resulting in the formation of hominin cultural and communication capabilities (Isaac 1976).

Perhaps the most direct relationship between hominin cognition and lithic remains at this time was made by John Gowlett, who also emphasized the imposition of arbitrary form, variability and standardization, but went further in proposing the analysis of the Acheulean Large Cutting Tool (LCTs, i.e. handaxes and cleavers) *chaîne opératoire* as a way of inferring forward planning and cognitive mapping (Gowlett 1979). As most studies at the time relied primarily on the aesthetic properties of tools and their possible use as symbols, Gowlett's emphasis on the use of the operational sequences involved in tool manufacture is striking, being especially critical of authors who minimized the skill and abilities required for it (Gowlett 1984).

Similarly, during the 1970s and '80s, several other researchers first attempted to apply formal cognitive models to the archaeological record using ontogenetic human models. These were used in Developmental Psychology to interpret phylogenetic sequences and implicitly assumed that human cognitive development recapitulates primate and human evolutionary history (Wynn 2017). Initially, many of these ECA models were based on Jean Piaget's theories on logical and spatial intelligence (Piaget & Inhelder 1956), such as the work of Parker and Gibson (1979) and Wynn (1979; 1981; 1985; 1989). Parker and Gibson (1979) applied Piaget's scheme to non-human primate cognition and to the *Homo habilis* home base model proposed by Isaac (1978), concluding that *H. habilis* possessed some sort of 'protolanguage' and rudimentary forms of sensorimotor and early preoperational intelligence similar to those proposed by Piaget for human children (Parker & Gibson 1979). Simultaneously and independently, Thomas Wynn (1979; 1981; 1985; 1989) used Piaget's stages of childhood development to analyse Oldowan and Acheulean artefacts through three main geometric concepts: topological (such as proximity, separation, order, continuity or whole-part competence), projective (perspective) and Euclidean concepts (such as radius, diameter and bilateral symmetry). Both Parker and Gibson's and Wynn's models were criticized due to the weakness of the theory underlying them and the lack of consistency in the lithic analyses used and performed. Indeed, by that time, Piaget's theories were already the subject of criticism (Atran 1982; Robson Brown 1993): not only do modern children not pass through all the proposed sequential stages of intelligence, but also many of the human cognitive abilities were not indicators of a unique general intelligence, and therefore needed to be treated separately (Wynn 2016; 2017). Moreover, Piaget's stages were developed from observation of modern human infants, and therefore their application to other species is problematic (Mithen 1995; Nowell 2000). Wynn's morphological analysis of the archaeological record ultimately failed to confirm the predictions of the Piagetian theory: according to Piaget's spatial competence development, fully Euclidean concepts appeared after projective concepts, while in Wynn's analysis, both concepts appeared at the same time, therefore placing the modern adult level of intelligence as far back as 500–300 Kya (Wynn 1979; 1989; 1999; 2016). The Piagetian theory did not match the neuroscience studies on brain functioning, and Wynn eventually abandoned this approach entirely in the 1990s to move into modular mind models and Cognitive Neuroscience (Wynn 2000; 2016; 2017). Wynn (2002) realized the limits of the Piagetian approach and argued that, while cognition evolved after 300 Kya, spatial perception was probably not an important component of this evolution (Wynn 2000; 2002).

Nevertheless, models based on developmental psychology were (and still are) used, as seen, for example, in the work by Robson Brown (1993) on the Zhoukoudian lithic assemblage and Stephen Mithen (1994; 1996), who placed the appearance of modern cognition around 60–30 Kya due to the increase of cognitive fluidity in the minds of the first *Homo sapiens*. Instead of using Piaget's theories, Robson Brown and Mithen's analyses (Mithen 1994; 1996; Robson Brown 1993; Wynn 2000; 2002) were based on the multiple intelligences and the modular mind models (Fodor 1983; Gardner 1983) and concepts of social intelligence. Linguistic models are also still in use nowadays, as in Robert Mahaney's work based on Acheulean experimental replication (2014; 2015), or Rudolf Botha's Windows Approach (2022).

Finally, other relevant studies in Cognitive Archaeology at this time were works by Merlin Donald (1993) and Davidson and Noble (1993; Davidson 2002). Donald (1993) proposed three major transitional periods in hominin cognitive evolution: 1) the appearance of *H. erectus* and increase in brain size; 2) a biological change that included an increase in brain size and descent of the larynx, and the emergence of spoken language; and 3) the Late Upper Palaeolithic and the 'invention of the first permanent visual symbols' (Donald 1993). Similarly, Davidson and Noble developed their own theory of language and perception from ecological psychology (Davidson *et al.* 1989; Davidson & Noble 1993), placing the appearance of modern human cognition around 60 Kya. Both approaches encountered considerable criticism because they were based on general assumptions about prehistory and the Palaeolithic (Wynn 2017) and lacked empirical support (Putt 2016).

Evolutionary psychology and social cognition: the social brain hypothesis and the theory of mind

In recent years, hominin social systems have gained importance in archaeological studies (Goren-Inbar & Belfer-Cohen 2020; Gowlett *et al.* 2012; Pappu & Akhilesh 2019). Through a combination of strategies from Palaeoneurology and Evolutionary and Cognitive Psychology, some Palaeolithic archaeologists (Cole 2011; 2012; 2014; 2015a; 2017; Gamble *et al.* 2011; Gowlett *et al.* 2012; Lycett 2008; Lycett *et al.* 2016; McNabb 2012; McNabb & Cole 2015; Shipton 2010; 2013; Shipton *et al.* 2009; Stade 2017; 2020) have tried to infer cognitive evolution from a Social Cognition perspective. This approach is justified by the fact that shape standardization in lithic implements is perceived as the result of social learning and/or socially agreed cultural practices within hominin groups.

In Evolutionary Psychology, Social Cognition evaluates the cognitive processes responsible for social behaviour and social relationships. One theory deriving from this discipline is the Social Brain Hypothesis, formerly named 'Machiavellian Intelligence Hypothesis' (Byrne & Whiten 1988), which refers to the direct relationship between primate relative brain size (especially neocortex volume) and social group size (Byrne & Whiten 1988; Cole 2017; Dunbar 1998; Dunbar & Shultz 2007; Gamble *et al.* 2011; Gowlett *et al.* 2012; Shultz & Dunbar 2007; Shultz *et al.* 2012). The neocortex area is related to cognitive processes associated with reasoning and consciousness (Dunbar 1998) and some researchers suggest that neocortex expansion was driven by the cognitive demands resulting from more complicated social relationships (Dunbar 1998). Recent analyses, however, diminish the role of social complexity and argue that, in fact, ecological explanations (DeCasien *et al.* 2017; González-Forero & Gardner 2018) and the stability of relationships seem to be more important than the number of individuals in the group (Dunbar & Shultz 2007; Shultz & Dunbar 2010).

Palaeoanthropological studies have used the Social Brain Hypothesis to estimate group size from the cranial volume of extinct hominins, which seems to indicate an increase in group size since the appearance of *H. heidelbergensis*/Archaic *H. sapiens* (AHS) around 600 Kya (Aiello & Dunbar 1993; Gowlett *et al.* 2012). According to Evolutionary Psychology and Primatology studies, these enhanced cognitive skills allow two kinds of social cognition present in primates but not in other species (Dennett 1983; Shultz & Dunbar 2014): self-recognition and the Theory of Mind (or mentalization: recognizing intention and emotion in other individuals). The Theory of Mind corresponds to Dennett's (1983) second-order intentionality (Table 1). While mammals and birds can reach first-order intentionality, great apes seem to be able to reach second-order intentionality (and therefore, Australopithecines should have been able to as well), while adult humans can normally attain a fifth order (Shultz & Dunbar 2014). Thus, these higher orders should have been acquired through the evolution of *Homo* and are linked to abstract or symbolic thinking, perhaps even to 'visualise the end product of a tool in the raw material of a core' (Gowlett *et al.* 2012). As hominin intentionality increased, such ability should be visible in the archaeological record, perhaps when artefacts were used as social representations or icons (McNabb & Cole 2015). In this sense, cultural continuity throughout the Acheulean technocomplex was related to the existence of stable forms of social transmission involving shared intentionality and imitation (Lycett & Gowlett 2008; Shipton 2010; 2013; Shipton *et al.* 2009).

Table 1. Orders of intentionality represent a scale for measuring cognitive complexity. Modern humans can operate at up to four or five orders of intentionality, although most everyday human relationships operate in the second order. (Adapted from McNabb 2012.)

0 order intentionality	Organisms that have no awareness that they possess a mind.
1st order intentionality	An organism is aware of its own mind and needs only.
2nd order intentionality	Holding a belief state about someone else. The organism needs to be aware of its own mind, be aware of another's mind, and be conscious of holding a belief about someone else's belief. This is the equivalent of a full Theory of Mind, and most everyday human relations operate at this level.
3rd order intentionality	The first subject has to include a third person's, not just simply guessing the third person's belief but thinking what a second person believes is the belief of the third person.

The Visual Display Hypothesis

James Cole (2011; 2012; 2014; 2015a,b; 2017) developed the Identity Model as a way of associating the Social Brain Hypothesis with the archaeological record. Cole (2011; 2012; 2014) correlated the Identity Model with the technological modes developed by Clark (1961), focusing on the Acheulean and Middle Stone Age/Middle Palaeolithic industries for his analysis. He considered the degree of standardization and deliberate imposition of form as a way of assessing the influence of social learning and social parameters in artefact manufacture. Cole's hypothesis is based on the increasing standardization of Acheulean LCT shape and the implicit, deliberate imposition of shape seen in Acheulean technology, which should have been influenced by social learning.

In terms of results, he associated the deliberate imposition of form and standardization of shape seen in Acheulean LCTs with a second order of intentionality, with artefacts not used for social signalling. However, prepared-core and composite technology is associated with third-order intentionality due to the increased complexity and hierarchization seen in the operational sequence. Based on the necessity for symbolic interaction, Cole also suggests that symbolic construction is only represented by a third to fourth order of intentionality and that speech–language arose with a fifth order of intentionality (Cole 2011; 2015a). Ultimately, he argues that the traditional way of measuring hominin cognitive evolution through artefact typology, refinement and standardization should be reassessed (Cole 2017).

The Visual Display Hypothesis

The Visual Display Hypothesis was also developed from the Social Brain Hypothesis (McNabb 2012). It suggests that primate group size is constrained by the ability of its members to recognize and interpret visual signals. Since palaeoanthropological and archaeological evidence suggests that Acheulean toolmakers did not possess language, the argument for the Visual Display Hypothesis is based on the argument that visual display would be the main channel of communication (McNabb 2012). It correlates Oldowan and Acheulean *chaînes opératoires* with orders of intentionality, suggesting that while Oldowan technology could have been produced by mimicry and imitative learning, for which a Theory of Mind is not necessary, in Acheulean toolmaking, the subject needed to hold mental representations of the different stages of the reduction sequence, embedded one within another (McNabb 2012; McNabb & Cole 2015).

Material Engagement Theory

Bridging anthropology, evolutionary psychology and materiality, archaeologists Colin Renfrew and Lambros Malafouris proposed, in the early twenty-first century, the Material Engagement Theory (MET), a theoretical framework that explores the interaction between the brain, the body and material culture (Malafouris 2013; Malafouris & Gosden 2020; Malafouris & Renfrew 2010; Renfrew 2012). MET challenges traditional brain-centred models that separate mind and matter, such as the concept of modular mind, advocating instead for an *extended-mind* hypothesis (Malafouris 2013; 2021a; Malafouris & Renfrew 2010) that addresses both extended and embodied cognition (Wynn *et al.* 2021).

MET argues that cognition is not just in the brain but extends into material interactions, so that objects — or '*things*' — actively shape human thought and behaviour. While MET serves primarily as an explanatory framework rather than a predictive theory, its applications have expanded significantly in recent years. Although early MET postulates rarely used early stone tool technology or the Acheulean technocomplex as case studies (Coward & Gamble 2009; Malafouris 2004; 2008; but see Malafouris 2010), more recently this theoretical framework has provided useful in the design and interpretation of analyses on social (Barona 2021) and haptic (Bruner *et al.* 2018; Cueva-Temprana *et al.* 2019; Wynn 2021) cognition, biomechanics (Baber & Janulis 2021; Key & Dunmore 2018), palaeoneurology (Coolidge 2021; Coward & Gamble 2009) and neuroarchaeology (Hecht *et al.* 2015; Malafouris 2009; Putt *et al.* 2017; Stout & Chaminade 2007; Stout *et al.* 2015; see extended discussion below), as it focuses on the interaction of mind, body and objects through the dynamic process of artefact toolmaking (Malafouris 2010; 2019; Overmann & Wynn 2019). Overall, MET reinforces the concept of metaplasticity, in the sense that human cognition is adaptable and continuously shaped by cultural (i.e. material) engagement, rejecting the idea of a so-called 'behavioural modernity' (Malafouris 2009; 2013; 2015; 2021b; Malafouris & Gosden 2020; Roberts 2016).

The boost of neuroarchaeology

Embracing the possibilities opened by neuroscience (Putt 2016), perhaps the most innovative studies recently made in ECA are based on neuroarchaeological models. Neuroarchaeology applies various neurosciences to solve cognitive archaeological questions, as well as including archaeological data in neuroscience theorizing (Hecht & Stout 2023; Laughlin 2015; Stout & Hecht 2023). Neuroarchaeology aims to analyse brain function in relation to hominin behaviour, normally through an experimental approach, so that it allows testing some of the theoretical models earlier discussed. Experimental replication of hominin behaviour, most commonly stone-tool making, is performed while simultaneously (or immediately after) brain activity and patterns of neuroactivation are being mapped through a neuroimaging device (Stout *et al.* 2000; Wynn 2017).

The earliest examples of neuroarchaeological studies appeared in the 2000s, with several analyses using different neuroimaging techniques such as Positron Emission Tomography (PET), functional magnetic resonance imaging (fMRI) or functional near-infrared spectroscopy (fNIRS), among others, to elucidate different aspects of stone-knapping behaviour. Images collected during experimental tasks are normally compared with those collected under controlled conditions so that isolated changes in brain-activation patterns during toolmaking can be identified (Stout 2005; Stout *et al.* 2000).

Some neuroarchaeological studies have been able to correlate brain functioning with Oldowan (Stout *et al.* 2000; 2011; 2015) and Acheulean (Stout *et al.* 2006; 2011; 2015) knapping techniques. These studies have revealed, for example, that when replicating Oldowan knapping strategies, the activated brain structures are related to complex spatial perception, grip perception and sensorimotor coordination (Stout 2005), while in Acheulean replication, other cortex areas implicated in hierarchical organization are also activated (Hecht *et al.* 2015; Stout *et al.* 2011). Moreover, other experiments have looked at brain activation in novice and expert knappers, intending to understand brain functioning during learning (Stout & Chaminade 2007; Stout *et al.* 2008; 2011; 2015; Putt 2016) with and without spoken language (Putt 2016). When comparing Oldowan and Acheulean tool manufacture, researchers (Stout *et al.* 2008; 2015; Putt *et al.* 2017; 2019) suggest that Oldowan technology activates areas of the brain related to visual attention and sensorimotor control, but not those required for executive functions (Stout & Chaminade 2007). According to these studies, Oldowan is an 'ape-like' technology, as previously proposed (Wynn 1989; Wynn & McGrew 1989). In contrast, Acheulean technology involved areas of the brain related to higher-order motor planning, the central executive of working memory and auditory feedback mechanisms, which suggests that Acheulean technology may have helped the development of neural connections involved in speech perception (Putt *et al.* 2017; Stout *et al.* 2015).

Of course, as with any other scientific field, neuroarchaeology has limitations. It primarily faces two major drawbacks: first, the use of modern human brains as analogues of those of extinct hominins (Pargeter *et al.* 2019; Putt 2016; Wynn 2017); second, experimental neuroarchaeology does not offer direct resources for inferring hominin behaviour from archaeological remains, which creates ambiguity in inferences about human evolution (Pargeter *et al.* 2019). Nevertheless, it has proved to be an extraordinary tool for interpreting hominin behaviour and the evolution of cognition. Neuroarchaeology demonstrated that earlier studies were at least partially right in assuming that manual and perceptual motor adaptations were important in the earliest hominin technologies and enhanced cognitive control was more important in later ones, reflecting the increasing complexity of hierarchical organization involved in Acheulean operational sequences (Stout *et al.* 2011; 2015).

Tennie's Zone of Latent Solutions

Yet another significant theoretical framework related to ECA and, especially, studies in the origins of stone-tool production is the Zone of Latent Solutions (ZLS) (Corbey *et al.* 2016; Tennie *et al*. 2009; 2016; 2017). This refers to novel behaviours (i.e. 'solutions') that lie dormant in an individual until triggered by social and/or environmental cues and sufficient motivation on the part of the learner (Tennie *et al.* 2016). That is, behaviours that are genetically driven (Corbey *et al.* 2016) and emerge within a species without any prior cultural transmission or cumulative culture (Tennie *et al.* 2009). ZLS behaviours are, therefore, those that arise solely through individual innovation but always within an organism's latent cognitive 'repertoire' (and when the appropriate learning conditions are met). Tennie's ZLS hypothesis highlights the significance of understanding triple (i.e. genes-culture-environment) inheritance theory (Tennie *et al.* 2016), while also emphasizing the need to distinguish between behaviours that rely on high-fidelity transmission from those that can be spontaneously discovered or rediscovered by individuals. Tennie *et al*. (2009) propose that ZLS low-fidelity behaviours arise from the interaction between an individual's genetic predisposition and their environment and that, additionally, the emergence of these behaviours can be shaped by the influence of low-fidelity social learning mechanisms.

In the context of lithic technology, the ZLS hypothesis serves as a framework for interpreting appearance and variations of Early Pleistocene cultural industries (Corbey 2020; Corbey *et al.* 2016; Tennie *et al.* 2016; 2017). Since primate archaeology and primatology studies suggest that behaviours such as chimpanzees' nut cracking or simple flaking by capuchins fall within their respective ZLS (Tennie *et al.* 2009), this raises the question of when and why high-fidelity social learning and cumulative culture appeared and whether the first lithic technologies, such as the Lomekwian and the Oldowan, were in fact dependent on cultural transmission as opposed to being rediscoverable innovations within the ZLS of early hominins (Corbey 2020; Corbey *et al.* 2016; Tennie *et al.* 2016; 2017).

Applying the ZLS framework to Acheulean technology, however, presents a more complex picture. Tennie argues that shape variation in Acheulean LCTs is due to differences in raw material variability and reduction intensity (Tennie *et al.* 2016, after White 1998; McPherron 2007), and this seems to be the case at least for the oldest Acheulean (Diez-Martín *et al.* 2019; Martín-Ramos 2022, but see Sharon 2008; 2010; McNabb *et al.* 2004). This overall idea of cultural conservatism is due, however, to a research bias that tends to look at the lithic record from a pure aesthetic (i.e. morphological) perspective (Tennie *et al.* 2016: 127). Even from a morphometrical approach alone, this view might still result in an oversimplification of a technocomplex that spans over 1.5 million years (McNabb 2019). While low-fidelity core-and-flake technologies might lie within the ZLS of early *Homo* (Morgan *et al.* 2015), the hierarchical organization and technical variability observed in Acheulean LCT and large-flake predetermination (Martín-Ramos 2022; Sharon 2008; 2010) necessarily implied the existence of more or less complex or enhanced cognitive processes (such as shared intentionality and cumulative cultural learning) and socially agreed and transmitted design imperatives and procedural knowledge (Herzlinger *et al.* 2017; Shipton 2010; Shipton & Nielsen 2015). Overall, this binary distinction between so-called individual learning and social learning represents a too-simplistic view, perhaps as much oversimplification of social and cultural processes as it is to reduce the vast spectrum of past human behaviours to the mere visual shape of lithic tools (Martín-Ramos 2022: 37). Still, while the ZLS theory may not fully explain the cognitive and cultural underpinnings of all lithic technologies, its emphasis on the role of individual learning and environmental affordances provides a valuable counterpoint to models emphasizing solely cultural transmission.

Working memory and the Expert Cognition model

An archaeologist, Thomas Wynn, and a neuropsychologist, Frederick Coolidge, together developed the 'enhanced working memory' approach based on Baddeley and Hitch's working memory system (1974). Working memory is a cognitive process with a long evolutionary history (Coolidge & Wynn 2009a; Putt 2016; Wynn & Coolidge 2011). It is inheritable, related to general fluid intelligence and short and long-term memory, and has been supported by cognitive psychology experiments (Baddeley 2010). The most widely accepted working memory model was proposed by Alan Baddeley and Graham Hitch (Baddeley 1993; 2010; Baddeley & Hitch 1974) (Fig. 1) and explains the operations of short-term memory, how memory is instructed and directed, and how it relates to long-term memory.

Through the application of the 'enhanced working memory' hypothesis, Coolidge and Wynn (2005; 2009a)

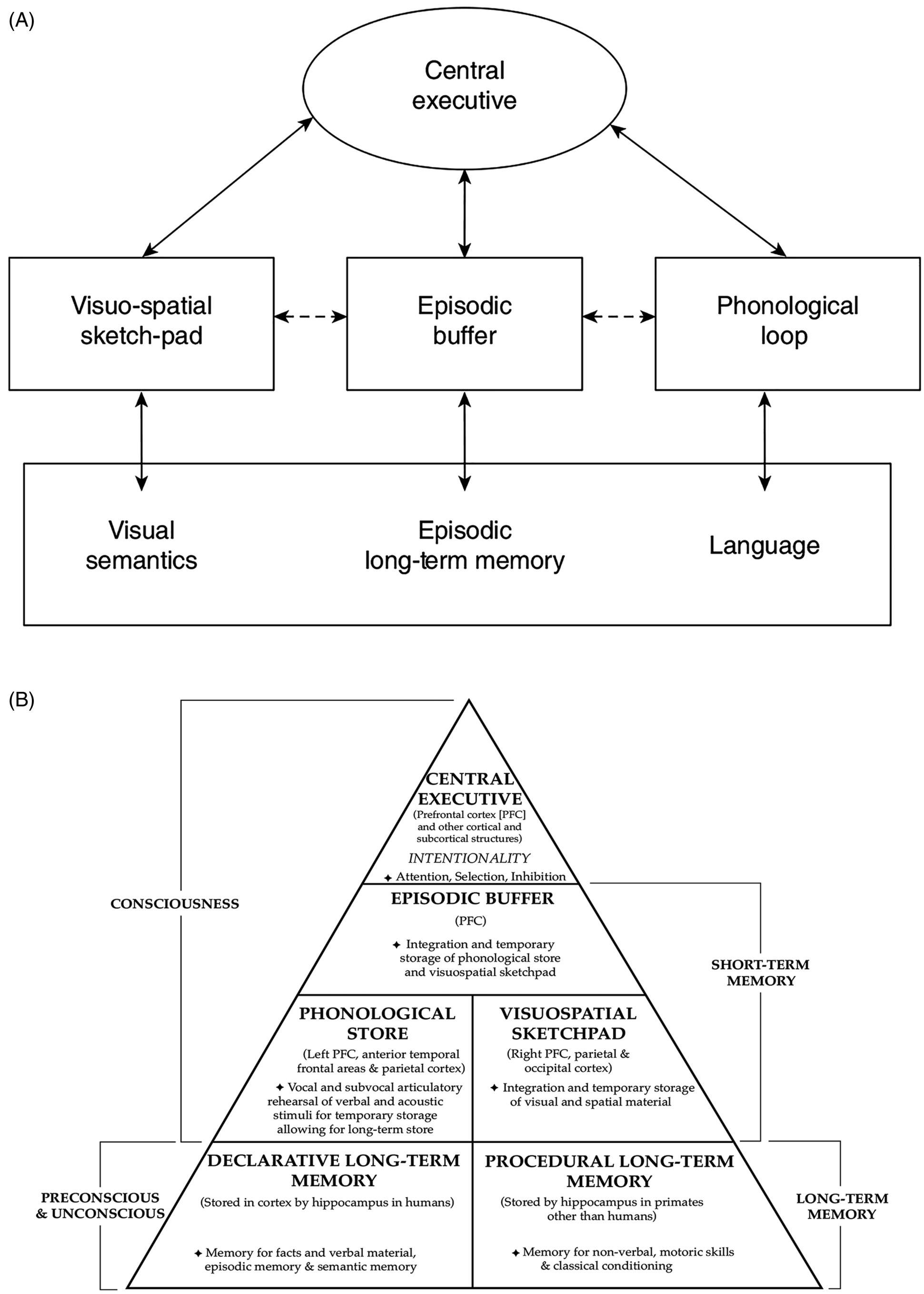

Figure 1. (A) Schematic representation of the multicomponent Working Memory Model by Alan Baddeley (2010); (B) extended version of Baddeley's (2001) model by Coolidge and Wynn (2005).

attempted to adapt Baddeley's model to the archaeological record. The technical evidence they use to correlate with enhanced working memory includes traps and snares, reliable weapons, and hafting technology (Wynn & Coolidge 2011). They argue for a late genetic mutation occurring at around 100 Kya that increased working memory capacity in *H. sapiens*, although preceded by other components of modern cognition that had evolved long before (Coolidge & Wynn 2005; Coolidge *et al.* 2016; Wynn & Coolidge 2004). Still, Coolidge and Wynn do not see any signals for a 'modern' working memory in the minds of *H. erectus* and other pre-*sapiens* hominins. They argue that there is no evidence for long-range planning and innovation (Coolidge & Wynn 2009b), although they acknowledge some cognitive development in *H. heidelbergensis*/AHS due to the existence of prepared core technique and the fact that Acheulean LCTs could have been seen as icons or 'something else than just tools' (Coolidge & Wynn 2009b).

Ultimately, according to Coolidge and Wynn's hypothesis, 'pre-*sapiens*' technologies required procedural and long-term memory but not enhanced working memory. Several researchers, particularly within neuroarchaeology, disagree with this hypothesis and support the emergence of different aspects of working memory over time (Putt 2016), suggesting, for example, that in comparison with Oldowan technology, Acheulean toolmaking required increased working memory and cognitive control (Putt *et al.* 2017; Stout *et al.* 2015). In addition, neuroarchaeological studies have recently shown that both Oldowan and Acheulean industries require visual working memory, and that Acheulean toolmaking requires complex motor planning (Putt *et al.* 2017; Stout 2008). Enhanced working memory would then have been a necessary component of Acheulean toolmaking, where the knapper needs to keep in mind the goal and sub-goals related to handaxe flaking. Technological studies, such as that performed by Herzlinger and colleagues (Herzlinger *et al.* 2017) on Large Flake Acheulean and cleaver manufacture at the Gesher Benot Ya'aqov site (Israel) suggest that Acheulean toolmaking required more and longer procedural sequences held in long-term memory and also an increase in working memory capacity. Furthermore, recent neuroarchaeological work by Shelby Putt (2016; Putt *et al.* 2019) proposes the 'working memory hypothesis for hominin brain expansion', suggesting that LCT production was a trigger for the evolution of larger working memory capacities because of the reproductive benefits this enhanced working memory would have had. Hominins who were better knappers and those whose tools were most functional would have been the healthiest in the population, something that would have reproductive benefits and advantages for the early years of their offspring (Putt 2016). Ultimately, the Enhanced Working Memory approach is related to expert skill. The Expert Cognition or Long-term Working Memory model is based on the fact that expert performance is stored in long-term memory and can be assessed through several characteristics (Table 2) evident in the stone tool record or through experimental replication (Coolidge *et al.* 2016; Fajardo *et al.* 2023; Wynn & Coolidge 2004; 2011; Wynn *et al.* 2017).

Essentially, working memory is the ability to keep a goal in mind when performing secondary duties (Baddeley 2010; Coolidge & Wynn 2005; 2009a; Hallos 2005; Wynn & Coolidge 2011), which is necessary when performing complex tasks (Fajardo *et al.* 2023; Putt 2016) and relates to inhibition and self-control (Green & Spikins 2020). Haidle (2010) expands this definition by adding that working memory serves to focus attention by maintaining memory representation in a conscious state despite interference or response competition (Coolidge & Wynn 2005; Haidle 2010). While neuroarchaeology has proved its validity in hominin cognitive evolution, there is still the problem of its application to the archaeological material record. Nevertheless, combined with procedural analysis of tool manufacture, so far, the Working Memory model has proved to be useful and reliable in the analysis of the cognitive implications of archaeological remains.

Table 2. Characteristics of expert performance, according to the Expert Cognition model (modified from Wynn *et al.* 2017)

Characteristics of expert performance
Novices require years and thousands of repetitions to attain expertise
Experts perform with higher levels of accuracy
Experts perform rapid, in-depth problem assessment
Experts can be interrupted and can return to a task with little or no loss of information
Experts learn new material rapidly
Expert performance is limited to narrow domains of activity
Experts respond mostly automatically, requiring lower active attention than novices

Lithic technology, the Acheulean technocomplex and the cognitive abilities of extinct hominins

Lithic technology, the Acheulean technocomplex and the cognitive abilities of extinct hominins are closely interlinked subjects that examine early human tool-making skills and mental capabilities. As shown throughout this paper, research on hominin cognition has often relied on stone tools to investigate the origins of language, abstract thought, symbolism and 'modern thinking' (Nowell *et al.* 2003). This focus is partly due to the excellent preservation of lithic artefacts in archaeological contexts as direct evidence of hominin behaviour. Additionally, stone tools offer insights into technological and subsistence strategies, which may have been shaped by cognitive differences among our ancestors.

In the case of the Acheulean technocomplex, it has been hypothesized, and so far also tested experimentally, that it required more cognitive control and working memory capacity than the preceding Oldowan technocomplex (Gowlett 1986; 1996; Isaac 1986; Stout *et al.* 2006; Wynn 1989; 1993b). This is based on the premise that LCT manufacture requires the toolmaker to proceed through a series of complex sequences of actions that involve long-term planning and hierarchical goals (Belfer-Cohen & Goren-Inbar 1994; Putt *et al.* 2017; Stout 2011; Wynn & Coolidge 2010). Likewise, Acheulean LCTs are also the first evidence of the deliberate imposition of shape and form. Such intentional *façonnage*, produced through more or less complex knapping strategies, reflects the existence of procedural and mental templates in the minds of knappers, as well as degrees of forward planning (Ashton & McNabb 1994; Gowlett 1986; 2006; Pope *et al.* 2006; Sharon *et al.* 2011).

Additionally, it has also been argued that LCT form is sometimes over-determined (i.e. excessively worked, beyond what would be functionally necessary), with Acheulean knappers applying special effort in producing specific shapes not necessary for functional reasons (Wynn & Gowlett 2018). This relates to perhaps the most debated feature of (some) Acheulean LCTs: symmetry. Whether bilateral, volumetric or cross-section, because it does not have a substantial effect on LCT performance (Machin *et al.* 2005; 2007) and it is not a by-product of the flaking process (Shipton *et al.* 2018), LCT symmetry has been taken as a consequence of brain (Hodgson 2009) and spatial cognition development (Wynn 1979; 1989; 2000; 2002).

Finally, cognitive implications have not solely relied on the visual aspect of LCTs. Discussions on cognitive evolution have also looked at the concept of predetermination of form and the increase of technological complexity when compared to Lomekwian and Oldowan artefacts (Petraglia *et al.* 1999; Ranov 2001). Thus, the Acheulean *chaîne opératoire* has been taken as a foundation for the study of *H. erectus* and Middle Pleistocene hominins' mental development, arguing that longer artefact transportation and more complex and hierarchized knapping sequences must have required enhanced working memory and forward planning (Cole 2011; Herzlinger *et al*. 2017; Hodgson 2015; Shipton 2013; Stout *et al.* 2015). All these are indicative of important cognitive developments occurring during the long time span of the Acheulean technocomplex.

Methodological approaches for assessing hominin cognition from a technological perspective

Hopefully, this review has highlighted the usefulness of experimental approaches (including neuroarchaeology) in the assessment of hominin cognitive capacity. Additionally, archaeologists have also employed the longstanding concept of the *chaîne opératoire* in the assessment of hominin cognitive capabilities through direct analyses of stone tools. This framework was proposed in the early years of cognitive archaeology as a way of understanding the evolution of hominin cognition and language (Leroi-Gourhan 1964; Schlanger 1994), with the idea of developing conceptual operative schemas already introduced in the 1980s and the early 1990s (Karlin & Julien 1994; Pelegrin 1990; Perlès 1992; Pigeot 1991; Schlanger 1994). Around this time, John Gowlett (1982; 1984) also mentioned 'operational chains' and 'procedural diagrams' as a way of mapping technological complexity and individual planned actions in Early Stone Age industries. In this sense, while some of the strictest applications of *chaînes opératoires* lack explicit cognitive justification and their conclusions are relatively vague (Stout 2011; Wynn *et al.* 2017), several authors recently developed different ways of addressing and representing conceptual operational sequences or 'mental *chaînes opératoires*' (Fairlie & Barham 2016; Haidle 2010; 2012; 2023; Muller *et al.* 2017; Stout 2011).

Dietrich Stout, for example, employed tree diagrams that represent hierarchical and subordinate actions and goals involved in Acheulean tool manufacture, providing a standard format for a technological comparison, which can be useful in assessing cognitive constraints. By using action hierarchies (Fig. 2A) he was able to represent goals, sub-goals and temporally prolonged processes, from the overall objective (i.e. Early Acheulean flake production) to specific motor acts (i.e. rotate core). Drawing action hierarchies of Oldowan and Acheulean technologies permitted him to infer cumulative cultural change in Lower Palaeolithic industries, with the appearance of more varied end-products being driven by an increase in technical and hierarchical complexity (Stout 2011).

Fairlie and Barham (2016) presented a method not based on direct stone technology analysis but on observational analysis derived from psychological science, the *chaîne opératoire* approach and the perception-action theory (which infers cognition processes from motor activities). They addressed several behavioural variables observable through experimental replication of stone-tool manufacture (handling and rotation of the object, flow and pace during the knapping sequence, etc.), which can be used to outline cognitive changes in Stone Age manufacture. As with neuroarchaeology, its drawback lies in the difficulties of applying their results to direct artefact analysis.

Miriam Haidle (2009; 2010; 2012; 2023; Lombard & Haidle 2012) developed an interesting way of addressing working memory and executive function development through archaeological remains: the cognigrams. The theoretical basis for her method is the problem-solution distance approach, which recognizes tool behaviour as a process of indirect thinking (Lombard & Haidle 2012). The model is related, in fact, to Holloway's (1969) approach, one of the earliest examples of ECA studies mentioned at the beginning of this paper, which suggested measuring the spatial and temporal distance between a stimulus and its subsequent action as a way of determining intelligence development. Haidle's methodology enables the measurement of cognitive complexity, flexibility and decision-making by reconstructing the thought-and-action sequence involved in tool manufacture and use. The model allowed her to compare the manufacture and use of tools between animals and hominins, including Oldowan and Acheulean technologies, and composite, projectile and complementary tools. Her studies (Haidle 2010; 2012; Lombard & Haidle 2012) indicated that problem-solving in animals is restricted to problems for which a solution can be found in the spatial and temporal vicinity. During human evolution, however, the complexity of tool behaviour increases with a higher number of active foci and operational steps and a larger spatial and temporal frame. Haidle's cognigram methodology (Haidle 2010; 2012) enables the representation of a subject's perception of a need and the different attention foci that are present throughout the following process until that need is satisfied, including goals, sub-goals, problems and sub-problems.

A second and more recent study also addressed cognitive complexity through problem-solution distance modelling and the reconstruction of thought-and-action chains. Through an experimental replication of bipolar, discoidal, Acheulean, Levallois and blade knapping techniques, Muller and colleagues (Muller *et al.* 2017) created, as Stout (2011) had done, hierarchical diagrams that allow quantitative assessment of the degree of hierarchical organization within knapping sequences (Fig. 2B). The resulting diagrams illustrate a 'primary focus' that is divided into a series of bifurcating and hierarchically structured sub-foci (similar to Haidle's cognigrams but with more emphasis on technological reconstructions of knapping sequences and less on mental perception).

All these studies represent discrete actions in modular structures that show a hierarchical organization of goals. Such methods can provide quantitative and qualitative results to argue for the presence/absence of certain cognitive traits and cumulative cultural change, and can also be applied to the study of the archaeological record. Combined with the insights provided by neuroarchaeological studies, these

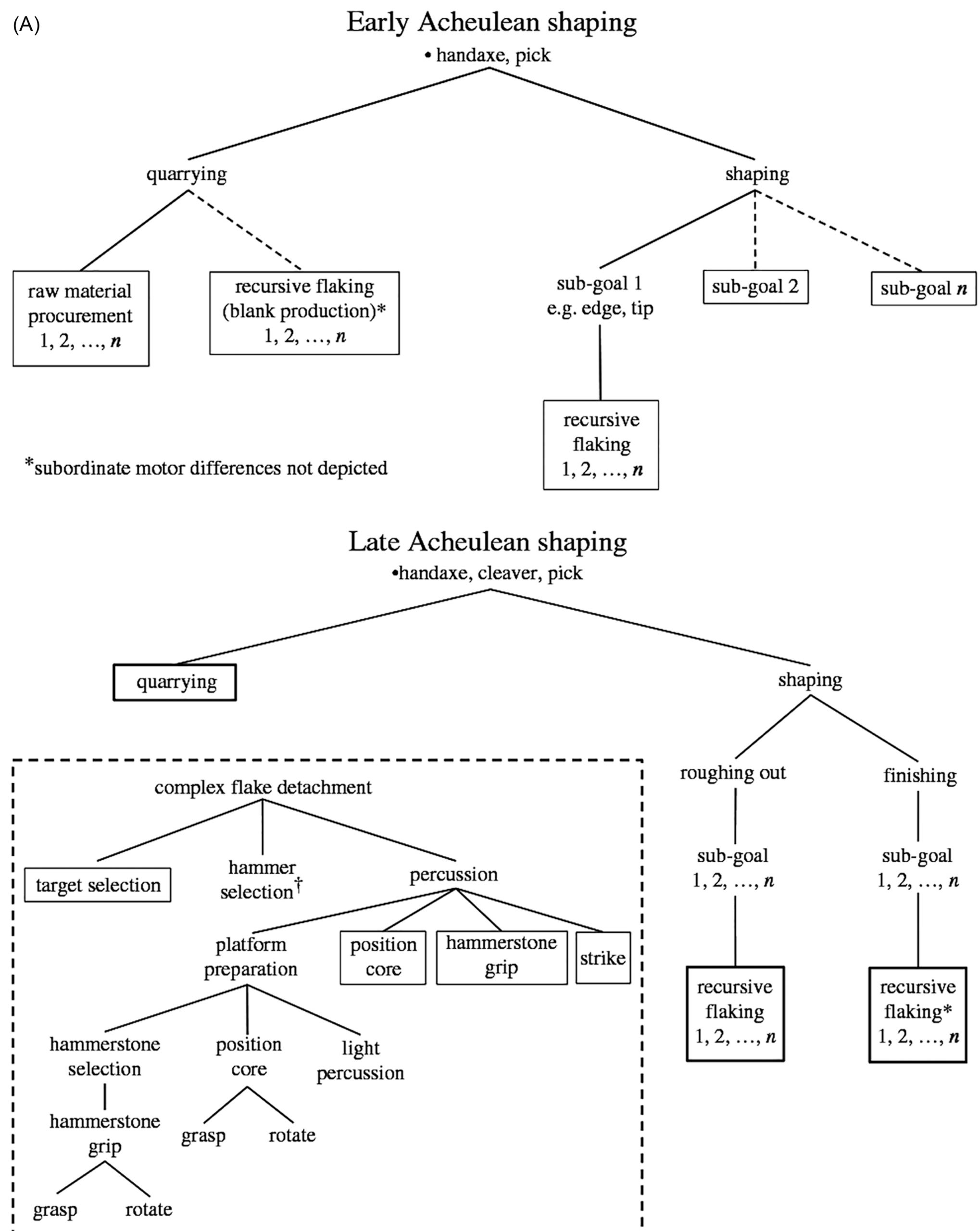

Figure 2. Hierarchical diagrams showing Early and Late Acheulean handaxe manufacture by (A) Stout (2011) and (B) Muller *et al.* (2017). Stout's models focus more on representing the *chaîne opératoire*, while Muller and colleagues underline mental goals and active foci through the knapping process.

analyses constitute promising methodological frameworks that contribute to a more nuanced understanding of the cognitive processes underlying stone tool manufacture and use.

Towards holistic approaches in ECA and lithic studies. A reflection

Beyond Acheulean technology and the study of stone tools themselves, it is now widely emphasiszed that ECA studies should account for the broader environmental and behavioural contexts surrounding tool production and use. For example, raw material procurement and adaptability can reflect changes in spatial cognition and working memory capabilities. Similarly, the evidence for curation and transportation of lithic tools indicates forward planning and an understanding of resource value over time. These behaviours, often inferred indirectly through lithic technological analyses, provide crucial insights into the selective pressures shaping hominin cognition. Likewise, the social dimensions of learning and teaching require greater emphasis. Cultural transmission, imitation and the role of active teaching and learning in knapping skill acquisition are vital for

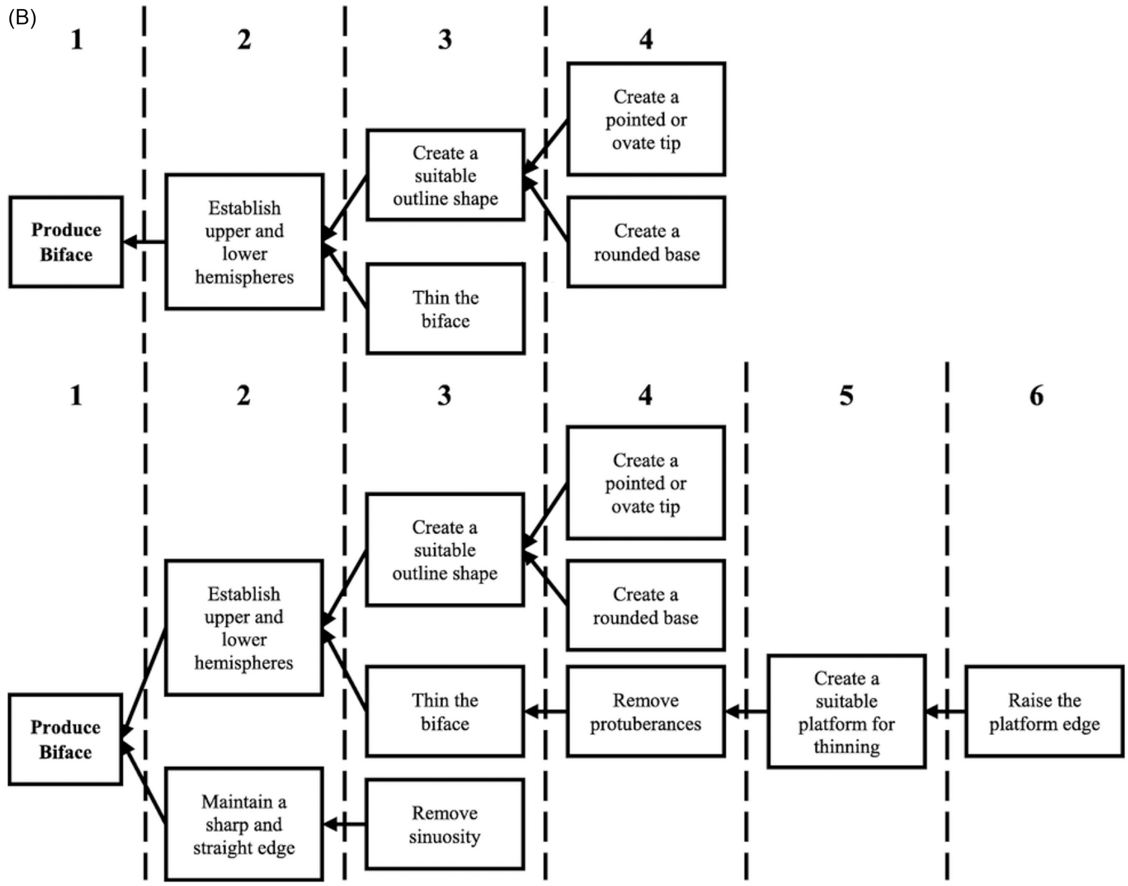

Figure 2 (continued).

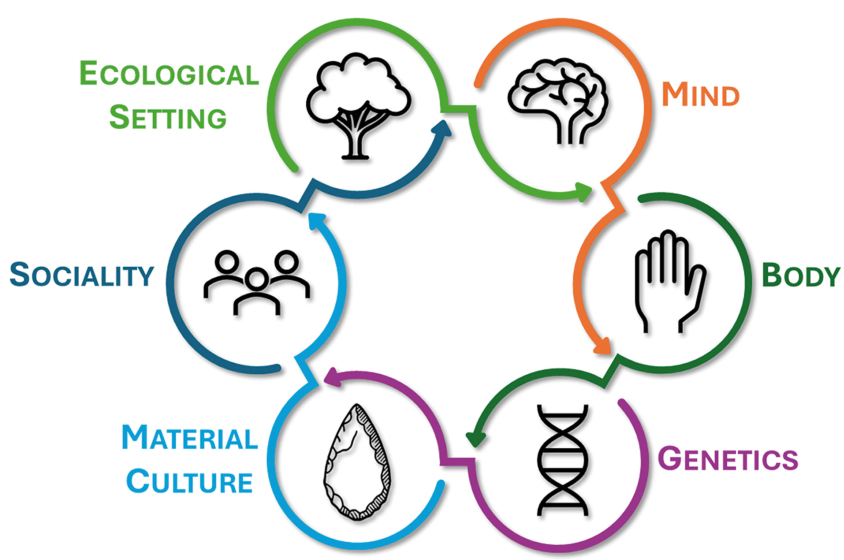

Figure 3. Evolutionary cognitive studies should prioritize empirically replicable methodological frameworks that integrate genetic paradigms, materialist perspectives and extended cognition theories, while also considering the social and ecological contexts that shaped the cognitive development of extinct hominins.

understanding how lithic technological traditions persisted and evolved. While this review has primarily focused on insights derivable directly from the analysis of lithic artefacts, future research should integrate these broader biological, behavioural and ecological dimensions to provide a fuller picture of hominin cognitive evolution (Fig. 3).

In some way, ECA must perhaps undergo a 'paradigm' shift comparable to that of the New Archaeology revolution, one that actively integrates qualitative scientific methods into its analytical framework. This is because while this field has produced extensive epistemological and theoretical discussions, these remain largely disconnected from empirical methodologies capable of supporting or challenging their claims. Exceptions to this, fortunately, do exist, such as experimental neuroarchaeological analysis or problem-solution distance approaches. The challenge lies still in linking these studies to the physiological, genetic, social and environmental contexts of extinct hominins.

A fundamental challenge within ECA is its reliance on evolutionary theory without a reliable and replicable methodological bridge to qualitative insights from cognitive science, anthropology and psychology. Similarly, while quantitative approaches—such as computational modelling and statistical inference—have significantly advanced our understanding of hominin cognition, they often overlook the interpretative and context-sensitive dimensions that qualitative methods can offer. To address these limitations, the ECA must embrace an interdisciplinary synthesis that integrates ethnographic analogies, experimental archaeology, phenomenology, materiality and neuroarchaeological approaches (Fig. 3). This shift would strengthen the empirical foundation of theoretical claims and provide a more nuanced understanding of how material culture and cognition co-evolved.

By fostering a methodological pluralism that values qualitative insights alongside quantitative approaches, ECA can move beyond theoretical speculation towards a more holistic empirically grounded discipline. Such a transformation would mirror the impact of the New Archaeology movement, which revolutionized archaeological practice by insisting on explicit methodologies and hypothesis-driven research. In doing so, ECA can better bridge the gap between theoretical discourse and scientific practice, ensuring a more comprehensive exploration of the development of human cognition.

Conclusion

This paper provides a comprehensive historiographic review of the field of Evolutionary Cognitive Archaeology (ECA), a discipline that explores the mental processes underlying human material culture. It aims to provide an up-to-date synthesis of the most relevant ECA approaches, with a particular focus on early stone tool manufacture and Acheulean technology. I hope to have consolidated in a summarized and synthesized manner the diverse theoretical and methodological perspectives within ECA and provided a comprehensive understanding of the cognitive capacities underlying stone-tool manufacture. By examining frameworks such as Piagetian models, working memory hypotheses and socio-cognitive theories, I sought to clarify how different cognitive and social processes intersect in shaping the lithic archaeological record.

Various (though certainly not all) ECA approaches have been described and discussed, highlighting the multidisciplinary nature of cognitive archaeological research. I hope to have demonstrated the significance of stone-tool production and use, specifically within the Acheulean technocomplex, as a key factor in understanding the cognitive capacities of extinct hominids. The synthesis presented here is particularly timely given the increasing availability of experimental and neuroarchaeological data, which call for integrative analyses to contextualize their implications. By synthesizing key frameworks and findings, I aim to clarify both the achievements and ongoing challenges in this field while outlining potential pathways for future ECA research.

Acknowledgements. The author thanks Prof. James Steele (University College London) for providing valuable feedback on an initial draft. This review paper draws on CMR's doctoral research, funded by the London Natural Environment Research Council Doctoral Training Partnership (London NERC DTP training grant NE/L002485/1). During her doctoral studies, CMR also received valuable support from the EU-funded project 'Biogeographical aspects of early human migrations' (ERC-Advanced Grant, Horizon 2020, BICAEHFID grant agreement No. 832980).

References

Aiello, L.C. & R.I.M. Dunbar, 1993. Neocortex size, group size, and the evolution of language. *Current Anthropology* 34(2), 184–93.

Ashton, N.M. & J. McNabb, 1994. Bifaces in perspective, in *Stories in Stone: Proceedings of the anniversary conference at St. Hilda's College, Oxford, April 1993*, eds N.M. Ashton & A. David. (Lithic Studies Occasional Paper 4.) London: Lithic Studies Society, 182–91.

Atran, S., 1982. Constraints on a theory of hominid tool-making behavior. *L'Homme* 22(2), 35–68.

Baber, C. & K. Janulis, 2021. Purposeful tool use in early lithic technologies. *Adaptive Behavior* 29(2), 169–80.

Baddeley, A.D., 1993. Working memory or working attention?, in *Attention, Selection, Awareness and Control. A tribute to Donald Broadbent*, eds A. Baddeley & L. Weiskrantz. Oxford: Clarendon Press, 152–70.

Baddeley, A.D., 2001. Is working memory still working? *American Psychologist* 56, 849–64.

Baddeley, A.D., 2010. Working memory. *Current Biology* 20(4), R136–40.

Baddeley, A.D. & G.J. Hitch, 1974. Working memory, in *Recent Advances in Learning and Motivation*, ed. G.A. Bower. New York: Academic Press, 47–89.

Barona, A.M., 2021. The archaeology of the social brain revisited: rethinking mind and material culture from a material engagement perspective. *Adaptive Behavior* 29(2), 137–52.

Belfer-Cohen, A. & N. Goren-Inbar, 1994. Cognition and communication in the Levantine Lower Palaeolithic. *World Archaeology* 26(2), 144–57.

Botha, R., 2022. Investigating cognitive abilities of early humans, in *The Oxford Handbook of Cognitive Archaeology*, eds T. Wynn, K.A. Overmann & F.L. Coolidge. Oxford: Oxford University Press, C48S1–C48N14.

Bounak, V.V., 1958. L'origine du langage, in *Les processus de l'hominisation* (Colloques internationaux du Centre national de la Recherche scientifique, Sciences humaines, Paris, 19–23 mai 1958). Paris: CNRS.

Bruner, E., E. Spinapolice, A. Burke & K. Overmann, 2018. Visuospatial integration: paleoanthropological and archaeological perspectives, in *Evolution of Primate Social* Cognition, eds L.D. Di Paolo, F. Di Vincenzo & F. De Petrillo. (Interdisciplinary Evolution Research 5.) Cham: Springer, 299–326.

Byrne, R.W. & A. Whiten, 1988. *Machiavellian Intelligence: Social expertise and the evolution of intellect in monkeys, apes and humans*. Oxford: Clarendon Press.

Clark, G., 1961. *World Prehistory: A new outline*. Cambridge: Cambridge University Press.

Cole, J.N., 2011. Hominin Cognitive and Behavioural Complexity in the Pleistocene: Assessment Through Identity, Intentionality and Visual Display. PhD thesis, University of Southampton.

Cole, J.N., 2012. The identity model: a theory to access visual display and hominin cognition within the Palaeolithic, in *Papers from the British Academy. Lucy to Language: Archaeology of the Social Brain. Seminar Series on Palaeolithic Visual Display*, eds J. Cole & K. Ruebens. *Human Origins* 1, 24–40.

Cole, J.N., 2014. The identity model: a theory to access visual display and hominin cognition within the Palaeolithic, in *Lucy to Language: The Benchmark Papers*, eds R.I.M. Dunbar, C.G. Gamble & J.A.J. Gowlett. Oxford: Oxford University Press, 90–107.

Cole, J.N., 2015a. Handaxe symmetry in the Lower and Middle Palaeolithic: implications for the Acheulean gaze, in *Settlement, Society and Cognition in Human Evolution*, eds F. Coward, R. Hosfield, M. Pope & F. Wenban-Smith. Cambridge/New York: Cambridge University Press, 234–57.

Cole, J.N., 2015b. Hominin language development: a new method of archaeological assessment. *Biosemiotics* 8, 67–90.

Cole, J.N., 2017. Accessing hominin cognition: language and social signaling in the Lower to Middle Palaeolithic, in *Cognitive Models in Palaeolithic Archaeology*, eds T. Wynn & F.L. Coolidge. Oxford: Oxford University Press, 157–96.

Coolidge, F.L., 2021. The role of the cerebellum in creativity and expert stone knapping. *Adaptive Behavior* 29(2), 217–29.

Coolidge, F.L., M.N. Haidle, M. Lombard & T. Wynn, 2016. Bridging theory and bow hunting: human cognitive evolution and archaeology. *Antiquity* 90, 219–28.

Coolidge, F.L. & T. Wynn, 2005. Working memory, its executive functions, and the emergence of modern thinking. *Cambridge Archaeological Journal* 15(1), 5–26.

Coolidge, F.L. & T. Wynn, 2009a. *Homo heidelbergensis* and the beginnings of modern thinking, in *The Rise of* Homo sapiens. *The evolution of modern thinking*, eds F.L. Coolidge & T. Wynn. Chichester: Wiley-Blackwell, 151–79.

Coolidge, F.L. & T. Wynn, 2009b. Working memory, in *The Rise of* Homo sapiens. *The evolution of modern thinking*, eds F.L. Coolidge & T. Wynn. Chichester: Wiley-Blackwell, 35–47.

Coolidge, F.L. & T. Wynn, 2016. An introduction to Cognitive Archaeology. *Current Directions in Psychological Science* 25(6), 386–92.

Corbey, R., 2020. Baldwin effects in early stone tools. *Evolutionary Anthropology* 29(5), 237–44.

Corbey, R., A. Jagich, K. Vaesen & M. Collard, 2016. The Acheulean handaxe: more like a bird's song than a Beatles' tune? *Evolutionary Anthropology* 25, 6–19.

Coward, F. & C. Gamble, 2009. Big brains, small worlds: material culture and the evolution of the mind, in *The Sapient Mind. Archaeology meets neuroscience*, eds C. Renfrew & L. Malafouris. Oxford: Oxford University Press, 51–69.

Cueva-Temprana, A., D. Lombao, J.I. Morales, N. Geribàs & M. Mosquera, 2019. Gestures during knapping: a two-perspective approach to Pleistocene technologies. *Lithic Technology* 44(2), 74–89.

Davidson, I., 2002. The finished artefact fallacy: Acheulean hand-axes and language origins, in *The Transition to Language*, ed. A. Wray. Oxford: Oxford University Press, 180–203.

Davidson, I. & W. Noble, 1993. Tools and language in human evolution, in *Tools, Language, and Cognition in Human Evolution*, eds K.R. Gibson & T. Ingold. Cambridge: Cambridge University Press, 363–88.

Davidson, I., W. Noble, D.F. Armstrong, *et al.*, 1989. The archaeology of perception: traces of depiction and language. *Current Anthropology* 30(2), 125–55.

DeCasien, A.R., S.A. Williams & J.P. Higham, 2017. Primate brain size is predicted by diet but not sociality. *Nature Ecology and Evolution* 1(5), 1–7.

Dennett, D.C., 1983. Intentional systems in cognitive ethology: the 'Panglossian paradigm' defended. *Behavioural and Brain Sciences* 6, 343–90.

Diez-Martín, F., T. Wynn, P. Sánchez-Yustos, *et al.*, 2019. A faltering origin for the Acheulean? Technological and cognitive implications from FLK West (Olduvai Gorge, Tanzania). *Quaternary International* 526, 49–66.

Donald, M., 1993. Précis of origins of the modern mind: three stages in the evolution of culture and cognition. *Behavioral and Brain Sciences* 16, 737–91.

Dunbar, R.I.M., 1998. The social brain hypothesis. *Evolutionary Anthropology* 6(5), 178–90.

Dunbar, R.I.M. & S. Shultz, 2007. Evolution in the social brain. *Science* 317, 1344–7.

Fairlie, J.E. & L.S. Barham, 2016. From *chaîne opératoire* to observational analysis: a pilot study of a new methodology for analysing changes in cognitive task-structuring strategies across different hominin tool-making events. *Cambridge Archaeological Journal* 26(4), 643–64.

Fajardo, S., P.R.B. Kozowyk & G.H.J. Langejans, 2023. Measuring ancient technological complexity and its cognitive implications using Petri nets. *Scientific Reports* 13, 14961.

Fodor, J.A., 1983. *The Modularity of Mind*. Cambridge (MA): MIT Press.

Gamble, C., J.A.J. Gowlett & R.I.M. Dunbar, 2011. The social brain and the shape of the Palaeolithic. *Cambridge Archaeological Journal* 21(1), 115–36.

Gardner, H., 1983. *Frames of Mind: The theory of multiple intelligences*. New York: Basic Books.

González-Forero, M. & A. Gardner, 2018. Inference of ecological and social drivers of human brain-size evolution. *Nature* 557, 554–7.

Goren-Inbar, N. & A. Belfer-Cohen, 2020. Reappraisal of hominin group size in the Lower Paleolithic: an introduction to the special issue. *Journal of Human Evolution*, 144, 102821.

Gowlett, J.A.J., 1979. Complexities of cultural evidence in the Lower and Middle Pleistocene. *Nature* 278, 14–17.

Gowlett, J.A.J., 1982. Procedure and form in a Lower Palaeolithic industry: stoneworking at Kilombe, Kenya. *Studia Praehistorica Belgica* (2), 101–9.

Gowlett, J.A.J., 1984. Mental abilities of early man: a look at some hard evidence. *Culture, Education & Society* 38(3), 199–220.

Gowlett, J.A.J., 1986. Culture and conceptualisation: the Oldowan-Acheulian gradient, in *Stone Age Prehistory. Studies in memory of Charles McBurney*, eds G.N. Bailey & P. Callow. Cambridge: Cambridge University Press, 243–60.

Gowlett, J.A.J., 1996. Mental abilities of early Homo: elements of constraint and choice in rule systems, in *Modelling the Early Human Mind*, eds P. Mellars & K. Gibson. Cambridge: McDonald Institute for Archaeological Research, 191–215.

Gowlett, J.A.J., 2006. The elements of design form in Acheulean bifaces: modes, modalities, rules, and language, in *Axe Age: Acheulian tool-making from quarry to discard*, eds N. Goren-Inbar & G. Sharon. London: Equinox, 203–22.

Gowlett, J.A.J., C. Gamble & R.I.M. Dunbar, 2012. Human evolution and the archaeology of the social brain. *Current Anthropology* 53(6), 693–722.

Green, J. & P.A. Spikins, 2020. Not just a virtue: the evolution of self-control. *Time and Mind* 13(2), 117–39.

Greenfield, P.M., 1991. Language, tools and brain: the ontogeny and phylogeny of hierarchically organized sequential behaviour. *Behavioral and Brain Sciences* 14, 531–95.

Haidle, M.N., 2009. How to think a simple spear, in *Cognitive Archaeology and Human Evolution*, eds S.A. de Beaune, F.L. Coolidge & T. Wynn Cambridge: Cambridge University Press, 57–73.

Haidle, M.N., 2010. Working-memory capacity and the evolution of modern cognitive potential. Implications from animal and early human tool use. *Current Anthropology* 51, S149–S166.

Haidle, M.N., 2012. The study of problem-solution-distance: basics, in *How to Think Tools? A comparison of cognitive aspects in tool behaviour of animals during human evolution. Cognitive Perspectives in Tool Behaviour* (Vol. 1). Tübingen: University of Tübingen Library, 155–64.

Haidle, M.N., 2023. Cognigrams: systematically reconstructing behavioral architectures as a basis for cognitive archaeology, in *The Oxford Handbook of Cognitive Archaeology*, eds T. Wynn, K.A. Overmann & F.L. Coolidge. Oxford: Oxford University Press, C12S1–C12S8.

Hallos, J., 2005. '15 minutes of fame': exploring the temporal dimension of Middle Pleistocene lithic technology. *Journal of Human Evolution* 49, 155–79.

Hecht, E.E., D.A. Gutman, N. Kreisheh, *et al.*, 2015. Acquisition of Paleolithic toolmaking abilities involves structural remodeling to inferior frontoparietal regions. *Brain Structure and Function* 220, 2315–31.

Hecht, E. & D. Stout, 2023. Methods in neuroarchaeology, in *The Oxford Handbook of Cognitive Archaeology*, eds T. Wynn, K.A. Overmann & F.L. Coolidge. Oxford: Oxford University Press, C7S1–C7S17.

Herzlinger, G., T. Wynn & N. Goren-Inbar, 2017. Expert cognition in the production sequence of Acheulian cleavers at Gesher Benot Ya'aqov, Israel: a lithic and cognitive analysis. *PLoS One* 12(11), e0188337.

Hodgson, D., 2009. Evolution of the visual cortex and the emergence of symmetry in the Acheulean techno-complex. *Comptes Rendus Palevol*, 8(1), 93–7.

Hodgson, D., 2015. The symmetry of Acheulean handaxes and cognitive evolution. *Journal of Archaeological Science: Reports* 2, 204–8.

Holloway, R.L., 1969. Culture: a human domain. *Current Anthropology* 10(4), 47–64.

Isaac, G.L., 1976. Stages of cultural elaboration in the Pleistocene: possible archaeological indicators of the development of language capabilities, in *Origins and Evolution of Language and Speech. Annals of the New York Academy of Sciences* 280(1) 275–88.

Isaac, G.L., 1978. Food sharing and human evolution: archaeological evidence from the Plio-Pleistocene of East Africa. *Journal of Anthropological Research*, 34, 311–25.

Isaac, G.L., 1986. Foundation stones: early artefacts as indicators of activities and abilities, in *Stone Age Prehistory. Studies in memory of Charles McBurney*, eds G.N. Bailey & P. Callow. Cambridge: Cambridge University Press, 221–41.

Karlin, C. & M. Julien, 1994. Prehistoric technology: a cognitive science?, in *The Ancient Mind: Elements of cognitive archaeology*, eds C. Renfrew & E.B.W. Zubrow. Cambridge: Cambridge University Press, 152–64.

Key, A.J.M. & C.J. Dunmore, 2018. Manual restrictions on Palaeolithic technological behaviours. *PeerJ*, 6, e5399.

Laughlin, C.D. 2015. Neuroarchaeology. *Time and Mind* 8(4), 335–49.

Leroi-Gourhan, A., 1964. *Gesture and Speech*. Cambridge (MA): MIT Press.

Lombard, M. & M.N. Haidle, 2012. Thinking a bow-and-arrow set: cognitive implications of Middle Stone Age bow and stone-tipped arrow technology. *Cambridge Archaeological Journal* 22(2), 237–64.

Lycett, S.J., 2008. Acheulean variation and selection: does handaxe symmetry fit neutral expectations? *Journal of Archaeological Science* 35(9), 2640–48.

Lycett, S.J. & J.A.J. Gowlett, 2008. On questions surrounding the Acheulean 'tradition'. *World Archaeology* 40(3), 295–315.

Lycett, S.J., K. Schillinger, M.I. Eren, N. von Cramon-Taubadel & A. Mesoudi, 2016. Factors affecting Acheulean handaxe variation: experimental insights, microevolutionary processes, and macroevolutionary outcomes. *Quaternary International* 411, 386–401.

Machin, A.J., R.T. Hosfield & S.J. Mithen, 2005. Testing the functional utility of handaxe symmetry: fallow deer butchery with replica handaxes. *Lithics* 26, 23–37.

Machin, A.J., R.T. Hosfield & S.J. Mithen, 2007. Why are some handaxes symmetrical? Testing the influence of handaxe morphology on butchery effectiveness. *Journal of Archaeological Science* 34, 883–93.

Mahaney, R.A., 2014. Exploring the complexity and structure of Acheulean stoneknapping in relation to natural language. *Paleoanthropology* 2014, 586–606.

Mahaney, R.A., 2015. Cognition and Planning in Palaeolithic Technology: Studies in Experimental Archaeology. PhD thesis, Indiana University.

Malafouris, L., 2004. The cognitive basis of material engagement: where brain, body and culture conflate, in *Rethinking Materiality: The engagement of mind with the material world*, eds E. DeMarrais, C. Gosden & C. Renfrew. Cambridge: McDonald Institute for Archaeological Research, 53–62.

Malafouris, L., 2008. Beads for a plastic mind: the 'blind man's stick' (BMS) hypothesis and the active nature of material culture. *Cambridge Archaeological Journal* 18(3), 401–14.

Malafouris, L., 2009. 'Neuroarchaeology': exploring the links between neural and cultural plasticity, in 'Cultural neuroscience: cultural influences on brain function', ed. J.Y. Chiao. *Progress in Brain Research* 178, 253–61.

Malafouris, L., 2010. Knapping intentions and the marks of the mental, in *The Cognitive Life of Things. Recasting the boundaries of the mind*, eds L. Malafouris & C. Renfrew. Cambridge: McDonald Institute of Archaeological Research, 13–19.

Malafouris, L., 2013. *How Things Shape the Mind: A theory of material engagement*. Cambridge (MA): MIT Press.

Malafouris, L., 2015. Metaplasticity and the primacy of material engagement. *Time and Mind* 8(4), 351–71.

Malafouris, L., 2019. Mind and material engagement. *Phenomenology and the Cognitive Sciences* 18, 1–17.

Malafouris, L., 2021a. How does thinking relate to tool making? *Adaptive Behavior* 29(2), 107–21.

Malafouris, L., 2021b. Making hands and tools: steps to a process archaeology of mind. *World Archaeology* 53(1), 38–55.

Malafouris, L. & C. Gosden, 2020. Mind, time, and material engagement, in *The Oxford Handbook of History and Material Culture*, eds I. Gaskell & S.A. Carter. Oxford: Oxford University Press, 104–20.

Malafouris, L. & C. Renfrew (eds), 2010. *The Cognitive Life of Things. Recasting the boundaries of the mind*. Cambridge: McDonald Institute of Archaeological Research.

Martín-Ramos, C., 2022. Acheulean Technology and Hominin Cognition. Analysis of Large Cutting Tools from Olduvai Gorge Beds III and IV, Tanzania. PhD thesis, University College London.

McNabb, J., 2012. The importance of conveying visual information in Acheulean society. The background to the visual display hypothesis, in *Papers from the British Academy. Lucy to Language: Archaeology of the Social Brain. Seminar Series on Palaeolithic Visual Display*, eds J. Cole & K. Ruebens. *Human Origins* 1, 1–23.

McNabb, J., 2019. Further thoughts on the genetic argument for handaxes. *Evolutionary Anthropology*, 29, 220–36.

McNabb, J., F. Binyon & L. Hazelwood, 2004. The large cutting tools from the South African Acheulean and the question of social traditions. *Current Anthropology* 45(5), 653–77.

McNabb, J. & J.N. Cole, 2015. The mirror cracked: symmetry and refinement in the Acheulean handaxe. *Journal of Archaeological Science: Reports* 3, 100–111.

McPherron, S.P., 2007. What typology can tell us about Acheulian handaxe production, in *Axe Age: Acheulian tool-making from quarry to discard*, eds N. Goren-Inbar & G. Sharon. London: Equinox, 267–86.

Mithen, S.J., 1994. From domain specific to generalized intelligence: a cognitive interpretation of the Middle/Upper Palaeolithic transition, in *The Ancient Mind: Elements of Cognitive Archaeology*, eds C. Renfrew & E.B.W. Zubrow. London: Thames & Hudson, 29–39.

Mithen, S.J., 1995. Palaeolithic archaeology and the evolution of mind. *Journal of Archaeological Research* 3(4), 305–32.

Mithen, S.J., 1996. *The Prehistory of the Mind*. London: Thames & Hudson.

Morgan, T.J.H., N.T. Uomini, L.E. Rendell, *et al.*, 2015. Experimental evidence for the co-evolution of hominin tool-making teaching and language. *Nature Communications* 6, 6029.

Muller, A., C. Clarkson & C.B.K. Shipton, 2017. Measuring behavioural and cognitive complexity in lithic technology throughout human evolution. *Journal of Anthropological Archaeology* 48, 166–80.

Nowell, A.S., 2000. The Archaeology of Mind: Standardization and Symmetry in Lithics and Their Implications for the Study of the Evolution of the Human Mind. PhD thesis, University of Pennsylvania.

Nowell, A.S., *et al.*, 2003. Deformation modeling: a methodology for the analysis of handaxe morphology and variability, in *Multiple Approaches to the Study of Bifacial Technologies*, eds M. Soressi & H.L. Dibble. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology, 193–209.

Overmann, K.A. & T. Wynn, 2019. Materiality and human cognition. *Journal of Archaeological Method and Theory* 26, 457–78.

Pain, R., C.B.K. Shipton & R.L. Brown, 2023. Archaeology and cognitive evolution: introduction to the thematic section. *Biological Theory* 18, 231–3.

Pappu, S. & K. Akhilesh, 2019. Tools, trails and time: debating Acheulian group size at Attirampakkam, India. *Journal of Human Evolution* 130, 109–25.

Pargeter, J., N. Khreisheh & D. Stout, 2019. Understanding stone toolmaking skill acquisition: experimental methods and evolutionary implications. *Journal of Human Evolution* 133, 146–66.

Parker, S.T. & K.R. Gibson, 1979. A developmental model for the evolution of language and intelligence in early hominids. *Behavioural and Brain Sciences* 2, 367–408.

Pelegrin, J., 1990. Prehistoric lithic technology: some aspects of research. *Archaeological Review from Cambridge* 9(1), 117–25.

Perlès, C., 1992. In search of lithic strategies: a cognitive approach to prehistoric chipped stone assemblages, in *Representations in Archaeology*, eds J.-C. Gardin & C.S. Peebles. Bloomington/Indianapolis: Indiana University Press, 223–47.

Petraglia, M.D., C.B.K. Shipton & K. Paddayya, 1999. The first Acheulian quarry in India: stone tool manufacture, biface morphology, and behaviors. *Journal of Anthropological Research* 55, 39–70.

Piaget, J. & B. Inhelder, 1956. *The Child's Conception of Space*. London: Routledge & Kegan Paul.

Pigeot, N., 1991. Réflexions sur l'histoire technique de l'Homme: de l'évolution cognitive à l'évolution culturelle. *Paléo* 3, 167–200.

Pope, M.I., K. Wells & K. Watson, 2006. Biface form and structured behaviour in the Acheulean. *Lithics* 27, 44–57.

Putt, S.S., 2016. Human Brain Activity During Stone Tool Production: Tracing the Evolution of Cognition and Language. PhD thesis, University of Iowa.

Putt, S.S., S. Wijeakumar, R.G. Franciscus & J.P. Spencer, 2017. The functional brain networks that underlie Early Stone Age tool manufacture. *Nature Human Behaviour* 1, 0102.

Putt, S.S., S. Wijeakumar & J.P. Spencer, 2019. Prefrontal cortex activation supports the emergence of early stone age toolmaking skill. *NeuroImage* 199, 57–69.

Ranov, V.A., 2001. Cleavers: their distribution, chronology and typology, in *A Very Remote Period Indeed: Papers on the Palaeolithic presented to Derek Roe*, eds S. Milliken & J. Cook. Oxford: Oxbow, 105–13.

Renfrew, C., 1994. Towards a cognitive archaeology, in *The Ancient Mind: Elements of cognitive archaeology*, eds C. Renfrew & E.B.W. Zubrow. Cambridge: Cambridge University Press, 3–12.

Renfrew, C., 2012. Towards a cognitive archaeology. Material engagement and the early development of society, in *Archaeological Theory Today*, ed. I. Hodder. Cambridge: Polity Press, 124–40.

Renfrew, C., 2016. Cognitive archaeology and the making of the human mind, in *Eurasia at the Dawn of History*, eds M. Fernandez-Gotz & D. Krausse. Cambridge: Cambridge University Press, 23–39.

Roberts, P., 2016. 'We have never been behaviourally modern': the implications of Material Engagement Theory and metaplasticity for understanding the Late Pleistocene record of human behaviour. *Quaternary International* 405, 8–20.

Robson Brown, K., 1993. An alternative approach to cognition in the Lower Palaeolithic: the modular view. *Cambridge Archaeological Journal* 3(2), 231–45.

Schlanger, N., 1994. Mindful technology: unleashing the chaîne opératoire for an archaeology of mind, in *The Ancient Mind: Elements of cognitive archaeology*, eds C. Renfrew & E.B.W. Zubrow. Cambridge: Cambridge University Press, 143–51.

Sharon, G., 2008. The impact of raw material on Acheulian large flake production. *Journal of Archaeological Science* 35, 1329–44.

Sharon, G., 2010. Large flake Acheulian. *Quaternary International* 223–224, 226–33.

Sharon, G., N. Alperson-Afil & N. Goren-Inbar, 2011. Cultural conservatism and variability in the Acheulian sequence of Gesher Benot Ya'aqov. *Journal of Human Evolution* 60, 387–97.

Shipton, C.B.K., 2010. Imitation and shared intentionality in the Acheulean. *Cambridge Archaeological Journal* 20(2), 197–210.

Shipton, C.B.K., 2013. *A Million Years of Hominin Sociality and Cognition: Acheulean bifaces in the Hunsgi-Baichbal Valley, India*. Oxford: Archaeopress.

Shipton, C.B.K., C. Clarkson & R. Cobden, 2018. Were Acheulean bifaces deliberately made symmetrical? Archaeological and experimental evidence. *Cambridge Archaeological Journal* 29(1), 65–79.

Shipton, C.B.K. & M. Nielsen, 2015. Before cumulative culture. *Human Nature* 26(3), 331–45.

Shipton, C.B.K., M.D. Petraglia & K. Paddayya, 2009. Inferring aspects of Acheulean sociality and cognition from lithic technology, in *Lithic Materials and Paleolithic Societies*, eds B. Adams & B.S. Blades. Chichester/Hoboken: Wiley-Blackwell, 219–31.

Shultz, S. & R.I.M. Dunbar, 2007. The evolution of the social brain: anthropoid primates contrast with other vertebrates. *Proceedings of the Royal Society B* 274, 2429–36.

Shultz, S. & R.I.M. Dunbar, 2010. Encephalization is not a universal macroevolutionary phenomenon in mammals but is associated with sociality. *Proceedings of the National Academy of Sciences* 107(50), 21582–6.

Shultz, S. & R.I.M. Dunbar, 2014. The Social Brain Hypothesis, in *Lucy to Language: The Benchmark Papers*, eds R.I.M. Dunbar, C.G. Gamble & J.A.J. Gowlett. Oxford: Oxford University Press, 45–66.

Shultz, S., E. Nelson & R.I.M. Dunbar, 2012. Hominin cognitive evolution: identifying patterns and processes in the fossil and archaeological record. *Philosophical Transactions of the Royal Society B* 367, 2130–40.

Stade, C.M., 2017. Lithic Morphological Variability as a Proxy for Palaeolithic Linguistic Ability: A Knapping Training Study Exploring Cultural Transmission, Theory of Mind and Language. PhD thesis, University of Southampton.

Stade, C.M., 2020. Theory of mind as a proxy for Palaeolithic language ability: an alternative to the search for the earliest symbolic material culture. *Language Dynamics and Change* 10(1), 59–85.

Steele, J., A. Quinlan & F.F. Wenban-Smith, 1995. Stone tools and the linguistic capabilities of earlier hominids. *Cambridge Archaeological Journal* 52, 245–56.

Stout, D., 2005. Neural foundations of perception and action in stone knapping, in *Stone Knapping: The necessary conditions for a unique hominin behaviour*, eds V. Roux & B. Bril. Cambridge: McDonald Institute for Archaeological Research, 273–86.

Stout, D. 2008. Technology and human brain evolution. *General Anthropology* 15(2), 1–5.

Stout, D., 2011. Stone toolmaking and the evolution of human culture and cognition. *Philosophical Transactions of the Royal Society B* 366, 1050–59.

Stout, D. & T. Chaminade, 2007. The evolutionary neuroscience of tool making. *Neuropsychologia* 45, 1091–1100.

Stout, D. & E. Hecht, 2023. Evolutionary neuroarchaeology, in *The Oxford Handbook of Cognitive Archaeology*, eds T. Wynn, K.A. Overmann & F.L. Coolidge. Oxford: Oxford University Press, C14.S1–C14.S11.

Stout, D., E. Hecht, N. Khreisheh, B. Bradley & T. Chaminade, 2015. Cognitive demands of lower Paleolithic toolmaking. *PLoS ONE*, 10(4), p. e0121804.

Stout, D., R. Passingham, C. Frith, J. Apel & T. Chaminade, 2011. Technology, expertise and social cognition in human evolution. *European Journal of Neuroscience*, 33, 1328–38.

Stout, D., N.P. Toth & K.D. Schick, 2006. Comparing the neural foundations of Oldowan and Acheulean toolmaking: a pilot study using Positron Emission Tomography (PET), in *The Oldowan: Case studies into the earliest Stone Age*, eds N.P. Toth & K.D. Schick. (Stone Age Institute 1.) Gosport (IN): Stone Age Institute Press, 321–31.

Stout, D., N. Toth, K. Schick & T. Chaminade, 2008. Neural correlates of early Stone Age toolmaking: technology, language and cognition in human evolution. *Philosophical Transactions of the Royal Society B* 363, 1939–49.

Stout, D., N. Toth, K. Schick, J. Stout & G. Hutchins, 2000. Stone toolmaking and brain activation: Positron Emission Tomography (PET) studies. *Journal of Archaeological Science*, 27, 1215–23.

Tennie, C., D.R. Braun, L.S. Premo & S.P. McPherron, 2016. The island test for cumulative culture in the paleolithic, in *The Nature of Culture*, eds M.N. Haidle, N.J. Conard & M. Bolus. Tübingen: Springer, 121–33.

Tennie, C., J. Call & M. Tomasello, 2009. Ratcheting up the ratchet: on the evolution of cumulative culture. *Philosophical Transactions of the Royal Society B* 364, 2405–15.

Tennie, C., L.S. Premo, D.R. Braun & S.P. McPherron, 2017. Early stone tools and cultural transmission: resetting the null hypothesis. *Current Anthropology* 58(5), 652–72.

White, M.J., 1998. On the significance of Acheulean biface variability in southern Britain. *Proceedings of the Prehistoric Society* 64, 15–44.

Wynn, T., 1979. The intelligence of Later Acheulean hominids. *Man*, n.s. 14(3), 371–91.

Wynn, T., 1981. The intelligence of Oldowan hominids. *Journal of Human Evolution* 10(7), 529–41.

Wynn, T., 1985. Piaget, stone tools and the evolution of human intelligence. *World Archaeology* 17(1), 32–43.

Wynn, T., 1989. *The Evolution of Spatial Competence*. (Illinois Studies in Anthropology 17.) Champaign (IL): University of Illinois Press.

Wynn, T., 1991. Tools, grammar and the archaeology of cognition. *Cambridge Archaeological Journal* 1(2), 191–206.

Wynn, T., 1993a. Layers of thinking in tool behaviour, in *Tools, Language, and Cognition in Human Evolution*, eds K.R. Gibson & T. Ingold. Cambridge: Cambridge University Press, 389–98.

Wynn, T., 1993b. Two developments in the mind of Early Homo. *Journal of Anthropological Archaeology* 12, 299–322.

Wynn, T., 1999. The evolution of tools and symbolic behaviour, in *Handbook of Human Symbolic Evolution*, eds A. Lock & C.R. Peters. Oxford: Blackwell, 263–87.

Wynn, T., 2000. Symmetry and the evolution of the modular linguistic mind, in *Evolution and the Human Mind: Modularity, language and meta-cognition*, eds P. Carruthers & A. Chamberlain. Cambridge: Cambridge University Press, 113–39.

Wynn, T., 2002. Archaeology and cognitive evolution. *Behavioral and Brain Sciences* 25, 389–438.

Wynn, T., 2009. Whiter evolutionary cognitive archaeology? Afterword, in *Cognitive Archaeology and Human Evolution*, eds S.A. de Beaune, F.L. Coolidge & T. Wynn. Cambridge: Cambridge University Press, 145–9.

Wynn, T., 2016. *Critique of Piagetian approach*, *Cognitive Archaeology Blog*. https://cognitivearchaeologyblog.wordpress.com/2016/02/10/critique-of-piagetian-approach/ (accessed 15 August 2023).

Wynn, T., 2017. Evolutionary cognitive archaeology, in *Cognitive Models in Palaeolithic Archaeology*, eds T. Wynn & F.L. Coolidge. Oxford: Oxford University Press, 1–20.

Wynn, T., 2021. Ergonomic clusters and displaced affordances in early lithic technology. *Adaptive Behavior* 29(2), 181–95.

Wynn, T. & F.L. Coolidge, 2004. The expert Neandertal mind. *Journal of Human Evolution* 46(4), 467–87.

Wynn, T. & F.L. Coolidge, 2010. Beyond symbolism and language. An introduction to Supplement 1, *Working Memory*. *Current Anthropology* 51(1), 5–16.

Wynn, T. & F.L. Coolidge, 2011. The implications of the working memory model for the evolution of modern cognition. *International Journal of Evolutionary Biology* 2011, 741357.

Wynn, T. & J.A.J. Gowlett, 2018. The handaxe reconsidered. *Evolutionary Anthropology* 27, 21–9.

Wynn, T., M. Haidle, M. Lombard & F.L. Coolidge, 2017. The Expert Cognition Model in human evolutionary studies, in *Cognitive Models in Palaeolithic Archaeology*, eds T. Wynn & F.L. Coolidge. Oxford: Oxford University Press, 21–44.

Wynn, T. & W.C. McGrew, 1989. An ape's view of the Oldowan. *Man* 24(3), 383–98.

Wynn, T., K.A. Overmann & L. Malafouris, 2021. 4E cognition in the Lower Palaeolithic. *Adaptive Behavior* 29(2), 99–106.

Carmen Martín-Ramos works as a Teaching Fellow in Early Prehistory and Human Evolution at the University of Leicester. She is a Palaeolithic archaeologist and Africanist, specializing in Human Evolution, Palaeoanthropology, lithic technology and cognitive archaeology. Before joining the University of Leicester, she was a postdoctoral researcher at the McDonald Institute for Archaeological Research (University of Cambridge) and completed a PhD at the Institute of Archaeology (University College London) and the Earth Sciences Department of the Natural History Museum. She often employs technological approaches to assess changes in hominin behaviour, with a special interest in field excavation techniques, geoarchaeology, and landscape use.