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4E Cognition in the Lower Palaeolithic

Introduction to a special issue of *Adaptive Behavior*

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About three-and-a-half million years ago, our early hominin ancestors began making stone tools, and in doing so, took the first steps on a long path of technical development and innovation. Kenneth Oakley (1957) even titled an influential article in *Antiquity* "Tools Makyth Man." Some archaeologists take this belief a step further and aver that the development of stone tools marked a cognitive Rubicon, the crossing of which forever separated hominin mental life from that of our ape cousins (Hovers, 2012; Roche et al., 2009; Schick & Toth, 2006). They suggest that making and using stone tools required "planning," "understanding" of conchoidal fracture, "complex thought," and even "mental templates." Others demur, suggesting instead that early lithic technology was instead very ape-like (Davidson & McGrew, 2005; Davidson & Noble, 1993; Gibson & Ingold, 1993; Hovers, 2012; Roche et al., 2009; Schick & Toth, 2006; Tennie et al., 2017; Wynn et al., 2011; Wynn & McGrew, 1989). But, with few exceptions, the two perspectives appear to agree that hominin thinking occurred in the heads of the hominins, and that technical evolution reflected developments in brains and cognition. Put simply, bigger brains made better tools. Scant attention has been given to the idea that the tools themselves were a constitutive part of cognition, or that hominin thinking literally played out through their hands and tools. Contributors to this special issue of *Adaptive Behavior* have been seeking to explore this idea influenced by what is now known as the 4E (embodied, embedded, enactive, extended; Gallagher, 2017; Menary, 2010; Newen et al., 2018) approach to hominin cognition, believing it provides a more fruitful understanding of technical cognition than the typological and representational cognitive approaches that have dominated the past fifty years of paleoanthropology.

Like other African apes, early (pre 3.5 Ma) hominins ate a primarily vegetarian diet, which they augmented with insects and meat from small mammals. Indeed, a vegetarian diet had selected for their derived dentition of thick enamel and reduced canines. African habitats had been changing for several million years, with shrinking forests and woodlands and expanding grasslands that placed pressure on the hominin niche. Some groups of hominins added scavenging to their foraging repertoires. But they were ill-equipped to do so. Leaving aside the serious challenge of competing with carnivores, accessing edible portions of carcasses required slicing teeth and crushing jaws that these medium-sized vegetarians lacked. Luckily, African apes, including hominins, had long experience using tools to access hard-to-get food, including tools to break into encased foods (Parker & Gibson, 1979). In a sense, the hominin addition of scavenging was a lateral shift in tool use, from vegetable foods (including nuts and USOs) to carcasses. Pounding had long been a component of anthropoid tool use, including the use of stone hammers and stone anvils (Arroyo et al., 2016; Boesch & Boesch-Achermann, 2000; Carvalho et al., 2008; Matsuzawa, 1994; Matsuzawa et al., 2014). When today's chimpanzees pound nuts with stone hammers and anvils, mis-hits occasionally break off small pieces of stone. These pieces are sharp and potentially useful

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as tools, but chimpanzees ignore them. After all, they retain respectable incisors and canines for cutting and slashing. Our 3.5-million-year-old ancestors did not ignore the sharp shards of stone. Instead, they used them as slicing tools, holding them with thumb and fingers and using them to cut through ligaments, tendons, and meat. The flaked hammers/anvils ("cores") also made good crushing tools for accessing marrow from bone.

These three components—flakes, cores, and hammers—became the first lithic technical intelligence. The earliest hominin stone knappers used two techniques to fracture stone to produce flakes. In one, which archaeologists label direct free-hand percussion, the knapper held a target stone in one hand (the core) and struck it with a hammer stone held in the other, aiming the blow toward an edge of the core. If successful, the blow stripped off a thin shard of stone (a flake). Large flakes would have been a few centimeters in maximum dimension, large enough to hold between fingers and thumb and use to cut or saw. In the second "bipolar" technique, the knapper held the core on a stable substrate, such as a stone anvil, and struck the core with a hammer stone. This, too, resulted in sharp flakes appropriately sized for manipulation with fingers and thumb. Some types of stone are better than others, and hominins quickly learned to recognize varieties of stone that were easier to knap and yielded sharper, more durable flakes. Such raw material selectivity is well-documented in anthropoid tool use, so this too was a lateral shift in an established ability.

It is possible—indeed, even likely—that many groups of early hominins, even different species, experimented with using stone cores, hammers, and flakes. The technical knowledge may have emerged and disappeared on multiple occasions. Eventually, it came to be well established. But archaeological remains of such activity dating to the early time period between 3.3 and 2.0 million years ago are rare.

Archaeologists have struggled with how to describe and characterize these remains. Since the beginning of academic archaeology in the nineteenth century, classification of artifacts has been an important analytical tool. This requires definition of types and sub-types, and labeling. Early on, the theoretical grounding of such classifications was rarely explicit; in the cases of stone tools, archaeologists relied on shape and presumed function (Shea, 2016). The first attempts at classifying stone tools made no attempt to incorporate anything linked to human psychology, whose study was at the time still in its infancy. The initial terminology developed by French and English archaeologists in the nineteenth century still governed the typologies of stone tools when archaeologists in Africa first encountered examples of extremely old artifacts. Louis Leakey, for example, used them as his basis for describing the very early stone tools he found at Olduvai Gorge in the 1930s, stratified below the first handaxes (Leakey, 1931). Mary Leakey used a modified version of these categories in her seminal 1971 volume that described the stone industries from Beds I and II (Leakey, 1971). She identified several categories of "core tools," including side-choppers, end-choppers, polyhedrons, and so on, and several categories of flake tools—scrapers, awls, and burins—all based on the shapes of the artifacts.

What can be confusing to non-archaeologists reading this literature is that archaeologists themselves were not strongly committed to the functional implications of the types. The labels were primarily a means of description and communication that all archaeologists knew. Prior to the 1970s, most archaeologists had little interest in hominin behavior; archaeology was a study of artifacts and how artifacts varied over time and space. This is not as sterile as it might seem, as recent publications by John Shea make very clear (Shea, 2011, 2013, 2016). However, in the 1970s, the archaeology of early hominins took on a more self-aware theoretical approach that tried to place hominin agents and their tools into an ecological context, a movement pioneered by Glynn

Isaac (1977, 1984; Sept & Pilbeam, 2011). From this perspective, the tool types of the Leakeys were misleading. The hominins did not have categories in their heads such as chopper or flake scraper. Indeed, as Nick Toth brilliantly demonstrated (Toth, 1985), the hominins themselves were primarily interested in sharp flakes (aka light duty tools), and the occasional crushing tool (heavy duty), for which they often employed flaked cores. The important shift here, which the alert reader has no doubt detected, was from a focus on tools to a focus on hominin agents. Archaeologists were now interested in the hominins themselves, especially how they adapted using tools. Not surprisingly, perhaps, some of these scholars also developed an interest in hominin minds.

In 1969, paleoneurologist Ralph Holloway published an ultimately (but not initially) influential article in *Current Anthropology* in which he used stone tools as evidence for hominin linguistic ability (Holloway, 1969). He grounded his analysis in structuralist models of language, and linked standardization in stone tools (this was prior to the demise of Leakey's typology) to rule-governed systems akin to language. Holloway's analysis was firmly rooted in the prevailing anthropological thinking of the time, which was primarily structuralist in its understanding of culture, and Chomskian in its understanding of language. Both situate mental phenomena firmly inside the head. Tool use and technology were not major components of this anthropological account of human mindedness; most anthropologists gave tools little consideration. Computers were the exception. Along with the rapid development of computer hardware and software, a computer analogy for the mind quickly came to rival linguistic models. This understanding of mind as a linguistic/computational homunculus housed in the hominin brain became the default understanding of cognition for most paleoanthropologists. A decade later, three independent papers firmly established this model of mind as the preferred subject of cognitive archaeology (Gowlett, 1979; Parker & Gibson, 1979; Wynn, 1979). These archaeologists considered stone tools to be windows into prehistoric minds, not components of thinking itself. Assigning agency to hominins and using artifacts to document minds provided useful insights into the evolution of certain cognitive abilities, but it ignored the role that tools themselves played in early hominin cognition, and how that role influenced the evolution of cognition itself. Beyond this lacuna, the cognitivist model has other shortfalls, which 4E models of cognition have the potential to address.

Despite its popularity, cognitivism poses serious challenges for archaeologists. Even if we accept that internal representations in some form do exist and have some analytical value (e.g., in the study of language), they are unhelpful for cognitive archaeology. They are unhelpful because they imply that human thought can only take place inside the head, that this is where all computation takes place. What we see in the archaeological record can therefore only be an "external" product or the behavioral trace of those "internal" computational processes. Cognition, in other words, does not preserve in the archaeological record. Cognitive archaeologists can only infer cognitive processes by way of a sequence of linked inferences (Botha, 2010, 2016; Wynn, 2009), and the more links in the chain, the greater the possibility of error.

The 4E approach to human cognition helps us to overcome this dualist representational logic, allowing us to engage directly with the archaeological record as an integral part of the thinking process, and thus ground a more parsimonious cognitive archaeology. It also treats stone tools, the primary vestiges of hominin thinking, as active participants in mental life. 4E approaches are a better grounding for understanding hominin technical expertise, a crucially important component of hominin cognitive evolution that has been underappreciated by the both the psychological and paleoanthropological communities (Osiurak et al., 2020; Osiurak & Reynaud, 2020).

The 4E approach offers more than a parsimonious way of interpreting ancestral cognitive evolution from stone tools or appreciating our technological continuity with non-human primates: It offers a new way of understanding the nature of cognition itself. Here it must be emphasized that while we are undoubtedly concerned with human cognition, the role of tools within it is not unique to humans. Rather, tools are a constitutive part of the cognition of all tool-using species. Of particular interest, then, are the demonstrable differences between human tools and the tools of other species, as this has specific implications for hominin cognitive evolution. 4E cognition has the advantage of placing hominins and non-human primates on a level playing field. For reasons embedded in the early history of anthropology and evolutionary science, scholars and educated lay people commonly think of non-human primates, when they think of them at all, as pre-human. From this perspective, non-human primate behavior and tools stand in as proxies for hominin tool users prior to the advent of stone tools. The advent of effective hard hammer percussion indicates possible changes in hominin cognition, a flash of insight that delivered an understanding of conchoidal fracture. By eschewing a hominin homunculus, 4E cognition focuses on the tools themselves and the very evident continuity with the range of anthropoid tool use, including hominin tools use.

For human cognition, the 4E approach acknowledges that what the brain does is influenced by being in a body (embodied) that is located in a particular environment (embedded). These claims have become accepted to the point that they are now fairly commonplace. Still, the exact meaning of embodied cognition remains much contested (see Malafouris, 2016, 2017). The key point here, especially for the material engagement approach advocated by the contributors of this special issue, concerns the meaning of the term “in”: When we say that the brain is “in” the body or that the body is “in” the world, we mean that brains and bodies are situated—that is, they are entangled and intertwined with their surrounding environment. This is a very different formulation than that used when we say that the water is in the glass. As the pragmatist philosopher John Dewey observes defining the term of “situation”: “The meaning of the word ‘in’ is different from its meaning when it is said that pennies are ‘in’ a pocket or paint is ‘in’ a can….The conceptions of situation and of interaction are inseparable from each other” (Dewey, 1938, p. 43).

More contentious are the claims that cognition includes more than what the brain does, “leaking out” into the world to include not just the body but material forms (extended), and that cognition *is* the interaction between brain, body, and world (enacted). Perhaps one familiar and intuitive example of cognition that is extended and enacted is reading; a person cannot be said to read something without interacting with the material form known as writing. The cognitive state that is reading necessarily involves a material form. As Hutchins (2008) noted, “A good deal of contemporary thinking, and probably an even greater proportion of ancient thinking, happens in *interaction* of brain and body with the world. This seems innocent enough, and many people take it to mean simply that thinking is something that happens in the brain as a consequence of interaction with the world. That is not the claim being made here. The claim here is that, first and foremost, thinking *is* interactions of brain and body with the world. Those interactions are not evidence of, or reflections of, underlying thought processes. They are instead the thinking processes themselves” (p. 2112).

When cognition is modeled as something more than neural activity inside the brain, there is a range of theoretical perspectives and degrees of commitment: Besides embodied, embedded, extended, and enactive, cognition can also be described as situated or distributed, for example, and interpretations can be conservative and fairly well accepted or radical and reflective of broad disagreement. For this special issue on 4E cognition in the Lower Palaeolithic, the contributors adopt theoretical frameworks like Material Engagement Theory (Malafouris, 2013, 2019) or constructs from ecological psychology like *affordance* (Gibson, 1977, 1979).

Material Engagement Theory, or MET, has three central commitments. First, cognition is *extended and enacted*. In arguing for this perspective, Malafouris does not merely assume that cognition is 4E; rather, he invites us to suspend disbelief, redraw the boundaries of cognition beyond the brain, and see what new insights might be generated. As was noted above, this perspective has particular advantages for the endeavor that is recreating ancient and ancestral ways of thinking from the material record. The second tenet is that *materiality has agency*. The argument here is that what we call "agency" is not a human property but the relational and emergent product of situated activity. There is no way that human agency (as capacity for action) and material agency (as the situational affordances for action) can be disentangled. MET's third central element is *enactive signification*, the idea that meaning emerges from the interaction between organisms and material forms. Here the distinction is between *hammer*, a noun that means a tool designed and sold for a specific function, and *hammer*, the verb that means to pound one thing with another. Arguably, doing precedes the emergence of not just meaning (to hammer; a hammer) but also of form (what attributes of form make an object suitable for use as a hammer).

Affordances are relations between what a material form is and what an agent can do with it; thus, they are relations between an agent's abilities and the exploitable features of its environment, rather than being properties of either: "The *affordances* of the environment are what it offers the animal, what it *provides* or *furnishes*, either for good or ill" (Gibson, 1979, p. 127). Gibson created the term *affordance* from the verb *to afford*, meaning by it "something that refers to both the environment and the animal" and implies their "complementarity" (p. 127). Malafouris (2013) identifies an affordance as a mechanism though which materiality exerts agency. Simply, affordances are properties of material forms that enable an agent to do something with them. Of course, the agent must also possess the behavioral, physiological, and/or psychological capacity to exploit the properties (Greeno, 1994; Scarantino, 2003). The corollary is that when a material form enables an agent to do something, its properties influence the results achieved and the concepts formed. Sextants and calculators—and, as will be argued by some of the contributors, stone tools—show that affordances can also be encoded in artifacts, making them available for other individuals and generations, influencing behaviors and outcomes in subsequent performances and problem-solving, and distributing cognitive effort over space and time (Hutchins, 1995; Smith, 2007).

In the special issue, the authors apply these and other 4E ideas to the question of cognition in the Lower Palaeolithic. The individual articles arose out of a series of workshops held at Keble College, University of Oxford, between February 2018 and November 2019. Several of the authors organize their essays around analyses of data, while others focus on theoretical and methodological issues.

Building on his Material Engagement Theory (2013), **Lambros Malafouris** sets out an ambitious reconfiguration of the meaning of cognition as employed by cognitive archaeologists, enabling a fundamental reassessment of how the mind of early hominins can be understood. His goal is to frame a more rigorous and productive cognitive archaeology that not only evaluates the hominin past but also contributes directly to how cognitive science understands the mind. His radical reconception of mindedness centers on the "ontological entanglement" of the mental with the physical. He does not deny a role for brains, but instead promotes extracranial resources to active participation. Rather than focusing on procedures or tool types with implicit normative implications—the traditional approach to understanding early stone tools—Malafouris focuses on cutting edges as material extensions of hominin action that restructured their mental engagement with the material world. But Malafouris' most provocative application is his discussion of the status of handaxes, a target of papers by several of the issue's authors. Cognitive archaeologists have typically used handaxes, the first which appeared about 1.7 million years ago, to argue for imposition of form and the role of normativity (Shipton, 2019; Shipton & White, 2020). Malafouris turns this conceit on its head and lays out how hominin engagement with large cutting tools was instead the vehicle by which hominins began to construct elements of normativity, reiterating **Overmann's** concern with the emergence of features as reflections of use and usability (in this special issue). This shift in understanding of mindedness provides an initial account of a mind unlike any encountered in the modern world.

Karenleigh A. Overmann proposes that the key difference that sets human cognition apart from that of all other species is the ability to leverage material forms for cognitive purposes, like accumulating and distributing cognitive effort between individuals and generations. She illustrates this cognitive purpose with writing in Mesopotamia, viewing it as a system that self-organized as script and literacy after some 15 centuries of incremental change in behaviors, brains, and material form. This self-organization intensified technological features that became maximized for use and usability through sustained, collective use of the tool. Overmann then applies these insights to the Lower Paleolithic, suggesting that stone tools also self-organized under conditions of sustained, collective use, a process in which emergent features reflected aspects of tool-use by particular species for specific purposes. She further speculates how and why such uses of material culture might emerge and intensify through processes like familiarity, an aspect of habituation, and their long-term effects on hominid cognition.

In her contribution, **Anna Barona** examines social perspectives on the evolution of the hominid brain, focusing on the Social Brain Hypothesis, which postulates a relation between the size of primate brains and social groups. Barona notes that such perspectives tend to reduce material culture to a mere product of and proxy for evolutionary cognitive change. This reduction excludes the possibility that material forms have an active role in cognition and its evolutionary trajectory. She recommends adopting the 4E approach toward an archaeology of the mind, positioning material artifacts as constitutive components of the ancient mind. Using Lower Paleolithic stoneknapping as an example, she applies Gibson's concept of *affordance* as a relation between agentive capabilities and environmental properties, concluding that agency should be reframed as a phenomenon that emerges from situated action.

Hannah Mosley deploys Gibsonian affordances and Material Engagement Theory to examine the use of probes and hammers by Brazilian capuchin monkeys (*Sapajus libidnosus*). In a refreshing counterpoint to the standard ecological accounts of non-human primate tool use, Mosley describes how local social and environmental contexts transform object affordances. From this perspective, she is able to explain site differences in capuchin tool use that have eluded explanation from the standard framework. Her account of non-human primate tool use provides a sound basis from which archaeologists can begin to explore the nature of affordances and artifact variability in early hominin lithic technology (e.g., **Wynn's** use of coalescent affordances).

Christopher Baber and **Klint Janulis** use dynamic system theory and Gibsonian ecological psychology to investigate one of the purposeful behaviors performed by early hominins—the fracture of large mammal bones to access marrow. They frame purposeful behavior retrospectively as the end state of an actor-tool-environment system responding to achieve and maintain equilibrium. No prospective mental representation is required. In support of their stance, they provide preliminary results of an experimental investigation into the ergonomics and biomechanics of bone cracking for marrow. Their account of the dynamic system is able to explain differences in basic tool features and identify optimal tool form for this particular task. The emphasis on ergonomics and purposive behavior ties in nicely with **Wynn's** discussion of Oldowan core and flake technology, and **Gowlett's** discussion of handaxes.

Thomas Wynn applies 4E concepts to the stone tools of early hominins, focusing on how affordances of stones and tasks, and ergonomic factors in their manipulation, could have been in impetus for the emergence of technical meta-cognition. He applies Gibsonian ecological psychology to view affordances as visual and haptic/motor features of objects on the landscape that are perceptually detected and structured by an agent's biological capacities and capabilities. On this account, "tools" emerge internal representations but simply from using objects for specific purposes and recognizing properties that made them usable (similar to **Overmann's** account). Ergonomic features like heft, balance, and edge would have emerged through flake removal, core manipulation, and tool manipulation, ultimately providing the basis for constructing an ontological category of "tool" as a "cluster" of co-occurrent features (similar to **Gowlett's** account). Features that were not directly perceivable—"displaced," "remote," and "meta-" affordances—could then become exploitable through mechanisms like behavioral sustainment, habituation, reuse, and testing.

John Gowlett takes a more traditional stance in his discussion of the origin of aesthetic sense. He, too, focuses on the emergence of the handaxe 1.7 million years ago as an indicator of significant cognitive developments, including antecedents to modern aesthetic experience. Gowlett suggests that there is a deep structure governing the form of handaxes, much of it rooted in materiality and the ergonomics of tool manipulation (similar to **Wynn's** account). But he also points to the "added value" that is apparent on many handaxes and uses this as an avenue to discuss the roles of social context, "appropriateness," and levels of intentionality.

Rounding out the issue is the contribution of **Frederick L. Coolidge**, who tackles the knotty problem of the nature of neural contributions to 4E cognition. He focuses on the role of the cerebellum, a brain structure long associated with fine motor movement. Coolidge invokes the research of Masao Ito and Larry Vandervert, who have identified higher level cognitive functions based in the cerebellum that utilize its motoric organizational features to control other neural phenomena. Coolidge explores the implications of this model for understanding early stone tools and the evolution of creativity.

References

Arroyo, A., Hirata, S., Matsuzawa, T., & De La Torre, I. (2016). Nut cracking tools used by captive chimpanzees (*Pan troglodytes*) and their comparison with Early Stone Age percussive artefacts from Olduvai Gorge. *PLoS One*, *11*(11), e0166788. https://doi.org/10.1371/journal.pone.0166788

Boesch, C., & Boesch-Achermann, H. (2000). The chimpanzees of the Taï Forest: Behavioural ecology and evolution. Oxford University Press.

Botha, R. (2010). On the soundness of inferring modern language from symbolic behaviour. *Cambridge Archaeological Journal*, *20*(3), 345–356. https://doi.org/10.1017/S0959774310000454

Botha, R. (2016). *Language evolution: The Windows Approach*. Cambridge University Press.

Carvalho, S., Cunha, E., Sousa, C., & Matsuzawa, T. (2008). Chaînes opératoires and resource-exploitation strategies in chimpanzee (*Pan troglodytes*) nut cracking. *Journal of Human*

Evolution, *55*(1), 148–163. https://doi.org/10.1016/j.jhevol.2008.02.005

Davidson, I., & McGrew, W. C. (2005). Stone tools and the uniqueness of human culture. *Journal of the Royal Anthropological Institute of Great Britain and Ireland*, *11*(4), 793–817. https://doi.org/10.1111/j.1467-9655.2005.00262.x

Davidson, I., & Noble, W. (1993). Tools and language in human evolution. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognition in human evolution* (pp. 363–388). Cambridge University Press.

Dewey, J. (1938). *Experience and education*. Macmillan and Co.

Gallagher, S. (2017). *Enactivist interventions: Rethinking the mind*. Oxford University Press.

Gibson, J. J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 127–143). Lawrence Erlbaum Associates.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin.

Gibson, K. R., & Ingold, T. (Eds.). (1993). *Tools, language and cognition in human evolution*. Cambridge University Press.

Gowlett, J. A. J. (1979). Complexities of cultural evidence in the Lower and Middle Pleistocene. *Nature*, *278*(5699), 14–17. https://doi.org/10.1038/278014b0

Greeno, J. G. (1994). Gibson's affordances. *Psychological Review*, *101*(2), 336–342. https://doi.org/10.1037/0033-295X.101.2.336

Holloway, R. L. (1969). Culture: A human domain. *Current Anthropology*, *10*(4), 395–412. https://doi.org/10.1086/201036

Hovers, E. (2012). Invention, reinvention and innovation: the makings of Oldowan lithic technology. *Developments in Quaternary Science*, *16*, 51–68. https://doi.org/10.1016/B978-0-444-53821-5.00005-1

Hutchins, E. (1995). *Cognition in the wild*. MIT Press.

Hutchins, E. (2008). The role of cultural practices in the emergence of modern human intelligence. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *363*(1499), 2011–2019. https://doi.org/10.1098/rstb.2008.0003

Isaac, G. L. (1977). *Olorgesailie: Archaeological studies of a Middle Pleistocene lake basin in Kenya*. University of Chicago Press.

Isaac, G. L. (1984). The archaeology of human origins: Studies of the lower Pleistocene in East Africa 1971–1981. In F. Wendorf & A. Close (Eds.), *Advances in world archaeology* (pp. 1–87). Academic Press.

Leakey, L. S. B. (1931). *The Stone Age cultures of Kenya Colony*. Cambridge University Press.

Leakey, M. D. N. (1971). *Olduvai Gorge. Vol. 3, Excavations in Beds I and II, 1960–63*. Cambridge University Press.

Malafouris, L. (2013). *How things shape the mind: A theory of material engagement*. MIT Press.

Malafouris, L. (2016). On human becoming and incompleteness: A material engagement approach to the study of embodiment in evolution and culture. In G. Etzelmüller & C. Tewes (Eds.), *Embodiment in evolution and culture* (pp. 289–305). Mohr Siebeck.

Malafouris, L. (2017). Material engagement and the embodied mind. In T. Wynn & F. L. Coolidge (Eds.), *Cognitive models in Palaeolithic archaeology* (pp. 69–87). Oxford University Press.

Malafouris, L. (2019). Mind and material engagement. *Phenomenology and the Cognitive Sciences*, *18*, 1–17. https://doi.org/10.1007/s11097-018-9606-7

Matsuzawa, T. (1994). Field experiments on the use of stone tools by chimpanzees in the wild. In R. W. Wrangham, W. C. McGrew, F. B. M. De Waal, & P. G. Heltne (Eds.), *Chimpanzee cultures* (pp. 351–370). Harvard University Press.

Matsuzawa, T., Humle, T., & Sugiyama, Y. (Eds.). (2014). *The chimpanzees of Bossou and Nimba*. Springer Science & Business Media.

Menary, R. (2010). Introduction to the special issue on 4E cognition. *Phenomenology and the Cognitive Sciences*, *9*(4), 459–463. https://doi.org/10.1007/s11097-010-9187-6

Newen, A., De Bruin, L., & Gallagher, S. (Eds.). (2018). *The Oxford handbook of 4E cognition*. Oxford University Press.

Oakley, K. (1957). Tools makyth man. *Antiquity*, *31*(124), 199–209. https://doi.org/10.1017/S0003598X00028453

Osiurak, F., Lesourd, M., Navarro, J., & Reynaud, E. (2020). Technition: When tools come out of the closet. *Perspectives on Psychological Science*, 1–18. https://doi.org/10.1177/1745691620902145

Osiurak, F., & Reynaud, E. (2020). The elephant in the China shop: When technical reasoning meets cumulative technological culture. *Behavioral and Brain Sciences*, *43*, E183. https://doi.org/10.1017/S0140525X20000291

Parker, S. T., & Gibson, K. R. (1979). A developmental model for the evolution of language and intelligence in early hominids. *Behavioral and Brain Sciences*, *2*, 367–408. https://doi.org/10.1017/S0140525X0006307X

Roche, H., Blumenschine, R. J., & Shea, J. J. (2009). Origins and adaptations of early *Homo*: What archaeology tells us. In F. Grine, J. G. Fleagle, & R. E. Leakey (Eds.), *The first humans: Origin and early evolution of the genus* Homo (pp. 135–147). Springer.

Scarantino, A. (2003). Affordances explained. *Philosophy of Science*, *70*(5), 949–961. https://doi.org/10.1086/377380

Schick, K. D., & Toth, N. P. (2006). An overview of the Oldowan Industrial Complex: The sites and the nature of their evidence. In N. P. Toth & K. D. Schick (Eds.), *The Oldowan: Case studies into the earliest Stone Age* (pp. 3–42). Stone Age Institute Press.

Sept, J., & Pilbeam, D. R. (Eds.). (2011). *Casting the net wide: Papers in honor of Glynn Isaac and his approach to human origins research*. American School of Prehistoric Research.

Shea, J. J. (2011). *Homo sapiens* is as *Homo sapiens* was: Behavioral variability versus “behavioral modernity” in Paleolithic archaeology. *Current Anthropology*, *52*(1), 1–35. https://doi.org/10.1086/658067

Shea, J. J. (2013). Lithic Modes A-I: A new framework for describing global-scale variation in stone tool technology illustrated with evidence from the East Mediterranean Levant.

Journal of Archaeological Method & Theory, *20*(1), 151–186. https://doi.org/10.1007/s10816-012-9128-5

Shea, J. J. (2016). *Stone tools in human evolution: Behavioral differences among technological primates*. Cambridge University Press.

Shipton, C. (2019). Three stages in the evolution of human cognition: Normativity, recursion, and abstraction. In T. B. Henley, M. J. Rossano, & E. P. Kardas (Eds.), *Handbook of cognitive archaeology: Psychology in prehistory* (pp. 153–173). Routledge.

Shipton, C., & White, M. (2020). Handaxe types, colonization waves, and social norms in the British Acheulean. *Journal of Archaeological Science: Reports*, *31*, 102352. https://doi.org/10.1016/j.jasrep.2020.102352

Smith, O. F. (2007). Object artifacts, image artifacts and conceptual artifacts: Beyond the object into the event. *Artifact*, *1*, 4–6. https://doi.org/10.1080/17493460600610707

Tennie, C., Premo, L. S., Braun, D. R., & McPherron, S. P. (2017). Early stone tools and cultural transmission: Resetting the null hypothesis. *Current Anthropology*, *58*(5), 652–672. https://doi.org/10.1086/693846

Toth, N. P. (1985). The Oldowan reassessed: A close look at early stone artifacts. *Journal of Archaeological Science*, *12*(2), 101–120. https://doi.org/10.1016/0305-4403(85)90056-1

Wynn, T. (1979). The intelligence of later Acheulean hominids. *Man*, *14*, 371–391. https://www.jstor.org/stable/2801865

Wynn, T. (2009). Hafted spears and the archaeology of mind. *Proceedings of the National Academy of Sciences of the United States of America*, *106*(24), 9544–9545. https://doi.org/10.1073/pnas.0904369106

Wynn, T., Hernandez-Aguilar, R. A., Marchant, L. F., & McGrew, W. C. (2011). “An ape’s view of the Oldowan” revisited. *Evolutionary Anthropology: Issues, News, and Reviews*, *20*(5), 181–197. https://doi.org/10.1002/evan.20323

Wynn, T., & McGrew, W. C. (1989). An ape’s view of the Oldowan. *Man*, *24*(3), 383–398. https://www.jstor.org/stable/2802697