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Cognitive Fluidity and Acheulean Over-imitation

Matt J. Rossano

This paper analyses recently discussed evidence of over-imitation in Acheulean biface construction. First, it evaluates the argument for over-imitation using the available archaeological and cognitive science evidence. Next, it applies the four major theories of over-imitation, (1) Copy and Correct (C&C), (2) Automatic Causal Encoding (ACE), (3) social affiliation and (4) normative theory, as potential explanations for Acheulean over-imitation. ACE theory is the most likely explanation for early biface over-imitation (before 500,000 years BP*), with social affiliation becoming increasingly likely after that. Normative over-imitation probably did not occur until around 300,000 years* BP*, when both the necessary hominin cognitive capacities and social conditions were present. An important conclusion emerging from this analysis is that over-imitation requires an integration of social and technical intelligence. Thus, the origins of cognitive fluidity may date back to as early as a million years ago, well before material evidence of fluidity is present.*

Using psychological theories and constructs to interpret archaeological remains has become common practice in cognitive archaeology. For example, Wynn (1985) analysed the cognitive competencies required in Oldowan *versus* (later) Acheulean tool manufacture using Piagetian stages of cognitive development. Similarly, Coolidge and Wynn (2010) employed Baddeley's model of working memory as a framework for assessing the emergence of modern cognition. Finally, Henshilwood and Dubreuil (2011) and Twomey (2013) assessed Late Stone Age tool industries (Howiesons Poort and Still Bay) and fire use (respectively) using the theoretical notions of theory of mind, perspective-taking, collective intentionality and decoupled representations. In all these cases, the goal was to gain insight into the cognitive capacities of our ancestors by using modern psychology as a guide to understanding their remains.

This paper sets out to achieve the same end by analysing recently discussed evidence of over-imitation in Acheulean biface construction using the four major theories of over-imitation:

1. Copy and Correct (C&C)
2. Automatic Causal Encoding (ACE);
3. social affiliation
4. normative theory

Additionally, the possibility that an ancestral primate learning strategy (APLS) could account for Acheulean over-imitation is also considered (and rejected). An important conclusion emerging from this analysis is that over-imitation requires an integration of social and technical intelligence. This indicates that the origins of cognitive fluidity may date back to as early as a million years ago, well before material evidence of fluidity is present.

In an influential book and subsequent publications, Steven Mithen (1996; 2007) argued that cognitive fluidity was critical to the emergence of modern human cognition and behaviour. Fluidity refers to the ability to integrate different, often isolated, forms of intelligence, thereby constructing novel, innovative concepts and artefacts. For example, chimpanzees can make simple tools (technical intelligence) and form social alliances (social intelligence), but show little evidence of combining the two (making a tool as a gift for establishing a social alliance).[1] Modern human cognition emerged when our ancestors started breaching the barriers separating these different forms of intelligence.

Though generally well received, Mithen's model has not been without criticism. Langbroek (2012), for example, argues that it takes a far too linear

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view of hominin cognitive evolution, thus leading to over-simplifications of the archaeological evidence and under-estimations of the intelligence of extinct hominins, especially Neanderthals. Mithen's dependency on 'content-rich, intuitive mental modules' as the basic architecture of the mind has also been criticized (e.g. Mitchell 1997). While these criticisms are not trivial, they do not fundamentally threaten a core facet of the theory, the idea that the modern human mind is unique in its ability to integrate widely disparate forms of knowledge. This has been independently voiced by other scientists using terms such as 'representational re-description' (Karmiloff-Smith 1992), 'mapping across domains' (Carey & Spelke 1994), or 'non-encapsulation' (Fodor 1983).

For most archaeologists (including Mithen), evidence of modern cognition does not appear until quite late in hominin evolution, either around 100,000–70,000 years BP with the emergence of beads and symbolic engravings on ochre plagues (Henshilwood *et al.* 2009; Vanhaeren *et al.* 2006), or around 30,000 with evidence of expanded working memory capacity (Coolidge & Wynn 2010). However, the recent evidence for over-imitation in Acheulean biface construction (Nielsen 2012; Shipton & Nielsen 2015) suggests that the mental foundation for cognitive fluidity may have been in place well before material evidence of full-blown modern cognition emerged.

Theories of over-imitation

Reproducing causally irrelevant actions, called over-imitation, appears to be a uniquely human and particularly effective technical and cultural learning strategy (Horner & Whiten 2005; Nagell *et al.* 1993). There are four theories of over-imitation, two emphasizing causal reasoning and two emphasizing social reasoning (Lyons *et al.* 2011; Marsh *et al.* 2014). The two causal reasoning theories are the 'Copy and Correct' (C&C) model of Whiten and colleagues (Whiten *et al.* 2009) and Lyons and colleagues' Automatic Causal Encoding (ACE) theory (Lyons *et al.* 2011). The theories are similar, focusing on the learning challenge children confront in a world populated by complex, causally opaque tools and devices (e.g. computers, cell phones, dishwashers etc.). An effective strategy, they contend, would be simply imitating all adult actions directed at those artefacts in order to acquire operational skill. Occasionally, this will produce errors of imitating causally irrelevant actions (over-imitation), but these can be 'weeded out' with experience.

ACE theory stakes out unique ground by arguing that only a very specific class of behaviours will be faithfully imitated—intentional actions on novel artefacts. Furthermore, this imitation will be automatic, driven by the assumption that intentional acts are causal. ACE theory has received important empirical support from studies showing that only intentional irrelevant behaviours are copied and this copying is unavoidable (thus confirming its automaticity). Even when motivated not to do so, such as when racing a competitor to gain access to a reward or when specifically instructed not to imitate unnecessary actions, children's over-imitation persists (Lyons *et al.* 2007; 2011).

The theories emphasizing social reasoning are the normative and social affiliation theories. Normative theory argues that children interpret causally irrelevant actions as indicators of culturally appropriate ways of completing certain tasks or achieving certain goals, such as 'this is how our group makes tools or cooks food' (Keupp *et al.* 2015; Kenward 2012; Kenward *et al.* 2011; Nielsen *et al.* 2015). This theory has received important empirical support from results showing that over-imitation is contextually contingent: that is, children over-imitate more when they engage in conventional rather than purely instrumental tasks (Keupp *et al.* 2015). Furthermore, children not only over-imitate, but also demonstrate normative enforcement by spontaneously protesting third-party failures of over-imitation (Kenward 2012; Keupp *et al.* 2015). Finally, the fact that children's imitation grows ever more faithful when they are primed by social exclusion also fits with the normative view (Watson-Jones *et al.* 2014).

Social affiliation theory argues that children over-imitate in order to identify with or share experience with the model (Nielsen 2006; Over & Carpenter 2009). In support of this theory are results showing that children's over-imitation is sensitive to the presence or absence of the appropriate model (Nielsen & Blank 2011). If the model who engaged in causally irrelevant behaviours is present, children over-imitate. However, if the model is absent, children do not.

These theories are not mutually exclusive. In a recent review, Over and Carpenter (2012) showed that children's imitation (including over-imitation) varies depending on goals and context. *What* children imitate and *why* they imitate depends on whether they are more focused on skill learning or social identification. When skill learning is paramount, such as when younger inexperienced children are confronted by novel artefacts, causal learning theories (C&C and ACE) are more applicable. In situations where more experienced children are dealing with familiar objects, social factors become more salient. Indeed, Marsh *et al.* (2014, 8) observed that studies supporting the ACE theory have used younger children (3–5 years old), while their own results found that older children were more sensitive to the social cues relevant to social theories. The two social theories (social affiliation and normative) may also be complementary (Keupp *et al*. 2015, 174). A desire to affiliate inter-personally can facilitate acceptance of collective social norms, especially when the child sees the adult model as representative of the larger culture (Over & Carpenter 2012, 186).

It does not seem unreasonable to suppose that over-imitation can be driven by different mechanisms which vary in relevance depending on circumstances. When young children learn about novel tool use, they may fully (and automatically) conflate intentional with causal. As children mature and gain greater experience with tools, their ability to distinguish intentional-causal actions from intentional-non-causal ones grows; but for social reasons they may still be inclined to imitate the latter.

It is not obvious which of these theories is most likely to explain Acheulean over-imitation. However, this analysis is guided by the assumption that in learning to make Acheulean tools, skill transmission was a higher priority than social identification. Thus, the causal reasoning theories (ACE and C&C) take priority over the social theories. Furthermore, of these theories, ACE places greater emphasis on automatic processing and is thus more likely to be grounded in simpler cognitive mechanisms. This leads to the working hypothesis that Acheulean over-imitation should be driven by ACE.

Acheulean over-imitation

The fact that humans, but not other primates, engage in over-imitation indicates that it arose sometime after the hominin evolutionary branch diverged from that of chimpanzees and bonobos. However, exactly when and why over-imitation emerged is unclear. Recently, Nielsen and Shipton (Nielsen 2012; Shipton & Nielsen 2015) have argued for the presence of over-imitation in Acheulean biface (hand axe and cleaver) construction beginning about one million years ago. This evidence includes the following:

1. The homogeneity of Acheulean biface form over time indicates faithful copying of the specifics of construction. For example, the size and symmetry of hand axes are more uniform than expected by chance (Kempe *et al.* 2012; Lycett 2008). This suggests that specific techniques of hand-axe construction were being faithfully reproduced from generation to generation (as would be expected if novices were imitating the motor routines of their teachers). Confirmation of this is present at the Gesher Benot Ya'aqov site in the Levant (750,000 years BP), where consistent strategies for flake blank production, retouching and final biface form existed for roughly 50,000 years (Shipton & Nielsen 2015, 335).
2. While intra-site uniformity in final biface form is present, reduction sequences (i.e. strategies for creating form) show inter-site variability. For example, while the Kombewa method of reduction was used at African Rift Valley sites such as Middle Awash in Ethiopia, further south in Kalambo Falls a discoid method was used. By contrast, there is no evidence of stylistic differences in Oldowan flaking as might be expected if modest inter-site variations in flaking procedures were faithfully copied and inter-generationally transmitted (Stout *et al.* 2010).
3. The reduction sequences used to create Acheulean bifaces involve causally opaque or ambiguous gestures. Thus, the faithful replication of these gestures constitutes over-imitation. For example, a recent analysis of hand-axe construction at Boxgrove, England (Stout *et al.* 2014), concluded that the platform preparation techniques used by the Boxgrove hominins added considerable non-intuitive complexity to the overall tool-making process. Thus, a novice watching an expert making a hand axe would very likely not understand the causal relevance of many of the observed actions, especially those occurring early in the construction process. Yet, despite their causal opaqueness, these actions would be faithfully reproduced. Indeed, detailed analyses from two sites in India, Isampur Quarry (1.2 million years BP) and Chirki-on-Pravara (780,000 years BP), indicate that this is precisely what took place. At these sites, the entire reduction sequence for biface manufacture has been documented. In both cases, biface production involved extended sequences of hierarchically organized motor routines where the early elements of the sequence are not clearly or obviously connected to the final product. Despite their causal ambiguity, these early procedures were faithfully imitated (hence, over-imitated. Note: it is significant that technically these gestures are ambiguous or opaque and not actually irrelevant, a point to be discussed later).

Putting these factors together, the argument for over-imitation in biface construction can be stated succinctly: The unlikely homogeneity in final biface form combined with inter-site variability in production procedures indicate faithful imitation of specific strategies of biface production. Some of the gestures of these copied strategies were causally opaque. Thus, causally opaque gestures were being faithfully replicated (over-imitated) in biface production. Three important claims are made in this argument:

1. that bifaces possess an unlikely homogeneity of form
2. that there is faithfully replicated inter-site variability in biface construction
3. that biface production is sufficiently complex that some of the imitated actions were causally opaque to the imitator

The next sections deal with each of these claims and the archaeological and cognitive science evidence relevant to them.

Controversy over biface form

Claim one, the presence of an unlikely homogeneity of biface form, is controversial, especially regarding hand axes. It has been generally accepted that hand-axe construction became increasingly refined over time (Hodgson 2015; Wynn 2002). Early hand axes, emerging around 1.7-1.4 million years BP, were crudely constructed and only rarely showed evidence of a concern for symmetrical shape. Later hand axes, emerging around 500,000 years BP, were more finely crafted and symmetrical, sometimes well beyond what might be necessary for any utilitarian purpose. However, recent quantitative assessments of hand-axe shape have called this into question.

For example, Cole (2015) found no evidence of increased symmetry or standardized form over time among a broad set of Acheulean hand axes from mostly British Isles sites dating from about 500,000–60,000 years BP. Furthermore, those hand axes assessed as 'symmetrical' comprised only a small, though consistent, percentage (about 8 per cent) over time. Similar results were found among hand axes from the Danjiangkou Reservoir Region of central China spanning a comparable time frame (Li *et al.* 2016). Finally, McNabb, Binyon and Hazelwood (2004) found little evidence of any culturally imposed standard form or concern for symmetry (although a few symmetrical examples were observed) in an assemblage from the Cave of Hearths, South Africa, dated to between 600,000–300,000 years BP. This result was similar to that found for six other mostly Middle Pleistocene South African sites.

While these studies did not support the idea of a culturally imposed final hand-axe form, they did find evidence of 'conceptual standardization' (McNabb *et al.* 2004). Conceptual standardization refers to a general, abstract idea of what constituted a hand axe and the procedures by which to create it. In the words of McNabb *et al.* (2004, 667), '[t]he idea of a large cutting tool and how to go about realizing it was held in the memory; the specificity of the end product was not'. Both Cole (2015) and Li *et al.* (2016) argued that their findings confirmed this notion. Thus, hominins understood what a hand axe was, what distinguished it from other tool types (flakes, cleavers, etc.) and that there was a particular sequence of motor actions necessary for creating that tool type. Furthermore, this sequence could be rather complicated, demanding skill, and had to be learned from a master (Hiscock 2014; Shipton *et al.* 2013).

Other studies, however, suggest that it may be too soon to dismiss entirely the idea of imposed form and increased temporal refinement in hand-axe construction. In two separate studies using different quantitative measures of symmetry, Saragusti and colleagues (Saragusti *et al.* 1998; 2005) found evidence for increasing symmetry in hand-axe assemblages from Levantine sites. Interestingly, the trend was found for sites dating from 1.4 million years BP to (roughly) 500,000 years BP, but not for more recent ones. Grosman, Goldsmith and Smilanski (2011) reported similar findings for a separate Levantine site comparing two different hand-axe samples dated 1.4 million years BP and (roughly) 350,000 years BP. Shipton, Petraglia and Paddayya (2009) also found evidence for increasing refinement (thinner, wider, and smaller in size/shape) in hand-axe production over time for sites in the Hunsgi-Baichbal basin in India dated from 1.2 million years BP to 280,000 years BP.

A rough trend is discernible in the studies cited above (a trend originally described in Saragusti *et al.* 2005): that is, when comparisons are made in the time frame running roughly from 1.4 million years BP to 400,000 years BP, evidence of increasing symmetry and refinement is often found (true for Beyene *et al.* 2013; Grosman *et al.* 2011; Saragusti *et al.* 1998; 2005; Shipton *et al.* 2009). When the time frame involved is from roughly 500,000 years BP to the end of the Middle Palaeolithic, then null results are often found (true for Cole 2015 and Lin *et al.* 2016). McNabb *et al.* (2004) may also conform to this pattern as most of the sites in that study were Middle Pleistocene (roughly 700,000–300,000 years BP) and the two sites considered Early Pleistocene (Doornlaagte and Pneil 6) were not precisely dated. The findings from Konso, Ethiopia (as reported in McNabb & Cole 2015), appear to be the only clear exception to this pattern.

Even if this pattern is real, one must bear in mind that the construction and use of large cutting tools was long in duration (over a million years) and geographically widespread. Thus, any generalized patterns are likely to be fraught with considerable temporal and regional variability. The controversy over final biface form leads to the following conclusion: if Acheulean over-imitation critically depends on a standardized form in the finished product, then over-imitation may only be occurring in certain contexts where evidence of a standardized form is strong. However, a final standardized form may not be integral to Acheulean over-imitation if what is being imitated is a process leading to a categorical tool type rather than a specific form (conceptual standardization). Even where evidence of a standardized form is weak, conceptual standardization is typically present.

Inter-site variability in biface production

Claim two, the presence of inter-site variability in biface production, is generally well accepted. Prior to 1 million years BP, numerous varied strategies for flake blank production arose in geographically distinct regions. For example, a 'rhomboidal' strategy involving unifacial removals from opposite sides of the core was done at the Olduvai site of TK (dated to 1.3 million years BP), while at sites at Gona in Ethiopia (dated to 1.6 million years BP) variable combinations of unifacial and bifacial removals from different surfaces of the core were used (de la Torre & Mora 2005; Semaw *et al.* 2009). Additionally, as mentioned earlier, at Middle Awash in Ethiopia a Kombewa method of blank production was used, while at Kalambo Falls a discoid method was used (Shipton 2010). The important point here is that producing the blank from which a biface would be fashioned could be done in various ways and different strategies were employed in different regions. Furthermore, this was only one step in a complex, often non-intuitive, motor sequence necessary for completion of the final product (Stout 2011; Stout *et al*. 2014).

The causal complexity of biface construction

Claim three, that biface construction is inherently complex and includes causally opaque actions, has been supported in numerous ways. However, it must be acknowledged that much (not all) of this evidence uses modern minds as models for the functioning of ancient ones. Though often unavoidable, this is an arguable assumption.

First (as mentioned earlier), Stout *et al.* (2014) found that complex, non-intuitive platform preparation procedures were employed by Boxgrove hand-axe makers. Second, Stout's (2011, 1053–4) analysis of Oldowan flaking *versus* Acheulean tool making found a qualitative distinction between the two processes, with the latter requiring up to three additional levels of nested hierarchical procedures. Third, studies using a variety of strategies to teach Oldowan flaking and Acheulean biface construction have shown that active teaching is necessary for the latter, but not the former (Morgan *et al.* 2015, 6034; Putt *et al.* 2014; Shelby Putt, pers. comm. 2015). Fourth, while our primate cousins have been taught to create Oldowan-like flakes (Davidson & McGrew 2005), biface construction appears to be beyond their capabilities. To some degree, this could be because of limitations in the non-human primate motor system. But studies of ape tool use in the wild suggest that cognitive factors are involved as well, in the form of memory limits on the number of motor actions that can be linked together in a causal chain.

Matsuzawa's (2001) analysis of natural chimpanzee tool use found that (by far) the most common motor routine was a simple pair-wise action involving the tool and the object upon which it was being directed, such as a tree branch being inserted into a termite mound (called 'level 1'). Occasionally, a more complicated form of tool use was observed where a second-level motor action was included, as in the chimpanzee first placing a nut upon a rock (called the anvil) and then using another rock to pound it open. Even rarer was a three-level action where a third rock (a wedge) might be employed to straighten the anvil if it was slanted. Even the (quite rare) three-level action sequence is far simpler than the up to nine levels that can be involved in hand-axe construction (Stout 2011).

Finally, additional complexity is added to the biface-making process because it involves using tools (different types of hammer-stones used variously at different stages of construction) to create a tool (the biface). Seed, Call, Emery and Clayton (2009) have shown that employing a tool in a motor routine can obscure the causal links in that routine. Thus, the varied, complex and cognitively demanding nature of biface production increases the likelihood that specific behavioural procedures would be causally ambiguous in the eyes of an observing novice, thus leading the novice to (over-) imitate non-causal gestures.

It is also noteworthy that, beginning around 800,000 years BP, biface production was only one of a number of complex, (presumably) actively taught culturally transmitted skills employed by hominins (Alperson-Afil 2008; Alperson-Afil *et al.* 2009). Evidence from the Gesher Benot Ya'aqov site in Israel shows that the hominins there were creating and controlling fire, processing and cooking food, hunting a diverse array of prey including fish, rodents, deer and elephants, and manufacturing a variety of tools. The skills necessary for these activities had to be acquired during one's formative years and passed along from generation to generation. This evidence indicates that hominins were *cultural* (meaning that important survival skills had to be actively taught and deliberately practised) in a fashion quite distinct from our primate cousins. It does not, however, show them to be *tribal* (meaning being ethnically marked by tool styles or distinct behavioural practices). This distinction is relevant for determining if over-imitation is normatively driven or not.

The argument for Acheulean over-imitation: summary

Three conclusions can be gleaned from this analysis of the claims present in Shipton and Neilson's argument for Acheulean over-imitation:

1. novice biface makers were probably imitating a process leading to a general tool type more often than one leading to a specific form, although form standardization probably occurred in certain contexts (i.e. conceptual standardization was more common than form standardization);
2. the biface construction process being imitated varied from place to place, was substantially more complex and cognitively demanding than Oldowan tool making and involved causally opaque gestures;
3. by about 800,000 years BP, among some hominins, biface construction was only one aspect of a suite of complex, culturally transmitted survival skills, others of which probably also entailed imitation and possibly over-imitation.

The next sections address the issue of what drove over-imitation. Before evaluating the four theories of over-imitation discussed earlier, the possibility that it could be the result of an APLS should be considered. As pointed out by Whiten and colleagues (2009), chimpanzees possess their own 'portfolio' of social learning strategies which likely would have been available to early hominins as well. Could this account for Acheulean over-imitation?

The ancestral primate learning strategy (APLS)

As part of their social learning 'portfolio', chimpanzees can both imitate and emulate. Chimpanzee imitation can produce something similar to over-imitation. Horner and Whiten (2005) presented chimpanzees and three- and four-year-old children with a task where a tool was used to remove a reward from a box. Chimpanzees and children observed as a demonstrator employed both causally relevant and irrelevant actions on boxes that were either transparent or opaque. In the opaque box condition, once the tool entered the box it could not be seen; thus observers were unaware of the effectiveness or ineffectiveness of any actions. In the transparent box condition, observers could clearly distinguish relevant from irrelevant actions. When actions were demonstrated using the opaque box, chimpanzees and children imitated both causally relevant and irrelevant actions. However, when actions were demonstrated using the transparent box, only children persisted in reproducing causally irrelevant actions.

The authors concluded that chimpanzees will faithfully imitate gestures, both causally relevant and irrelevant, when the causal status of those gestures is unclear. However, when task-relevant causal information is available, they will switch from imitation to emulation in order to achieve the most efficient solution. By contrast, children are less concerned with problem-solving efficiency and more concerned with intentionality—that is, faithfully reproducing what appear to be a model's purposeful behaviours (be they causally relevant or irrelevant).

What this study shows is that chimpanzees approach motor learning tasks with a strategy that can be described as 'imitate when uncertain about the causal status of the observed behaviours'. In all likelihood, this would have been true of our hominin ancestors as well. Thus, if novice hand-axe makers were unsure about the causal relevance of some of the gestures being modelled, their natural bias would have been faithfully to imitate those gestures—not because they believed those gestures to be normative or to identify socially with the teacher, but simply because imitation in the face of uncertainty was an ancestrally inherited strategy for successful problem solving. It is important to note the APLS entails causal analysis of the observed procedure. This distinguishes it from both C&C and ACE. In C&C, all gestures are copied, regardless of their causal status; while in ACE, intentional gestures are copied and simply assumed to be causal.

The primate mind and the Acheulean challenge

Confronted with the complexity of Acheulean biface making, hominins had three options:

1. the APLS: copy what is causally relevant and uncertain
2. C&C: copy everything, drop irrelevancies later
3. ACE: copy the intentional assuming it to be causal.

The fact that chimpanzees have never created anything remotely resembling an Acheulean biface (while they have been taught to create Oldowan-like flakes) strongly suggests that the APLS is inadequate for learning biface construction. This may be because chimpanzee working memory capacity is not capable of handling the sheer quantity of gestures that must be imitated in the biface sequence (Carruthers 2013; Read 2008), and/or their causal reasoning abilities may not be able to categorize gestures adequately as 'causal', 'non-causal' or 'uncertain' in order to emulate the biface procedure effectively (Martin-Ordas & Call 2009; Penn & Povinelli 2007; Vaesen 2012).

If hominins could not use their APLS for solving the biface dilemma, did they use C&C or ACE? The critical difference between the two is that C&C requires imitation of all gestures, while ACE requires imitation of just intentional gestures. Significantly, neither requires causal analysis of the task. Identifying which gestures are causally relevant, irrelevant, or uncertain is set aside for either blanket copying of everything (C&C) or intention reading (ACE). In this way, both C&C and ACE may reduce the working memory requirements of the task. The advantage of one over the other would appear to be in terms of cost/benefits. If the cost of intention reading is offset by the reduction in the quantity of imitated gestures, then ACE wins. If not, C&C wins.

There are good reasons to believe that ACE has the advantage. First, C&C entails the elimination of causally irrelevant gestures over time. Acheulean biface construction, however, involves causally *opaque*, not causally *irrelevant* gestures. Therefore, there is nothing to correct! The only gestures that might be 'corrected' (meaning eliminated from the construction procedure) over time would be incidental, non-intentional ones, such as the tool-maker randomly tapping on the core stone, or rolling the hammer stone around in his palm as he contemplates his next move. Given that ACE would eliminate these from the start (because of their non-intentional nature), ACE accomplishes initially what C&C would take numerous trials to achieve.

Second, ACE is further advantaged by the fact that its cognitive 'cost' of implementation would seem to be quite low. First, it is an automatic process, and automatic processes are known to require far fewer cognitive resources than consciously controlled ones (Shiffrin & Schneider 1977). Second, it is based on intention reading, which is a pre-existing part of the primate 'portfolio' of social intelligence. Chimpanzees can read intentions and use them to regulate their social behaviour. For example, they adjust their begging dependent upon whether a human handler is unable or unwilling to provide a food reward, and they are more likely to retaliate against a chimp who steals food directly from them compared to one who receives food from a human handler—the handler being responsible for the stealing (see review in Call & Tomasello 2008; Jensen *et al.* 2007).

Finally, there is evidence that apes can use intention reading to guide non-social goal-directed motor procedures. Buttelmann and colleagues (2007) found that human-raised chimpanzees would imitate an odd utilitarian behaviour (turning on a light with one's foot rather than hand) if it appeared to be intentional (the model's hands were free) rather than forced by circumstances (the model was carrying a large object). This shows that chimpanzees raised under unusual social conditions can swap the problem-solving efficiency of emulation for imitation of an intentional but causally inefficient behaviour. It could also be argued that a primordial form of cognitive fluidity appears to be present here: intention reading (social intelligence) is used to guide a simple technical act (turning on a light). Thus, the implementation of ACE had minimal demands: take an already existing social skill (intention reading) and strengthen its connection to non-social goal-directed motor routines such that it can automatically guide the execution of those routines. All this indicates that ACE is the better explanation for Acheulean over-imitation.

If ACE is indeed cognitively 'cheap', then it can explain a potential dilemma raised by the emergence of the Acheulean. There is little question that biface construction is more complicated than Oldowan flaking. While there is evidence of a brain size increase prior to the Acheulean (Shultz *et al.* 2012), the archaeological record shows little evidence of an increase in working memory capacity in early Acheulean tool makers (apart from biface construction itself). Strong evidence of increased working memory capacity does not emerge until very late in the Acheulean (to be discussed later). This creates a potential dilemma. How did hominins master this more complicated skill in the absence of a substantial increase in memory capacity? ACE offers a solution. By trading causal analysis of the biface construction process for intention reading, the novice can use a less memory-intensive learning strategy. Rather than consciously determining what is to be imitated by assessing causality, actions are automatically imitated based on already existing primate skill—intention reading.

The ACE solution represents a significant change. Social information (intentionality) is used as an index of causality in a technical procedure (tool construction). By forgoing any causal analysis of the tool-making process, ACE saves working memory capacity relative to the APLS. By imitating only intentional acts, it reduces the quantity of imitated gestures relative to both C&C and the APLS. The ACE solution entails an integration of social and technical intelligence where a social cue is used to guide a technical procedure automatically—an early form of cognitive fluidity.

ACE or social affiliation?

Acheulean bifaces were around for over a million years. That social factors might, at some point, play an important role in the transmission of tool-making skill seems quite likely. Shipton and Nielsen (2015, 338–40) discuss possible evidence supporting this notion by noting that the region of the hominin brain containing the *pars opercularis* expanded at around 1.8 million years BP—just prior to the emergence of the Acheulean. The *pars opercularis* is part of the mirror neuron system used in learning novel motor actions. Mirror neurons are active both when a behaviour is executed and when it is observed. An enhancement in mirror-neuron function amongst Acheulean hominins likely gave them greater empathetic capacity in social learning situations, such as during the transmission of tool-making skills from expert to novice. If the earliest Acheulean tool makers possessed enhanced social intelligence, then might it be the case that their acquisition of tool-making skill involved over-imitation based on social affiliation rather than ACE? While possible, two lines of evidence suggest that over-imitation based on social affiliation arose after ACE: (1) social affiliation is cognitively more demanding than ACE, and (2) archaeological evidence of shared intentionality does not become widespread until late in the Acheulean, around 500,000 years BP.

The greater cognitive demands of social affiliation

Deciding between ACE and social affiliation would appear to turn on a single pivotal question: were novices aware of the causal irrelevancy of the behaviours they were imitating? ACE theory says 'no'—they imitated the behaviours because they were intentional and therefore assumed them to be causal as well. Social affiliation theory says 'yes'—but they were imitated anyway in order to identify socially with the master. Indeed, studies show that children sometimes over-imitate despite being aware of the causal irrelevancy of the behaviour (Kenward *et al.* 2011; Nielsen & Tomaselli 2010). Thus, just as ACE was less cognitively demanding than the APLS, it also appears to be less cognitively demanding than social affiliation. While ACE reduces the cognitive demands of biface construction, social affiliation compounds them. This is because (in contrast to ACE) social affiliation requires the learner to distinguish intentional-causal behaviours from intentional-non-causal behaviours (or, in the case of biface construction, intentional-but-not-directly-causal), and consciously imitate the latter for social reasons (to identify or share experience with the expert).

It might be possible, however, that experience could reduce social affiliation's increased cognitive load. ACE specifically applies to learning about novel objects. Over time, biface construction and the objects it entailed would have become quite familiar, allowing for easier recognition of intentional-causal *versus* intentional-non-causal actions. Inexperienced novices may have imitated based on ACE, while more experienced novices may have imitated based on social affiliation. Recent brain-imaging research may offer support for this. Stout and colleagues (2011) found that when novices viewed hand-axe construction, areas of the brain associated with motor resonance (premotor, left posterior inferior frontal) were active, whereas for experts the areas activated were associated with intention reading (medial frontal, anterior intraparietal sulcus). The authors argued that this implies a strategy switch from learning by simulating observed motor actions (for novices) to learning by reading goals and intentions (for experts).

There are two challenges, however, to this reasoning. First, it assumes that the brains and cognitive powers of Acheulean tool makers are comparable to modern hand-axe makers. This may not be true, especially for early Acheulean tool makers. Second, (as discussed in the next section) archaeological support for social affiliation does not emerge until late in the Acheulean, suggesting that early Acheulean tool makers were not imitating based on social affiliation regardless of their tool-making experience.

Archaeological evidence of shared intentionality

The social affiliation model of over-imitation claims that novices imitate in order to identify with or share experience with the model. This assumes some capacity for shared intentionality, where two individuals have common goals, mental states and intentions (Tomasello *et al.* 2005). A way of testing for this (as pointed out by Shipton & Nielsen 2015) would be to look for other archaeological indicators of shared intentionality, such as cooperative hunting.

Evidence that hominins were gaining first access to the choicest parts of prey dates back to 1.5 million years BP (Pobiner *et al.* 2008). Exactly how hominins were procuring prey at this time is unclear. Cooperative hunting is possible, but since evidence of hunting technology does not emerge until about one million years later (Wilkins *et al.* 2012), some scepticism is warranted. More convincing evidence of cooperative hunting begins to emerge around 800,000 years BP and becomes increasingly frequent from 500,000 years BP onwards.

For example, at Gesher Benot Ya'aqov (Israel), researchers found evidence of systematic butchery of deer (Rabinovich *et al.* 2008). The skill and efficiency with which these hominins acquired and exploited this resource led the authors to conclude that they regularly hunted deer, possessed sophisticated knowledge of deer anatomy and used impressive communication skills and foresight in both acquisition and processing of their prey.

Somewhat later, an even larger but potentially more dangerous prey, elephant, was being exploited at such sites as Notarchirico in Italy (dated to around 640,000 years BP: Piperno & Tagliacozzo 2001), Gesher Benot Ya'aqov (500,000 years BP: Goren-Inbar *et al.* 1994), Holon (500,000 years BP, but see Porat 2007 for a different dating: Ben-Dor *et al.* 2011) and Aridos in Spain (around 400,000 years BP: Villa 1990). So common was the occurrence of elephant remains at Levantine sites prior to 400,000 years BP that Ben-Dor *et al.* (2011) argued that the fat content derived from elephant had become an essential part of the *Homo erectus* diet. Of these sites bearing elephant remains, the case for hunting seems strongest at Gesher Benot Ya'aqov, although at Aridos the author claims that the organized exploitation of elephant goes beyond 'marginal scavenging' (Villa 1990, 299). Though hunting elephant need not involve hafted projectiles, it can still be quite challenging. Strategies include sneaking up behind an elephant and slicing its tendons, trapping them in pits covered in branches, and dropping heavy objects on them from above (while perched in a tree) and then spearing them (Ben-Dor *et al.* 2011). The advantage or necessity of cooperative action in these endeavours is fairly obvious.

Probably the clearest evidence of cooperative hunting is from Qesem Cave in Israel, where deer and other large game were regularly exploited beginning around 400,000 years ago (Stiner *et al.* 2009). From this date on, evidence of cooperative hunting accumulates at various sites (Gaudzinski 1995; Stiner 2005; Yeshurun *et al.* 2007). If shared intentionality as indexed by cooperative hunting becomes widespread sometime between 800-400,000 years BP, then this makes it increasingly likely that during this period of time over-imitation based on social affiliation emerged as well.

Note that, as with ACE, social affiliation entails a commingling of social and technical intelligence. In this instance, however, it is a social goal (sharing experience or social identification) that is guiding the execution of the technical procedure used to create the tool (e.g. 'I make the tool the way you make the tool in order to be like you or to connect with you socially/emotionally').

Expanded working memory and over-imitation

An emergent theme in this review is the undemanding cognitive nature of ACE relative to other strategies such as C&C, social affiliation, or the APLS. ACE would also be less demanding than the normative strategy, given that the normative strategy requires parsing intentional-causal gestures from intentional-non-causal ones and imitating the latter for normative reasons (rather than personal ones, as in social affiliation). Thus, another approach in determining when socially based over-imitation (social affiliation or normative) emerged would be to look for evidence of expanded attentional and working memory capacity. Interestingly, the earliest evidence of this roughly coincides with that of cooperative hunting, further strengthening the case for the emergence of over-imitation based on social affiliation at around 500,000 years BP.

The earliest evidence taken to be indicative of a significant increase in working memory capacity is the emergence of composite tool construction beginning about 500,000 years BP (Ambrose 2001; McBrearty & Tryon 2006; Wilkins *et al.* 2012). Composite tools are ones composed of distinct, separately created elements, such as a hafted spear made of a shaft (one), a sharpened point (two) and an adhesive or binding material (three) used to affix the point to the shaft. The individual construction of separate elements that must ultimately be joined together to create the tool imposes unique demands on the hominin cognitive system. As Ambrose explains:

> The acquisition and modification of each component of a composite tool involve planned sequences of actions that can be performed at different times and places, such as flaking a stone point, cutting and shaping a wooden shaft, and collecting and processing binding materials. The complex problem solving and planning demanded by composite tool manufacture may have influenced the evolution of the frontal lobe. (Ambrose 2001, 1752)

Residing, of course, in the frontal lobe are the attentional and working memory functions that allow for the planning, sequencing and executing of goal-directed actions (including the inhibition of irrelevant signals and actions). As has been shown by Wadley *et al.* (2009), the preparation of adhesives alone can be a highly demanding process extending over hours or even days, requiring extensive knowledge of natural materials and their reaction when combined and heated.

The oldest stone points thought to have been used to tip hunting spears are from the Kathu Pan 1 site in South Africa, dated to around a half-million years ago (Wilkins *et al.* 2012). Hafting becomes increasingly common beginning about 300,000 years ago and was practised extensively by both *H. sapiens* and Neanderthals (McBrearty & Tryon 2006). Around this same time, other indicators of expanded working memory and attentional capacities are present in the archaeological record as well.

For example, about 400,000 years ago at the Boxgrove site in England, a hominin left a pile of knapped flakes when he or she apparently stopped to complete work on a hand axe (Roberts & Parfitt 1999). The abandoned flakes provide the first evidence of multitasking in the hominin archeological record. The tool maker not only finished the hand axe (task one), but simultaneously monitored the removed flakes for larger, well-shaped ones that might also serve as useful tools (task two). These potentially useful flakes were separated from the main pile and a few were carried off when the hand axe was done. Keeping two goals in mind and switching between them during an ongoing task is an indicator of expanded working memory capacity and greater executive control (Coolidge & Wynn 2010, 159–60, 170, 178).

Around 300,000 years ago, a new tool-making technique, Levallois core preparation, also emerges (see Ambrose 2001 for review). Levallois was a reduction strategy whereby a core was carefully prepared so that a flake of predetermined size and shape could be reliably produced. This procedure often led to nearly standardized lithic forms. It has been argued that Levallois represents an important advance in plan-ahead abilities (Pelegrin 2009; Schlanger 1996).

What these data tell us is that we cannot be confident that the cognitive abilities for either socially affiliative or normative over-imitation were present prior to around 500–300,000 years BP. Thus, ACE is probably the best explanation for the over-imitation of the earliest Acheulean bifaces, roughly 1.2–0.5 million years BP. By about half a million years ago or slightly later, social affiliation likely played a larger role in over-imitation. However, it is probably not until around 300,000 years ago or later that normatively driven over-imitation appeared.

The emergence of normatively based over-imitation

Group norms are typically defined as communal behavioural rules that carry moral weight (Rossano 2012). Failing to follow group norms calls someone's character into question. Thus, being a respected group member entails understanding and following group norms. When simple cultural traditions would have taken on this added dimension is very difficult to determine from archaeological remains. Group consciousness—the awareness that one belongs to a certain group distinctive from other groups—would appear to be an important part of normative awareness. Indeed, most attempts at modelling the emergence of normative and ethnic markers have required inter-group interactions of some type (Boyd & Richerson 1987; McElreath *et al.* 2003). Thus, one archaeological indicator of normativity would be remains used as ethnic markers, something that identified or distinguished one group from another.

Among traditional societies, one tribal or cultural marker is tool style, such as distinctions in projectile points (Wiessner 1983). The first clear evidence of regionally or culturally divergent tool styles is not present in archaeological remains until sometime after 300,000 years BP (Clark 1992). It is also around this time that large collections of red ochre and other mineral pigments begin to appear at hominin sites (see Rossano 2015 for review). While mineral pigments can have utilitarian uses, at most sites the quantities and types of pigments collected strongly indicate ritual use. Red ochre is used extensively among extant traditional societies in culture-specific ritual activities. Thus, at around 300,000 years BP we can be fairly confident that human-like cultures with identifying behavioural practices, rituals and artefacts are present. It may not have been until this point that over-imitated tool-making techniques were clearly transmitting culturally normative information ('this is how *our tribe* makes projectile points').

Conclusion

The evidence reviewed leads to the following conclusions:

1. Where skill transmission (whether in tool making or other activities) involves motor routines clearly beyond the cognitive capabilities of our ape cousins and where over-imitation of those routines is implicated, imitation based on ACE is the most likely explanation. This is so because ACE appears to minimize cognitive demands by taking an already well-developed primate cognitive ability, intention reading, and applying it to the acquisition of a technical skill. The earliest bifaces emerge sometime between 1.7–1.4 million years BP. The motor routines for their construction are more complex than Oldowan flaking and clearly beyond non-human primate capabilities. Thus, the best explanation for early biface imitation (up to about 500,000 years BP) is ACE.
2. Where over-imitation is accompanied by evidence of cooperative activities entailing shared intentionality (such as cooperative hunting), then

over-imitation based on social affiliation is possible. Convincing evidence of cooperative hunting does not emerge until sometime between 800–400,000 years BP. Furthermore, evidence of the expanded working memory capacity necessary for social affiliation does not emerge until around 500,000 years BP. Together, these suggest that over-imitation based on social affiliation would not have been present until around half a million years ago.
3. Where over-imitation is accompanied by evidence of ethnic marking and other forms of tribalism, then the possibility of normative over-imitations arises. Archaeological evidence indicates that by 800,000 years BP (some) hominins were cultural creatures in a way qualitatively different from our ape cousins. Being cultural, however, is not the same as being tribal. Tribalism requires an awareness of alien groups and efforts to distinguish one's native group from others. This probably did not happen until very late in the Acheulean, after 300,000 years BP, when evidence of ethnic markers is present.

The issue of conceptual standardization *versus* form standardization in hand-axe construction may also be relevant in explaining over-imitation. Part of the hominin culture that emerged around 800,000 years BP involved biface construction and use. Over-imitating a set of conceptually standardized motor procedures leading to a hand axe of variable form probably qualifies as cultural, but not necessarily tribal. Since form specificity is often a component of the stylistic differences that serve as ethnic markers, where hand axes exhibit form standardization the possibility of normative over-imitation is heightened. It is odd, though, that the evidence for form standardization diminishes after 500,000 years BP, before strong evidence of tribalism emerges. This suggests that symmetrical form in hand axes was not serving as an ethnic marker. Instead, it may have had more to do with intra-group social signalling (e.g. males signalling mate quality to females).

To the extent that modern cognition depends on cognitive fluidity, the emergence of over-imitation indicates that the roots of fluidity extend deeper into hominin evolution than previously suspected. Mithen (1996, chapter 7) argues that *H. erectus* had greatly advanced social, natural history and technical intelligence relative to earlier hominins. However, he finds no evidence of any interaction among these forms of intelligence in the archaeological record (no bone or antler tools, specialized hunting tools or multicomponent tools). This conclusion, however, is based on products, not process. What over-imitation indicates is that the process of creating some tools (and possibly other artefacts) may have involved an interaction among different intelligences, even if the end product did not. Given that this interaction may have been largely implicit, it did not (at least initially) lead to conscious, reflective interactions that hominins might then translate into innovative tools and other artefacts.

Thus, the hominin mind may have been capable of some forms of cognitive fluidity sooner than artefactual remains indicate. This should not be surprising. Mental and behavioural competencies frequently precede archaeological signatures of those competencies. Our ancestors were probably anthropomorphizing (social intelligence) their prey in order to predict their behaviour (natural history intelligence) long before leaving any material record testifying to the strategy.

The evolutionary model outlined in this review generates predictions to guide future research, specifically regarding the evolutionary position of the ACE strategy. By automatically conflating intention with causation, ACE is predicted to be both sparing of working memory capacity (relative to the APLS) and less demanding regarding the quantity of necessary imitated acts (relative to both C&C and the APLS). While there are reasons to suspect both of these to be true (as discussed earlier), direct tests have yet to be conducted. Furthermore, the current model offers a potential mechanism by which cognitive fluidity led to modern cognition. Given its automaticity, the initial connection between social and technical intelligence used to solve the Acheulean dilemma was very likely task-specific, pertaining exclusively to biface construction. Other automatized, task-specific cross-domain connections may have emerged as well over time as our ancestors confronted various fitness challenges. Eventually, increasing brain size and interconnectivity gave hominins greater conscious control over these cross-domain connections, extending them beyond their narrow scope; and modern cognition ensued.

Note

1. This example is intended only to clarify what is meant by cognitive fluidity and should not be taken as a definitive description of the chimpanzee mind. Whether or not chimpanzees have a domain-specific form of technical intelligence is debatable. Their tool-making ability could be more attributable to general intelligence, as Mithen argues.

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