Imitation and Shared Intentionality in the Acheulean

Ceri Shipton

Imitation and shared intentionality are traits essential to the socio-cultural adaptation of Homo sapiens. *Non-human apes display some capacity for imitation and shared intentionality, but are deficient in comparison to* Homo sapiens. *The Acheulean archaeological record provides evidence that imitation and shared intentionality were part of the behavioural repertoire of the hominins manufacturing that industry. The palaeoneurological record suggests some early* Homo *specimens possessed the neural architecture associated with modern human imitation. From this evidence it is suggested that a propensity for imitation and shared intentionality evolved soon after 2 million years ago.*

Social learning is by definition critical to the maintenance of any cultural trait. The degree to which social learning occurs in non-human primates has been the subject of debate for over a century (e.g. Watson 1908; Haggerty 1909). Several mechanisms of social learning have been differentiated, which vary in the fidelity of transmission and the degree of understanding of intentions between copier and demonstrator (Thorpe 1956; Tomasello & Call 1997). Stimulus enhancement is when primates witnessing conspecifics interacting with something in their environment are attracted to it, but there is no understanding of the relationship between the object and what it is being used for (Thorpe 1956). Emulation learning is where the relationship between a tool and a goal is understood, but the behavioural strategies of the demonstrator are not (Tomasello *et al.* 1987). The strongest type of social learning is imitation, when both the goal and the method of the observed behaviour are reproduced, through an understanding of the actor's intention. For example, in a study where an adult human bent at the waist to touch his head on a panel, causing a light to be switched on, the observing infant replicated the behaviour exactly, not simply achieving the same goal by using the easier means of pushing the panel with his hands (Meltzoff 1995). When imitating, human infants either selectively reproduce the intentional, but not the accidental actions of adults (Carpenter *et al.* 1998; Tomasello & Carpenter 2005), or produce a result that an adult intended but did not actually produce (Meltzoff 1995; Warneken & Tomasello 2006). Thus true imitation requires an understanding of the intentions of others.

Recent neurobiological and psychological studies have highlighted imitation and shared intentionality as being essential to the development of social behaviour in *Homo sapiens*. At the same time primatological studies are revealing that imitation and shared intentionality are two of the critical distinguishing features between human and non-human ape behaviour. In this article we review this evidence and then examine the archaeological and palaeontological records to assess when imitation and shared intentionality evolved in the human lineage.

The ontogeny of sociality in *Homo sapiens*

Here the evidence for the development of social behaviour in our species is reviewed to demonstrate the fundamental role played by the twin traits of shared intention and imitation. Neonatal copying has been used as evidence of an innate genetic proclivity to identify with conspecifics in human infants (Meltzoff & Gopnik 1993). Newborns replicate the actions of adults even across perceptual modalities that they cannot see on their own bodies, such as opening the mouth and protruding the tongue, reflecting the innateness of these reactions (Meltzoff & Moore 1989). Neonates have also been shown to preferentially track an image of three high-contrast blobs (similar to a defocused face) over other stimuli (Johnson & Morton 1991). No preference was shown

Cambridge Archaeological Journal 20:2, 197–210 © 2010 McDonald Institute for Archaeological Research
doi:10.1017/S0959774310000235 Received 26 May 2009; Revised 5 Oct 2009; Accepted 15 Oct 2009

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

for a face with full-features over face-like blobs until around two months, suggesting that there is a minimal representational predisposition for face-like stimuli at birth (Johnson 1990). The environment presents many competing sources of information, but innate biases serve to channel infant attention towards inputs appropriate for subsequent learning. These simple early biases profoundly affect subsequent experience and development.

Armed with the initial notion of other humans as being like themselves (Meltzoff & Gopnik 1993), infants begin to learn about self–other correspondences through subsequent interactions such as face-to-face proto-conversations (Trevarthern 1993; Barresi & Moore 1996; Stern 1977). Around nine months infants begin to demonstrate behaviours that are clearly intentional (Tomasello 1999; Tomasello *et al*. 2005). Identification of self with others earlier in ontogeny, ensures that when infants are forming their own intentions they are able to attribute these to others. For an infant the world is apparently populated by intentional agents as they express surprise when objects that appear to be behaving intentionally cease to do so (Bloom 2004). From nine to twelve months, infants demonstrate that they understand other individuals as possessing intentionality and begin to display shared intention behaviours (Tomasello *et al*. 1993). Infants begin to seek others as sources of information in evaluating novel objects (social referencing) (Meltzoff 1995). They also exhibit imitative learning, declarative pointing and symbolic play (Tomasello 1999; Liszkowski *et al*. 2007). At this age face-to-face interactions are transformed, as the infant now knows she is interacting with an intentional agent who is like her, and consequently must perceive her and intend things towards her. Infants are thus able to reference others attitudes towards them thereby developing self-reflective attributes such as self-consciousness and self-esteem. This is evidenced by the fact that around their first birthday infants begin showing signs of shyness around other persons and mirrors (Lewis *et al*. 1989). Brain-imaging studies have shown that the perception of others and the perception of the self share a common neural substrate in the medial prefrontal cortex (Kelley *et al*. 2002; Schmitz *et al*. 2004).

As the human infant approaches one year changes in the brain occur which may have ramifications for the developments described above. The hippocampus, known to be critical for long-term memory, becomes fully operational at around eight or nine months and at this time babies begin to show attachment to their primary care-giver and anxiety towards strangers (Gunnar 1998). The capacity of babies to remember individuals is probably crucial for their ability to understand them as beings like them, with their own set of intentions. From six to twelve months the prefrontal cortex forms synapses at such a rate that it consumes twice the energy of an entire adult brain (Perry *et al*. 1995). The face-to-face interactions that occur between the infant and mother at this time produce intense states of excitement in the infant, which are then modulated by the mother's responsiveness. These high-arousal states induce the production of dopamine-releasing neurons that link the prefrontal cortex with the mid-brain, allowing the prefrontal cortex to regulate emotions originating in the mid-brain (Schore 1994). By internalizing the mother's ability to modulate the baby's intense emotions, the baby is able to regulate its own emotions (Bion 1962). The positive emotional exchanges occurring between an infant and mother at this time are the foundation for attachment, acting as an internal working model for subsequent intimate relationships, and enabling the development of shared emotions and intentions (Bowlby 1988; Karr-Morse & Wiley 1997). When this process is not given adequate opportunities to occur, synapses are over pruned (Schore 1997) so the cortex is not able to properly regulate impulses from the brain stem, leading to violent anti-social tendencies in later life (Perry 1997).

By fourteen months infants engage in shared intention behaviours where they have an action plan and are able to co-ordinate with others in mutually supportive roles (Tomasello *et al*. 2005). Infants of this age will also demonstrate to others what their role should be if they are not performing it correctly (Carpenter *et al*. 2005). Children's demonstration that they can attribute mental states to themselves emerges virtually concurrently with their understanding of others as possessing mental states and attempts to manipulate them, at around four years (Meltzoff 1995). The development of this 'theory of mind' occurs from an initial identification of self with others, through shared intentionality, eventually leading to an understanding of others' beliefs and psychological states as a child becomes aware of his own (Meltzoff 1995; 1996; Tomasello *et al*. 2005). Language acquisition is also heavily dependent on imitation and shared intentions. Imitation establishes social norms and conventions such as linguistic codes (Tomasello 1999), and only through a common understanding of intention can the meaning of linguistic symbols be deciphered (Tomasello & Rakoczy 2003).

Ground-breaking neurobiological work has identified the neural substrate for imitation: the mirror neuron system (Rizzolatti *et al*. 1996). Mirror neurons

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

fire when observing another's actions as though the observer is mentally rehearsing the same action (Rizzolatti *et al*. 1996; Iacoboni *et al.* 2005). Equivalent mirroring neurons for internalizing emotional and intentional states witnessed in others have also been identified (Gallese *et al*. 2004; Fogassi *et al*. 2005). It is proposed that through this internal simulation one individual achieves motor, emotional and intentional attunement with another and so understands others as goal-directed-agents with emotional motivations (Gallese *et al*. 2004). Mirror neurons thus provide a neural substrate for our social cognition. The mirror neuron system is composed of the rostral part of the inferior parietal lobule and by the caudal sector (*pars opercularis*) of the inferior frontal gyrus and the adjacent part of the premotor cortex. The *pars opercularis* is one of the three portions of Broca's area for language production, underlining the link between language and imitation (Binkofski *et al.* 2000). Unlike those of monkeys, human mirror neurons fire when observing miming and intransitive actions (Gallese *et al*. 2004). This indicates that the default mode of operation in our mirror neuron system is to interpret actions as intentional and that the human mirror neuron system codes not only the goal of an action, but also the way that it is performed.

Autistics present a natural experiment for the above socialization schema, as they have been defined as lacking interpersonal identification (Baron-Cohen 1999), so we would not expect them to exhibit the above characteristics of socialization. Indeed this is exactly the case as autistics have difficulty imitating (Williams *et al*. 2004); their sense of self does not rely on reflective self-awareness (Hobson 1993); they do not engage in early joint attention behaviours (Charman *et al*. 1997); they do not perform mutually supportive roles, or role reversals; and they often acquire few linguistic conventions (Carpenter *et al*. 2005). Early developmental failures in the mirror neuron system may result in a cascade of impairments characterized by the clinical syndrome of autism (Williams *et al.* 2001) and indeed the dysfunction of mirror neurons has been demonstrated in children with autism (Oberman *et al*. 2005).

A crucial question is to what extent these socialization properties are unique to humans and to what extent they are shared by other primates? Selective attention to the faces of conspecifics and habituation to the mother's voice is in the general primate and perhaps mammalian pattern. Evidence also suggests that neonatal chimpanzees may engage in the same kind of facial mimicking as humans (Myowa-Yamakoshi *et al*. 2004), however despite this early social bias it appears that subsequent proto-conversations are unique to humans (Tomasello 1999). This suggests that the later behaviours dependent on these early social experiences are also unique to humans. The evidence for and against this will be discussed in the following section.

Great ape imitation and understanding of intentions

Non-human great apes in the wild may have a capacity for understanding the intentions of their group members. A longitudinal study of a group of chimpanzees in the Taï Forest of West Africa has revealed behaviours that suggest such a capacity (Boesch & Boesch-Achermann 2000). The alpha male of the group, Brutus, drummed on tree buttresses to change the direction of the group, or initiate resting times, using a code involving the number of drumming incidents and the location of the drumming. This suggests that Brutus knew how to change the behaviour of others and that the others could understand Brutus's intentions. Similarly bonobos have been observed dragging branches to indicate their proposed direction of movement (Ingmanson 1996), while beating the ground was associated with starting or turning group movement in eastern lowland gorillas (Mori 1983). In the Taï Forest when a neighbouring rival group was heard, drumming by several chimpanzees was used in conjunction with screaming as an intimidation tactic to ward off the rivals by exaggerating the size of the group. This suggests that the study group understood that their actions could alter the intentions of the rival group.

If wild chimpanzees have the capacity to understand the intentions of their conspecifics then we should also expect them to be able to imitate. The Taï chimpanzees have standardized ways of nut cracking, ant dipping and leaf clipping, from which there is very little deviation, suggesting these behaviours are acquired by imitation not emulation (Boesch 1993). When ant dipping, the Taï chimpanzees hold the stick with one hand and dip it among the soldier ants guarding the nest entrance. When the ants have swarmed about 10 cm up the tool they withdraw it and directly sweep off the ants with the lips. Taï chimpanzees use sticks 30 cm long on average and perform the dipping movement about 12 times per minute (Boesch & Boesch 1990). The same species of soldier ants (*Dorylus nigricans*) is fished at Gombe using a different technique. At Gombe, chimpanzees hold the stick with one hand among the ants guarding the nest entrance and, once they have swarmed about halfway

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

up the tool, withdraw the stick and sweep it through the closed fingers of the free hand; the mass of insects is then rapidly transferred to the mouth. Gombe tools are on average 66 cm long (15–113 cm range), and the dipping is performed 2.6 times per minute (McGrew 1974). A third population of chimpanzees at Bossou, uses both these techniques depending on the aggressiveness and gregariousness of the *Dorylus* ant species (Humle & Matsuzawa 2002). This has been used to argue that the different dipping strategies are merely a function of ant behaviour. However even if this is the case, chimpanzees at Bossou are still choosing from a repertoire of standardized strategies. Standardization is also seen in other technical behaviours (Whiten 1998). It has been noted that different populations of chimpanzees across Africa employ different techniques to crack the same nut (McGrew 1992). A comparison of the nut-cracking techniques used by a group of naïve chimpanzees in the Zurich zoo, with the techniques used by the Taï chimpanzees who habitually crack nuts, found that of the fourteen techniques attempted by the Zurich chimpanzees, only six were observed at Taï and one technique used by the Taï chimpanzees was never attempted in Zurich (Boesch & Boesch-Achermann 2000). Population-specific details of nut cracking, which cannot be explained by ecological differences, are also evident among the chimpanzees of Bossou (Biro *et al*. 2003). Likewise, the plant-processing techniques in a mountain gorilla population have been noted to be highly standardized (Byrne 1999). In the Balimbing swamp in Borneo a young female orangutan was learning to fish for insects by observing her mother. On one occasion the mother broke off two branches, stripped them and shortened them from both ends. Her daughter was then observed making two tools in the same way, yet other than this incident, orangutans have never been observed shortening a fishing stick from both ends (Fox *et al*. 1999). These examples suggest that beyond emulation learning where only the tools and the goal are understood, some form of imitation must be used in order for specific techniques to be conveyed in social transmission.

While reports of imitation and an understanding of intentions in the wild are compelling, they lack the experimental design to rule out the possibility that these behaviours are actually governed by simple rules of thumb, rather than genuine understanding. Attempts to experimentally demonstrate an understanding of intentions in captive non-human great apes have met with mixed results. Chimpanzees failed a task that required collaboration between two of them to pull on two ends of a rope (Povinelli & O'Neill 2000). Experiments may underestimate non-human ape understanding of others intentions because non-human apes are not motivated to collaborate with strangers or enemies (Hare *et al*. 2001). When two chimpanzees who normally shared food were paired in the rope-pulling task, they did in fact succeed, and further tests have shown that chimpanzees will also choose the best collaborator in these tasks (Melis *et al*. 2006). Although chimpanzees collaborated with some individuals, there was almost no communication between them during the task (Povinelli & O'Neill 2000; Melis *et al*. 2006). In competitive experimental situations, subordinate chimpanzees are seen to modify their behaviour according to whether or not dominants have seen the food they are competing for, suggesting they understand the intentions of the dominant (Hare & Tomasello 2004; Tomasello & Carpenter 2005).

In a study designed to test for imitation, chimpanzees and human children witnessed a human demonstrator raking in food, but one group was shown a demonstrator using the more efficient method of flipping the rake over on its back before drawing it back. Both groups were found to reproduce the behaviour but, whereas the human children reproduced the method they had witnessed regardless of its efficiency, the chimpanzees discovered their own idiosyncratic methods of raking in the foods, regardless of which method they had witnessed (Nagell *et al.* 1993). In a follow-up study the same results were reproduced in orangutans with an orangutan, rather than a human demonstrator, ruling out the possibility that the previous findings were a result of species biasing (Call & Tomasello 1994). A similar study involving two methods of breaking into a tube produced the same conclusion that chimpanzees emulated the result using pre-existing behavioural strategies, whereas human children imitated the entire procedure (Call *et al*. 2004). An experiment in which a demonstrator first performed a deliberate, but redundant action and then a necessary step to acquire a target object, showed that while chimpanzees only copied the necessary behaviour human children copied the entire sequence (Horner & Whiten 2005).

Recent studies have successfully seeded standardized behaviours in captive non-human apes. When two primate groups were shown two different methods of performing a task, a cultural tradition emerged whereby each group conformed to the strategy that was demonstrated to them (Whiten *et al*. 2005; Horner *et al*. 2006; Bonnie *et al*. 2007). In one of these studies the transmission of a behaviour was compared between chimpanzees and three-year-old

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

human children. It was found that while transmission in the chimpanzee groups was reliable enough to maintain a cultural tradition, there were several instances in which transmission failed, whereas in human children the techniques were replicated with 100 per cent fidelity across the transmission chains (Horner *et al*. 2006). Failure to transmit the behaviour between the chimpanzees occurred either because an individual was unsuccessful or unmotivated, or because of aggression between the model and the observer.

Rather than a dichotomy between the presence or absence of imitation, it has been proposed that human imitation differs from the other great apes in the precision and fidelity of encoding; the number of exposures required to learn a new technique; the range of behaviour that can be understood; and the number of behavioural components that can be combined (Russon 1999). Human children will imitate all deliberate aspects of a sequence of actions, whereas chimpanzees are rationally selective in their imitation. Humans also tend to be more tolerant of conspecific observers than chimpanzees, allowing for more opportunities for social learning.

Humans appear to differ from non-human apes in having a proclivity for joint attention behaviours and sharing information (Call & Tomasello 1998; Hare *et al*. 2001; Tomasello *et al*. 2003; Call *et al*. 2004; Tomasello & Carpenter 2005; 2007; Liszkowski *et al*. 2007). Chimpanzees are not motivated to engage in goalless shared intention activities and if someone is not performing a role, they will simply try to perform it themselves without engaging their collaborator (Warneken *et al*. 2006). Human children by contrast will engage in shared intention activities purely for their own sake. They will divide a task into mutually supportive roles, which they are also able to swap, and they will encourage a collaborator to carry out their role if they are not performing it adequately (Warneken & Tomasello 2006; Carpenter *et al*. 2005).

Humans then appear to differ from the other extant great apes in their proclivity for imitation and shared intentionality. To determine when these differences arose in the human lineage we must turn to the archaeological and fossil records.

The evidence for imitation and shared intentionality in the Acheulean

Mithen (1994) has suggested that the Lower Palaeolithic Clactonian industry represents periods when hominins lived in wooded environments in small groups and consequently social transmission was weak and technology was simple. By contrast the Acheulean in Britain, which interdigitates with the Clactonian at some sites, represents periods when hominins lived in open environments in large groups and imitated one another, allowing the more complex Acheulean technology to be maintained. The idea that larger groups are better able to maintain more complex technology is now well established because in larger groups there may be more experts from whom novices can learn (Shennan 2001). However the mechanism of social transmission between individuals is unlikely to be affected by group size, but rather will be an innate cognitive property of a species.

Social learning of knapping skills to non-human apes allows us to determine the level of technological complexity that can be sustained by our closest relatives. The archaeologist Nicholas Toth demonstrated knapping to the bonobo Kanzi (Toth *et al.* 1993). Initially Kanzi could not replicate Toth's technique so he made flakes by throwing cores against a concrete floor. He then developed a new technique of throwing one rock against another and after several years he has learned direct free-hand percussion, using the sound of a stone as a cue to attempt a flake detachment (Savage-Rumbaugh *et al.* 2004). Panbanisha, Kanzi's sister who had more human influence in her upbringing, has also been taught to knap and appears to be more adept than her brother. Panbanisha knaps by direct free-hand percussion and appears to calculate appropriate angles before hitting the core (Davidson & McGrew 2005). Bonobos can learn to make the simplest stone tools, and they appear to do so by emulation and perhaps limited imitation. At the early Oldowan site of Lokalalei 2C standardized knapping methods that exceed Kanzi and Panbanisha's knapping in complexity, are replicated across numerous cores (Delanges & Roche 2005). This suggests an evolving social-transmission mechanism with greater fidelity than that of the non-human great apes. The strongest evidence for imitation however is when hominins begin to deliberately shape core-tools sometime after 2 million years ago, because this requires the immediate goal of successful flake detachment to be subordinated to the ultimate goal of the final tool form (Roche 2005). Shaping core-tools therefore fulfils the strictest definition of imitation which requires both the method and the end product to be reproduced from one individual to the next.

Acheulean bifaces are the quintessential shaped core-tool. They were manufactured for 1.5 million years by hominins in East Africa (Asfaw *et al*. 1992; Wendorf *et al*. 1994) and are found as far afield as north Wales (Aldhouse-Green 2001) and south India

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

(Pappu & Akhilesh 2006). Between Acheulean biface assemblages there are differences in symmetry (Saragusti *et al*. 1998; Wynn 2002), morphology (White 1998; Shipton *et al*. 2009a), flake-scar density (Gilead 1970; Shipton *et al*. 2009a;), tool-type ratio (Clark & Sharma 1983) and manufacturing technique (Sharon 2009). However all Acheulean assemblages are united by the presence of one or both of the bifacial tools that we call handaxes and cleavers. Handaxes are teardrop-shaped in plan view, with the bifacial cutting edge extending around much of the perimeter, but not normally encompassing the globular butt where they are thought to have been held. Cleavers by contrast have a broad bit at their tip, set transverse to the long axis of the tool and the cutting edge does not normally extend beyond this. Both handaxes and cleavers have bilateral and bifacial equilibrium planes which tend towards symmetry, particularly in the finer-made specimens. While large bifacial cutting tools occur in areas and periods beyond the extent of the Acheulean, the distinctive morphologies of handaxes and cleavers, and the frequency with which they occur, are such that we can ascribe all Acheulean industries to the same cultural tradition. Cultural continuity on this vast geographic and temporal scale must have been supported by a reliable social-transmission system unlike anything seen in extant non-human great apes. It has been proposed that among Acheulean hominins there was a propensity for imitation that maintained this industry over vast expanses of time and space (Toth & Schick 1993; Mithen 1999; Petraglia *et al*. 2005; Shipton *et al*. 2009b).

While the scale of the Acheulean is impressive, perhaps some of the best evidence for imitation and shared intentionality comes from the specific reduction strategies employed at various Acheulean sites. Unless we propose the unlikely scenario that a single individual was responsible for manufacturing each tool type at a particular locality or series of localities, then reduction strategies provide evidence of the complexity of behaviours that were transmitted between hominins.

At the earliest Acheulean sites, such as EF-HR in Bed II at Olduvai Gorge, large flake biface blanks are produced from casual large cores, where flakes are removed from boulders in an *ad hoc* manner. However, in most Acheulean assemblages, large flake biface blanks are produced using some form of standardized prepared-core technique. The most common type of prepared core for the production of Acheulean flake blanks are discoids, in use at sites such as Kalambo Falls (Toth 2001). Here boulders are bifacially flaked into a large disc, allowing sequential flakes to be detached while maintaining an acute edge angle around the circumference. The Victoria West cores of central South Africa display a standardized technique for the production of cleaver blanks, in which flakes were removed from medium-sized dolerite and andesite boulders (15–25 cm max. dimension: Sharon & Beaumont 2006). The cores were trimmed radially in order to flatten one of the faces and then a striking platform was prepared at right angles to this, for striking a large side-struck flake (Clark 2001). In the Middle Awash Valley in Ethiopia, as well as other sites throughout the Rift Valley (Clark 2001), the Kombewa method was widely used for the production of large flakes. The Kombewa method works by splitting a large boulder in two leaving one half with a positive scar or bulb. When a large flake is removed from this half, the resulting Kombewa flake will characteristically have a bulb on each surface and can be retouched into a biface, usually a cleaver. In the Kapthurin Formation in Kenya, biface blanks are produced by a prepared-core technique resembling the Levallois method, whereby the flaking axis coincides with the length of the tool (McBrearty 1999). Variations on this technique are found in northwestern African sites. At Tabalbala for example, divergent cleavers are made on Levallois-like flakes with plunging terminations. A further method used in northwest Africa was the Tachengit technique, which involved radial preparation of the upper face of a core and the preparation of a striking platform on one of the long sides, before striking off a large cleaver blank (Clark 2001). At Gesher Benot Ya'qov in the Levant, large basalt cores (over 30 cm long) were flaked bifacially in order to produce biface blanks (Madsen & Goren-Inbar 2004). Platforms, which were generally plain, were located among facets whose morphologies were used to control the form of the flake. At the site of Chirki-Nevasa in central India, large dolerite blocks (up to 50 cm max. dimension) were prepared by removing a few flakes from two surfaces intersecting at right angles, to prepare an angle and platform for striking a large flake, suitable for a cleaver blank (Corvinus 1983).

At the site of Isampur Quarry in south India cleaver production used thick slabs of limestone as cores, which were flaked at right angles to the bedding plane to set up appropriate angles and platforms for striking large flakes oblique to the bedding plane (Shipton *et al.* 2009c; Fig. 1). These oblique flakes were then retouched into cleavers (Fig. 1). At the same site handaxes were produced according to an entirely different protocol whereby thinner limestone slabs were reduced to leave the handaxe

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

shape in plan view. This correspondence between manufacturing method and end-product shows that both the goal and the means to achieve it were being transmitted between hominins, indicating true imitation and a shared understanding of intention.

At many Acheulean sites the small initial clast form precludes the use of core preparation to strike large flake blanks. This is particularly true of northwestern Europe and the later Acheulean of the Levant where most bifaces are manufactured on flint cobbles, and also at Indian, African and southwestern European sites where bifaces were produced on quartzite cobbles. However, in these cases many of the characteristics of prepared cores are seen on the bifaces themselves. The bifaces from each site vary around a modal shape (McPherron 2006), and often have distinctive regularized scar patterns such as at Kalambo Falls (Edwards 2001) or Tabun Cave (Gisis & Ronen 2006). In addition the flakes detached from Acheulean bifaces often have their own distinctive properties, such as thin flakes with a remnant of the bifacial edge or tip (Roberts & Parfitt 1999; Goren-Inbar & Sharon 2006). At Gesher Benot Ya'aqov manufacturing experiments have been used to demonstrate the existence of archaeological biface debitage in the absence of the bifaces themselves (Goren-Inbar & Sharon 2006). The distinctive standardized flakes which are detached from Acheulean cobble bifaces indicate that the bifaces are technologically equivalent to prepared cores, and it has even been proposed that it was the debitage flakes rather than the bifaces that were the hominins' principal goal in manufacture (Noble & Davidson 1996).

Prepared-core technology is often viewed as the exclusive prerogative of late *Homo* species such as Neanderthals and *Homo sapiens* and indicative of advanced cognition (White & Ashton 2003; Hopkinson 2007). Contrary to this we see prepared-core methods and the production of bifaces which are of equivalent complexity, as being widespread throughout the Acheulean. The production of large flakes and cobble bifaces by the techniques outlined above represent the complexity of behaviours that were transmitted between Acheulean hominins. In order for hominins to learn biface manufacturing techniques from one another they must have understood the ultimate goal of the final tool form from the outset when the initial clast was selected, and quite probably from when they began the search for appropriate raw material. Hominins must therefore have had a shared intentionality in order for the correspondence between clast selection, manufacturing method and final tool form to be understood and transmitted.

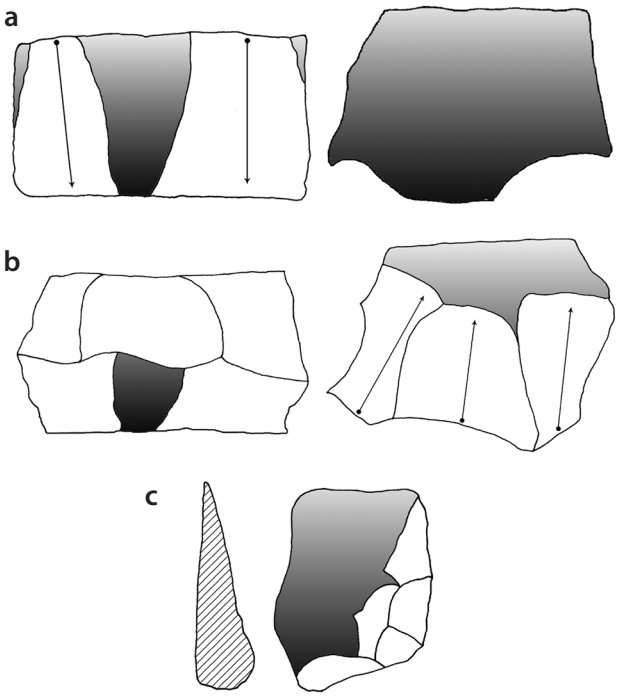


Figure 1. *A model of cleaver reduction at Isampur Quarry (after Shipton* et al. *2009c): a) profile (left) and plan (right) of limestone slab with two flakes removed from the core perimeter in order to set up a platform; b) profile (left) and plan (right) of slab with three flake scars struck oblique to the upper core surface; c) profile (left) and dorsal surface displaying cortex (right) of a flake struck obliquely to the upper core face, that has been retouched into a cleaver. (After Shipton* et al. *2009c, fig. 7.)*

The prepared-core techniques described above are complex manufacturing sequences, requiring the acquisition of both meta-tools (the hammerstones) and a substrate to flake; the preparation of an intermediary stage (the core); and the finishing retouch of the biface itself, before the tool can even be used. Recently a *chaîne opératoire* has been outlined for one of the most complex material manipulations observed among chimpanzees: nut cracking (Carvalho *et al*. 2008). While such behaviour in chimpanzees might be transmitted through imitation and some understanding of the intentions of others, it is exceeded in complexity by the Acheulean prepared-core techniques. The use of a meta-tool, such as a wedge, is rarely seen in chimpanzee nut cracking (McGrew 1992), and the use of preparatory manufacturing stages is wholly absent (Carvalho *et al*. 2008). The manufacture of chimpanzee stick tools is far simpler than that for Acheulean bifaces; chimpanzee sticks are broken to a required length in one dimension, as opposed to the

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

scores of flake removals required to produce a biface whose shape and symmetry are standardized in two and sometimes three dimensions (Wynn 2002). Honey gathering by chimpanzees can involve up to three sequentially organized actions such as pounding a hive, levering it open then dipping for honey, each action using a different-sized stick as a tool (Bermejo & Illera 1999; Sanz & Morgan 2009). The serial ordering of different actions here is impressive, but outweighed by the different stages of manufacture in many Acheulean reduction sequences. At the Acheulean site of Isampur Quarry for example, cleaver production involved six distinct serially ordered stages (Shipton *et al.* 2009c):

1. extraction of limestone slabs for handaxe and cleaver manufacture using a large hammerstone (heavier than 900 g) to expose joint intersection in the bedrock and then prying up slabs;
2. selection of a slab thicker than 8 cm suitable for the cleaver-reduction sequence;
3. flaking of slab perimeter using a large hammerstone to remove joint cortex and set up an overhang (Fig. 1);
4. striking large flakes obliquely to the bedding plane of the limestone slab which have a wedge-shaped profile appropriate for cleaver manufacture (Fig. 1);
5. flipping the core and striking further large flakes oblique to the bedding plane, using the bifacial edge created by the previous removals as a platform;
6. marginal trimming of cleaver blanks using small hammerstone, less than 700 g.

Evidence of co-operation in lithic manufacture is elusive but provides tantalizing suggestions of shared intentions. At sites such as Bodo in the Middle Awash, giant cores estimated to weigh 100 kg appear to have been transported 2–3 km from the nearest basalt flow (Kalb 2001; Clark 2001). At many Acheulean sites hammerstones and lithic substrate materials are transported from diverse locations several kilometres distant to a single locality (e.g. Feblot-Augustins 1997; Petraglia *et al*. 2005). While it might be possible for a single individual to carry out these transport activities it seems more probable that multiple individuals were working together towards a shared goal by carrying heavy clasts or collecting material from different locations.

Based on observations of adults and children in modern limestone quarries and the life-history estimates of early *Homo* species (Bogin 1997) we have produced a preliminary model of how manufacturing behaviours were transmitted across generations at the Acheulean site of Isampur Quarry (Petraglia *et al.* 2005). Handling stone tools is likely to have begun in infancy when children carried around by their parents would have been drawn to the objects their parents were using. By four years old, once a child understood the intentions and beliefs of older individuals around him, he may have been motivated to bang small clasts together. There is anecdotal evidence from our own species that children begin hitting rocks together when in the company of older knappers (Shennan & Steele 1999). During the juvenile period from 7 to 11 years these attempts at stone-tool manufacture would have become increasingly sophisticated and may have been aided by instruction and facilitation from adults. As an adolescent, stone-tool manufacture would have become proficient as adult strength and dexterity emerged, and from the onset of adulthood at 15 years knapping skills would have become progressively refined. Ethnographic observation indicates that among modern humans proficiency in biface manufacture may be facilitated by a decade-long period of apprenticeship beginning in adolescence (Stout 2002).

The palaeoneurological evidence for the origins of the modern human mirror neuron system

Brain-imaging studies of modern novice Oldowan knappers has shown activation of the ventral premotor cortex in the left Brodmann area 6, bordering Broca's area (Stout & Chaminade 2007). Sulcal anatomy (Rizzolatti *et al.* 1998) architectonics and electrophysiology (Petrides *et al.* 2005) demonstrate that this region is homologous to area F5 in macaque monkeys. The mirror neuron system was in fact originally identified in area F5 in macaques (Rizzolatti *et al.* 1996), therefore this region is both structurally and functionally homologous across the catarhine primates.

The activation of mirror neurons during Oldowan knapping shows the importance of this system for acquiring technical skills such as stone knapping. When expert knappers were asked to make fine Acheulean artefacts there was a bilateral activation of Brodmann's area 6 and an activation of the right Brodmann's area 45 (part of the right hemisphere homologue of Broca's area), indicating the greater bimanual demands of Acheulean knapping on the mirror neuron system (Stout *et al*. 2008).

Broca's area, which is responsible for the fine oro-facial motor control in language production, is adjacent to and probably derived from the cortical area for precise manual control and mastication (Greenfield 1991; MacNeilage & Davis 2001). The posterior portion of Broca's area, Brodmann's area 44, mediates higher-order forelimb movement as well as subserving speech (Binkofski *et al.* 2000), and its

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

non-human primate homologue is implicated in fine manual control and mastication, but not vocalizations (Rizzolatti & Arbib 1998; Rizzolatti *et al*. 1996). The evolution of the modern configuration of Broca's area is thus linked to both language and high-fidelity imitation.

The malleable nature of the cranium during brain growth ensures that neuro-anatomical correlates of endo-cranial shape exist (Enlow 1990) and can be determined on well-preserved hominin fossils (Holloway 1996; Holloway *et al*. 2004). This endo-cranial perspective is complicated by intervening tissues between the brain and the skull and posthumous deformations of the cranium (Holloway 1996).

One aspect of endocranial evidence which has been widely accepted is that the KNM-ER 1470 early *Homo* cranium, possess a third inferior frontal convolution containing Broca's area, resembling that of *Homo sapiens* (Holloway 1975; 1996; Falk 1983; Tobias 1987). The left Broca's region on this endo-cranium is laterally and inferiorly projecting, an asymmetry not caused by distortion (Holloway *et al*. 2004). This distinctive shape allies KNM-ER 1470 with later *Homo* species, including *Homo sapiens* and distinguishes it from both older australopithecine species and extant non-human apes.

The fossil hominin KNM-ER 1470, is dated to 1.88 million years ago (Tattersall *et al*. 1988; Fitch *et al*. 1996), just prior to the appearance of the earliest Acheulean. KNM-ER 1470 is succeeded by hominins who display similar configurations of Broca's area; including KNM-ER 3733 dated to 1.6 million years ago (Wood 1991; Holloway *et al.* 2004) and KNM-WT 15000 dated to 1.5 million years ago (Begun & Walker 1993; Walker & Leakey 1993). Around 1.9 million years ago lithics whose shape is not determined by the original clast morphology, such as polyhedrons and spheroids, begin to appear in the archaeological record (Roche 2005). From *c.* 1.7 to 1.4 million years ago several distinctive variants of the Oldowan emerge in east Africa at Peninj, Koobi Fora, Gadeb and Olduvai Gorge Bed II (Leakey 1971; Clark 1987; Kimura 2002; de la Torre *et al*. 2003). Hominins were experimenting with new manufacturing techniques that sometimes involved the production of large flakes and/or bifacial working (Gowlett 1986; Toth 1985; Kimura 2002; de la Torre *et al*. 2003). During this period the earliest Acheulean bifaces appear at east African sites such as Kokisleiei, Olduvai Gorge EF-HR, Konso-Gardula and Peninj (Leakey 1971; Asfaw *et al*. 1992; Roche & Kibunjia 1994; Dominguez-Rodrigo *et al*. 2001; Roche *et al*. 2003). We suggest that the transmission of complex Lower Palaeolithic lithic technologies, such as the Acheulean, was dependent on the evolution of true imitation, and that this behaviour emerged alongside changes in the mirror neuron system around 2 million years ago.

Conclusion

Tomasello (1999) suggests that a propensity for imitation and shared intentions is a unique property of *Homo sapiens*. Reliable social transmission in our species has produced a cultural ratchet effect whereby cultural innovations are maintained and added to across generations giving rise to the vast cultural complexity which we see today (Tomasello & Rakoczy 2003; Tomasello *et al*. 2005). The evidence, however, suggests that a propensity for imitation and shared intentions predates *Homo sapiens*. The temporal and geographical scale of the Acheulean and the complexity of techniques required to maintain it demonstrates an unsurpassed fidelity in social transmission on the part of Acheulean hominins. This conclusion is supported by the palaeoneurological evidence, which has revealed that a modern-human-like Broca's area, part of the neurological substrate for imitation, appeared in *Homo* species 1.9 million years ago.

If a propensity for imitation appeared *c.* 2 million years ago we may begin to speculate on the selective pressures that led to the evolution of this capacity. From 2.6 million years ago it is apparent that hominins were intentionally creating sharp stone flakes (and probably other technologies which have not survived) (Semaw *et al*. 1997; Panger *et al.* 2002; Roche 2005), which presumably had a direct impact on their fitness. This would have created a selective pressure for increased fidelity in social transmission, so that each hominin in a group would not have to invent their own knapping techniques. The demands placed on the mirror neuron system would have selected for enhanced intentional attunement, culminating in the true imitation displayed by Acheulean hominins, who transmit both manufacturing techniques and the shape of the finished artefact. The evolution of more regular and more symmetrical bifaces (Saragusti *et al.* 1998; 2005) that occurs within the Acheulean may be attributed to other aspects of hominin cognition, as from the outset of the Acheulean it is clear that standardized symmetrical shapes were an intended goal of Acheulean knappers (Wynn 2002).

Imitation and shared intentionality are the developmental foundations of many of the ultra-social traits of our species, including task co-operation, sharing information and language. The imitation and shared intentionality evident in Acheulean behaviour suggests these ultra-social traits have their origins

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

among Lower Palaeolithic hominins. Co-operation and communication would have been adaptive in exploiting a niche based on technologically assisted foraging, food-sharing and long-term pair-bonding. This is not to say that Lower Palaeolithic hominins possessed modern language or cognition, for instance they seem to have lacked the innovation rate of our own species. However the archaeological and palaeontological records do not indicate that the singularities of human cognition appeared suddenly with our own species, but instead evolved gradually, with a propensity for imitation and shared intentions emerging soon after 2 million years ago.

Acknowledgements

The author would like to thank Mike Petraglia, Bill McGrew, Mark White and four anonymous reviewers for their comments which have guided this work to completion.

Ceri Shipton
Leverhulme Centre for Human Evolutionary Studies
Henry Wellcome Building
Fitzwilliam Street
Cambridge
CB2 1QH
UK
Email: ceri.shipton@cantab.net

References

Aldhouse-Green, S., 2001. *Ex Africa aliquid simper novi*: the view from Pontnewydd, in *A Very Remote Period Indeed: Papers on the Palaeolithic Presented to Derek Roe*, eds. S. Milliken & J. Cook. Oxford: Oxbow Books, 114–19.

Asfaw, B.,Y. Beyene, G. Suwa *et al.*, 1992. The earliest Acheulean from Konso-Gardula. *Nature* 360, 732–5.

Baron-Cohen, S., 1999. Evolutionary approaches to autism, in *The New Cognitive Neurosciences*, ed. M.S. Gazzaniga. Cambridge (MA): MIT Press, 1235–47.

Barresi, J. & C. Moore, 1996. Intentional relations and social understanding. *Behavioural and Brain Sciences* 19, 107–54

Begun, D. & A.C. Walker, 1993. The endocast, in *The Nariokotome* Homo erectus *skeleton*, eds. A.C. Walker & R. Leakey. Cambridge (MA): Harvard University Press, 326–58.

Bermejo, M. & G. Illera, 1999. Tool-set for termite-fishing and honey extraction by wild chimpanzees in the Lossi Forest, Congo. *Primates* 40, 619–27.

Binkofski, F., K. Amunts, K.M. Stephan *et al.*, 2000. Broca's region subserves imagery of motion: a combined cytoarchitectonic and fMRI study. *Human Brain Mapping* 11(4), 273–85.

Bion, W.R., 1962. *Learning from Experience.* London: Heinemann.

Biro, D., N. Inoue-Nakamura, R. Tonooka, G. Yamakoshi, C. Sousa & T. Matsuzawa, 2003. Cultural innovation and transmission of tool use in wild chimpanzees: evidence from field experiments. *Animal Cognition* 6, 213–23.

Bloom, P., 2004. *Descartes' Baby: How the Science of Child Development Explains What Makes Us Human*. New York (NY): Basic Books.

Boesch, C., 1993. Toward a new image of culture in chimpanzees. *Behavioural and Brain Sciences* 16, 514–15.

Boesch, C. & H. Boesch, 1990. Tool use and tool making in wild chimpanzees. *Folia Primatologica* 54, 86–99.

Boesch, C. & H. Boesch-Achermann, 2000. *The Chimpanzees of the Tai Forest: Behavioural Ecology and Evolution.* Oxford: Oxford University Press.

Bogin, B., 1997. Evolutionary hypotheses for human childhood. *Yearbook of Physical Anthropology* 40, 63–89.

Bonnie, K.E., V. Horner, A. Whiten & F.B.M. de Waal, 2007. Spread of arbitrary conventions among chimpanzees: a controlled experiment. *Proceedings of the Royal Society* Series B 274, 367–72.

Bowlby, J., 1988. Developmental psychiatry comes of age. *American Journal of Psychiatry* 145, 1–10.

Byrne, R., 1999. Object manipulation and skill organization in the complex food preparation of mountain gorillas, in *The Mentalities of Gorillas and Orang-utans,* eds. S.T. Parker, L. Miles & R. Mitchell. Cambridge: Cambridge University Press, 147–59.

Call, J. & M. Tomasello, 1994. The social learning of tool use by orangutans (*Pongo pygmaeus*). *Human Evolution* 9, 297–313.

Call, J. & M. Tomasello, 1998. Distinguishing intentional from accidental actions in orangutans (*Pongo pygmaeus*) chimpanzees (*Pan troglodytes*) and human children (*Homo sapiens*). *Journal of Cognition & Development* 3, 445–64.

Call, J., B. Hare, M. Carpenter & M. Tomasello, 2004. 'Unwilling' versus 'unable': chimpanzees' understanding of human intentional action. *Developmental Science* 7, 488–98.

Carpenter, M., N. Akhtar & M. Tomasello, 1998. Fourteen through 18-month-old infants differentially imitate intentional and accidental actions. *Infant Behavior and Development* 21, 315–30.

Carpenter, M., M. Tomasello & T. Striano, 2005. Role reversal imitation and language in typically-developing infants and children with autism. *Infancy* 8, 253–78.

Carvalho, S., E. Cunha, C. Sousa & T. Matsuzawa, 2008. *Chaînes opératoires* and resource-exploitation strategies in chimpanzee (*Pan troglodytes*) nut cracking. *Journal of Archaeological Science* 55, 148–63.

Charman, T., J. Swettenham, S. Baron-Cohen, A. Cox, G. Baird & A. Drew, 1997. Infants with autism: an investigation of empathy, pretend play, joint attention, and imitation. *Developmental Psychology* 33, 781–9.

Clark, J.D., 1987. Transitions: *Homo erectus* and the Acheulean: the Ethiopian sites of Gadeb and the Middle Awash. *Journal of Human Evolution* 16, 809–26.

Clark, J.D., 2001. Variability in primary and secondary

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

technologies of the Later Acheulian in Africa, in *A Very Remote Period Indeed: Papers on the Palaeolithic Presented to Derek Roe,* eds. S. Milliken & J. Cook. Oxford: Oxbow Books, 1–18.

Clark, J.D. & G.R. Sharma (eds.), 1983. *Palaeoenvironment and Prehistory in the Middle Son Valley, Madhya Pradesh, North Central India*. Allahabad: Abinash Prakashan.

Corvinus, G., 1983. *A Survey of the Pravara River System in Western Maharashtra*, vol. 2: *The Excavations of the Acheulean Site of Chirki-on-Pravara, India*. Tübingen: Institut fur Urgeschichte.

Davidson, I. & W. McGrew, 2005. Stone tools and the uniqueness of human culture. *Journal of the Royal Anthropological Institute* 11, 793–817.

Delanges, A. & H. Roche, 2005. Late Pliocene hominid knapping skills: the case of Lokalalei 2C, West Turkana, Kenya. *Journal of Human Evolution* 48, 435–72.

Dominguez-Rodrigo, M., J. Serralonga, J. Juan-Tresserras, L. Alcala & L. Luque, 2001. Woodworking activities by early humans: a plant residue analysis on Acheulian stone tools from Peninj (Tanzania). *Journal of Human Evolution* 40, 289–99.

Edwards, S.W., 2001. A modern knapper's assessment of the technical skills of the Late Acheulean biface workers at Kalambo Falls, in *Kalambo Falls Prehistoric Site*, vol. III, ed. J.D. Clark. Cambridge: Cambridge University Press, 605–11.

Enlow, D.H., 1990. *Facial Growth.* 3rd edition. Philadelphia (PA): Saunders.

Falk, D., 1983. Cerebral cortices of East African early hominids. *Science* 221, 1072–4.

Feblot-Augustins, J., 1997. *La Circulation des Matières Premières au Paléolithique*. (ERAUL 75.) Liege: ERAUL.

Fitch, F.J., J.A. Miller & J.G. Mitchell, 1996. Current events: dating of the KBS tuff and *Homo rudolfensis*. *Journal of Human Evolution* 30, 277–86.

Fogassi, L., P.F. Ferrari, B. Gesierich, S. Rozzi, F. Chersi & G. Rizzolatti, 2005. Parietal lobe: from action organization to intention understanding. *Science* 302, 662–7.

Fox, E.A., A.F. Sitompul & C.P. Van Schaik, 1999. Intelligent tool use in wild Sumatran orangutans, in *The Mentalities of Gorillas and Orang-utans,* eds. S.T. Parker, L. Miles & R. Mitchell. Cambridge: Cambridge University Press, 99–116.

Gallese, V., C. Keysers & G. Rizzolatti, 2004. A unifying view of the basis of social cognition. *Trends in Cognitive Sciences* 8, 396–403.

Gilead, D., 1970. Handaxe industries in Israel and the Near East. *World Archaeology* 2, 1–11.

Gisis, I. & A. Ronen, 2006. Bifaces from the Acheulian and Yabrudian layers of Tabun Cave, Israel, in *Axe Age: Acheulian Toolmaking from Quarry to Discard,* eds. N. Goren-Inbar & G. Sharon. London: Equinox, 267–86.

Goren-Inbar, N. & G. Sharon, 2006. Invisible handaxes and visible Acheulian biface technology at Gesher Benot Ya'aqov, Israel, in *Axe Age: Acheulian Toolmaking from Quarry to Discard,* eds. N. Goren-Inbar & G. Sharon. London: Equinox, 111–36.

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

Greenfield, P.M., 1991. Language, tools, and brain — the ontogeny and phylogeny of hierarchically organized sequential behavior. *Behavioral and Brain Sciences* 14, 531–50.

Gunnar, M.R., 1998. Quality of early care and buffering of neuroendocrine stress reactions: potential effects on the developing human brain. *Preventive Medicine* 27, 208–11.

Haggerty, M.E., 1909. Imitation in monkeys. *The Journal of Comparative Neurology and Psychology* 19, 337–455.

Hare, B. & M. Tomasello, 2004. Chimpanzees are more skilful in competitive than in co-operative tasks. *Animal Behaviour* 68, 571–81.

Hare, B., J. Call & M. Tomasello, 2001. Do chimpanzees know what conspecifics know? *Animal Behaviour* 61, 139–51.

Hobson, P., 1993. *Autism and the Development of Mind*. Hillsdale (NJ): Lawrence Erlbaum Associates.

Holloway, R.A., 1975. Early hominid endocasts: volumes, morphology and significance for hominid evolution, in *Primate Functional Morphology and Evolution,* ed. R.H. Tuttle. The Hague: Mouton, 417–41 .

Holloway, R.A., 1996. Evolution of the human brain, in *Handbook of Symbolic Evolution,* eds. A. Lock & C.R. Peters. Oxford: Oxford University Press, 74–125.

Holloway, R.A., D.C. Broadfield & M.S. Yuan, 2004. *The Human Fossil Record*, vol. 3: *Brain Endocasts. The Palaeoneurological Evidence*. New York (NY): Wiley-Liss.

Hopkinson, T., 2007. The transition from the Lower to the Middle Palaeolithic in Europe and the incorporation of difference. *Antiquity* 81, 294–307.

Horner, V. & A. Whiten, 2005. Causal knowledge and imitation/emulation switching in chimpanzees (*Pan troglodytes*) and children. *Animal Cognition* 8, 164–81.

Horner, V., A. Whiten, E. Flynn & F.B.M. de Waal, 2006. Faithful replication of foraging techniques along cultural transmission chains by chimpanzees and children. *Proceedings of the National Academy of Sciences of the USA* 103, 13,878–83.

Humle, T. & T. Matsuzawa, 2002. Ant dipping among the chimpanzees of Bossou, Guinea, and some comparisons with other sites. *American Journal of Physical Anthropology* 58, 133–48.

Iacoboni, M., I. Molnar-Szakacs, V. Gallese, G. Buccino, J.C. Mazziotta & G. Rizzolatti, 2005. Grasping the intentions of others with one's own mirror neuron system. *PLoS Biology* 3, 529–35.

Ingmanson, E.J., 1996. Tool-using behaviour in wild *Pan paniscus*: social and ecological considerations, in *Reaching into Thought: the Minds of the Great Apes,* eds. A.E. Russon, K.A. Bard & S.T. Parker. Cambridge: Cambridge University Press, 190–210.

Johnson, M.H., 1990. Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience* 2, 81–95.

Johnson, M.H. & J. Morton, 1991. *Biology and Cognitive*

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

Development: the Case of Face Recognition. Oxford: Blackwell.

Kalb, J., 2001. *Adventures in the Bone Trade: the Race to Discover Human Ancestors in Ethiopia's Afar Depression*. New York (NY): Copernicus.

Karr-Morse, R. & M.S. Wiley, 1997. *Ghosts from the Nursery: Tracing the Roots of Violence*. New York (NY): The Atlantic Monthly Press.

Kelley, W.M., C.N. Macrae, C.L. Wyland, S. Caglar, S. Inati & T.F. Heatherton, 2002. Finding the self? An event-related fMRI study. *Journal of Cognitive Neuroscience.* 14(5), 785–94.

Kimura, Y., 2002. Examining time trends in the Oldowan technology at Beds I and II, Olduvai Gorge. *Journal of Human Evolution* 43, 2921–321.

Leakey, M.D., 1971. *Olduvai Gorge: Excavations in Beds I and II, 1960–1963*. Cambridge: Cambridge University Press.

Lewis, M., M. Sullivan, C. Stanger & M. Weiss, 1989. Self-development and self-conscious emotions. *Child Development* 60, 146–56.

Liszkowski, U., M. Carpenter & M. Tomasello, 2007. Pointing out new news, old news and absent referents at 12 months of age. *Developmental Science* 10, 1–7.

MacNeilage, P.F. & R.L. Davis, 2001. Motor mechanisms in speech ontogeny: phylogenetic, neurobiological and linguistic implications. *Current Opinions in Neurobiology* 11, 696–700.

Madsen, B. & N. Goren-Inbar, 2004. Acheulian giant core technology and beyond: an archaeological and experimental case study. *Eurasian Prehistory* 2, 3–52.

McBrearty, S., 1999. Archaeology of the Kapthurin Formation, in *Late Cenozoic Environments and Hominid Evolution: a Tribute to Bill Bishop,* eds. P. Andrews & P. Banham. London: Geological Society, 143–56.

McGrew, W.C., 1974. Tool use by wild chimpanzees in feeding upon driver ants. *Journal of Human Evolution* 3, 501–8.

McGrew, W.C., 1992. *Chimpanzee Material Culture.* Cambridge: Cambridge University Press.

McPherron, S.P., 2006. What typology can tell us about Acheulian handaxe production, in *Axe Age: Acheulian Toolmaking from Quarry to Discard*, eds. N. Goren-Inbar & G. Sharon. London: Equinox, 267–86.

Melis, A.P., B. Hare & M. Tomasello, 2006. Chimpanzees recruit the best collaborators. *Science* 311, 1297–300.

Meltzoff, A., 1995. Understanding the intentions of others: re-enactment of intended acts by 18 month old children. *Developmental Psychology* 31, 838–50.

Meltzoff, A.N., 1996. The human infant as imitative generalist: a 20-year progress report on infant imitation with implications for comparative psychology, in *Social Learning in Animals: the Roots of Culture*, eds. C.M. Heys & B.G. Galef Jr. London: Academic Press, 347–70.

Meltzoff, A. & A. Gopnik, 1993. The role of imitation in understanding persons and developing a theory of mind, in *Understanding Other Minds,* eds. S. Baron-Cohen, H. Tager-Flusberg & D. Cohen. Oxford: Oxford University Press, 335–66.

Meltzoff, A. & K. Moore, 1989. Imitation in newborn infants: exploring the range of gestures imitated and the underlying mechanisms. *Developmental Psychology* 25, 954–62.

Mithen, S., 1994. Technology and society during the Middle Pleistocene: hominid group size, social learning and industrial variability. *Cambridge Archaeological Journal* 4(1), 3–32.

Mithen, S., 1999. Imitation and cultural change: a view from the Stone Age, with specific reference to the manufacture of handaxes, in *Mammalian Social Learning: Comparative and Ecological Perspectives*, eds. H.O. Box & K.R. Gibson. Cambridge: Cambridge University Press, 389–99.

Mori, A., 1983. Comparison of the communicative vocalizations and behaviours of group ranging in eastern gorillas, chimpanzees and pygmy chimpanzees. *Primates* 24, 486–500.

Myowa-Yamakoshi, M., M. Tomonaga, M. Tanaka & T. Matsuzawa, 2004. Imitation in neonatal chimpanzees (*Pan troglodytes*). *Developmental Science* 7, 437–42.

Nagell, K., K. Olguin & M. Tomasello, 1993. Processes of social learning in the tool use of chimpanzees (*Pan troglodytes*) and human children (*Homo sapiens*). *Journal of Comparative Psychology* 107, 174–86.

Noble, W. & I. Davidson, 1996. *Human Evolution, Language and Mind: a Psychological and Archaeological Enquiry*. Cambridge: Cambridge University Press.

Oberman, L.M., E.M. Hubbard, J.P. McCleery, E.L. Altschuler, V.S. Ramachandran & J.A. Pineda, 2005. EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Cognitive Brain Research* 24, 190–98.

Panger, M.A., S.A. Brooks, B.G. Richmond & B. Wood, 2002. Older than the Oldowan: rethinking the emergence of hominin tool use. *Evolutionary Anthropology* 11(6), 235–45.

Pappu, S. & K. Akhilesh, 2006. Preliminary observations on the Acheulian assemblages from Attirampakkam, Tamil Nadu, in *Axe Age: Acheulian Toolmaking from Quarry to Discard*, eds. N. Goren-Inbar & G. Sharon. London: Equinox, 155–80.

Perry, B.D., 1997. Incubated in terror: neurodevelopmental factors in the cycle of violence, in *Children in a Violent Society*, ed. J.D. Osofsky. New York (NY): Guilford Press, 124–9.

Perry, B.D., R.A. Poland, T. Blakely, W.L. Baker & D. Vigilante, 1995. Childhood trauma, the neurobiology of adaptation and use dependent development of the brain: how states become traits. *Infant Mental Health Journal* 16, 271–91.

Petraglia, M.D., C. Shipton & K. Paddayya, 2005. Life and mind in the Acheulean: a case study from India, in *The Hominid Individual in Context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and Artefacts*, eds. C. Gamble & M. Porr. London: Routledge, 197–219.

Petrides, M., G. Cadoret & S. Mackey, 2005. Crofacial somatomotor responses in the macaque monkey homologue of Broca's area. *Nature* 435, 1235–8.

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

Povinelli, D.J. & D. O'Neill, 2000. Do chimpanzees use their gestures to instruct each other?, in *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience*, eds. S. Baron-Cohen, H. Tager-Flusberg & D. Cohen. 2nd edition. Oxford: Oxford University Press.

Rizzolatti, G. & M.A. Arbib, 1998. Language within our grasp. *Trends in Neuroscience* 21, 188–94.

Rizzolatti, G., L. Fadiga, V. Gallese & L. Fogassi, 1996. Premotor cortex and recognition of motor actions. *Cognitive Brain Research* 3, 131–41.

Rizzolatti, G., G. Luppino & M. Matelli, 1998. The organization of the cortical motor system: new concepts. *Electroencephalography and Clinical Neurophysicology* 106, 283–96.

Roberts, M.B. & S.A. Parfitt, 1999. *Boxgrove*: *a Middle Pleistocene Hominid Site at Eartham Quarry, Boxgrove, West Sussex*. London: English Heritage.

Roche, H., 2005. From simple flaking to shaping: stone-knapping evolution among early hominins, in *Stone Knapping: the Necessary Conditions for a Uniquely Hominin Behaviour*, eds. V. Roux & B. Bril. (McDonald Institute Monographs.) Cambridge: McDonald Institute for Archaeological Research, 35–48.

Roche, H. & M. Kibunjia, 1994. Les sites archéologiques plio-pleistocènes de la Formation de Nachukui, West Turkana, Kenya. *Comptes Rendus de l'Académie des Sciences de Paris* 318, série II, 1145–51.

Roche, H., J.P. Brugal, A. Delanges *et al.*, 2003. Les sites archeologiques plio-pleistocenes de la formation de Nachukui, Ouest-Turkana, Kenya: bilan synthetique 1997–2001. *Comptes Rendus Palevol* 2, 663–73.

Russon, A.E., 1999. Orangutans' imitation of tool use: a cognitive interpretation, in *The Mentalities of Gorillas and Orang-utans,* eds. S.T. Parker, L. Miles & R. Mitchell. Cambridge: Cambridge University Press, 117–46.

Sanz, C.M. & D.B. Morgan, 2009. Flexible and persistent tool-using strategies in honey-gathering by wild chimpanzees. *International Journal of Primatology* 30, 411–27.

Saragusti, I., I. Sharon, O. Katzenelson & D. Avnir, 1998. Quantitative analysis of the symmetry of artefacts: Lower Paleolithic handaxes. *Journal of Archaeological Science* 25, 817–25.

Saragusti, I., K. Avshalom, I. Sharon & U. Smilansky, 2005. Quantitative analysis of shape attributes based on contours and section profiles in artefact analysis. *Journal of Archaeological Science* 32, 841–53.

Savage-Rumbaugh, E.S., W.M. Fields & T. Spircu, 2004. The emergence of knapping and vocal expression in a *Pan*/*Homo* culture. *Biology & Philosophy* 19, 541–75.

Schmitz, T.W., T.N. Kawahara-Baccus & S.C. Johnson, 2004. Metacognitive evaluation, self-relevance, and the right prefrontal cortex. *Neuroimage* 22, 941–7.

Schore, A.N., 1994. *Affect Regulation and the Origin of the Self*. Hillsdale (NJ): Laurence Erlbaum.

Schore, A.N., 1997. Early organisation of non-linear right brain and development of a predisposition to psychiatric disorders. *Development and Psychopathology* 9, 595–631.

Semaw, S., P. Renne, J.W.K. Harris *et al.*, 1997. 2.5-million-year-old stone tools from Gona, Ethiopia. *Nature* 385, 333–6.

Sharon, G., 2009. Acheulian giant-core technology. *Current Anthropology* 50(3), 335–67.

Sharon, G. & P. Beaumont, 2006. Victoria West: a highly standardized prepared core technology, in *Axe Age: Acheulian Toolmaking from Quarry to Discard,* eds. N. Goren-Inbar & G. Sharon. London: Equinox, 181–99.

Shennan, S., 2001. Demography and cultural innovation: a model and its implications for the emergence of modern human culture. *Cambridge Archaeological Journal* 11(1), 5–16.

Shennan, S. & J. Steele, 1999. Cultural learning in hominids, in *Mammalian Social Learning*, ed. K.R. Gibson. Cambridge: Cambridge University Press, 367–88.

Shipton, C., M. Petraglia & K. Paddayya, 2009a. Acheulean biface refinement in the Hunsgi-Baichbal Valley, Karnataka, India, in *Theoretical and Methodological Issues in Evolutionary Archaeology: Towards a Unified Darwinian Paradigm*, eds. H.J. Muscio & G.E.J. Lopez. Oxford: Archaeopress, 95–102.

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

Shipton, C., M.D. Petraglia & K. Paddayya, 2009c. Stone tool experiments and reduction methods at the Acheulean site of Isampur Quarry, India. *Antiquity* 83, 769–85.

Stern, D., 1977. *The First Relationship: Infant and Mother*. Cambridge (MA): Harvard University Press.

Stout, D., 2002. Skill and cognition in stone tool production: an ethnographic case study from Irian Jaya. *Current Anthropology* 43(5), 693–722.

Stout, D. & T. Chaminade, 2007. The evolutionary neuroscience of tool making. *Neuropsychologia* 45, 1091–100.

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

Tattersall, I., E. Delson & J. Van Couvering, 1988. *Encyclopedia of Human Evolution and Prehistory.* New York (NY): Garland Publishing

Thorpe, W.H., 1956. *Learning and Instinct in Animals*. London: Methuen & Co.

Tobias, P.V., 1987. The brain of *Homo habilis*: a new level of organisation in cerebral evolution. *Journal of Human Evolution* 16, 741–61.

Tomasello, M., 1999. *The Cultural Origins of Human Cognition.* Cambridge (MA): Harvard University Press.

Tomasello, M. & J. Call, 1997. *Primate Cognition.* Oxford: Oxford University Press.

Tomasello, M. & M. Carpenter, 2005. The emergence of social cognition in three young chimpanzees. *Monographs of the Society for Research in Child Development* 70, 7–152.

Tomasello, M. & M. Carpenter, 2007. Shared intentionality. *Developmental Science* 10, 121–5.

Tomasello, M. & H. Rakoczy, 2003. What makes human cog-

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press

nition unique? From individual to shared collective intentionality. *Mind and Language* 18, 121–47.
Tomasello, M., M. Davis-Dasilva, L. Camak & K. Bard, 1987. Observational learning of tool use by young chimpanzees. *Journal of Human Evolution* 2, 175–83.
Tomasello, M., A.C. Kruger & H.H. Ratner, 1993. Cultural learning. *Behavioural and Brain Sciences* 16, 495–552.
Tomasello, M., J. Call & B. Hare, 2003. Chimpanzees understand psychological states — the question is which ones and to what extent. *Trends in Cognitive Sciences* 7, 153–7.
Tomasello, M., M. Carpenter, J. Call, T. Behne & H. Moll, 2005. Understanding and sharing intentions: the origins of cultural cognition. *Behavioural and Brain Sciences* 28, 675–91.
de la Torre, I., R. Mora, M. Dominguez-Rodrigo, L. Luque & L. Alcala, 2003. The Oldowan Industry of Peninj and its bearing on the reconstruction of the technological skills of Lower Pleistocene hominids. *Journal of Human Evolution* 44, 203–24.
Toth, N., 1985. The Oldowan reassessed: a close look at early stone artefacts. *Journal of Archaeological Science* 12, 101–20.
Toth, N., 2001. Experiments in quarrying large flake blanks at Kalambo Falls, in *Kalambo Falls Prehistoric Site*, vol. III: *The Earlier and Middle Stone Age,* ed. J.D. Clark. Cambridge: Cambridge University Press, 600–604.
Toth, N. & K. Schick, 1993. Early stone industries and inferences regarding language and cognition, in *Tools, Language and Cognition in Human Evolution,* eds. K.R. Gibson & T. Ingold. Cambridge: Cambridge University Press, 346–62.
Toth, N., K.D. Schick, E.S. Savage-Rumbauh, R.A. Sevcik & D. Rumbaugh, 1993. *Pan* the tool-maker. *Journal of Archaeological Science* 20, 81–91.
Trevarthern, C., 1979. Instincts for human understanding and for cultural co-operation: their development in infancy, in *Human Ethology: Claims and Limits of a New Discipline,* eds. M. von Cranach, K. Foppa, W. Lepenies & D. Ploog. Cambridge: Cambridge University Press, 530–71.
Trevarthern, C., 1993. The function of emotions in early communication and development, in *New Perspectives in Early Communicative Development*, eds. J. Nadel & L. Camaioni. London: Routledge, 48–81.
Walker, A.C. & R. Leakey (eds.), 1993. *The Nariokotome* Homo erectus *Skeleton*. Cambridge (MA): Harvard University Press.
Warneken, F. & M. Tomasello, 2006. Altruistic helping in human infants and young chimpanzees. *Science* 3, 1301–3.
Warneken, F., F. Chen & M. Tomasello, 2006. Cooperative activities in young children and chimpanzees. *Child Development* 77, 640–63.
Watson, J.B., 1908. Imitation in monkeys. *Psychological Bulletin* 5, 169–78.
Wendorf, F., A.E. Close & R. Schild, 1994. Africa in the period of *Homo sapiens neanderthalensis* and contemporaries, in *History of Humanity*, vol. 1: *Prehistory and the Beginnings of Civilization*, eds. S.J. De Laet, A.H. Dani, J.L. Lorenzo & R.B. Nunoo. New York (NY): Routledge & UNESCO, 117–35.
White, M.J., 1998. On the significance of Acheulean biface variability in southern Britain. *Proceedings of the Prehistoric Society* 64, 15–44.
White, M.J & N.M. Ashton, 2003. Lower Palaeolithic core technology and the origins of the Levallois method in NW Europe. *Current Anthropology* 44, 598–609.
Whiten, A., 1998. Imitation of the sequential structure of actions by chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology* 112, 270–81.
Whiten, A., V. Horner & F.B.M. de Waal, 2005. Conformity to cultural norms of tool use in chimpanzees. *Nature* 437, 737–40.
Williams, J.H.G., A. Whiten & T. Singh, 2004. A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism Developmental Disorders* 34, 285–99.
Williams, J.H., A. Whiten, T. Suddendorf & D.I. Perrett, 2001. Imitation, mirror neurons and autism. *Neuroscience and Biobehavioural Review* 25(4), 287–95.
Wood, B., 1991. *Koobi Fora Research Project: Hominid Cranial Remains*. Oxford: Clarendon Press.
Wynn, T., 2002. Archaeology and cognitive evolution. *Behavioural and Brain Sciences* 25, 389–438.

Author biography

Ceri Shipton received his doctorate from Cambridge University in 2008. He is currently working as an excavation director in Papua New Guinea for Monash University. His research interests include socio-cognitive evolution, lithic technology and function, hominin dispersals, and the entire gamut of Indian cultural evolution. He has recently published an article in *Antiquity* demonstrating true imitation at an Acheulean quarry.

https://doi.org/10.1017/S0959774310000235 Published online by Cambridge University Press