Origins of human intelligence: The chain of tool-making and brain evolution

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Abstract

Although the definition of intelligence is debatable, it can be allocated to only one anatomical location: the brain. Arguments regarding general measures of animal intelligence and discussions of its evolution up to the Neanderthals arise only because hominids have evolved to have larger brains; i.e., they have become more "intelligent". Hominids clearly evolved in the past, but whether evolution is still ongoing is debated. Ironically, because hominids have created technologies and innovations to aid their survival, their evolution has included adaptation to the environment generated by their inventions. Similar to the recent evolution of ADHD traits or gluten tolerance, the hominid brain has undergone major changes over the past seven million years due to man-made habitats and technologies. Tool-making creates an environment conducive to increased social interactions, as it facilitates increased provisioning and protection, while increased opportunities for interactions and observations lead to advances in tool-making. These changes have been offset by the concurrent evolution of language and tool-making. Biologically, hominid brains have increased in size in areas where tool-making and language-processing coincide. This increase in brain size allowed advanced provisioning and tools, including the use of fire, and the technological advances during the Palaeolithic that stood on the shoulders of the previous evolutionary innovations of bipedalism and versatile hands enhanced the momentum of brain evolution. The beginnings of the reciprocal cause and effect between brain evolution and tool-making cannot be identified. The applicability of the hunting and fire hypotheses to the evolution of human intelligence is further discussed.

KEYWORDS: Acheulean, homo habilis, Oldowan, palaeolithic, prefrontal cortex

ANTHROPOLOGICAL NOTEBOOKS 22 (1): 5–22.
ISSN 1408-032X

Introduction

Human intelligence refers to the mental capacity of humans, which is characterised by perception, consciousness, self-awareness, and volition. With their advanced intelligence, humans have the cognitive capabilities to experience, think, recognise patterns and solutions, comprehend ideas, plan, and utilise complex language to communicate (Legg & Hutter 2007). Although the concept of intelligence is debatable, biological intelligence can be pinpointed to only one location in the human body: the human brain.

The evolutionary history of the human brain primarily reveals a gradual increase in brain size in relation to body size during the evolutionary path from early primates to ancient hominids and finally to *Homo sapiens* (Buckner & Krienen 2013). The early *Australopithecus* brains were only slightly larger than those of chimpanzees, but human brain size has increased rapidly over the last two million years (Zhang 2003). Various studies have demonstrated that hominids have increasingly devoted energy toward brainpower during evolution (Leonard & Robertson 1992; Navarrete et al. 2011).

Furthermore, the brain-to-body size ratio is used for comparing and estimating an animal's general intelligence or cognition. The encephalisation quotient (EQ) is a measurement of the relative brain size, which is defined as the ratio of the actual to the predicted brain mass of an animal of a given size (Schmidt-Nielsen 1984), and is calculated using the equation:

$$\mathbf{EQ} = \frac{\textbf{brain-weight}}{(\mathbf{0.12\ x\ \textbf{body-weight}^{(2/3)}})} \tag{1}$$

EQ calculations take into account allometric effects, which detail that the skeleton becomes markedly more robust and massive in relation to the size of the body as the latter increases. It is hypothesised that EQ provides an estimate of the intelligence level or cognition of a certain animal.

The raw brain size also remains a convenient tool for comparing intelligence between closely related species (Fragaszy & Perry 2008). Recent research has, however, indicated that the absolute brain size is a better measure of cognitive abilities than the EQ, at least for primates (Gibson et al. 2001; Deaner et al. 2007).

The EQ (brain-to-body-size ratio) is an effective tool for estimating the intelligence of a wide variety of species, but whole brain size is a better tool for measuring the intelligence of related species (Deaner et al. 2007; Reader & Laland 2002). A correlation between the intelligence quotient and brain size has also been shown in humans (Willerman et al. 1991); however, researchers have debated about the oversimplification of this association caused by using simple brain size as a measure of intelligence in humans, due to controversial definitions of intelligence/IQ and complex racial issues (Neisser 1997; Mackintosh 2011). Nonetheless, it is clear that humans have become smarter during the evolution from their ape-like hominid ancestors, which lived seven million years ago, to Neanderthals:

> The human brain has grown from the size of chimpanzee brains to that of early hominid brains and finally to the size of Neanderthal brains. The size increased slowly during the first two-thirds of its evolution. Beginning two million years ago, a modest increase in brain size occurred (Buckner & Krienen 2013: 17).

In general, for the human species as a whole, we can state that the brain is related to intelligence and that the evolution of this particular organ is linked to the evolution of human intelligence (Roth & Dicke 2005). This manuscript presents a set of theories that attempt to explain how human intelligence has evolved. These theories are closely tied to the evolution of the human brain and the emergence of human language. In addition, the reasons underlying the limited evolution of the brain up to Neanderthals, whose brains were similar to or sometimes even larger than those of humans (Ponce de León et al. 2008) will also be discussed.

Explaining evolution from seven million years ago to the Neanderthals

Neanderthals, who were also capable of handling complex upper Paleolithic tools, had similar-sized or sometimes even larger brains than modern humans (Ponce de León et al. 2008); however, studies have suggested that these closest-known evolutionary relatives coexisted with *Homo sapiens* for more than 5,000 years and largely interbred with modern humans (Higham et al. 2014). At least one-fifth of the Neanderthal genome may lurk within modern humans, influencing the skin and hair, as well as diseases, present in people today and indicating that there may not have been a true “extinction” of Neanderthals (Evans et al. 2006; Sankararaman et al. 2014). Genetic evidence shows that archaic hominids, such as Denisovans and Neanderthals, interbred with *H. sapiens* (Reich et al. 2011; Vernot & Akey 2014). Furthermore, recent studies have shown that some populations blended with Neanderthals or Denisovans much more so than others did (Abi-Rached et al. 2011; Vernot & Akey 2015). Neanderthals, Denisovans, and modern humans (*H. sapiens*) all descended from *H. heidelbergensis*.[1]

In *The Descent of Man*, Darwin (1871) explained that hominids started walking on two legs in order to use their hands. He states in his book, ‘However, the hands and arms could hardly have become perfect enough to have manufactured weapons, or to have hurled stones and spears with a true aim, as long as they were habitually used for locomotion.’ Unfortunately, a dilemma arises. Bipedal specialisations are already found in *Australopithecus and Ardipithecus ramidus* fossils from 4.4 to 3.9 million years ago (McHenry 2009), while the Lower Paleolithic (Stone Age) began later, 2.5 million years ago, with the appearance of the genus *Homo habilis*. In fact, the evolution of bipedalism is believed to have begun even before *Australopithecus*, as it has been suggested that Miocene hominids that lived five to seven million years ago had a limited ability to walk upright.

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[1] For convenience, this discussion of brain evolution will address *H. heidelbergensis* and the preceding hominids due to complications involving race.

The earliest ape-like hominid ancestors took a long time to ultimately descend to the ground, even if they had the capability of walking on two legs. *Ardipithecus*, for example, had a grasping hallux or big toe adapted to arboreal locomotion (Lovejoy 2009; White et al. 2009). The hominid that appeared next, *Australopithecus afarensis*, was still suited for tree-climbing, with upward facing shoulder joints (Green & Alemseged 2012). Scientists have also observed the existence of primitive features in *Australopithecus africanus* and *Australopithecus afarensis*, such as ape-like curved fingers and phalanges for tree climbing (Reed et al. 2013).

The first man-made tools were classified as Oldowan millions of years after hominins settled into ground-dwelling life. Up to that time, hominids were not capable of making any sophisticated tools that could be classified as such, but early hominid ancestors, such as *Australopithecus afarensis* or *Ardipithecus*, were capable of making simpler tools (Panger et al. 2002; Roche et al. 2009). In fact, our closest living relatives, chimpanzees, can devise spear-like stick tools for hunting prosimians in tree hollows and use stone tools to crack nuts, but have yet to exhibit the full scope of intelligence exhibited by early hominins (Wrangham 1994; Whiten et al. 1999; Carvalho et al. 2008; Boesch et al. 2009; Sanz & Morgan 2013). In addition, for millions of years, these unclassified simple tools continued to develop, and carvings and finishing touches likely became more distinguishable and more associated with the classification now used for Paleolithic tools (Whiten et al. 2009). Comparable to human evolution itself, tools developed continuously, yet, suddenly, *Homo habilis*, who possessed a larger cranial volume (610 cc) and was mostly ground-dwelling (although possessing curved phalanges for tree-climbing), predominantly used Oldowan tools (Leakey et al. 1964; Susman & Stern 1982).

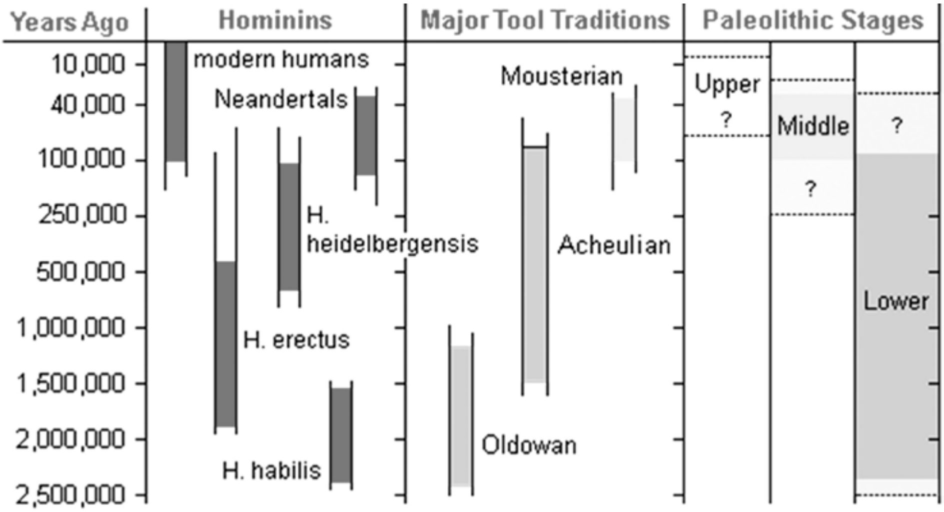

Figure 1: The timeline for the evolution of hominins, archaeological industries, and the Paleolithic stages (O'Nei 2012).

As hominids evolved to have larger brains and became more intelligent, they were able to engage in effective food gathering, the complex use of tools, and fire-making (Flinn et al. 2005). Moreover, hominids evolved to exercise smaller portions of their muscles at will, while non-human primates lack the neurological structure for restraining muscles (Walker 2009). Humans can employ only a few muscle fibres for complex tool-making, and cumulatively recruit more fibres for tasks that demand more power, and have greater control over individual muscles.

Some might acknowledge that the evolution of bipedalism is responsible for the supposed superiority of humans as compared with other animals, because it permitted the manipulation of nature at will; however, bipedalism per se was established prior to the advent of marked hominid intelligence and the making of fire or even simple tools (Buss 1999). It has also been suggested that the common ancestors of ancient hominids and even chimpanzees were partially bipedal (Nelson 2013; Zollikofer et al. 2005). Furthermore, the size of their brains was slightly larger than that of chimpanzees. Ultimately, the evolution of an enlarged brain, combined with full bipedalism and intricate hand movements, allowed tool-making.

Our ancestors were originally limited bipeds that strived to survive without tool-making and underwent a natural selection process, similar to other animals. Hominids were initially not biologically capable of utilising complex hand-made tools. However, as evolutionary time passed, this situation changed. Hominids became terrestrial and fully bipedal for a number of reasons (Fialkowski 1986). As they became more intelligent and more capable of using their hands and legs freely, their tools became more sophisticated than the simple tools that our closest relative can use.

A New Perspective

Although *H. sapiens* appeared only 200,000 years ago, the issue of whether human evolution has stopped is a controversial and heated one among researchers (Johanson & Edgar 1996). Some state that natural selection in humans has ceased (Meikle 2013) since recent innovations in modern medicine and the industrial revolution have permitted safe and prosperous living, while technological advancements have exempted humans from natural selection. Conversely, other researchers argue that the evolution of humans has not stopped (Hawks 2014). Researchers have obtained comprehensive scans of the human genome, which reveal that hundreds of human genes show evidence of changes during the past several thousand years of human evolution (Voight et al. 2006). The answer to this question is both complex and straightforward.

Humans have interfered with natural selection with numerous innovations and tool-making, which themselves are also evolving (Wynn 1985). Ironically, due to the technological advancements that have intervened in the process of natural selection, or survival of the fittest, humans are evolving. Hominids have developed ‘cultural adaptation’ to harness the environment and protect them from the harshness of nature in a way that no other species have managed (Stock 2008). In addition to having adapted to survive in the natural environment, similar to other animals, humans have evolved and continue to evolve in order to adapt and survive in the artificial environment built by their achievements and innovations.

Even *H. sapiens* that lived 10,000 years ago are not the same as those that inhabit Earth today. A comprehensive scan of the human genome has revealed that hundreds of human genes have undergone positive natural selection during the past 10,000 years of human evolution, including changes in bone development, skeleton, brain size, and carbohydrate metabolism (Evans 2005; Mekel-Bobrov 2005; Voight et al. 2006).

The most obvious example of recent man-made "artificial evolution" is gluten tolerance, which allows humans to digest proteins in wheat. Approximately 10,000 years ago, before humans began farming and domesticating animals, people were unable to digest wheat (Greco 1997). Another example of recent artificial evolution is the loss of "hyperfocus", or ADHD-related traits. Most humans are adapted to farming cultures; however, individuals with ADHD retained some of the older characteristics of the hunter-gatherer societies that preceded agriculture (Hartmann 2005). The studies of isolated nomads in Kenya and the frequency of genetic variants that contribute to ADHD indicate that the trait provided a survival advantage in the past (Arcos-Burgos & Acosta 2007).

Numerous changes involving various genes have occurred in the last 10,000 years, and countless changes, particularly those involving the brain, have occurred in the five to seven million years of hominid evolution from *Sahelanthropus* to *H. neanderthalensis*. Previous studies have suggested that technologies and innovation would have played an evolutionary role alongside the evolution of hominids (Washburn 1959). In particular, the evolution of the human brain is distinct from other evolutionary processes, because free and usable limbs and tools had an impact on the survival of the hominid species (Darwin 1871). Hominids were talented throwers and waders. Sharpened bones/stones, spears, and fire became the insurmountable fangs of hominids. This intervention by artificial, hominid-generated forces would have served humans well. The knowledge of how to make tools, or the tools themselves, would be passed down from generation to generation to assist in feeding and protecting the family. Consequently, hominids would have evolved to adapt to changes in the environment that had been shaped by Paleolithic innovations and new industries (Figure 1).

The first stone tools classified as Oldowan did not appear in the archaeological record until approximately 2.6 million years ago in Ethiopia (Semaw et al. 2003). Due to a lack of conclusive evidence, the time at which events began remains unclear. However, it is important to note that no effective tool-making is known to have existed prior to *H. habilis* (Backwell & d'Errico 2001). Chimpanzees (*Pan troglodytes*), the closest living relatives of humans, can fashion and use spear-like weapons and tools for hunting and foraging, but these tools have yet to approach the sophistication of the Oldowan tools (Pruetz et al. 2015; Roffman et al. 2015). Therefore, it is reasonable to assume that at some stage before the Paleolithic, hominins devised proto-Oldowan tools that fall between Oldowan tools and the tools devised by chimps. In fact, discoveries in Kenya demonstrated that, even 3.3 million years ago, hominids used advanced stone tools that are comparatively coarser than Oldowan tools (Harmand et al. 2015). Initially, humans modified simple Oldowan choppers, sharp flakes created by knapping or striking a hard stone, such as quartz, flint, or obsidian, via direct percussion. Rough flake tools were made by hitting a suitable stone with a hammerstone. The flakes that broke off from the stone would have a naturally sharp edge. Humans then designed more complex bifacial hand axes and cleavers in the Acheulean tradition that were markedly more effective tools for guarding and hunting. Acheulean hand axes were harder to master due to the presence of two finely chipped convex surfaces that intersected at a sharp edge (Yamei et al. 2000). This progress was followed by the development of efficient Middle Paleolithic weapons, such as spears and awls, which granted humans even more power (Villa et al. 2009). Along with these innovations, effective provisioning had long been made possible by free, usable limbs, with which the hominids would move around bipedally, carrying armfuls of food for the family or the group.

Tools have allowed hominids to adapt and obtain provisions from a greater range of habitats (Plummer et al. 2009). At a certain point in time, these tools, weapons, and the use of fire gave humans an overwhelming advantage over other animals. Simple Paleolithic tools, including weapons, such as arrowheads, spears, hand axes, and fire, were unprecedented factors that played a role in altering the process of evolution. Therefore, Paleolithic tools have been helpful to humans (Eisele et al. 1995). However, the following question remains: why would brain size have increased over millions of years, and how did tools affect brain evolution? The answer is sociality.

Their complex social structure ranks dolphins among the most intelligent and opportunistic species. Dolphins form strong social bonds, staying with injured or ill individuals and even helping them breathe by bringing them to the surface. These animals also enjoy a game of catch, in which they throw a fish back and forth to one another without the intention of eating it (Paulos et al. 2010). Dolphins also play games that are similar to the human game of tag, in which one dolphin will nudge another, and they then take turns chasing each other (McCowan et al. 2000). These are social activities that require individual identification. The association between social cohesion and intelligence is not limited to dolphins. For many other species, such as hyenas, corvids, and primates, their societal structure is believed to be responsible for driving their intelligence to higher levels (Dunbar & Shultz 2007: 362; Holekamp et al. 2007).

However, social interaction is widely observed in many other non-human animals. Elephants, for example, show empathy and express concern for other individuals, while corvids and crows are also known for cooperative breeding and elaborate social games involving following the leader, racing, and passing twigs (Gill 1995).

What would have differentiated the social interactions of hominins from those of any other species? Van Schaik (2006) conducted a specific behavioural study with orangutans and chimps. The groups in which each great-ape had more opportunities to observe others exhibited a greater variety of learned behaviours than those who had fewer such opportunities. Previous studies have demonstrated that chimpanzees learn to use tools more efficiently by watching how others use them (van Schaik et al. 1999; Yamamoto et al. 2013). A wider variety of tools and behaviours have been documented in captive apes than in wild apes, because the captive apes are exposed to increased social learning; this is termed the captivity bias (Shumaker et al. 2011; Haslam 2013). In cases of food shortages in the wild, individuals had to spend more time hunting and foraging while avoiding predators. Similar to captive and wild chimpanzees, ancient hominids were distinguished from all other species because they spent extended periods of time within their groups, observing and communicating with each other (Candland 1993). The evolution of hominids towards a terrestrial life via bipedalism smoothed a path for the development of Paleolithic tools. Improved tools led to safer living and greater food availability. In turn, bountiful and safe living, moulded by advanced technologies, produced an environment in which hominids with socially active and innovative brains could thrive. Biologically, the hominid brain reorganised its functions away from visual processing, which is essential for survival in the wild, and more towards other functional areas, such as planned movements, cognition, and language, which are crucial for increased sociality and tool-making. In turn, the evolution of the brain would drive stone tool technologies even further.

Researchers had found that the brain patterns of language processing and tool-making are correlated. Previous studies have demonstrated that language and stone tool-making, which are considered unique features of humankind that evolved over millions of years use the same area of the brain (Uomini & Meyer 2013). The earliest Oldowan tools were simply made by chipping off a stone core through direct percussion (Toth & Schick 2009). However, the ability to make a Lower Paleolithic hand axe depends on complex cognitive control by the prefrontal cortex (Stout et al. 2015).

Acheulean axes from 1.7 million years ago had symmetrical edges that were shaped by chipping flakes off both sides with a stone or bone (Lepre et al. 2011). A simple form of human-like communication is a prerequisite for the widespread use of Acheulean tools. Some researchers hypothesise that creativity is responsible for driving innovation of technologies, but the importance of the diffusion of an invention surpasses the original invention (Diamond 1998). The receptivity of whole societies to the invention leaves an archaeological mark. As Diamond (1999) stated, “Invention is the mother of necessity”. Innovative tools are often created out of curiosity and are later adopted or popularised for widespread commercial use. This phenomenon is also observed in our closest cousins, the bonobo chimpanzees, who use a wide variety of tools. Two such distinguished individuals are Kanzi and his sister Panbanisha, both of whom are language-competent bonobos (*Pan paniscus*), who comprehend syntax and understand more than 2000 spoken words in English and use 480 words via their computer Lexigram symbol keyboard, have been able to design early Oldowan-type tools. Nevertheless, this does not imply that whole populations of chimpanzees have the adaptability or compatibility for such stone-age tools, although they have the potential to do so (Uddin et al. 2004; Arbib 2006; Savage-Rumbaugh et al. 2007; Roffman et al. 2012).

Consequently, some form of human language would have existed not only for devising Acheulean tools but also for promoting their universal use. Coincident with language-processing regions, strategic thinking for attaining the final product or for predicting the resulting flake relies on the prefrontal cortex and the posterior parietal lobe (Stout et al. 2015). Specifically, simple sounds of communication, such as the words *yes* and *no*, words used for planning and following step-by-step instructions, predicting where flakes will fall, and words that define egocentric direction, including *right* and *left*, are needed between tool-makers. In this regard, the prefrontal lobe controls cognition and language processing (Freberg 2006). Although a prolonged period of growth in humans is responsible for the enlarged prefrontal area, the lateral frontal pole of the ventrolateral prefrontal cortex, which is involved in strategic planning, is uniquely human (Neubert et al. 2014). Similar to the prefrontal cortex, the posterior parietal cortex increased in size during evolution. The posterior parietal lobe, which when damaged causes receptive aphasia, directs perceptual motor movements and comprises specialised regions for guiding planned movements of the eyes, head, arms, and hands (Buneo & Andersen 2006). The boundaries of the areas used for language, cognition, tool-making, etc., are not clearly defined, because individual variations occur and combinations of different regions frequently work together. The evolution of the brain, language, and tool-making was not limited to post-Acheulean development. Further studies have suggested that the basics of language, teaching, and learning were implanted earlier due to the development of Oldowan tool competencies (Morgan et al. 2015). Hominids gradually evolved to build more complex tools and became better at communicating. Because hominids did not have anatomical structures for enunciating, such as those found in modern humans, for a very long time, language would have consisted of short grunts that were easy to make and interpret. In addition, facial expressions and gestures, which are frequently documented in chimpanzees, would have aided hominid communication (Goodall 1986; Roberts et al. 2012a).

Before tool-making

Before sophisticated tool-making, the evolution of bipedalism and a male-provisioning, terrestrial life commenced, and this development paved the way for the development of future technologies. Lovejoy (1981) proposed that walking on two legs was the main adaptation that allowed pair-bonding to succeed, because carrying food with two hands was an effective way of transporting it. Originally, hominids were more foragers than hunters; thus, using two hands for gathering food promoted a relatively food-rich environment (Lovejoy 1988). Furthermore, hominids left the arboreal life as a result of the evolutionary advantages provided by life on the savannah, such as endurance running and thermo-regulation (Bramble & Lieberman 2004.

After hominids achieved bipedal walking and descended from trees, evolutionary anatomical changes that allowed delicate muscle movements occurred. In members of the genus *Homo*, the third metacarpal styloid process enabled the hand bone to lock into the wrist bones, permitting greater amounts of force to be applied by a grasping thumb and fingers (Ward et al. 2013). This provides humans the dexterity and strength to make and use complex tools. The earlier direct ancestors of the human lineage probably did not have a styloid process but possessed human-like trabecular patterns in their metacarpals (Skinner et al. 2015). Even 3.3 million years ago, as suggested by findings in Kenya, hominids had made and improved proto-Oldowan stone tools that helped them to survive (Harmand et al. 2015). Hominids could eventually employ selected muscle fibres for complex tool-making and cumulatively recruit more fibres for tasks that demand more power (Walker 2009). Humans gradually initiated technological advances to defend themselves against dangerous carnivores. They learnt to build primitive shelters and developed stone tools. Humans also began to hunt and were originally talented at aimed throwing and clubbing (Young 2003). Members of the genus *Homo* initially modified relatively simple Oldowan tools and then designed Acheulean (bifacial) hand axes that were more complex than those of the Oldowan culture (Faisal et al. 2010). Stone, hardwood, antler, or bone would have been used to produce the lens-shaped core that ends in symmetrical sides. More efficient weapons, such as spears and projectile points, were later developed in the Middle Paleolithic.

The control of fire by hominins was a pivotal point in evolution. The use of fire and safe shelters near a river or cave freed our ancestors from the necessity to be watchful at all times. Fire drove away predators and insects, allowed better tool-making, and provided additional warmth to early/pre-humans. Importantly, by cooking food, the later members of the genus *Homo* conserved energy during digestion, as indicated by studies conducted by Wrangham (2009). Fire enabled the inclusion of indigestible or toxic components of plants, such as starch, mature roots, tubers, raw cellulose, thick stems, enlarged leaves, and seeds, in the hominid diet. Archaeological evidence suggests that fire-making has been widely used for one million years, but fire-making would have begun much earlier (Goren-Inbar et al. 2004; Pruetz & LaDuke 2010). The size of the hominid brain increased steadily over time, but in the last million years, the brain size increased more rapidly (Berna et al. 2012; Buckner & Krienen 2013). This steeper increase in brain size is explained by the early control of fire by *H. erectus,* as it makes food easier to digest, and early/pre-humans would thus have had access to extra calories.

Tools or the brain: which came first?

Some scholars have stated that the increase in brain size allowed the development of complex tools and innovations, whereas others have claimed that tool use influenced human evolution. The chain of causation would have operated in both directions, but which came first remains debatable. The link between the evolution of tools, including fire, provisioning, and the evolution of the brain is a two-way process, and thus attempting to determine the first event in a circular cause-and-effect process is futile.

The hunting hypothesis proposes that human evolution was primarily influenced by the activity of hunting relatively large and fast animals (Ardrey 1976). Hunting differentiated human ancestors from earlier hominids (Washburn 1968). Advocates of the hunting hypothesis believe that the use of tools and effective hunting were a crucial part of human evolution; this is not compatible with scenarios that emphasize that the omnivorous status of the human social interaction, including mating behaviour, was essential to the emergence of language and culture. Buss (1999) noted that modern tribal societies use hunting as their primary means of acquiring food. Although humans eventually did hunt animals for meat, several findings do not support the hunter hypothesis.

First, humans are not physically adept or sufficiently strong to hunt down an animal without weapons. In the absence of efficient tools for catching animals, it is difficult for humans to obtain meat by killing other animals. A study conducted in the 1960s revealed that the strength of chimpanzees can reach twice that of a human (Edwards 1965). A study published in the *Proceedings of the Royal Society B* found that leaping bonobos can exert as much force as humans who are nearly twice their weight (Scholz et al. 2006). The maximum human sprint speed is also strikingly lower than that of many animals even though humans are able to run efficiently for an extended period of time (Bramble & Lieberman 2004; Lieberman et al., 2009). Prior to the widespread use of effective Upper Paleolithic tools, such as projectile points or spears, humans, due to their slow speed, could not have hunted animals. Of course, similar to chimpanzees, hominids occasionally caught and ate small animals, such as rabbits and small primates (Watts 2008: 54). Hominids also scavenged the meat of larger animals, but the general hominid diet could not have depended solely on unstable meat availability.

Some researchers may argue that humans could have hunted many animals using more complex forms of weapons. Nonetheless, sophisticated tools for hunting, such as spears, arrows, bows, and fishing nets, were developed later. Humans could initially construct simple Oldowan choppers, and from approximately 1.7 million years ago, hominids designed more complex, bifacial Acheulean hand axes (Lepre et al. 2011). The development of polished Middle Paleolithic weapons, such as the spear, axe, and arrow, required an extended period. The oldest throwing spears, known as Schöningen Spears, appeared 300,000 years ago, whereas the earliest arrows from South Africa date from 64,000 years ago (Thieme 1997). Effective weapons that could be used to hunt down animals were not developed until nearly the end of the human evolution timeline.

Furthermore, evidence suggests that the evolutionary precursors of *Homo sapiens* were engaged in entomophagy. Coprolites found in Ozark Mountain caves were shown to contain ants, beetle larvae, lice, ticks, and mites (Reinhard & Bryant 1992). Cave paintings in Altamira, northern Spain, which dated from approximately 30,000 to 9,000 BC, depict the collecting of edible insects and wild bee nests, possibly indicating an entomophagous society (McGrew 2014). Cocoons of wild silkworms (*Theophila religiosae*) were discovered in ruins in the Shanxi province of China from 2,000 to 2,500 years BC. The uncovered cocoons had large holes, indicating that the pupae were consumed (Capinera 2004). Similar to the other great apes, humans ate fruits, nuts, plant seeds, and tubers, in addition to insects, and their main source of protein would have been insects, rather than animal meat (Copeland 2009: 57; Yen & Paoletti 2005; Van Huis 2003: 23). To this day, the diets of aboriginal populations, hunter-gatherers, and people in underdeveloped nations consist mostly of fruits, plants, and/or insects, in addition to small animals (Zhi-Yi 1997; Yen 2009).

The downsizing of human teeth has been observed in early hominids, and humans could not have evolved to eat raw meat. A reduction (“feminisation”) in the male canine teeth was observed in early hominids, and some body-size dimorphism was seen in *Ardipithecus* and *Australopithecus*. A reduction of the inter-male antagonistic behaviour was also observed in early hominids, and the hominid body size had also decreased in this period.

Fire drives away predators and insects and provides additional warmth for humans, and allows components of plants that are not typically edible to be part of the hominid diet, and would give humans access to additional calories. Cooking food also allows humans to conserve energy during digestion. 'The energetic consequences of eating cooked meat are very high,' wrote Wrangham (2009). A study conducted by Carmody (2011) revealed that mice provided with cooked meat gained 29% more weight than mice that were fed raw meat over a period of five weeks. Mice eating raw calories weighed less, yet they consumed more meat (Carmody et al. 2011). In short, this hypothesis proposes that human evolution was driven by fire.

This hypothesis is very compelling, and there is no doubt that fire played a major role in evolution; however, this hypothesis is not without concerns. First, hominids did not initially have the ability to make fire, and the time at which fire control became widespread is controversial. Recent claims for the earliest definitive evidence regarding the control of fire by a member of the genus *Homo* date from 1 million years ago (Berna et al. 2012). Conscious fire-making, which would have required a complex knowledge set, would have been difficult for an ape-like ancestor. Wrangham suggests that humans were cooking their food as far back as the first appearance of *H. erectus* 1.9 million years ago. Nevertheless, fire alone cannot account for the evolution of the brain, because brain volume increased prior to the advent of fire (7–1.9 million years ago).

However, an important detail in human evolution is left out by this hypothesis: tool-making. Indisputably, making fire constitutes a great force in human evolution. However, fire-making was accompanied by the evolution of tool-making, which resulted in the gradual development of more sophisticated tools. At first, tools were nothing more than sticks or sharp rocks. Man-made tools started with simple Oldowan hand axes, and after some time, humans designed more complex bifacial scrapers and ficrons in the Acheulean industry. Efficient hunting tools, such as spear points, axes, and awls, which would have granted humans more security and strength, were developed in the Middle Paleolithic. Moreover, fire hardening, which is also known as fire-polishing, a process that removes the moisture from wood and changes its structure and properties by charring the tool over a fire, was an increasing trend in weapon-making (Toth & Schick 2015). This process increases the durability of the projectile points of a spear or a knife.

In addition, previous studies have proven that fire increases caloric intake. However, the fire hypothesis presumes that conserved calories from cooking would fuel brain evolution (Fonseca & Herculano 2012). It is true that the tremendous amounts of energy used by the modern brain require the eating of cooked foods. Nevertheless, this does not explain what type of evolutionary pressure would direct the extra energy saved from cooking toward the evolution of the brain. Long before hominins used fire, sociality was the evolutionary momentum that directed the energy saved by fire toward the evolution of the brain. Only in the context of the progression of evolution, where tool-making and fire contributes to increases in sociality and intelligence, can the use of fire direct conserved energy to the evolution of a larger brain.

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Povzetek

Čeprav je opredelitev inteligentnosti sporno, jo lahko omejimo le na eno anatomsko lokacijo: možgane. Argumenti, ki se nanašajo na splošne mere živalske inteligentnosti in razprave glede njenega razvoja do neandertalcev so nastale samo zato, ker so se pri človečnjakih razvili večji možgani, se pravi, da so postali bolj "inteligentni". Človečnjaki so se seveda razvil v preteklosti, ampak še vedno poteka razprava o tem, ali se razvijajo še naprej. Ironično je, da zato, ker so človečnjaki ustvarili tehnologije in inovacije, ki jim lajšajo preživetje, njihova evolucija sedaj vsebuje tudi prilagoditve okolju, ki so ga ustvarili ti izumi. Podobno kot pri nedavnem razvoju ADHD in glutenske intolerance, so se možgani človečnjakov v zadnjih sedmih milijonih letih najbolj sprrmenili zaradi antropogenih okolij in tehnologij. Izdelovanje orodja ustvarja okolje, ki spodbuja socialne interakcije, saj povečuje dostopnost stvari in zaščito, večje možnosti za interakcijo in opazovanja pa vodijo do napredka na področju izdelave orodja. Te spremembe je sprožil sočasni razvoja jezika in izdelovanja orodja. Biološko so se možgani človečnjakov povečali na področjih, kjer sovpadata izdelovanje orodja in jezik. To povečanje možganov je omogočilo napreden dostop do stvari in orodij, vključno z uporabo ognja in tehnološkim napredkom v času paleolitika, ki je temeljilo na prejšnjih evolucijskih novostih bipedalizma ter vsestranske rabe rok in je pospešilo dinamiko razvoja možganov. Začetkov vzajemnih vzrokov in posledic med razvojem možganov in izdelavo orodja ni mogoče določiti, zaradi česar nadaljujemo diskusijo o hipotezi ognja in lovstva kot dejavnikov evolucije človeške inteligentnosti.

KLJUČNE BESEDE: Acheulean, homo habilis, Oldowan, paleolitik, čelni korteks

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