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THE HUMAN BRAIN EVOLVING:

Paleoneurological Studies in Honor of Ralph L. Holloway

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FRONT COVER CAPTIONS

Center: Portrait of Ralph L. Holloway.
Upper left: A modern human brain.
Upper right: Ralph measuring landmarks on an endocast ca. 1976.
Lower right: Homo habilis cranium KNM-ER-1813 from Koobi Fora, Kenya (photo by Holloway).
Lower left: Ralph with an endocast of the Flores "hobbit" cranium.

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CHAPTER 19

Hominin Brain Reorganization, Technological Change, and Cognitive Complexity

Nicholas Toth and Kathy Schick

Abstract

This chapter will discuss the relationships between hominin brain evolution (encephalization, reorganization) and the prehistoric archaeological record, most notably prehistoric technological material culture and behavioral patterns, to assess the cognitive capabilities evident within different grades of hominins through time. Seven time intervals, spanning from 3.25 million years ago to the present, are sampled to examine major changes in hominin evolution, technology, and behavior over that period of time. Holloway *et al*.'s (2004) proposed three major stages of hominin brain evolution will be discussed in this context. We will argue that each of these three stages appear to be correlated with important changes in material culture and behavior as well. Hypotheses that attempt to explain the causes of hominin encephalization and brain reorganization are discussed.

Key Words

Brain evolution, evolution of human cognition, Palaeolithic archaeology, stone tools

Introduction

"The earliest phases of hominid existence are particularly open to speculative embroidery. But when all is said and done, it remains the stone tool industries or traditions that can inform us most about hominid cognitive abilities. This does not mean that we disregard archaeological contexts such as the faunal remains, home bases, the evidence (or lack of it) for fire, importation over long distances of stones used in making tools, de-fleshing carcasses, or even cannibalism. Holloway (1967, 1969, 1981) suggested that stone tool making and language might have had similar cognitive underpinnings, particularly if the stone tools showed clear evidence of standardization of form from elements (e.g. cobbles) that had very different initial shapes."

Ralph Holloway, Douglas Broadfield, and Michael Yuan, 2004. *The Human Fossil Record, Volume Three: Brain Endocasts - The Paleoneurological Evidence.* Hoboken: John Wiley & Sons. Pp. 288-289.

"If brains were lard, Jethro couldn't grease a skillet."

Jed Clampett discussing his hapless nephew in the 1960's sitcom *The Beverly Hillbillies*.

The hominin fossil record, built up over the past 150 years, has shown us many of the major trends in human evolution pertaining to anatomy and functional morphology. Studies of extant non-mammalian and mammalian (of particular interest, primate) species have shown us relationships between brain anatomy and behavioral, perceptual, and problem-solving capabilities. Ralph Holloway has been at the forefront of human brain evolution studies for over four decades. We have personally known him for three of those decades, and have valued his scholarship, collegiality, and friendship. This chapter is inspired by the corpus of work that Ralph and his colleagues have done in paleoneurology, and the impact this work has had in human origins research.

The human palaeontological record and the prehistoric archaeological record are the two major lines of evidence that shed light on the evolution of human cognitive abilities. Brain endocasts from fossil hominin crania can yield important information regarding brain size, possible brain to body relationships, and brain structure and organization. The archaeological record can yield important information regarding technological patterns, foresight and planning, skill, cognitive capabilities, and dexterity. In this chapter we will review the human palaeontological and archaeological record, sampling time intervals of 500,000 years to explore the relationships between hominin brain reorganization, technological change, and cognitive complexity. We will examine the major stages of brain evolution forwarded by Holloway *et al.* (2004) and see whether these appear to be roughly contemporaneous with behavioral punctuations in the prehistoric archaeological record.

As palaeoanthropologists and experimental archaeologists focusing on Palaeolithic archaeology, we each have over 35 years of experience in stone-knapping and other forms of material culture over a wide range of human technologies through time. This experience hopefully gives us enhanced insights into the level of skill and planning that is required to produce a given artifact form or set of artifacts, as well as into what types of prehistoric artifacts may have been intentionally produced or simply represent by-products of manufacture or use. We also have extensive experience in experimentally using stone tools for a host of activities, including animal butchery for meat consumption, bone-breaking for marrow and brain tissue processing, nut-cracking, wood-working, hide-scraping, etc. These experiments have provided us a wealth of experience to inform insights into the subtle relationships between tool form and tool function.

In past publications we have discussed aspects of the relationships between prehistoric material culture and hominin brain evolution and cognition, including Schick and Toth, 1993, 2009; Toth, 1985a, 1985b, 1990;Toth and Schick, 1993, 2006; Toth, Schick, and Semaw, 2006; Stout *et al.*, 2000, 2006, 2009, 2010. We refer the reader to a number of other publications involving hominin brain evolution and the archaeological record, for example Allman, 2000; Ambrose, 2001; Bar Yosef, 2002; Coolidge and Wynn, 2009; Deacon, 1997; Falk, 1987; Gibson, 1986; Gowlett, 1996; Gibson and Ingold, 1993; Holloway, 1967, 1969, 1981; Isaac, 1986; Lindly and Clark, 1990; McBrearty and Brooks, 2000; McGrew, 1992; Mellars and Gibson, 1996; Mellars et al., 2007; Mithen, 1996; Noble and Davidson, 1996; Parker and Gibson, 1979; Parker and McKinney, 1999; Pelegrin, 2005; Renfrew and Scarre, 1998; Renfrew *et al.* 2009; Roux and Bril, 2005; Schoenemann, 2006; Stout 2002, 2005a, 2005b, 2006; Washburn 1959, 1960; Wynn 1989; and Wynn and McGrew 1989. For overviews of the Palaeolithic archaeological record, see Ambrose, 2001; Delson *et al.*, 2000; Klein, 2009; Oakley, 1976; Schick and Toth, 1993; Toth and Schick, 2007.

This chapter will use the conventional designations for geological periods as opposed of the highly controversial restructuring of the Plio-Pleistocene boundary: here we will show dates for the Pliocene (ca. 5.3 to 1.8 million years ago); Early Pleistocene (ca. 1.8 million to 780,000 years ago); Middle Pleistocene (ca. 780,000-125,000 year ago); Late Pleistocene (ca. 125,000 years ago to 11,000 years ago); Holocene (11,000 years ago to the present.) The dating of hominin fossils, notably those found on the surface in contexts without applicable radiometric dating techniques, is sometimes ambiguous, so we have been as cautious as possible in assigning dates to these important fossils. The earliest dates for *Homo erectus* are somewhat controversial, but here we will use a date of approximately 1.75 million years.

There is much debate regarding the taxonomic status of early hominin fossil as well as evolutionary ancestor-descendant relationships between taxa. In this chapter we will take a conservative position, for example sometimes grouping the taxa *Homo rudolfensis* and *Homo habilis* into "early *Homo*." We group the proposed taxa *Homo ergaster, Homo georgicus,* and *Homo antecessor* into *Homo erectus*. We also group most non-*erectus* hominin fossils between 750,000 and 250,000 years ago into *Homo heidelbergensis* (what some researchers prefer to call "archaic *Homo sapiens."* We will assign the Neandertals to their own taxon, *Homo* neandertalensis, although some anthropologists would include them in our own species. We will also group most non-Neandertal fossils of the last 250,000 years (excluding relict *Homo* erectus fossils of East Asia and the enigmatic Flores fossils) into *Homo sapiens* (anatomically modern or near-modern humans). This includes all of the African fossils from North Africa and Sub-Saharan Africa in this time period. In this chapter we will also use the mean cranial capacities of hominin taxa and estimated anthropocentric encephalization quotient or EQ (modern human =1.00; modern chimpanzees = 0.34) reported by Holloway *et al.* (2004).

While it is appreciated that at any stage of human evolution, we can only be sure we are seeing *minimal*, but not necessarily *maximal* expressions of cognitive abilities in the form of the material culture and behavioral patterns of prehistoric hominins (for example the relatively simple, traditional material culture of the protohistoric Tasmanians is the product of one *Homo sapiens* society with modern cognitive and language abilities, but clearly not manifesting such complex abilities in their tools and technology relative to contemporary agricultural and industrialized societies), this is nonetheless the most important and reliable source of information that we can recover in the archaeological record. We can also search for the most complex and exceptional forms of material culture at a particular stage of human evolution to see evidence for the most advanced level of cognitive abilities and skill manifested at that time.

Stages of Hominin Brain Evolution (Holloway et al., 2004)

Holloway *et al.* (2004, pp. 289-291) has proposed three major stages of hominin brain reorganization (here we will also add a "Stage 0" to denote a hypothetical ape-like last common African ape/human ancestor):

STAGE 0: Last common ancestor of African chimpanzees/bonobos and hominins (ca. 7-8 million years ago). Ape-like features of brain organization (hypothetical) might include:

a. An ape-like, anterior position of the lunate sulcus indicating more primary visual cortex than seen in hominins
b. Less posterior association cortex than seen in hominins
c. An overall African ape-like (gorilla-, chimpanzee-, bonobo-like) size (ca. 350-450 cc) and ape-like organization of the brain

STAGE 1: Earlier australopithecine grade (e.g. *Australopithecus afarensis* and *africanus*, by ca. 3.5 million years ago). Neurological and cognitive changes at this stage include:

a. Reduction of primary visual cortex (as seen in a more posterior position of the lunate sulcus)
b. Relative increase in posterior association cortex (a human-like pattern)
c. A reorganization of the brain before any major expansion in overall brain size
d. The beginnings of a development in cerebral asymmetries (beyond that seen in modern apes?)
e. By inference, the possibility of more foresight and memory as compared to modern apes

STAGE 2: early Homo grade (e.g. *Homo rudolfensis*, *Homo habilis*, early *Homo ergaster*/*erectus*, by ca. 1.9 million years ago). Neurological and cognitive changes at this stage include:

a. An overall increase in brain volume and encephalization quotient
b. Clear-cut and modern human-like brain asymmetries
c. A prominent Broca's cap region
d. By inference, more strongly developed language capabilities and language behavior
e. By inference, increased postnatal development and learning
f. By inference, social leaning in tool-making, hunting, collecting, scavenging, and reproductive strategies

STAGE 3: *Homo heidelbergensis*/*neandertalensis*/*sapiens* grade (by ca. 500,000 years ago to present). Neurological and cognitive changes at this stage include:

a. An overall increase in brain size and encephalization quotient
b. Refinement in hemispherical asymmetries and specializations for visuospatial, verbal, and sociality skills
c. By inference, growing elaboration of cultural skills based on language
e. By inference, arbitrary symbol systems
f. By inference, feedback between behavioral complexity (including stone technology) and brain enlargement

The authors point out that there is little structural or brain size difference evident (based on endocasts) between *Homo heidelbergesis, neandertalensis,* and *sapiens.*

Theories of Encephalization and Hominin Cognitive Evolution

There is a general appreciation that, in primate evolution, larger brains and larger brain/body size ratios are correlated with higher cognitive skills. Popular theories of *why* hominins became encephalized and more cognitively complex has been vigorously debated. One complication in this debate is that many hypotheses have been difficult or impossible to test in the prehistoric record, at least at our present state of knowledge and methodological sophistication. To date, there does not seem to be one overarching theory that has been championed by palaeoanthropologists and palaeoneurologists. Various theories offered to help explain the profound encephalization observed in the course of hominin evolution have included the extracted food hypothesis (Gibson, 1986, 2002), the predation hypothesis (Shipman and Walker, 1989), the social brain hypothesis (Dunbar 1992, 1993, 2003), the expensive tissue hypothesis (Aiello and Wheeler, 1995), the maternal energy hypothesis (Martin, 1996, this volume), and the symbolic hypothesis (Deacon, 1997).

Rationale for this Study and The Time Intervals Sampled Here

We have decided to sample human evolutionary time in half-million year intervals (with the exception of the last time period sampled being the last 250,000 years) in order to see robust changes in hominin brain evolution and material culture as manifested in the prehistoric record. The intervals that we have selected, in our opinion, best show the emergence of new hominin taxa and, potentially, new patterns of hominin neurological reorganization. These neurological changes will be correlated with changes in the material culture and known behavior of these hominins. We have started our first time interval (Time Interval One) to include a phase which pre-dates any definite archaeological record. Time Interval Two includes the emergence of the first definitive flaked stone tools. For each time interval, we will normally only cover the *new* technological and behavioral traits that emerge for the first time in the prehistoric record; it can be assumed that traits that emerged in previous time intervals continue on in more recent times.

Our time intervals and the most encephalized hominins are:

Time Interval One: (3.25-2.75 Ma) *Australopithecus afarensis (*Holloway *et al.* Stage 1)
Time Interval Two: (2.75-2.25 Ma) *Australopithecus garhi/africanus* (Holloway *et al.* Stage 1)

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Time Interval Three: (2.25-1.75 Ma) early *Homo (habilis/rudolfensis)* (Holloway et. al. Stage 2)
Time Interval Four: (1.75-1.25 Ma) early *Homo erectus* (Holloway *et al.* Stage 2)
Time Interval Five: (1.25-0.75 Ma) later *Homo erectus* (Holloway *et al.* Stage 2)

…………………………………………………..

Time Interval Six: (0.75-0.25 Ma) *Homo heidelbergensis* (Holloway *et al.* Stage 3)
Time Interval Seven: (0.25 Ma-present) *Homo neandertalensis/H. sapiens* (Holloway *et al.* Stage 3)

An Examination of the Prehistoric Archaeological Record

Please note: For further general information and detailed references for the sites, fossils, taxa, and archaeological localities discussed here, the reader is referred to encyclopedic references in the field such as Klein (2009) and Delson et al. (2000). References included here will center on specific information and arguments made regarding the subjects discussed below.

Time Interval One: 3.25 Million to 2.75 Million Years Ago (Middle Pliocene).

Overview: This is the time period of the small-brained bipedal hominin *Australopithecus afarensis*. There is no definitive archaeology associated with this hominin form, although there are footprints of three individuals in a volcanic ash deposit at Laetoli, Tanzania at 3.5 million years. (The Stage 1 brain reorganization may have happened at an earlier, *Ardipithecus*-grade hominin, possibly including fossils assigned to *Sahelanthropus* and Orrorin dating to between 4.5 and 6 million years ago, but this has yet to be demonstrated).

Most encephalized hominin: *Australopithecus afarensis.*

Holloway et al. brain evolution stage: Stage 1.

Key hominin cranial fossil sites: Hadar, Ethiopia.

Other fossil sites: Laetoli, Tanzania; Maka (Middle Awash), Ethiopia.

Average cranial capacity: 445 cc (Holloway *et al.*, 2004). For comparison, the mean for modern gorillas is 500 cc, and the mean for chimpanzees is 405 cc.

Estimated encephalization quotient (Homocentric): 0.43. For comparison, the mean EQ for gorillas is 0.24, and the mean for chimpanzees is 0.34.

Technological stage: unknown.

Discussion of the Archaeological Record

There is no definitive evidence of hominin modified stones, bones, or other materials during this time period. Based on own knowledge of chimpanzee material culture and cultural traits (McGrew, 1992; Whiten *et al.* 1999), we can speculate on a range of possible types of tool-use and other types of cultural phenomenon, but without hard prehistoric evidence it still remains a matter of conjecture. In a study carried out by the authors (Toth and Schick, 2009d; Whiten *et al.* 2009), the relationship between the number of shared cultural traits in wild chimpanzees versus distance between study areas was carried out. At the subspecies level (but not the species level) a strong and statistically significant correlation was found, with study areas in closer proximity having more shared cultural traits than study areas further apart. At approximately 700 kilometers there was a drop-off of less than half the number of maximum shared traits (from a maximum of eight to less than four traits), which was used as a model for possible patterns of shared cultures among early hominin Early Stone Age archaeological sites. Archaeological localities closer than 700 kilometers (about 450 miles) to each other at a given time would theoretically share more cultural traits than sites more distant from each other.

It should be noted that a recent claim has been made for stone tool use and bone modification at approximately 3.4 million years (McPherron *et al.*, 2010). This is based on two surface mammal bones at Dikika, Ethiopia with alleged chop-marks and cut-marks. Since these bones were found on the surface, their provenience cannot be ascertained with confidence, and a number of researchers have voiced skepticism regarding the cut-mark evidence, e.g. Dominguez-Rodrigo *et al*., 2010 and Shipman, 2010. There have been four decades of research in fossiliferous deposits between 2.6 and 3.5 million years ago, and not one stone artifact or cut-marked bone has ever been discovered. Until such time as clear-cut modified stone artifacts or non-controversial tool-modified bones are found in a well-dated, stratified context, such claims must remain unsubstantiated.

Time Interval Two: 2.75 to 2.25 Million Years Ago (Later Pliocene)

Overview: This time interval documents the emergence of the first identifiable stone tools (Oldowan Industrial Complex) and new hominin taxa: in East Africa, the emergence of *Australopithecus garhi* and the megadont *Australopithecus (Paranthropus) aethiopicus*; in South Africa, the emergence of *Australopithecus africanus*. There does not appear to be a significant increase in brain size or EQ from the previous *Australopithecus afa-*

rensis time period. Surface occurrences of cut-marked bones are known also from this time period, notably from the Gona and the Middle Awash of Ethiopia.

Most encephalized hominins: *Australopithecus garhi*, *Australopithecus africanus*, *Australopithecus (Paranthropus) aethiopicus.*

Holloway et al. brain evolution stage: Stage 1.

Key hominin cranial fossil localities: Bouri, Middle Awash, Ethiopia (*A. garhi*); Sterkfontein, Makapansgat, and Taung, South Africa (*A. africanus*); West Turkana, Kenya [*A. (P.) aethiopicus*].

Average cranial capacity:

Australopithecus garhi: 450 cc (one specimen).

Australopithecus africanus: 461 cc.

Australopithecus (Paranthropus) aethiopicus: 431 cc (one specimen).

Estimated encephalization quotient (Homocentric): 0.46 (*A. africanus*).

Technological stage: early Oldowan.

Key archaeological sites: Gona, Hadar, and Omo, Ethiopia; Lokalalei (West Turkana), Kenya.

Discussion of the Archaeological Record

It is during this time interval that the first clear evidence of hominin material culture is found. The archaeological sites from this time are all on the African continent. At Gona in the Afar Rift region of Ethiopia, several sites (EG-10, EG-12, OGS-6, OGS-7, DAN 1, DAS 7) are dated to between 2.6 and 2.5 million years ago. Several sites are dated to approximately 2.3 million years ago: sites AL-666 and AL-894 at Hadar, Ethiopia; sites Omo 71, Omo 84, Omo 57, Omo 123, FtJj1, FtJi2, and FtJi5 in the Omo Valley, Ethiopia; and sites Lokalalei 1 and 2c at West Turkana, Kenya. Stone artifacts have also been found in situ at the Pliocene site of Ain Boucherit in Algeria, and biostratigraphy may suggest a similar date (M. Sahnouni, pers. comm.) The archaeological record is characterized by:

- A **simple Oldowan technology**, normally with river cobbles or chunks knapped to produce sharp flakes and fragments. **Unifacial and bifacial chopper cores** are most common, with polyhedrons, heavy-duty scrapers, and discoids also present. Experimentation has shown that these core forms can be produced as a by-product of flake production, although some of the larger, sharper cores could have been used for wood-working or other activities. Summaries of the Oldowan include Schick and Toth, 2006 and Semaw, 2006.

- **Battered percussors** are found in the form of river cobbles that exhibit battering and small-scale flaking on discrete cortical surfaces, indicating their use as a hammerstones.

- **Flakes and fragments** struck from cores, normally **unmodified** (not retouched).

- **Later stages of cobble reduction** (Toth *et al.*, 1985b, 2006) are typical at many sites, suggesting transport of partially-flaked cores and further reduction at the excavated sites.

- Even in this early period there seems to be some indication of **selection for higher-quality raw materials** and **some transport of stone** from their sources (mainly river gravels flowing out of volcanic highlands and quartz-rich outcrops).

- Probable **cut-marks, chop-marks, and hammerstone striations** on animal bones, indicating processing with stone tools for meat and marrow/brains. Surface bones from Gona and bones from the Hata Beds in the Middle Awash of Ethiopia show such features, but confirmation of these features from in situ, excavated, stratified sites (as we will see in the next time interval) will be important in the future.

Experiments with bonobos (Toth *et al.*, 1993, 2006; Schick *et al.*, 1999) have shown that these modern apes (with average cranial capacities just slightly smaller than *Australopithecus garhi*) can master the basic principles of percussive stone fracture of unmodified Gona volcanic cobbles, although the resultant products appear to show less knapping skill than that of the early Oldowan hominins 2.6 million years ago at Gona, Ethiopia. In particular, the bonobo cores are less reduced and show more battering on core edges from unsuccessful hammerstone blows. The evidence suggests that the bonobos are striking the cores with their hammerstones at a significantly lower velocity than the Gona hominins, so that the major differences in skill in stone knapping may be more biomechanical than cognitive.

It would appear that, at our present state of knowledge, the earliest known stone tool-makers were relatively small-brained, bipedal australopithecines that exhibit no evidence of marked encephalization or evidence of a significant tooth reduction. Nonetheless, the earliest flaked stone artifacts suggest a gradual technological and adaptive shift towards the human condition. Whether even earlier Palaeolithic archaeological sites, possibly from Time Interval One (3.25-2.75 million years ago), will be found still remains uncertain.

Time Interval Three: 2.25 to 1.75 Million Years Ago (Late Pliocene/Early Pleistocene)

Overview: This is the beginning of Holloway *et al.*'s brain evolution Stage 2. There is clear evidence of encephalization and probable rise in EQ of these forms, probably important reorganization in the hominin brain leading to more profound hemispheric asymmetries (petalias), and possibly preferential right-handedness in these tool-making populations (Toth, 1985a).

Most encephalized hominins: *Homo habilis/ rudolfensis.*

Holloway et al. brain evolution stage: Stage 2.

Other hominins: *Australopithecus (Paranthropus) boisei/robustus.*

Key hominin cranial fossil localities: Koobi Fora (East Turkana), Kenya; Olduvai Gorge (Bed I), Tanzania.

Average cranial capacity:

Homo rudolfensis: 788 cc.

Homo habilis: 610 cc.

"Early *Homo*": 698 cc.

Estimated encephalization quotient:

Homo rudolfensis: 0.66.

Homo habilis: 0.62.

"Early *Homo*": ca 0.64.

Key archaeological sites: Fejej, Ethiopia; East Turkana (KBS Member sites) and Kanjera, Kenya; Bed 1 Olduvai Gorge (Bed I), Tanzania; Ain Hanech and El-Kherba, Algeria; Sterkfontein, and Kromdraai, South Africa.

Technological stage: Oldowan and Developed Oldowan.

Discussion of the Archaeological Record

A larger number of sites date to this time interval compared to the previous time interval. This suggests that flaked stone technologies were becoming more widespread and there was more habitual use of flaked and battered stone technology in these hominin populations. All of the sites in this time period would be grouped into the Oldowan Industrial Complex.

- Oldowan **archaeological sites become more common** in this time interval, all found on the African continent.

- For the first time, **retouched forms,** usually made on flakes or flake fragments (such as "**scrapers**" and "**awls**") become common at some sites after two million years ago. Such retouch might be done to resharpen an edge. Experiments have shown that such retouched denticulated ("toothed") flake edges make very good, long-lasting butchery knives (Toth and Schick, 2009c, in press). Retouch may also be done to shape or strengthen an edge for a specific activity, such as scraping wood or hide, or to remove irregularities or spurs along edges to make the tools more ergonomic in the hand. Based on the fact that it does not appear that hominins prior to 2.0 million years were retouching edges to any great extent, and that our experimental program with bonobos has not shown them to retouch flake edges (even when given a flake whose edge has been ground down to make cutting impossible), it is likely that such lithic retouch of flake edges may require more complex cognitive abilities. For the first time, hominins appear to be *intentionally* shaping stone, albeit in a simple way.

- Highly battered **spheroids and subspheroids** in quartz and lava become more common in this time interval. Experiments have shown that these forms are probably hammerstones, some of which were used for several hours of knapping, either because the spheroid/subspheroid was carried around or because sites were revisited on a regular basis and the hammers re-used (Schick and Toth, 1994; Toth and Schick, 2009c). Using a quartz hammerstone for four hours can produce thousands of flaked stone artifacts (fragments, flakes, cores), so that this time could have been spread over weeks or months.

- **Cut-marks** on animal bones are present at a number of sites, especially at the FLK Zinj site in Bed I of Olduvai Gorge show that early hominins were **exploiting a wide range of large mammals**. Whether these animals were obtained through more passive scavenging (e.g remains of carnivores, or carcasses obtained from streams during migrations), confrontational scavenging, or active hunting is hotly debated by zooarchaeologists.

- Although most raw materials were obtained within a few kilometers of archaeological sites, some sites suggest **transport of some rock for longer distances**, on the order of ten to twenty kilometers. This is far beyond the range of transport of food or tools by chimpanzees today.

Time Interval Four: 1.75 to 1.25 Million Years Ago (Early Pleistocene)

Overview: This time interval documents the emergence of *Homo erectus* and the disappearance of other forms of early *Homo*. Early *Homo erectus* (sometimes called *Homo ergaster*) had a significantly larger brain than earlier and other contemporary hominin forms and had body proportions more like modern humans. The first evidence of hominins outside of Africa is found early in this time interval. The earliest Acheulean handaxe and cleaver industries are also found in this time interval.

Most encephalized hominins: earlier *Homo erectus (ergaster/georgicus).*

Holloway et al. brain evolution stage: Stage 2.

Other hominins: *Homo habilis* (?relict populations); *Australopithecus (Paranthropus) boisei/robustus.*

Key hominin cranial fossil localities: Gona, Ethiopia; Koobi Fora (East Turkana), Nariokotome (West Turkana), Kenya; Olduvai Gorge (Bed II), Tanzania; Nyambusosi, Uganda; Swartkrans, South Africa; 'Ubeidiya, Israel; Dmanisi, Republic of Georgia; Sangiran, Java.

Average cranial capacity: ca. 800 cc.

Estimated encephalization quotient: 0.58.

Key archaeological sites: Konso Gardula, Melka Kunture, Ethiopia; East Turkana (Okote Member sites) and Chesowanja, Kenya. Olduvai Gorge (Bed II) and Peninj, Tanzania; Nyambusosi, Uganda; Swartkrans, South Africa; Dmanisi, Republic of Georgia; 'Ubeidiya, Israel.

Technological stage: early Acheulean (and simpler industries).

Discussion of the Archaeological Record

This time interval includes typical Oldowan sites and so-called "Developed Oldowan" sites (with more retouched forms and battered spheroids and subspheroids), and the emergence of the first Acheulean sites.

- Early Acheulean forms include crude **handaxes, cleavers, and picks** made on **large flakes** struck from boulder-cores (usually lava, quartz, or quartzite) or made on **large cobbles**. Much of the rest of the stone technology associated with early Acheulean sites is very similar to Oldowan and Developed Oldowan assemblages.
- This time period witnesses the first evidence of hominins out of Africa and **dispersal into Eurasia** at sites such as Dmanisi in the Republic of Georgia, 'Ubeidiya in Israel, and Sangiran in Java.
- Although there is evidence for the presence of **fire** at some sites (e.g. Swartkrans Cave in South Africa and the FxJj20 site complex at Koobi Fora, Kenya), it cannot be demonstrated that hominins were the agents of manufacture or use of fire, and these burnt bones and/or thermally fractured stone artifacts could be the result of natural fires sweeping across the landscape. Whether early hominins at this stage could have maintained naturally occurring fires for a certain time period cannot be demonstrated at our present state of knowledge.

Time Interval Five: 1.25 to 0.75 Million Years Ago (Later Early Pleistocene)

Overview: It is during this time interval that the robust australopithecines appear to go extinct, leaving *Homo erectus* as the sole hominin (in all its regional variations in Africa and Eurasia). Average cranial capacity appears to go up in this time interval (ca. 950 cc compared to 800 cc in the previous time interval). In much of Africa and the Near East there is a continuation of the Acheulean handaxe/cleaver industries, but Oldowan-like Mode 1 industries (sometimes called "Tayacian") are common in East Asia and Europe. This technological dichotomy is sometimes called the "Movius Line" after Harvard professor Hallum Movius who was one of the first to note this (Movius, 1948; Schick, 1994).

Most encephalized hominin: later *Homo erectus.*

Holloway et al. brain evolution stage: Stage 2.

Other hominins: possibly *Austalopithecus (Paranthropus) boisei/robustus.*

Key hominin cranial fossil localities: Buia, Eritrea; Daka (Middle Awash), Ethiopia; Sambungmacan and Trinil, Java; Lantian, China; Atapuerca Gran Dolina (TD6), Spain; Ceprano, Italy.

Average cranial capacity: ca. 950 cc.

Estimated encephalization quotient: 0.68.

Technological stage: middle Acheulean (and simpler industries).

Key archaeological sites: Buia, Eritrea; Daka (Middle Awash), Ethiopia; Olorgesailie and Kariandusi, Kenya; Olduvai Gorge (Beds 3 and 4 and Masek Beds); Ternifine (Tighenif), Algeria; Gesher Benot Ya'aqov, Israel; Orce and Atapuerca Gran Dolina, Spain; Nihewan Basin, China.

Discussion of the Archaeological Record

- During this time interval we see **better-made handaxes and cleavers**, more symmetrical and more extensively flaked. Examples of typical Acheulean forms come from sites in the Buia area of Eritrea; sites in the Daka member of the Middle Awash, Ethiopia; Olorgesailie, Kenya; Ternifine, Algeria; and Gesher Benot Ya'aqov in Israel. Hard-hammer percussion seems to be the technological norm in biface (handaxe and cleaver) production, often made on large flakes struck from boulder-cores. By this technological stage there are recurrences of very similar forms that suggest to us the emergence of **style** and a concept of a "**mental template"** or the idea of a distinct artifact form in the mind of the toolmaker (Deetz, 1967). Such templates become even more standardized in the subsequent later Acheulean, Middle Palaeolithic, and Upper Palaeolithic, to be discussed in later time intervals.
- There is evidence of the use of **fire** at Gesher Benot Ya'aqov in Israel (Goren-Inbar et al., 2004), but most sites of this time period do not show the use of fire in the form of hearth features or concentrations of burnt bones or stones. Fire-making is a very complex technology (most modern humans, even if they know the basic principles, cannot easily produce fire), so this may be evidence of the maintenance of natural brushfires rather than production. Consistent use (and presumably knowledge of manufacture) of fire does not appear until the subsequent time interval.
- Gesher Benot Ya'aqov in Israel also bears evidence of early **fish and crustacean (crab) exploitation** on the edge of an ancient lake in the Jordan Rift Valley (Alperson-Afil et al., 2009). Such exploitation will only become common in the last time scale (last 250,000 years).

- There is evidence for **nut-cracking** in the form of broken nuts (five species) and pitted anvils at Gesher Benot Ya'aqov in Israel, but since wild chimpanzees do similar activities, this is probably not a significant cognitive milestone (Goren-Inbar et al., 2002).

Time Interval Six: 750,000 to 250,000 Years Ago (Earlier Middle Pleistocene)

Overview: This time interval documents the emergence of the larger-brained *Homo heidelbergensis* (sometimes called "archaic *Homo sapiens*"). It also documents the development of finely made Acheulean handaxes and cleavers and a gradual shift to flake tool industries, some with prepared core technologies, of the Middle Stone Age/Middle Palaeolithic. The earliest wooden spears are known from this time as well as the first possible evidence of ritualistic behavior.

Holloway et al. brain evolution stage: The beginning of Stage 3. Hominins in Africa, Europe, and western Asia show encephalization (about 300 cc larger than later *Homo erectus*).

Most encephalized hominins: *Homo heidelbergensis.*

Holloway et al. brain evolution stage: Stage 3.

Other hominins: *Homo erectus* (e.g. Asia, Java).

Key hominin cranial fossil localities: Bodo (Middle Awash) and Gona, Ethiopia; Ndutu, Tanzania; Kabwe (Broken Hill), Zambia; Saldanha, South Africa; Zuttiyeh and Tabun (lower levels), Israel; Swanscombe, England; Atapuerca Sima de Los Huesos, Spain; Arago, France; Altamura, Italy; Steinheim, Germany; Petralona, Greece; Narmada, India; Dalia and Yunxian, China.

Average cranial capacity: 1260 cc.

Estimated encephalization quotient: 0.81.

Technological stage: later Acheulean, early Middle Stone Age/Middle Palaeolithic (and simpler technologies).

Key archaeological sites: Bodo, Ethiopia; Olorgesailie, and Kapthurin, Kenya; Isimila, Tanzania; Kalambo Falls, Zambia; Elandsfontein and Montagu Cave, South Africa; Tihodaine, Algeria; Boxgrove, Hoxne, Clacton, and Swanscombe (England); Torralba, Ambrona, and Atapuerca Sima de Los Huesos (Spain); Arago Cave, Lazaret Cave, and Terra Amata (France), Isernia, Italy; Bilzingsleben and Schöningen (Germany); Vertesszollos, Hungary; Zhoukoudian, China.

Discussion of the Archaeological Record

A number of technological advances are observed in the archaeological record during this time interval. These include much more refined forms of artifacts, more formal tool forms, new and more elaborate techniques for tool production, new categories of tools in evidence at some sites, indirect evidence of improved hunting technology, and possible evidence of symbolic behavior, including the use of ocher pigments.

- **Refined handaxes and cleavers** (some made by a soft-hammer technique with careful platform preparation, as discussed below) become common in this time interval. Microwear analysis of later Acheulean handaxes from some well-preserved sites, e.g. Hoxne (Keeley, 1980) and Boxgrove (Mitchell, 1995; Pitts and Roberts, 1997; Roberts and Parfitt, 1999), indicate wear-patterns consistent with **animal butchery**.

- **Soft hammers** of antler, bone, or ivory or softer stone were evidently used at many localities to produce finely flaked stone artifacts beginning around 500,000 years ago. Use of such soft hammers is evident in the pattern of flaking observable in stone tools, and in some instances such soft hammers themselves have been found, e.g. antler and bone percussors from Boxgrove, England (Pitts and Roberts, 1997; Roberts and Parfitt, 1999). Use of such soft hammers allowed for thinner flakes and more controlled shaping of stone tools than did the use of harder stone hammers.

- **Platform preparation** on the edges of cores and bifaces becomes common in this time interval, especially at later Acheulean sites. Such striking platform preparation consists of steepening edges before flake removal, which normally produces flakes (e.g. Levallois flakes and points, handaxe thinning flakes) with "facetted" striking platforms (platforms showing multiple flake scars). Such careful preparation begins around 500,000 years ago.

- We think that **stylistic norms** become more prevalent and more clearly defined in later Acheulean times. Recurrent shapes suggest that hominin toolmakers had more formal "mental templates" than earlier hominins had, although not as standardized as later hominins. They also appear to have had more consistent control and skill in stone flaking. For example, at the later Acheulean site of Hargufia A4 in the Middle Awash, perhaps 300,000 years old, small lava handaxes made on flakes are remarkably similar in size, shape, and symmetry (de Heinzelin et al., 2000).

- **Prepared cores** appear sporadically in the latter part of this time interval, but become more common in the succeeding intervals.

- **Wooden spears** are seen at such well-preserved sites as Schöningen in Germany (ca. 400,000 years old) (Thieme, 1997, 1998, 2005) and the broken spear tip from Clacton in England (ca. 300,000) (Oakley et al., 1977). Carefully sharpened and shaped wooden spears suggest that they were part of hunting paraphernalia, either as hand-held stabbing weapons or as thrown projectiles.

- **Possible big-game hunting** has also been suggested at some sites such as the Acheulean site of Boxgrove in England (ca. 500,000 years ago). The remains from several rhinoceros and horse skeletons bear butchery marks from stone tools (Pitts and Roberts, 1997; Roberts and Parfitt, 1999).
- Micro-wear analysis on retouched flake scrapers from sites of this period (e.g. Clacton, Hoxne) (Keeley, 1980) indicate that a number of these tools were used for **hide-scraping**, suggesting that cured hides could have been used for such items as blankets, simple garments, thongs for stitching or tying things together, or containers.
- **Ground pigment** pieces from sites such as Twin Rivers, Zambia, are believed to be about 300,000 years old (Barham, 2002). These facetted pieces of hematite may have been ground to produce a powder to decorate an object (or body).
- Possible **ritualistic or funerary behavior** may be seen at the Atapuerca locality, Sima de Los Huesos (ca. 400,000 years ago), where the remains of approximately thirty individuals appear to have been disposed of down a forty-foot shaft in a cave (Arsuaga and Martinez, 2004). Found with this incredibly dense concentration of hominin bones was one well-made quartzite red handaxe, which may have been intentionally put there by the hominins. Such behavior is not seen again until the last 100,000 years.
- **Abstract decoration** may be seen in a geometric, evenly-spaced fan-shaped set of cut-marks on a fragment of elephant tibia from the site of Bilzingsleben in eastern Germany, estimated to be between 280,000 and 400,000 years ago (Mania and Mania, 2005). This is an unusual and anomalous occurrence, and such design will not be seen again until the last 100,000 years.
- At the Acheulean site of Berekhat Ram in the Golan Heights, dating to about 400,000 years ago a small lava pebble with three apparent linear grooves has been interpreted by some (but not all) palaeanthropologists as an enhancement to create a crude representation of a human figure (Goren-Inbar and Peltz, 1995). Convincing representations of human figures are only seen in the early Upper Palaeolithic of Europe in the last 40,000 years.

Time Interval Seven: 250,000 Years Ago to Present (Later Middle Pleistocene, Late Pleistocene, Holocene)

Overview: Hominin average brain size increases by about 200 cc over *Homo heidelbergensis* in the previous time interval. During this time, the Neandertals (*Homo neandertalensis*) emerged and flourished in cold-adapted conditions in Europe and parts of western Asia, going extinct ca. 30,000 years ago. Anatomically modern humans, *Homo sapiens*, emerged in Africa over 150,000 years ago and gradually spread to all inhabitable parts of the globe, including the Near East by about 100,000 years ago, much of Eurasia by 40,000 years ago, Sahul (the landmass when Australia, New Guinea, and Tasmania were connected at low sea levels) by 40,000 years ago and the Americas by 12,000 years ago.

Most encephalized hominins: *Homo neandertalensis and Homo sapiens.*

Holloway et al. brain evolution stage: Stage 3.

Other hominin taxa: possibly *Homo erectus* (East Asia and Java); *Homo floresiensis*(?)

Key hominin cranial fossil localities:

Neandertal: Devil's Tower and Forbes Quarry, Gibraltar; La Ferrassie, La Chapelle-aux-Saints, La Quina, Le Moustier and Saint-Cesaire, France; Feldhofer Grotto, Germany; Spy and Engis, Belgium; Krapina and Vindija, Croatia; Moldova, Ukraine; Grotta Guattari (Monte Circeo) and Saccopastore, Italy; Amud and Tabun, Israel; Shanidar, Iraq; Teshik-Tash, Uzbekistan.

Modern or near-modern human: Herto (Middle Awash) and Omo Kibbish, Ethiopia; Ngaloba, Tanzania; Florisbad, Border Cave, Fish Hoek (Skildergat), and Tuinplaas, South Africa; Singa, Sudan; Eyasi, Tanzania; Jebel Irhoud and Dar es Soltane, Morocco; Jebel Qafzeh and Skhul, Israel; Cro-Magnon, Solutre, Chancellade, Abri Pataud, and Combe Capelle, France; Vogelherd, Germany; Grimaldi Caves, Italy; Mladec, Zlaty Kun, Pavlov, Predmosti, Brno, Pavlov, and Dolni Vestonice, Czech Republic; Bacho Kiro, Bulgaria; Zhoukoudian Upper Cave, China; Lake Mungo and Kow Swamp, Australia.

Average cranial capacity:

Homo neandertalensis: 1427 cc.

Homo sapiens: 1496 cc (Pleistocene); today's humans: 1335 cc.

Estimated encephalization quotient:

Homo neandertalensis: 0.99.

Homo sapiens: 0.90 (this e.q. disparity relative to today's humans [1.00] may be due to overestimates of body size in the Pleistocene sample.)

Technological stage: very late Acheulean, Middle Palaeolithic/Middle Stone Age, Late Palaeolithic (Upper Palaeolithic, Later Stone Age, Palaeoindian, etc.)

Key archaeological sites:

1. Neandertal archaeological sites: La Ferrassie, Le Moustier, La Quina, Combe-Grenal, Pech de l'Aze, Arcy-sur-Cure, and Saint-Cesaire, France; La Cotte de St. Brelade, Jersey; Zafarraya, Spain; Tabun Cave, Amud Cave, Kebara Cave, and possibly Quneitra, Israel; Tata and Szeleta Cave, Hungary; Krapina, Croatia.

2. Modern or near modern human archaeological sites: Pietersburg, Klasies River Cave, Die Kelders Cave, Blombas Cave, Howieson's Poort, Apollo-11 Cave; Skildergat, Nelson Bay Cave, Border Cave, Eland Bay Cave, Pinnacle Point (Mossel Bay), and Rose Cottage Cave, South Africa; Mumba, Tanzania; Ishango, Zaire; Dar-es-Soltane, Morocco; Haua Fteah, Libya; Skhul, Qafzeh, and Boker Tachtit, Israel; Ksar 'Akil, Lenanon; Chauvet, Laugerie Haute, Abri Pautaud, Solutre, La Madeleine, Mas d'Azil, Enlene, Pincevent, and Lascaux Cave, France; Parpallo, Castillo, Altamira, Cueva Morin, and El Juyo, Spain; Vogelherd, Hohlenstein-Stadel, and Gonnersdorf, Germany; Dolni Vestonice and Pavlov, Czech Republic; Mezhirich and Menzin, Ukraine; Istallosko, Hungary; Kostienki and Sunghir, Russia; Mal'ta, Siberia; Zhoukoudien Upper Cave (China); Lake Mungo, Australia; Monte Verde, Chile; Blackwater Draw, United States.

Other contemporary hominins: *Homo erectus, Homo soloensis, Homo floresiensis*

Discussion of the Archaeological Record

A number of technological and behavioral changes emerge in the earlier part of this time interval associated with Neandertal populations. Sites bearing evidence of early modern humans early in this time period, contemporary with the Neandertal sites, also tend to show patterns similar to those observed at Neandertal sites. Late in this time interval, when Neandertal populations were declining and disappearing, many new behavioral and technological advances associated with fully modern humans emerge in the archaeological record.

Neandertal technological and behavioral traits include:

- **Retouched flake tools** predominate in the Neandertal Middle Palaeolithic (Mousterian) tool kit, notably side scrapers, denticulated scrapers, backed knives, and points.

- **Points**: Some stone point forms (Levallois points, retouched unifacial Mousterian points, bifacial "Blattspitzen" points) could have been hafted onto wooden shafts, for thrusting or thrown spears. Some of these points have thinned bases, possibly to facilitate this hafting. Unifacial points made on thin flakes are first known from the Middle Palaeolithic of Europe and the Near East.

- **Intentional burials** are known from Neandertal times (e.g. La Ferrassie, Le Moustier, and La Chapelle in France; Shanidar, Iraq; and Kebara in Israel) but usually without any clear grave goods.

- **Prepared cores**: Prepared core forms, most notably Levallois tortoise-cores and Levallois point cores are found in many Middle Stone Age/Middle Palaeolithic assemblages. Neandertals continue using prepared core methods for removing flakes of a predetermined shape. Most notable are disc-shaped Levallois tortoise-cores as well as Levallois point cores for removing triangular flakes. Such cores require careful preparation of the core topographical surface and also careful preparation of the striking platform in order to successfully remove the target flakes. This platform preparation usually included faceting (removing small flakes from the striking platform to steepen and strengthen an edge before flake removal) and carefully shaping the striking platform to isolate one area of high topography to strike with a percussor (giving the edge as shape that the French call the "chapeau de gendarme," showing the profile of a 19th century policeman's Napoleonic hat). These are quite sophisticated cognitive operations, requiring a good sense of three-dimensional geometry as well as the mechanics of stone fracture.

- There appears to be **more variability** in Neandertal lithic assemblages compared to earlier time periods. Archaeologists in Western Europe, for example, have identified a number of Middle Palaeolithic variants, including the Typical Mousterian, Denticulate Mousterian, Quina Mousterian, Ferrassie Mousterian, and Mousterian of Acheulean Tradition A and B. Explanations for these variants have included cultural, functional, and chronological ones. It can also be argued that there are **more tool types** than is seen in earlier time periods.

- **The Chatelperronian**: Late Neandertals in France, around 32,000 years ago, are associated at several sites with blade technologies, backed blades or points, and ornamentation in bone and ivory. This so-called Chatelperronian industry is contemporary with anatomically modern humans in France and Upper Palaeolithic (Aurignacian) blade technology. At present there is a lively debate regarding the nature of the Chatelperronian: Did it develop out of local Middle Palaeolithic tradition, was it adopted by contact with Aurignacian peoples, or is it the product of admixture of materials from Middle and overlying Upper Palaeolithic strata?

Anatomically modern human technological and behavioral traits:

Anatomically modern humans, in the first part of this time interval, show little or no major technological or behavioral differences with contemporary Neandertal populations. But as time goes on, much more complex technological and behavioral innovations can be seen. Major behavioral and technological innovations observed in sites associated with anatomically modern humans during the latter phases of the Pleistocene include:

- **Elaborate burials**: The first burials with elaborate grave goods are found associated with anatomically modern humans. Elaborate burials may include red ochre, stone or bone tools, as well as high-status items, possibly denoting social rank, at some sites. Instances include the very early burial at Skhul in Israel of a modern human male cradling a wild pig mandible approximately 90,000 years ago, and the very elaborate burial of several individuals at the 28,000 year-old site of Sunghir in Russia, including two juveniles and one 60-year old man, with thousands of small beads that appear to have been sewn onto clothing, the two juveniles flanked by long mammoth tusks, and many other special tools and materials accompanying the grave.

- **Blades**: Although sporadic blade industries are found in earlier times, systematic blade production based upon specially-prepared prismatic cores becomes prevalent in the Upper Palaeolithic/Later Stone Age as well as some Middle Stone Age industries of Subsaharan Africa (e.g. Howieson's Poort). Blades, which are flakes at least twice as long as they are wide, can be produced by hard hammer percussion, soft hammer percussion, and punch (indirect percussion) methods. Blades were made into a range of forms such as **end scrapers**, **burins**, **backed knives**, **awls**, and **points**.

- **Personal adornment**: The earliest probable beads are perforated shells from South Africa, North Africa, and the Levant. These include shells from Blombos Cave in South Africa, dated to approximately 80,000 years ago (Henshilwood et al., 2004), specimens from North Africa dated to approximately 82,000 years ago (Bouzouggar et al., 2007), and ones from Israel dated by chemical means to between 100,000 and 125,000 years ago (Vanhaeren et al., 2006). Interestingly, this may have been a short-lived or sporadic tradition, and the next probable beads are found in Kenya at Enkapune Ya Muto at about 40,000 years ago (Ambrose, 1998) and in the Aurignacian of Europe and the Near East between 40,000 and 35,000 years ago.

- **Abstract decoration**: A clear geometric designed was inscribed with a stone tool on a piece of ochre at Blombos Cave in South Africa, dated to between 75,000 and 100,000 years ago (Henshilwood et al., 2009). Abstract designs are well-known in the Upper Palaeolithic art traditions in cave paintings, engravings and mobilary art of Europe, and later around the world. Some of these designs may symbolically represent specific words or concepts, although this is very difficult to verify archaeologically. Although the precise meaning of this abstract art is unknown, it has been argued that much of it could be entopic hallucinatory images seen during shamanistic trances (Lewis-Williams, 2002). Other repetitive abstract designs might stand for specific words or concepts and be a form of incipient writing. Yet others classified as abstract may, in fact, be representational, perhaps illustrating traps, huts or tents, or geographical features.

- **Very refined stone tools**: By the later Upper Palaeolithic of Europe, incredibly skilled stone tools were being made, such as the bifacial Solutrean leaf points. Heat treatment was also reportedly used on silcretes at the site of Pinnacle Point in South Africa about 72,000 years ago (Brown et al., 2009). Possible evidence of pressure flaking has been argued for some bifacial points at the site of Blombos in South Africa from approximately 80,000 years ago (Moure and Henshilwood, 2010), but in our judgement the flaking of these pieces appears to be indistinguishable from delicate soft hammer retouch.

- **Bone, antler, and ivory tools**: Bone tools (excepting soft hammers for knapping) are very rare prior to the Upper Palaeolithic/Later Stone Age. Beginning about 40,000 years ago, there is a major technological shift to other materials that can be shaped into a range of forms that might not be possible in stone, notably needles, spear throwers, and barbed harpoons. These materials would have been worked with stone tools such as burins and scrapers. Other artifacts include points, perforated batons, and pressure flakers.

- **Ground stone tools**: Archaeological evidence from Australia indicates that hunter-gatherers there began to manufacture ground stone axes beginning possibly about 35,000 years ago (Australian Archaeology, December 2010; Morwood and Trezise, 1989). Ground stone tools such as axes are normally not as sharp as a flaked stone tool, but ground edges can stay functional for longer periods of time before resharpening (re-grinding) is required. Ground axes are a substantial investment in time (requiring hours or even days to produce) and are normally hafted to a handle with some form of binding material (hide, sinew, vine, vegetable cordage, adhesive mastic, etc.) Such ground stone tools become especially common in the last 10,000 years with the rise of agricultural communities around the world as forests were cleared to plant crops.

- **Representational art**: The first clear evidence of representational art is seen in the form of early

Upper Palaeolithic (Aurignacian) starting after 40,000 years ago, including animal and human sculptures in ivory as seen at Vogelherd (>30,000 years ago) and Hohle Fels (35,000 years ago) in Germany (Conard, 2009), and cave paintings such as at Chauvet Cave (32,000 years ago) in southwest France (Clottes, 2001). Interestingly, the first representational art in the prehistoric record is remarkably skilled and well-executed; unlike other aspects of technology, there is no evidence of a long period of simplicity that predates this expressive competence. The earliest representational art known in Africa comes from Apollo-11 Rockshelter in Namibia in southern Africa (Bednarik, 2003), dating to about 26,000 years ago.

- **Religion:** Although the roots of human religion very likely pre-date anatomically modern humans, many scholars point to the rich symbolic content of Upper Palaeolithic art and elaborate mortuary practices to argue that there must have been well-established religious and ritualistic behavior as well as a belief in an afterlife and a spirit world (Dickson, 1990). Some cave art authorities (e.g. Clottes and Lewis-Williams, 1998; Lewis-Williams, 2002) have suggested that the best interpretation of Upper Palaeolithic religion was a trance-induced shamanistic one. In one study of Upper Palaeolithic art caves in the Pyrenees (Reznikoff and Dauvois, 1988), it was found that high concentrations of art in caves coincided with areas of these caves with unusual acoustic properties (resonance and echoes), and suggested that these painted areas were also areas of chanting or singing during rituals.

- **Musical instruments:** Although there have been claims of musical instruments from the Middle Palaeolithic, these have not been substantiated on closer scrutiny. The earliest definitive musical instruments are in the form of bone flutes and whistles from the Aurignacian stage of the early Upper Palaeolithic, ca. 35,000 to 40,000 years ago (Conard et al., 2009).

- **Notational tallies:** During the Upper Palaeolithic, there are a number of marked bones, antlers, and stones, beginning around 32,000 years ago, which suggest that these objects may have been recording devices for counting or documenting natural phenomena (e.g., days, lunar months, numbers of people or animals, etc.) (Marshack, 1991). Notable examples include the Aurignacian bone plaques from Abri Lartet and Blanchard in the French Dordogne region.

- **“Supernatural” imagery**: Some of the iconography in Upper Palaeolithic art appears to represent entities which are not found in the natural world, and may represent some mythological creatures. This includes the ivory sculpture of a “lion-man” from Hohlenstein Stadel in Germany dated to 32,000 years ago (Wynn et al., 2009), the “Unicorn” (actually a two-horned fantastic animal) from Lascaux Cave from the French Perigord dated to about 15,000 years ago and the so-called antlered “Sorcerer” from Trois Freres Cave (Leroi-Gourhan, 1967) in the French Pyrenees also dated to approximately 15,000 years ago.

- **Tanged points**: The Aterian of North Africa has tanged points which may date as early as 100,000 years ago. Such tangs must denote hafting, presumably for a spear. Tanged points also emerge in the Solutrean of Europe about 25,000 years ago.

- **Spear Throwers**: The first mechanical devices for propelling spears are found in the Upper Palaeolithic of Europe going back to about 20,000 years ago. These hooked sticks (known in the Aztec world as *atlatls*) gave a hunters arm a longer lever with which to impart more speed (and distance and/or penetration power) to a spear.

- **Geometric microliths**: Small retouched forms, often made on blades or bladelets and in geometric shapes (trapezoids, crescents, etc.), could have been used as elements of composite tools such as arrows and knives. These forms emerge especially in the later Upper Palaeolithic and become widespread in the Mesolithic of early Holocene Eurasia and in many Later Stone Age industries in Africa.

- **Ceramic figurines**: At Dolni Vestonice in the Czech Republic, fired clay figurines of animals and humans are dated to approximately 26,000 years ago (Vandiver et al., 1989). These are the earliest known ceramic technologies, pre-dating pottery by some 14,000 years.

- **Mythology and folklore motifs**: It is likely that true folk traditions were passed on from generation to generation by the Upper Palaeolithic. One such folklore motif (a story or joke) may be manifested in the form of a sculpture of a deer or ibex, peering back at its rear, perhaps in the act of either defecating or giving birth. On the end of the protruding object is a bird, which forms the hooked end of the spear-thrower. Several sites in the French Pyrenees (and one site over 100 km north of the sites in the Pyrenees) have yielded such sculptures engraved on antler spear-throwers, including very complete specimens from the Magdalenian site of Mas d’Azil in the French Pyrenees dating to about 16,000 years ago and from the nearby site of Bedeilhac (Bahn, 1982). This recurring motif almost certainly represents a specific story maintained by oral tradition, presumably over a wide area in this region.

- **Natural history:** Many of the representational animal images in painting, engraving, and sculpture in the Upper Palaeolithic show a remarkable degree of anatomical and behavioral detail. One specimen in particular is exceptionally fascinating. At the French Magdalenian site of Mas d'Azil, an antler carving (possibly part of a spear thrower) shows three horse heads: a small one (possibly a young individual), a larger head (probably an adult), and another large 'flayed' head showing the skull of a horse (Leroi-Gourhan, 1967). This piece could represent the life history of a horse.

- **Architecture**: Although there may be a few structures associated with European Middle Palaeolithic (presumably Neandertal) hominins, most recognizable hut or tent structures are known from the Upper Palaeolithic, such as those from Mezhirich and Molodova (21,000 years ago) in the Ukraine, Dolni Vestonice and Pavlov (27,000 years ago) in the Czech Republic, and Pincevent (12,000 years ago) in France (Vasil'ev et al., 2003).
- **Weaving**: Impressions on fired clay at Dolni Vestonice and Pavlov in the Czech Republic indicate that by 26,000 these occupants were weaving plant materials into baskets, mats, or textiles (Soffer et al., 1998). Before the advent of pottery this could have been a very important technology for making containers to carry foods, material culture, or, if lined with a waterproof material such as pitch, the storage or transport of water.
- **Needles/Sewing** The first bone needles appear about 25,000 years ago in the Upper Palaeolithic, suggesting sophisticated sewn apparel. Upper Palaeolithic figurines from Siberia show humans with parka-like outfits, denoting their adaptation to these severe environments.
- **Grinding stones**: Early mortars and pestles that were used to grind wild cereals are found in early agricultural sites in many parts of the world. Very early instances of such grinding stones have been reported from a Palaeolithic site in Italy, where evidence is claimed for the grinding of starch grains into flour 25,000 years ago (Aranguren *et al*., 2007), and from an early Holocene site in China, where evidence for the grinding of acorns has been suggested from 11,000 years ago (Liu *et al*., 2010). Such grinding stones became much more common with the rise of agricultural communities around the world in the last 10,000 years.
- **Hearths/boiling**: Clearly-made hearth structures, sometimes delineated by a circle of stones, are common in the Upper Palaeolithic (e.g., see Movius, 1966 and Leroi-Gourhan and Brézillon, 1983). Large quantities of fire-cracked rocks have suggested to some prehistorians that Upper Palaeolithic people were dropping hot stones into water (ethnographically, this could be done in a greased hide put over a depression in the ground to hold water) to boil the water for cooking (e.g. at El Miron Cave in Cantabrian Spain about 15,500 years ago) (Nakazawa et al., 2009). One advantage of boiling over roasting is that all of the nutrition of a food (e.g. fats, prized by hunter-gatherers) can be retained in a broth rather than drip away into a fire.
- **Lamps**: The earliest stone lamps are known from the Upper Palaeolithic of Europe starting approximately 40,000 years ago, pecked or carved out of a variety of softer stones (Beaune, 1987). These lamps probably used an animal fat as a fuel and a wick of moss or some other vegetable material. It is likely that torches were also used by this period, but no direct evidence has yet been found for these.
- **Pottery vessels**: The first fired **clay pots** are known from late Pleistocene and early Holocene hunter-gatherer populations in eastern Asia including sites in Japan (known as the early Jomon culture and possibly in eastern China and Russia, beginning at least 13,000 years ago (Kuzmin, 2006; Rice, 1999)). Such ceramic vessels could be storage containers or cooking pots (or both). During Holocene times pottery would be independently invented I the Near East, East Asia, and the Americas.
- **The emergence of "ethnicity"**: There is a general appreciation that beginning about 40,000 years ago, hominin material culture becomes much more variable in time and space. Stone tool types and art styles can become very particular and geographically and temporally diagnostic (for example, Aurignacian split-based bone points and carinated end scrapers, Gravettian backed points, Solutrean leaf points, Magdalenian sagaie and harpoons, and parrot-beaked burins) and Azilian painted pebbles.)
- **Longer-distance trade**: The Upper Palaeolithic indicates that trade reciprocity networks were greater than in earlier times, particularly between 25,000 and 15,000 years ago, with raw materials such as high-quality flint sometimes moving more than 200 kilometers, and exotic materials such as sea shells or Baltic amber also moving appreciable distances (Mellars, 1996).
- **The peopling of New Worlds: Australia, the Americas, and Siberia**: In the latter part of this Time Interval, human populations made significant incursions into new areas of the earth not previously inhabited by humans. Early occupation of Australia by modern humans began between 40,000 and 60,000 years ago during a glacial period when sea levels were lower, but still requiring the crossing of at least 60 miles of open sea between the Sunda land mass of southeastern Asia and the Sahel land

mass that included Australia, New Guinea, Tasmania, and nearby islands. Siberia was occupied by Upper Palaeolithic times, as early as 40,000 years ago in southern Siberia, and with substantial sites throughout much of northeastern Asia established between 30,000 and 20,000 years ago. This region is widely thought to be the staging ground for human immigrations into Beringia, the land bridge between Siberia and Alaska exposed during the glacial maximum and whose steppe-like grassland likely supported large herds of herbivores, and then for the ultimate spread of these human populations into North America as the ice sheets began to recede. Such migrations would indicate populations armed with the appropriate tools and technology to cope successfully with challenging environments and crossings.

- **Broader-spectrum economies and the rise of farming communities**: Towards the end of the Pleistocene there is evidence, around the world, of intensification of foraging patterns among many hunter-gatherer groups. In many areas, a wider range of food items were exploited, including shellfish (mussels, oysters, crabs, lobster), fish (e.g. salmon), cereals (wheat, barley, millet, sorghum, rice, maize), etc. These so-called "broad spectrum economies" would, at the end of the Ice Age and the beginning of the Holocene, lead to the first farming communities. Intensification of certain types of hunting prey (e.g. sheep and goats) would lead to the domestication of certain animal species as well. Farming would ultimately allow much larger, sedentary communities which would lay the foundations for the first complex state societies or "civilizations."

Summary and Conclusion

Table 1 summarizes the major trends for each time interval discussed in this chapter. Overall, a gradual progression of technological sophistication is observed relative to Holloway *et al*.'s three stages of hominin brain evolution.

During Holloway *et al*.'s Stage 1 of hominin brain evolution, the first evidence of hominin stone tools emerges at 2.6 mya during the time of *Australopithecus garhi*. Fragmentary jaws and teeth may suggest that early *Homo* goes back to 2.3 million years ago (e.g. Hadar jaw AL-666), a few hundred thousand years after the first appearance of stone tools, but without crania and endocasts, it is not clear whether these non-paranthropine forms (i.e., not showing the dental features of robust australopithecines) show any evidence of encephalization or brain reorganization.

Holloway *et al.* Stage 2 (early *Homo*) is seen in the prehistoric record about 700,000 years after the first recognizable stone tools. Many palaeoanthropologists believe that this neurological evolution may be the consequence of expanding diet breadth and higher diet quality supported by the use of stone tools and allowing for the larger brain evident in evolving *Homo* (*Homo habilis* and *Homo rudolfensis*) during this time. During Holloway et al.'s Stage 2, Oldowan sites become more prevalent and widespread on the African landscape, and we see the emergence of Acheulean tools, with large handaxes and cleavers shaped from large flakes or cobbles. The spread of hominins and tool cultures over much of the southern to middle latitudes of Eurasia is also evident during Stage 2 of hominin brain evolution.

During Holloway et al.'s Stage 3 of brain evolution, significant technological and adaptive advances are observed in the archaeological record. During the early part of this phase, associated with *Homo heidelbergensis*, these include the development of refined Later Acheulean tools, commonly including extremely symmetrical and finely fashioned handaxes and cleavers, and often showing very intricate, controlled flaking and use of careful platform preparation and of soft hammer percussion in their production. Additional advances observed in the archaeological record and associated with *Homo heidelbergensis* include the use of wooden spears and apparent evidence of some controlled use of fire (though its incidence was still rare and may not have involved skilled production of fire), as well as possible emergence of early ritual or symbolic behavior. Changes associated with Neandertals add more complex (hafted) tools, apparent habitual use of fire, use of personal adornment, and burial of the dead to the adaptive and behavioral repertoire.

Such trends continued in earnest among the modern human populations as they grew and spread, eventually involving the emergence of flourishing art traditions, addition of other materials (bone, antler, ivory) to the toolmaking systems, appearance of needles and sewing, development of habitual architecture in various forms, and evidence for long-distance transport and trade of materials. By the time of the Upper Palaeolithic, regional patterns emerge in the archaeological record which would appear to indicate geographically distinct clusters of traditions, perhaps indications of 'ethnicity' mirroring that observed among human groups in recent and modern times. The emergence and evolution of complex symbolic behavior during this stage of brain evolution is evidenced in highly endowed burials, often prolific use of ornaments, and the proliferation of artistic traditions (including sometimes elaborate decoration of utilitarian tools). The emergence of such regional patterning and the evidence for complex symbolic behaviors may indicate evolution of complex language systems and abilities during this stage of brain evolution.

Thus, there are important changes in hominin behaviors indicated in the archaeological record correlated with the progressive stages of hominin brain evolution proposed by Holloway et al. (2004) based upon their study of hominin fossil and endocranial evidence. These

Table 1.

Time Interval	Age	Hominin form	cc	EQ	Holloway et al. Stage	Technology, behavior, other
ONE	3.25-2.75 Ma	*Australopithecus afarensis*	445	(0.43)	Stage 1	(no established evidence)
TWO	2.75-2.25 Ma	*Australopithecus garhi*	450	(.45?)		Oldowan artifacts Early sites in Africa
THREE	2.25-1.75 Ma	*Homo habilis* *Homo rudolfensis* Early Homo (grouped)	610 788 698	(.62) (.66) (~.64)	Stage 2	Cut-marked bone Oldowan artifacts
FOUR	1.75-1.25 Ma	Early Homo erectus	800	(0.58)	Stage 2	Early Acheulean (& Oldowan) Africa & Eurasia
FIVE	1.25-0.75 Ma	*Homo erectus*	950	(0.68)	Stage 2	Acheulean
SIX	0.75-0.25	*Homo heidelbergensis*	1260	(0.81)	Stage 3	Later Acheulean Soft hammers Spears Some control of fire Ritual?
SEVEN	0.25-0.03 Ma	*Homo neandertalensis*	1427	(0.99)	Stage 3	Middle Palaeolithic Habitual control of fire Hafting (composite tools) Burial Decoration (late)
SEVEN	0.20 Ma – present	*Homo sapiens*	1496	(0.90)	Stage 3	Middle & Upper Palaeolithic Blade tools Habitual control of fire Habitual shellfish exploitation Decoration Iconic art Musical instruments Bone, antler, ivory tools More complex composite tools Habitual architecture Longer-distance transport Accelerating elaboration of technology Last 10,000 years: food pro-duction, complex societies

changes involve appearance and evolution of new technologies, adaptive behavioral shifts indicated by the new technologies, ultimate spread and adaptation to very new environments, and, eventually, emergence of a full-blown symbolic dimension among human ancestors.

In addition to major changes from one stage to the next in technologies and behaviors, there are also some notable changes over time that can be observed within a single stage in terms of technology, behavior and adaptation. This is particularly during Holloway et al.'s Stage 2 and Stage 3 of hominin brain evolution. Stage 2 involves early *Homo* and *Homo erectus* and archaeological evidence that chronicles significant behavioral changes, including the addition of Acheulean technology to the Oldowan stone tool repertoire, and the spread of hominins into Eurasia and consequent adaptation to new environments. During Stage 3, which involves the hominin forms *Homo heidelbergensis*, *Homo neandertalensis*, and finally *Homo sapiens*, archaeological evidence shows technological transitions from Later Acheulean, to Middle Palaeolithic/Middle Stone Age, and then Upper (or Late) Palaeolithic/Later Stone Age technological periods of the Pleistocene, involving increasing complexity and sophistication of the tool-kit and of overt symbolic dimensions, and, ultimately, cultural developments supporting complex societies and profound, accelerating technological innovations of the Holocene.

Such behavioral transitions within a single stage of hominin brain evolution could be due to various factors, including possible neurological changes and potential cultural dynamics. Possible neurologically-based changes could include reorganization of neural pathways in the brain that might support more complex behaviors and conceptualization or enable increased capacity for more complex communication and or language. In the case of language, other biological complements of such neurological changes, also with a presumed genetic basis, could include structural/musculoskeletal changes in the vocal tract. Cultural factors which might support such profound behavioral changes within a single stage of brain evolution could involve increased contact and sharing among individuals and groups and enhanced cultural means of storing information so as to increase the cultural repertoire of knowledge and, potentially, gradually but dramatically increase the rate of cultural change. It is possible that both major types of factors played a role in cultural elaboration and innovations during Stages 2 and 3 of hominin brain evolution, with the cultural aspects likely playing an increasingly important role over time.

References

Aiello L., and Wheeler, P., 1995. The expensive tissue hypothesis: the brain and the digestive system in humans and primate evolution. Current Anthropology 36, 199-221.

Allman, J., 2000. Evolving Brains. New York: Scientific American Library.

Alperson-Afil, N., Sharon, G., Kislev, M., Melamed, Y., Zohar, I., Ashkenazi, S., Rabinovich, R., Biton, R., Werker, E., Hartman, G., Feibel, C., Goren-Inbar, N., 2009. Spatial organization of hominin activities at Gesher Benot Ya'aqov, Israel. Science 326, 1677-1680.

Ambrose, S., 2001. Palaeolithic technology and human evolution. Science 291, 1748-1753.

Ambrose, S., 1998. Chronology of the Later Stone Age and food production in East Africa. Journal of Archaeological Science 25, 377-392.

Aranguren, B., Becattini, R., Mariotti Lippi, M., Revedin, A., 2007. Grinding flour in Upper Palaeolithic Europe (25,000 years bp). Antiquity 81, 845-855.

Arsuaga, J., Martinez, I., 2004. Atapuerca y la Evolución Humana. Barcelona: Fundació Caixa Catalunya.

Bahn, P., 1982. Inter-site and inter-regional links during the Upper Palaeolithic: the Pyrenean evidence. Oxford Journal of Archaeology 1. 247-268.

Barham, L., 2002. Systematic pigment use in the Middle Pleistocene of south-central Africa. Current Anthropology 43, 181-190.

Bar-Yosef, O., 2002. The Upper Palaeolithic revolution. Annual Review of Anthropology 31, 363-393.

Beaune, S., 1987. Palaeolithic lamps and their specialization: A hypothesis. Current Anthropology 28, 569-577.

Bednarik, R., 2003. The earliest evidence of Paleoart. Rock Art Research 20, 95.

Bouzouggar, A., Barton, N., Vanhaeren, M., d'Errico, F., Collcutt, S., Higham, T., Hodge, E., Parfitt, S., Rhodes, E., Schwenninger, J-L., Stringer, C., Turner, E., Ward, S., Moutmir, A., Stambouli, A., 2007. 82,000-year-old shell beads from North Africa and implications for the origins of modern human behavior. Preceedings of the National Academy of Sciences 104, 9964-9969.

Brown, K., Marean, C., Herries, A., Jacobs, Z., Tribolo, C., Braun, D., Roberts, D., Meyer, M., Bernatchez, J., 2009. Fire as an engineering tool of early modern humans. Science 325, 859-862.

Clottes, J. (Ed.), 2001. La Grotte Chauvet: L'Art des Origines. Paris: Seuil.

Clotte, J., Lewis-Williams, D., 1998. The Shamans of Prehistory: Trance and Magic in the Painted Caves. New York: Abrams.

Conard, N., 2009. A female figurine from the basal Aurignacian of Hohle Fels Cave in southwestern Germany. Nature 459, 248-252.

Conard, N., Malina, M., Munzel, S., 2009. New flutes document the earliest musical tradition in southwestern Germany. Nature 460, 737-740.

Coolidge, F., Wynn, T., 2009. The Rise of *Homo sapiens*: The Evolution of Modern Thinking. Malden, MA: Wiley-Blackwell.

Deacon, T., 1997. The Symbolic Species: The Co-Evolution of Language and the Brain. New York: Norton.

de Heinzelin, J., Clark, J.D., Schick, K., Gilbert, W.H., 2000. The Acheulean and the Plio-Pleistocene Deposits of the Middle Awash Valley, Ethiopia. Tervuren: Musée Royal de l'Afrique Central, Volume 104.

Delson, E., Tattersal, I., Van Couvering, J., Brooks, A., (Eds), 2000. Encyclopedia of Human Evolution and Prehistory, second edition. New York: Garland.

Deetz, J., 1967. Invitation to Archaeology. Garden City: Natural History Press.

Dickson, D., 1990. The Dawn of Belief: Religion in the Upper Palaeolithic of Southwestern Europe. Tucson: University of Arizona Press.

Domínguez-Rodrigo, M., Pickering, T., Bunn H., 2010. Configurational approach to identifying the earliest hominin butchers. Proceedings of the National Academy of Sciences 107.

Dunbar, R. 1992. Neocortex size as a constraint on group size in primates. Journal of Human Evolution 20, 469-493.

Dunbar, R. 1993. Coevolution of neocortical size, group size, and language in humans. Behavioral and Brain Sciences 16, 681-735.

Dunbar, R., 2003. Evolution of the social brain. Science 302, 1160-1161.

Falk, D., 1987. Hominid paleoneurology. Annual Review of Anthropology 16, 13-30.

Gibson, K., 1986. Cognition, brain size, and the extraction of embedded food resources. In: Else, J., Lee, P. (Eds.), Primate Ontogeny, Cognition and Social Behavior. Cambridge: Cambridge University Press, pp. 93-103.

Gibson, K., 2002. Evolution of human intelligence: the role of brain size and mental construction. Brain Behavior and Evolution 59, 10-20.

Gibson, K., Ingold, T., (Eds.), 1993. Tools, Language and Cognition in Human Evolution. Cambridge University Press.

Goren-Inbar, N, Peltz, S., 1995. Additional remarks on the Berekhat Ram figure. *Rock Art Research* **12,** 131-132

Goren-Inbar, N., Sharon, G., Melamed, Y., Kislev, M., 2002. Nuts, nut cracking, and pitted stones at Gesher Benot Ya'aqov, Israel. Proceedings of the National Academy of Sciences 99, 2455-2460.

Goren-Inbar, N., Alperson, N., Kislev, M., Simchoni, O., Melamed, Y., Ben-Nun, A., Werker, E., 2004. Evidence of hominin control of fire at Gesher Benot Ya`aqov, Israel. Science 304, 725-727.

Gowlett, J., 1996. Mental abilities of early *Homo*: Elements of constraint and choice in the rule system. In: Mellars, P. and Gibson. K. (Eds.), Modeling the Early Human Mind. Cambridge: McDonald Institute for Archaeological Research, pp. 191-215.

Henshilwood, C., d'Errico, F., Vanhaeren, M., Van Niekerk, K., Jacobs, Z., 2004. Middle Stone Age shell beads from South Africa. Science 304, 404.

Henshilwood, C., d'Errico, F., Watts, I., 2009. Engraved ochres from the Middle Stone Age levels at Blombos Cave, South Africa. Journal of Human Evolution 57, 27-47.

Holloway, R.L., 1967. The evolution of the human brain: Some notes towards a synthesis between neural structure and the evolution of complex behavior. International Journal of General Systems 12, 3-19.

Holloway, R.L., 1969. Some questions on parameters of neural evolution in primates. In: Petras, J. and C. Noback (Eds.), Comparative and Evolutionary Aspects of the Vertebrate Central Nervous System. Annals of the New York Academy of Sciences 16, 332-340.

Holloway, R.L., 1981. Culture, symbols, and human brain evolution: A synthesis. Dialectical Anthropology 5, 287-303.

Holloway, R., Broadfield, D., and Yuan, M., 2004. The Human Fossil Record. Volume Three: Brain Endocasts: The Palaeoneurological Evidence. Hoboken: John Wiley & Sons, Inc.

Isaac, G., 1986. Foundation stones: early artifacts as indicators of activities and abilities. In: Bailey, G. and Callow, P. (Eds.), Stone Age Prehistory: Studies in Honor of Charles McBurney. London: Cambridge University Press, pp. 221-241.

Jerison, H., 1973. Evolution of the Brain and Intelligence. New York: Academic Press.

Keeley, L., 1980. Experimental Determination of Stone Tool Uses: A Microwear Analysis. Chicago: University of Chicago Press.

Klein, R.G., 2009. The Human Career: Human Biological and Cultural Origins. Third edition. Chicago: University of Chicago Press.

Kuzmin, Y., 2006. Chronology of the earliest pottery in East Asia: progress and pitfalls. Antiquity 80, 362-371.

Leroi-Gourhan, A., 1967. Treasures of Prehistoric Art. New York: Abrams.

Leroi-Gourhan, A., Brézillon, M., 1983. Fouilles de Pincevent: Essai d'Analyse Ethnographique d'un Habitat Magdalénien. Paris: Éditions du Centre Nationale de la Recherche Scientifique.

Lewis-Williams, D., 2002. The Mind in the Cave: Consciousness and the Origins of Art. London: Thames and Hudson.

Lindly J., Clark, G., 1990. Symbolism and modern human origins. Current Anthropology 31, 233-261.

Liu, L., Field, J., Fullagar, R., Bestel, S., Chen, X., Ma, X., 2010. What did grinding stones grind? New light on Early Neolithic subsistence economy in the Middle Yellow River Valley, China. Antiquity 84, 816-833.

Martin, R., 1996. Scaling the mammalian brain: the maternal energy hypothesis. News in Psychological Sciences 11, 149-156.

Marshack, A., 1991. The Roots of Civilization. Mount Kisco, New York: Moyer Bell Limited.

McBrearty, S., Brooks, A. The revolution that wasn't: a new interpretation of the origin of modern human behavior. Journal of Human Evolution 39, 453-463.

McGrew, W., 1992. Chimpanzee Material Culture: Implications for Human Evolution. Cambridge: Cambridge University Press.

McPherron, S., Alemseged, Z., Marean, C., Wynn, J., Reed, D., Geraads, D., Bobe, R., Bearat, H., 2010. Evidence for stone-tool-assisted consumption of animal tissue before 3.39 million years ago at Dikika, Ethiopia. Nature 466, 857-860.

Mellars, P., 1996. The Neandertal Legacy: An Archaeological Perspective from Western Europe. Princeton: Princeton University Press.

Mellars, P., and Gibson, K. (Eds.), 1996. Modeling the Early Human Mind. Cambridge: McDonald Institute for Archaeological Research.

Mellars, P., Boyle, K., Bar-Yosef, O., Stringer, C. (Eds.), 2007. Rethinking the Human Revolution. Cambridge: McDonald Institute for Archaeological Research.

Mitchell, J., 1995. Studying biface utilization at Boxgrove: Roe deer butchery with replica handaxes. Lithics 16, 64-69.

Mithen, S., 1996. The Prehistory of the Mind: The Cognitive Origins of Art, Religion, and Science. London:

Morwood, M., Trezise, P., 1989. Edge-ground axes in Pleistocene Greater Australia: new evidence from S.E. Cape York Peninsula. Queensland Archaeological Research 6, 77-90.

Mourre V., Villa, P., and Henshilwood, C., 2010. Early use of pressure flaking on lithic artifacts at Blombos Cave, South Africa. Science 330, 659-662.

Movius, H., 1949. The Lower Palaeolithic cultures of southern and eastern Asia. Transactions of the American Philosophical Society 38, pt. 4, 329-420.

Movius, H., 1966. The Hearths of the Upper Périgordian and Aurignacian Horizons at the Abri Pataud, Les Eyzies (Dordogne), and Their Possible Significance. American Anthropologist 68, 296-325.

Nakazawa, Y., Straus, L., Gonzalez-Morales, M., Solana, D., Saiz, J., 2009. On stone-boiling technology in the Upper Paleolithic: behavioral implications from an Early Magdalenian hearth in El Mirón Cave, Cantabria, Spain. Journal of Archaeological Science 36, 684-693.

Oakley, K.P, 1976. Man the Tool-Maker. Seventh Edition. Chicago: University of Chicago Press.

Oakley, K., Andrews, P., Keeley, L., Clark, J.D., 1977. A reappraisal of the Clacton spear point. Proceedings of the Prehistoric Society 43, 13-30.

Mania, D. Mania, U., 2005. The natural and socio-cultural environment of Homo erectus at Bilzingsleben, Germany. In: (Gamble, C. Porr, M., Eds.), The Hominid Individual in context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales, and Artefacts. London: Routledge, pp. 98-114.

Noble, W., Davidson, I., 1996. Human Evolution, Language and Mind. Cambridge: Cambridge University Press.

Parker, S., Gibson, K., 1979. A developmental model for the evolution of language and intelligence in human evolution. Behavioral and Brain Sciences 2, 367-408.

Parker, S., McKinney, P. (Eds.), 1999. Origins of Intelligence: The Evolution of Cognitive Development in Monkeys, Apes, and Humans. Baltimore: Johns Hopkins University Press.

Pelegrin, J., 2005. Remarks about archaeological techniques and methods of knapping: elements of a cognitive approach to stone tools. In: Roux, V., Bril, B (Eds.), Stone Knapping: The Necessary Conditions for Uniquely Human Behavior. Cambridge: McDonald Institute for Archaeological Research, pp. 23-34.

Pitts, M., Roberts, M., 1997. Fairweather Eden: Life Half a Million Years Ago As Revealed at the Excavations at Boxgrove. London: Century Books, Ltd.

Renfrew, C. and Scarre, C. (Eds), 1998. Cognition and Material Culture: The Archaeology of Symbolic Storage. Cambridge: McDonald Institute for Archaeological Research.

Renfrew, C., Frith, C., Malafouris, L. (Eds), 2009. The Sapient Mind: Archaeology Meets Neuroscience. Cambridge: Cambridge University Press.

Reznikoff, I., Dauvois, M., 1988. La dimension sonare des grottes ornées. Bulletin de la Société Préhistoriques Francaise 85, 238-246.

Rice, P., 1999. On the origins of pottery. Journal of Archaeological Method and Theory 6, 1-54.

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

Roux, V., Bril, B (Eds), 2005. Stone Knapping: The Necessary Conditions for Uniquely Human Behavior. Cambridge: McDonald Institute for Archaeological Research.

Schick, K. 1994. The Movius Line reconsidered: perspectives on the earlier Palaeolithic of Eastern Asia. In: Corruchini, R., Ciochon, R. (Eds) Integrative Paths to the Past: Palaeoanthropological Advances in Honor of F. Clark Howell. Englewood Cliffs, New Jersey: Prentice-Hall, pp. 569-596.

Schick, K., Toth, N., 1993. Making Silent Stones Speak: Human Evolution and the Dawn of Technology. New York: Simon & Schuster.

Schick, K., Toth, N. 1994. Early Stone Age technology in Africa: a review and case study into the nature and function of spheroids and subspheroids. In: Corruchini, R., Ciochon, R. (Eds), Integrative Paths to the Past: Palaeoanthropological Advances in Honor of F. Clark Howell. Englewood Cliffs, New Jersey: Prentice-Hall, pp. 429-449.

Schick, K., Toth, N., 2006. An overview of the Oldowan Industrial Complex: the sites and the nature of their evidence. In: Toth, N., Schick, K. (Eds.), The Oldowan: Case Studies into the Earliest Stone Age. Gosport, Indiana: Stone Age Institute Press, pp. 3-42.

Schick, K., and Toth, N., 2009. The Cutting Edge: New Approaches to the Archaeology of Human Origins. Gosport, Indiana: Stone Age Institute Press.

Schick, K.D., Toth, N., Garufi, G., Savage-Rumbaugh, E.S., Rumbaugh, D., Sevcik, R., 1999. Continuing Investigations into the Stone Tool-making and Tool-using Capabilities of a Bonobo (*Pan paniscus*). Journal of Archaeological Science 26(7), 821-832.

Schoenemann, P.T. 2006. Evolution in the size and functional areas of the brain. Annual Review of Anthropology 35, 379-406.

Semaw, S., 2006. The oldest stone artifacts from Gona (2.6-2.5 Ma), Afar, Ethiopia: Implications for understanding the earliest stages of stone knapping. In: Toth, N., Schick, K. (Eds.), The Oldowan: Case Studies into the Earliest Stone Age. Gosport, Indiana: Stone Age Institute Press, pp. 43-75.

Shipman, P., 2010. The Cutting Edge: Can stone-tool marks on fossils be distinguished from tooth marks? American Scientist 462.

Shipman, P., Walker, A. 1989. The costs of becoming a predator. Journal of Human Evolution 18, 373-392.

Soffer, O., Adovasio, J., Hyland, D., Klima, B., Svoboda, J., 1998. Perishable technologies and the genesis of the eastern Gravettian. Anthropologie 36, 43-68.

Stout, D., 2002. Skill and cognition in stone tool production: a case study from Irian Jaya. Current Anthropology 45, 693-722.

Stout, D., 2005a. Neural foundations of perception and action in stone knapping. In: Roux, V., Bril, B (Eds) Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behavior. Cambridge: McDonald Institute for Archaeological Research, pp. 273-286.

Stout, D., 2005b. The social and cultural context of stone-knapping skill acquisition. In: Roux, V., Bril, B. (Eds) Stone Knapping: The Necessary Conditions for a Uniquely Hominin Behavior. Cambridge: McDonald Institute for Archaeological Research, pp. 273-286.

Stout, D., 2006. Oldowan toolmaking and hominin brain evolution: Theory and research using positron emission tomography (PET). In: Toth, N., Schick, K., (Eds) The Oldowan: Case Studies into the Earliest Stone Age. Gosport, Indiana: Stone Age Institute Press, pp. 267-305.

Stout, D., Toth, N., Schick, K., Stout, J., Hutchins, G., 2000. Stone tool-making and brain activation: positron emission tomography (PET) Studies. Journal of Archaeological Science 27, 1215-1223.

Stout, D., Toth, N., Schick, K., 2006. Comparing the neural foundations of Oldowan and Acheulean toolmaking: a pilot study using positron emission tomography (PET). In: Toth, N. Schick, K. (Eds.) The Oldowan: Case Studies into the Earliest Stone Age. Gosport, Indiana: Stone Age Institute Press.

Stout, D., Toth, N., Schick, K. Chaminade, T., 2009. Neural correlates of Early Stone Age toolmaking: technology, language and cognition in human evolution. In Renfrew, C., Frith, C., and Malafouris, L. (Eds.) The Sapient Mind: Archaeology Meets Neuroscience. Cambridge: Cambridge University Press, pp. 1-19.

Stout, D., Toth, N., Schick, K., 2010. Understanding Oldowan knapping skill: an experimental study of skill acquisition in modern humans. In: (Schick, K., Toth, N., Eds.), The Cutting Edge: New Approaches to the Archaeology of Human Origins. Gosport, Indiana: Stone Age Institute Press, pp. 247-265.

Thieme, H., 1997. Lower Palaeolithic hunting spears from Germany. Nature 385, 807-810.

Thieme, H., 1998. The oldest spears in the world: Lower Palaeolithic hunting weapons from Schöningen, Germany. In: (Carbonell, E., Bermudez de Castro, J., Arsuaga, J., Rodriguez, X., Eds.), The First Europeans: Recent Discoveries and Current Debate. Burgos: Caja de Burgos, pp. 171-193.

Thieme, H. 2005. The Lower Palaeolithic art of hunting: the case of Schoeningen 13 II-4, Lower Saxony, Germany. In: (Gamble, C. , Porr, M. Eds.), The Hominid Individual in Context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and Artefacts. London: Routledge. pp. 115-132.

Toth, N., 1985a. Archaeological evidence for preferential right-handedness in the Lower and Middle Palaeolithic, and its possible implications. Journal of Human Evolution 14, 607-614.

Toth, N., 1985b. The Oldowan reassessed: a close look at early stone artifacts. Journal of Archaeological Science 12, 101-120.

Toth, N., 1990. The prehistoric roots of a human concept of symmetry. Symmetry: Culture and Science 1, 257-281.

Toth, N., Schick, K., 1993. Early stone industries and inferences regarding language and cognition. In: (Gibson, K., and Ingold, T., Eds.), Tools, Language and Cognition in Human Evolution. Cambridge: Cambridge University Press, pp. 346-362.

Toth, N., Schick, K. (Eds), 2006. The Oldowan: Case Studies into the Earliest Stone Age. Gosport, Indiana: Stone Age Institute Press.

Toth, N., Schick, K., 2007. Overview of Palaeolithic archaeology. In: Henke, W., and Tattersal, I. (Eds). Handbook of Palaeoanthropology: Volume 3. New York: Springer, pp. 1943-1963.

Toth, N., Schick, K., 2009a. Early hominids. In: (Cunliffe, B., Goshden, C., and Joyce, R. ,Eds.). The Oxford Handbook of Archaeology. Oxford: Oxford University Press.

Toth, N., Schick, K., (Eds), 2009b. The Cutting Edge: New Approaches to the Archaeology of Human Origins. Gosport, Indiana: Stone Age Institute Press.

Toth, N., Schick, K., 2009c. The Importance of Actualistic Studies in Early Stone Age Research: Some Personal Reflections. In (Schick, K. and Toth, N., Eds,), The Cutting Edge: New Approaches to the Archaeology of Human Origins. Gosport, Indiana: Stone Age Institute Press, pp. 267-344.

Toth, N., Schick, K., 2009d. The Oldowan: the tool making of early hominins and chimpanzees compared. Annual Reviews of Anthropology 38, 289-305.

Toth, N., Schick, K., in press. Why the Acheulean? Experimental studies of the manufacture and function of Acheulean tools. Proceedings, Colloque internationale: Les Culture a Bifaces du Pleistocene Inferieur et Moyen dans la Mode.

Toth, N., Schick, K.D., Savage-Rumbaugh, E.S., Sevcik, R.A., Rumbaugh, D.M., 1993. Pan the Tool-Maker: Investigations into the Stone Tool-Making and Tool-Using Capabilities of a Bonobo (*Pan paniscus*). Journal of Archaeological Science 20(1), 81-91.

Toth, N., Schick, K., Semaw, S., 2006. A comparative study of the stone tool-making skills of Pan, Australopithecus, and Homo sapiens. In: Toth, N., Schick, K. (Eds), The Oldowan: Case Studies into the Earliest Stone Age. Gosport, Indiana: Stone Age Institute Press.

Vandiver, P., Soffer, O., Klima, B., Svoboda, J, 1989. The origins of ceramic technology at Dolni Věstonice, Czechoslovakia. Science 246, 1002-1008.

Vanhaeren, M., d'Errico, F., Stringer, C., James, S., Todd, J., Mienis, H., 2006. Middle Paleolithic shell beads in Israel and Algeria. Science 312, 1785-1788.

Vasil'ev, S., Soffer, O., Kozlowski, J., 2003. Perceived Landscapes and Built Environments: The Cultural Geography of Late Paleolithic. Oxford: Archaeopress.

Washburn, S., 1959. Speculations on the interrelations of the history of tools and biological evolution. In (Spuhler, Ed.) The Evolution of Man's Capacity for Culture. Detroit: Wayne State University Press.

Washburn, S., 1960. Tools and human evolution. Scientific American 203(9), 63-75.

Whiten, A., Goodall, J., McGrew, W., Nishida, T., Reynolds, V., Sugiama, Y., Tutin, C., Wrangham, R., Boesch, C. 1999. Culture in chimpanzees. Nature 399, 682-685.

Whiten, A., Schick, K., Toth, N., 2009. The evolution and cultural transmission of percussive technology: integrating evidence from palaeoanthropology and primatology. Journal of Human Evolution 57, 420-435.

Wynn, T., 1989. The Evolution of Spatial Competence. Urbana: University of Illinois Press.

Wynn, T., McGrew, W., 1989. An ape's view of the Oldowan. Man 24, 383-398.

Wynn, T., Coolidge, F., Bright, M., 2009. Hohlenstein-Stadel and the evolution of human conceptual thought. Cambridge Archaeological Journal 19, 73-84.