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Doing with less: Hominin brain atrophy



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ABSTRACT

In contrast to hominin encephalization, the final Pleistocene and Holocene reduction in cranial volume has attracted very little attention and remains unexplained. Here it is examined in the light of current neuroscientific and archaeological understanding, and it is shown that the most parsimonious explanation is via the domestication hypothesis of recent humans. Accordingly, rapid atrophy of the brain is partly explained by the culturally based process of sexual selection, first detectable in late robust *Homo sapiens* perhaps 40,000 years ago. Furthermore it is suggested that this deleterious process of neotenzation and brain atrophy was compensated for by the concurrent development of exograms, i.e. means of storing memory outside the brain. Consequently most of human memory and cultural information is now stored external to the brain, which has altered that organ significantly and facilitated a cultural complexity that would be impossible to maintain by biological memory alone. The escalating use of exograms, neotenzation and reduction in cranial volume all appear to co-occur with numerous other changes to the human genome.

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Introduction

One of the most frequently cited indices of human evolution is the marked encephalization characterizing the entire history of the genus, which is said to be almost without parallel in the natural

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world (De Miguel and Henneberg, 2001: Figs. 1 and 2). This relentless increase in brain size had led to a volume of about 750 ml by the beginning of the Pleistocene (Hawks and Wolpoff, 2001; Leigh, 1992; Rightmire, 2004), only to again double subsequently (Lee and Wolpoff, 2003; Ruff et al., 1997). The last 800,000 years (800 ka) account for much of the increase, which during that time averages about 7 ml in brain capacity per 10 ka. This significant enlargement of an energetically expensive organ is of great significance for two reasons: it has been credited with underwriting the sophisticated cognitive and intellectual development of hominins, but it also came with great biological, metabolic, social and neurological costs (Bednarik, 2011). Nevertheless, the continuing existence and eventual flourishing of the genus seems to imply that these costs were outweighed by the considerable benefits encephalization also engendered.

This corollary, so central to hominin evolution, has received extensive attention in countless commentaries. However, another development in brain size that is just as important, if not more so, has attracted very little consideration by comparison. It is the significant decrease in endocranial volume (at a rate 37 times greater than the previous rate of encephalization) during the terminal Pleistocene and the subsequent Holocene. There appear to be two reasons for the relative neglect of this phenomenon. The enlargement of the brain is seen as documenting the ascent of the species from primitive creature to the pinnacle of evolution, which is rather more satisfying than having to explain the sudden reversal of the process. Secondly, this turnaround has not so far been explained, and it even seems to contradict the reasons given for the preceding parietal expansion. If the selective factor was greater intelligence or social complexity or cognition, has the reversal provoked a decline in these capacities? If not, why should one assume that the enlargement was required for these supposed benefits? Thus the decrease in brain volume is an “inconvenient” aspect of human development, and the deficit of a credible explanation is an added disadvantage. If the empirical data cannot be explained, why should one accept an explanation for the benefits of encephalization? Moreover, the notion of encephalization driving greater intelligence needs to be tempered by the observation that when the ratio of average brain diameter (calculated as a cube root of average cranial volume) to average body height is compared for various hominin species there is no significant difference from *Australopithecus afarensis* to modern humans (Henneberg and Saniotis, 2009: Fig. 2).

This paper presents a scientific (falsifiable) hypothesis, explaining first why encephalization may have become reversed so dramatically, and second how it was possible that the human brain decreased rapidly without apparent functional loss. First, the relevant current empirical data will be briefly reviewed, followed by a discussion of various competing explanations for the reduction in brain size. The rise in the evidence for the human use of exograms will then be considered, leading to the presentation of a testable hypothesis.

The shrinking brain

Beals et al. (1984) were among the first to document the evidence for changes in endocranial volume and its decrease in recent times. The most comprehensive records are those from Europe, where Henneberg (1988, 1990) has examined the records of thousands of skulls. He reports a “Mesolithic” mean volume for males of 1567 ml ($n = 35$); for Neolithic/Eneolithic males it is 1496 ml ($n = 1017$); and there are further reductions in Bronze and Iron Age specimens to 1468 ml, in Roman times to 1452 ml, early Middle Ages to 1449 ml, late Middle Ages to 1418 ml; while the males of post-Mediaeval and recent times yielded a mean of 1391 ml. Similar decreases in endocranial volume were observed in the female samples, from a mean of 1502 in the early Holocene, via 1373 ml in Neolithic times to 1241 ml in recent centuries.

To place these momentous changes into context, the reduction of 261 ml represents 37 times the rate of the long-term increase in brain size during the second half of the Pleistocene, which experienced the most dramatic encephalization. Moreover, this gradual brain atrophy occurring throughout the Holocene was preceded by previous reduction during the terminal Pleistocene. It commenced perhaps 40 or 50 ka ago, when the ancestral European hominins of *Homo sapiens neanderthalensis* stock possessed significantly greater brains (c. 1200–1900 ml). The reduction since then has occurred at an exponentially increasing rate (Henneberg, 2004: Fig. 1), initially affecting especially the females and coinciding with the rapid gracilization experienced by all robust populations in the world (Bednarik,

2008). Indeed, this trend appears to be universal. For instance [Henneberg and Steyn \(1993\)](#) document a similar decline in cranial capacity in sub-Saharan Africa, from Later Stone Age to Iron Age people, reporting a reduction between 100 and 150 ml (cf. [Carlson, 1976](#); [Van Gerven et al., 1977](#)). In northern China, [Brown \(1992\)](#) and [Brown and Maeda \(2004\)](#) report a decline from the mean of 1510 ml in early Neolithic to 1400 ml in the present-day population, i.e. over a period of under 6000 years. Of particular interest are [Brown's \(1987\)](#) data from Australia, where the mean endocranial volume changed from 1405 ml in terminal Pleistocene males to a corresponding recent value of 1272 ml. Since this population continued as hunters–foragers throughout the period, the potential explanation of significant effects of changes in lifestyle cannot apply here.

Another possibility, that the brain shrank in response to a diminution of either body weight or body height (stature), is also negated by the empirical data available. For instance the decline in body mass during the Holocene, less than 5 kg ([Ruff et al., 1997](#)), would translate into a corresponding lowering of brain volume of little more than 20 ml, which is only a fraction of that actually documented. Moreover, there is no such correlation between body size and the continuous expansion in endocranial volume marking almost the entire Pleistocene ([Rightmire, 2004](#)). Hominins of the early part of the Pleistocene were of much the same height as extant humans, as indicated for instance by KNM-WT 15,000 (Turkana boy), KNM-ER 736 and KNM-ER 1808.

One potential explanation, genetic drift, is negated by several factors. That endocranial volume has universally changed by a standard deviation or more, during a period when the world's human population increased relentlessly and rapidly, renders chance decrease by genetic drift almost impossible as a valid explanation. Similarly, there are no compelling reasons to attribute the diminution to climate, despite [Beals et al. \(1984\)](#) attempted correlation between smaller endocranial volume and warmer climates (see also [Bailey and Geary, 2009](#)). Throughout the Pleistocene, the climate changed numerous times, and no such effect has been noted; nor have the Inuit the largest brains today. Moreover, the reduction in brain size began during the early Würm glacial, not during a time of significant climatic amelioration. Another potential interpretation involves somatic developmental plasticity as a function of foetal and early childhood environments (disease and nutrition) (cf. [Bennett et al., 1964](#); [Bedi and Bhide, 1988](#)). However, the healthy brain's size is much less susceptible to somatic plasticity than any other body part, approaching its adult state long before them, and the final Pleistocene/Holocene atrophy is apparently unrelated to stature or body mass.

The documented Holocene reduction of human brain size is likely to be attributed to the significant dietary changes imposed by the newly introduced agrarian economies, because of the nutritional challenges these have undoubtedly involved. As the brain is the most energetically demanding organ, smaller brains may have been selected for their energetic efficiency, 'provided that they were functionally equivalent'. But again, the onset of brain atrophy precedes the agricultural revolution by tens of millennia, and demands made on the brain are widely thought to have increased over this period. This points to the most plausible of the traditional explanations: that a smaller brain, in which shorter white matter tracts could have resulted in more compact cortical areas, or better neurotransmitter systems ([Previc, 2009](#)) might have offered advantages for selection. It could be argued, for instance, that the neuronal packing density of the brain ([Semendeferi et al., 2001](#): Table 5) could have been lower in the past, although there is no evidence for this. In fact the neuronal density is significantly lower in humans than in all other primates. Nevertheless, unless a more parsimonious rationalization becomes available, this would seem to be the most eligible, particularly in combination with the reasoning that brain development after the attainment of adult size might have been constrained by other causes.

Such alternative factors have been identified, and a significantly more parsimonious and persuasive explanation is now available for the atrophy of the brain in recent hominin history. The 'domestication hypothesis' ([Bednarik, 2008, 2011](#)) attributes the distinctive neotenization of humans during the most recent 40,000 years or so to sexual selection driven by cultural constructs, which effectively resembles a domestication process. The most obvious somatic changes as gracile hominins emerged from robust subspecies of *Homo sapiens* during the terminal Pleistocene, occurring concurrently in all four continents then occupied, were a rapid loss of skeletal robusticity and thinning of the cranium; reduction in tori, facial prognathism and nose size; and atrophy of cranial volume. As the brain shrank by between 10% and 13% in the course of the last few tens of millennia – an instant in evolutionary

time – robusticity of the masticatory equipment (including sizes of molars) also declined gradually, as did that of the skull generally and as the orthognathous face developed. Sheer physical strength, as indicated by muscle attachments on certain bones, waned profoundly over the same time span.

All of these and other somatic changes in the most recent hominin history are neotenuous physical traits, identical to those arising from the domestication of other animals. Universal features deriving from domestication include changes in reproductive cycles (oestrus), fewer or shortened vertebra, curly tails (Trut, 1999), loss of hair, larger eyes, rounded forehead, and shortened muzzle (Bertone, 2006). Domestication has in all affected species resulted in significant reduction of brain size relative to body size, and brain volume is more variable in domestic animals than in their wild counterparts (Coppinger and Coppinger, 2001; Ebinger, 1974, 1995; Hemmer, 1978, 1990; Kruska, 1980, 1987, 1988, 1989; Price, 2002). For instance canines (*Canis familiaris*, *C. lupus*, *C. latrans*, *C. aureus*) all have the same brain dimensions when they are born and their growth trajectories tend to be similar until the age of 10–12 weeks. Wolves then grow 10% bigger brains relative to body size, which implies that the smaller volume of the domestic dog is a neotenuous feature (Weidemann, 1970). The corresponding brain size differences between wild and domestic forms are 18% in gerbils (Stuermer et al., 1997), 20% for minks (Kruska, 1996), 17% for llamas and alpacas relative to guanacos (Kruska, 1982), 16% for domestic horses versus Przewalski horses (Röhrs and Ebinger, 1978, 1998), and 34% for domestic pigs versus wild boars (Röhrs and Kruska, 1969). These universal trends contrast with the effects when domestic animals are returned to the wild: the brain sizes of feral dogs, cats, goats and donkeys appear to remain stable (Herre and Röhrs, 1990; Kruska and Röhrs, 1974). Perhaps feralization has not been in progress long enough for a reversal to become detectable, but it is more likely that the changes to the genome are not automatically reversible. The greatest reduction in size, across most species affected (the mink being the notable exception), as a result of domestication is that of the cerebrum or telencephalon (the cerebral hemispheres: cerebral cortex, basal nuclei, basal forebrain nuclei and amygdaloid nucleus). It would therefore be of interest to determine which part of the human brain has undergone the greatest reduction in size. It is noted that the cerebrum, with assistance of the cerebellum, controls all voluntary actions in the body.

Non-somatic attributes of domestication include changes in behaviour towards playfulness, behavioural plasticity (compare the juvenile behaviour of a dog with that of a wolf), exploratory pattern (characterizing human behaviour especially since terminal Pleistocene times), and, in the case of humans, neuropathology (Bednarik, 2011; Helvenston and Bednarik, 2011). Domesticated mammalian species lack the seasonal reproduction of their wild ancestors and most can reproduce themselves at almost any time of the year. Apart from domesticated animals, the abolition of oestrus is rare in mammals, but is fully established in extant humans. Even exclusive homosexuality, which is *biologically* unexplainable in a sexually reproducing species (Miller, 2000), may need to be attributed to domestication. Humanity has actively contributed to self-domestication, at least in Holocene times, by systematically diminishing the genetic traits of “noncompliant” individuals. Throughout much of known human history, people who were independently minded, especially gifted or enterprising, or those who were recalcitrant or rebellious have been selectively persecuted, culled, exiled or burned at the stake. This applied not only in the political or religious spheres, but also even at the individual family level, where social compliance was systematically selected for. The cumulative effects of sustained selection of compliant personality traits the human species has practiced at least throughout known history mirror the domesticating selection of compliant traits in other animals (Hare et al., 2012) – except those specifically bred for fighting (roosters, pit bulls, fighting bulls).

The recent gracilization of humans is a process of accelerated neotenuation by pedomorphism, and practically all traits (somatic and extrasomatic) distinguishing so-called anatomically modern humans (see Tobias (1995) for a pertinent critique of this anthropocentric term) from their robust predecessors are ultimately attributable to unintentional self-domestication by culturally mediated sexual selection (Bednarik, 2007, 2008 *et passim*; in the sense the term is applied here it is unrelated to Leach [2003], which merely deals with effects of the built environment, decreased mobility and changes in diet). This is the only suggested process that can logically account for the Keller and Miller (2006) paradox: why natural selection has not suppressed the thousands of neuropathologies, genetic disorders and neurodegenerative conditions afflicting modern humans (Bednarik, 2012). It also provides a rationalization that is more parsimonious than any other to account for the long list of neotenuous

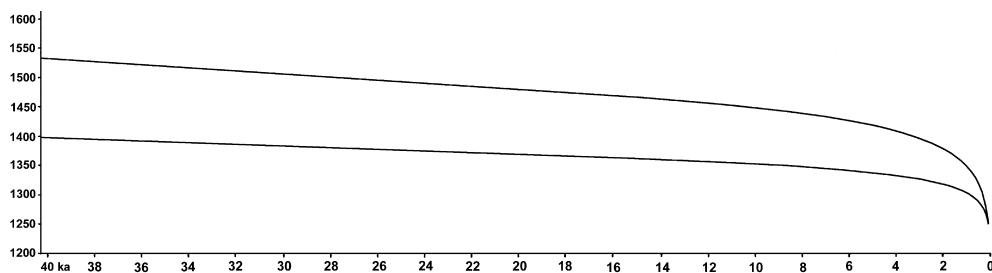


Fig. 1. The approximate decline in brain volume from *Homo sapiens neanderthalensis*, 40,000 years ago, to present-day humans, shown in ml for males (upper curve) and females (below).

developments determining the recent trajectory of human characteristics. Moreover, this explanation also clarifies what would have constrained brain development after the attainment of adult size: a key factor in neoteny is that sexual maturation is attained before somatic maturation. Nevertheless, the toleration of brain atrophy still requires clarification, because conventional wisdom would suggest that if it affected functionality, such development would be vigorously selected against, even in the absence of purely natural selection. Unintentional human self-domestication is not explored in any detail here; the topic has been exhaustively examined since 2007, and in embryonic form has been considered by Franz Weidenreich many decades ago.

Atrophy of any part of the body can have a variety of causes, such as mutations in the genes responsible for its development; inadequate nutrition or circulation; loss of nerve supply or hormonal support; excessive cell apoptosis; and lack of use or specific tissue disease. None of these candidates seem applicable in the case of brain size reduction. Naturally it is not the size of the brain that dictates its effectiveness, but primarily its level of interconnectivity or physiology, especially the neurotransmitters, that determine “intelligence”. Therefore the smaller brain could be functionally equivalent if it had been reorganized in some way to operate more efficiently. The challenge posed by this possibility is to explain why it should be assumed that the relentless Pliocene and Pleistocene encephalization of the human taxon, which involved enormous evolutionary and other costs (prolonged infant dependency, reduced fertility, etc. (Bednarik, 2011; Joffe, 1997; O’Connell et al., 1999) was essential in achieving the cognition or intelligence attained, when a smaller brain could have been perfectly adequate. Not only does this rationalization question some of the most fundamental tenets about the process of brain evolution (Shultz and Dunbar, 2010), there is an even more disturbing aspect. The trajectory Henneberg (2004: Fig. 1) demonstrates for the reduction of brain volume over the past sixteen millennia implies the distinctive possibility that this is an exponentially escalating process. Therefore the traditional reasoning offered in this context, of some unspecified selective advantages, may simply not suffice: how does it propose to explain a change in brain volume index that seems to be approaching free-fall? (Fig. 1).

Since there is simply no adequate hypothesis available from the usual sources, perhaps it is time to introduce a new hypothesis. The memory size of a computer can be reduced if some of the required content can be stored outside it, in the form of external hard drives. In much the same way, if some of the brain’s functions could be transferred to external storage, its size could be reduced without impairing its effectiveness. As it happens, such a mechanism does exist, thanks to the rise of exograms during hominin history.

The nature of exograms

The term exogram derives from the concept of the engram, which was first proposed by Richard Semon about a century ago. An engram is a memory trace, a hypothesized but never demonstrated, persistent protoplasmic alteration of neural tissue thought to occur upon stimulation of the brain, and accounting for memory. The change was thought to be biophysical or biochemical, prompted by external stimuli. In mooted its existence, Semon (1904, 1921:24) used the term “mnemonic trace” in

his book. The idea is based on the then dominant atomic concept of the brain, as an organ composed of elements, each of which carried out some definable function. Karl Lashley spent the best part of his working life searching unsuccessfully for engrams, instead establishing that there is no single biological locus of memory in the brains of rats. His work suggests that memories are not localized to one part of the brain, but are widely distributed throughout the cerebral cortex (Lashley, 1923a, 1923b, 1924, 1930, 1932, 1935, 1943, 1950). Subsequently Richard Thompson sought to locate engrams in the more primitive cerebellum, rather than the cerebral cortex, but ultimately the blinking responses he focused on produced no conclusive evidence of engrams (Christian and Thompson, 2005; Steinmetz et al., 1987, 1992; Steinmetz and Thompson, 1991; Steinmetz et al., 1992; Thompson, 1967, 1986, 1990; Thompson et al., 1976).

The concept of the storage of memory traces outside the brain, as “symbolism”, i.e. in a variety of objects and their properties, was first proposed by Gregory (1970:148). He realized that this would be a relatively stable and permanent expression. This idea of an external, “surrogate cortex” was developed further by Goody (1977), and later by Carruthers (1990, 1998). Actually it is not an entirely new idea; its basis can be traced back all the way to Plato, who stated “[i]f men learn this [writing], it will implant forgetfulness in their souls: they will cease to exercise memory because they will rely on that which is written, calling things to remembrance no longer from within themselves but from external marks” (*Phaedrus*, 274e–275a). In the same sense Plato thus foresaw the concept of neuroplasticity.

The notion that such deliberate markings as early non-figurative rock art represent an externalized, permanent form of “engram” to which the human intellect could refer was introduced by Bednarik (1987), who subsequently speculated about the cognitive development of hominins on that basis. He considered the externalization of memory traces in the form of rock art in some detail, but retained Anati’s (1981:206) neologism “psychogram” rather than creating a new one:

“Externalisation dieses Beziehungsrahmen [stellt] eine ‘biologische Notwendigkeit’ dar, die ihm zugrunde liegenden kognitiven Systeme fanden Ausdruck in sensuell perzeptiblen Materialien, als Engramme.” (Externalization of this reference frame represents a ‘biological necessity’; the underlying cognitive systems found expression in sensuously perceptible materials, as engrams [Bednarik, 1987:223]).

He refers to certain cave art as “sensorisch wahrnehmbare Projektionen ‘koagulierter’ neuraler Systeme” (“sensuously perceptible projections of ‘coagulated’ neural systems”; 1987:225) and “Projektionen neuraler Strukturen” (“projections of neural structures”; 1987:226); and he notes that such engram-based phenomena would have significant communication potential because other hominins would have possessed “resonating” cerebral systems.

It was Donald (1991: 308–333, 1993, 2001:305–315) who coined the name “exogram”, also contrasting it with the concept of the engram. He seemed as oblivious of Bednarik’s previous ideas as Richard Dawkins was of Semon’s when he invented the concept of the “meme” 72 years after Semon (1904) had named the “mnemonic trace”. Similarly, Merlin Donald’s three stages of cultural evolution had been foreshadowed by Fairservice (1975). The main significance of Donald’s work is not his definition of exograms as external memory records of ideas, made symbolic inventions that may have undergone a process of repeated examination, testing and improvement; but his observation that they are often permanent, are unconstrained and reformatable, can be of any medium, have virtually unlimited capacity and size, and can be subjected to unlimited iterative refinement. Engrams, by comparison, would be impermanent (i.e. if they existed), of constrained format, fixed physical medium, limited capacity and size and not easily refinable.

There has been extensive debate of Donald’s hypotheses, such as his pronouncement that “unlike the constantly moving contents of biological working memory, the products of thinking, when reformatted exogrammatically, could be frozen in time, held up to scrutiny at some future date, altered and re-entered into storage” (Donald, 1991). Adams and Aizawa (2001:58) state that “there can be no cognitive science of transcorporeal processes” (Adams and Aizawa, 2008; Aizawa and Adams, 2005; Block, 2005; Malafouris, 2004; Prinz, 2006; Rupert, 2004). They define cognition by two factors: non-derived, intrinsic or original content (not replicable by a computer); and cognitive processes of a special kind, the mechanisms by which organisms remember, perceive, attend and learn. Although Adams and

Aizawa cite three “theories of content” (Cummins, 1996; Dretske, 1981; Fodor, 1990), explaining how original content arises naturally, none of them is universally accepted today. According to Menary’s (2007:15) definition of cognition, as the completion of a cognitive task by the manipulation of representations, there would need to be concurrence on which tasks count as cognitive, which is not the case. Therefore a universally accepted theory of cognition remains elusive. Adams and Aizawa’s choice between the hypothesis of extended cognition and the hypothesis of extended cognitive systems raises the question, does the cognition of a blind man end at the point of his stick? If the system that accomplishes cognition comprises the brain together with extra-cranial aids, it needs to be justified why parts of it should be considered constituents of a cognitive process rather than causal contributors to cognitive processes taking place in the brain.

Critiques of Donald’s work have not been limited to the discussion of issues of cognition. His “cavalier misuse of information available from anatomy, anthropology, and archaeology” (Brace, 1993, cf. Brace, 1996, 1999), his inadequate presentation of the relevant neurology and his neglect of cognitive ethology (Cynx and Clark, 1993) have been addressed. He relies on various redundant hypotheses about hominin capacities, such as Lieberman and Crelin’s (1971) notions of “Neanderthal” vocal competence (Lieberman et al., 1972, 1992), which were refuted before Donald’s thesis appeared (Arensburg et al., 1989, 1990; Bickerton, 1990; Falk, 1975, 1987) and today are superfluous (Bickerton, 2010; cf. Enard et al., 2002; Falk, 2009; Krause et al., 2007; Sanjuan et al., 2006; Zhang et al., 2002). Another flaw of Donald’s reasoning refers to his reliance on the now discredited replacement hypothesis (Bednarik, 2008, 2011); and, more specifically, his lack of familiarity with the empirical information on presumed early symboling abilities (Bednarik, 1992, 2003; Hodgson, 2003). He seems to have been entirely unaware of pre-Upper Palaeolithic exograms, which is perhaps the most crucial of Donald’s obstacles in understanding the origins and roles of the phenomenon he focused on. Brace (1993) defines Donald’s belief that “Neanderthals underwent a drastic, rapid extinction” as “unsupported assertion based on a kind of current “folk-wisdom” that has to be relegated to the realm of pop-science, “comparable to phrenology”. As Cynx and Clark (1993) note, Donald’s contention that the introduction of language would speed up the rate of cognitive evolution is analogous to claiming that the rate of mutation determines the rate of genetic evolution.

Nevertheless, the formalization of Donald’s concept of exograms provides a valuable benchmark for the consideration of hominin capacities, because some forms of them can survive for very long periods of time. If their roles as exograms could be correctly identified, these material finds would represent the most instructive forms of empirical evidence for the cognitive evolution of humans, as well as for the origins of human modernity (Bednarik, 2008, 2011), and for the proliferation of “symboling” ability during the Middle Pleistocene (c. 780,000–130,000 years ago). It is this potential of ancient exograms as a means of exploring neuroscientific aspects of hominin evolution that will be investigated next.

Archaeological narratives

Before this becomes realistically feasible it is essential to dispel certain misconceptions about very early exograms. These range from lithocentric models of the Pleistocene to inadequate consideration of the taphonomic effects of time on such remains. Pleistocene archaeology has failed to define emic cultures, because its constructs of cultures are based on tool types, usually invented or etic stone artefact types and their combinations within assemblages, which are regarded as diagnostic in identifying cultures (Thompson, 2012). These “observer-relative, institutional facts” (Searle, 1995) are taphonomically truncated information, and tools obviously do not define cultures. In creating the Pleistocene chronological taxonomy, authentic cultural indicators such as palaeoart (collective term for all art-like manifestations of the distant past) have been consistently eschewed and relegated to decorative significance (Bednarik, 1992, 2003). Since palaeoart consists entirely of exograms, archaeology has not only substituted technological indices for cultural manifestations, it has also ignored the role of exograms in human history. It has instead invented a series of etic tool types, contrived cultures based on them, and even created fictitious ethnic identities that almost certainly never existed as collectively identifiable political, tribal, linguistic or cultural societies. Thus the unstable orthodoxies of

Pleistocene archaeology should not form a departing basis for a scientific consideration of hominin history or cognitive “evolution”.

The incommensurability between archaeological and scientific concepts, for instance of evolution, confirms this. Biological evolution is a dysteleological process, whereas archaeological progressivism, based as it is on a Eurocentric construct of reality, implicitly views it as teleological. If the cognitive development of hominins were evolutionary, it would be wrong to interpret it as a process leading towards more complex forms, which is how conventional archaeology perceives it. Regarding evolution as having an ultimate purpose, the creation of a superior species, is an ideologically inspired falsity. The significance of this observation is that hominin development can be assumed to begin as an evolutionary process, millions of years ago, but ended up being teleological. The question of how this came about is fundamental to exploring the human journey (Bednarik, 2011), yet it has attracted no sustained attention.

Predictably, scientific review of archaeological models yields significant disagreements. The dominant dogma of Pleistocene archaeology places the origins of human modernity in the period named the early Upper Palaeolithic and regards the preceding hominins as different species, and as radically more primitive. From the bioscientific perspective this is absurd. The most dramatic somatic development in human evolution is encephalization, the phenomenal increase in cranial volume, which is almost unparalleled in biology (the increase in brain size within the horse lineage during the same time span was slightly greater; Jerison, 1973). Its evolutionary cost was massive, for instance in its obstetric demands (O’Connell et al., 1999), but also for its burden to society and to the breeding cycle (Bednarik, 2011; Falk, 2009). To suggest that such a severe impediment to reproductive fitness (Joffe, 1997) as this abnormally enlarged organ was tolerated by evolutionary selection without some very significant compensatory developments is biologically untenable. Such major benefits are likely to have included the advanced communication required to underwrite increasing societal complexity (Bickerton, 1990, 1996, 2010; Falk, 2009) and several other cognitive advantages. Therefore the null hypothesis should be that language ability and the development of behavioural modernity can be correlated with the increase in brain size, which commenced at least three million years ago (De Miguel and Henneberg, 2001). This clashes severely with the primitiveness orthodox Pleistocene archaeology prescribes for all hominins up to *Homo sapiens sapiens*.

The point is well illustrated by beads, which are among the most instructive exograms of the distant human past. Theory of mind (ToM), consciousness and self-awareness (De Veer and Van Den Bos, 1999; Gallup, 1970, 1998; Gallup et al., 2002; Heyes, 1998; Keenan et al., 2003; Mitchell, 1993, 1997, 2002) have been demonstrated in several species, including extant primates, and can safely be attributed to all hominins and hominids. In a child it is at the age of about 40 months that the ToM surpasses that of the great apes, and homology would suggest that australopithecines had considerably more developed cognitive faculties at their disposal than chimpanzees or bonobos. Body adornment is a consequence of self-awareness and in incipient form may be present in some chimpanzees (McGrew and Marchant, 1998; McGrew, 2004; Nishida et al., 2009), therefore from a biological perspective it is surprising that evidence of it appears ‘so late’ in the archaeological record: during the Acheulian traditions (Bednarik, 2005; Boucher de Perthes, 1846; Prestwich, 1859:52; Rigollot, 1854; Smith, 1894; Wyatt, 1862). Beads and pendants are quintessential to defining self-awareness archaeologically, but they are stringently selected against by taphonomy, which probably accounts for this discrepancy between bioscientific anticipation and empirical evidence. Yet despite the realistic expectation of such finds as beads, conventional archaeology endeavours to reject all those preceding what it calls the “anatomically modern humans” (AMH). At this point its disparity with science comes into sharp focus: in its subliminal anxiety to preserve the unique status of its perceived crown of evolution it seeks to reject that which meets reasonable scientific expectations. In this it fields arguments that are mistaken and misleading (e.g. d’Errico, 1989; d’Errico and Nowell, 2000; d’Errico and Villa, 1997; Rigaud, 2006–2007; Rigaud et al., 2009; Vishnyatsky, 1994), driven by the subconscious subtext of archaeology, self-aggrandisement of one’s own subspecies.

Other manifestations of this intuitive bias include the notion that the perceived modern human “mind” is shared by all AMHs, for the past 30,000 or 40,000 years in Europe. This fantasy of archaeology is almost impossible to displace, and yet it is readily falsifiable. Due to neuroplasticity (Draganski et al., 2004; Maguire et al., 2000; Smail, 2007), the structures and functioning of the brains of literate

individuals differ so greatly from non-literate ones that the presumption of extant humans sharing the “mind” of “Aurignacian” people is preposterous (Bednarik, 2012; Helvenston, 2013). It is based primarily on the perceived modernity of “Upper Palaeolithic” palaeoart, conflating modernity of anatomy, behaviour, “mind” and “artistic appreciation”. The absence of evidence that this Aurignacian “art” is the work of AMHs and the availability of many indicators that it is attributable to Neanderthaloid humans (Bednarik, 1995, 2007; Sadier et al., 2012; or the Zarzamora Cave petroglyphs) provide a significant impediment to this hypothesis (also Morin and Laroulandie, 2012; Turk and Dimkaroski, 2011; Turk et al., 1995). It is attributable to the “African hoax”, introduced in its initial version in 1973 (Bednarik, 2011; Protsch von Zieten, 1973; Protsch, 1975), according to whose more recent offshoot all extant humans derive from one single ancestral woman in sub-Saharan Africa, whose descendants were all incapable of breeding with other humans. It is here that the ideological underpinnings of Pleistocene archaeology become fully transparent.

Early exograms

Taphonomy (which determines the selective survival of material evidence, and thus the qualitative and quantitative composition of all samples in archaeology) has seen to it that most exograms could have never survived from the Pleistocene, and most of those that could endure would probably not be recognizable as having functioned as exograms. Nevertheless, there are several classes of such materials that can, under fortunate circumstances, remain not only recoverable, but are identifiable as exograms. Such examples from the Middle Pleistocene have been classified into beads and pendants, petroglyphs, portable engravings and notches, proto-sculptures, pigments and other manuports (Beaumont and Bednarik, 2013; Bednarik, 1992, 2003). They are universally rejected by the “African Eve” advocates as being in any way meaningful products of human activity. The earliest published examples are briefly listed here.

Beads

Among the oldest examples are the several hundred centrally perforated fossil sponges from Acheulian deposits in France and England (Bednarik, 2005). First reported by Boucher de Perthes (1846), Rigollot (1854), Prestwich (1859:52), Wyatt (1862) and Smith (1894), they remained widely ignored for the entire 20th century and were correctly identified as *Porosphaera globularis* only recently, and their extensive modification and use wear as beads were only then recognized (Bednarik, 2005). Although their perforations were partly made by a parasite, they had to be completed by humans. Other examples of the use of fossil casts as beads are the worn crinoids from the Acheulian in Israel (Goren-Inbar et al., 1991). The pendants from an Austrian cave (Bednarik, 1992; Mottl, 1951) are also of the Lower Palaeolithic, as are the more than forty Acheulian ostrich eggshell beads from a Libyan site (Ziegert, 2007).

Petroglyphs

Two sites in India and a few in southern Africa provide the presently earliest evidence of rock art, consisting in most cases of cupules. Both Indian sites, Auditorium Cave and Daraki-Chattan, yielded petroglyphs from below Lower Palaeolithic occupation strata (Bednarik, 1993). There is no such clear stratigraphic context available from two southern Kalahari sites, and their tentative attribution to Fauresmith remains is not yet secure (Beaumont and Bednarik, 2013). Again, most of these petroglyphs are cupules. Those on a sandstone slab from Nubia are dated to 200 ka ago (Van Peer et al., 2003), and a lattice pattern on a lower grindstone from East London, South Africa (Laidler, 1933, 1934), is thought to be in the order of twice that age. A similar lattice petroglyphs has recently been attributed to Neanderthals in Gorham’s Cave at Gibraltar (Rodríguez-Vidal et al., 2014).

Engravings

Portable engravings occurring in Lower Palaeolithic occupation strata have been reported from Bilzingsleben, Germany (Mania and Mania, 1988), Sainte Anne I, France (Raynal and Séguy, 1986), and Wonderwerk Cave, South Africa (Beaumont and Bednarik, 2013), but the number of such materials across Eurasia and Africa increases considerably towards the terminal Middle Pleistocene (Bednarik, 1992, 2003).

Proto-sculptures

There are only two examples known from Lower Palaeolithic contexts, one from Israel (Goren-Inbar, 1986) and one from Morocco (Bednarik, 2003). Both are natural cobbles that have been extensively modified to better resemble human figures, and in the latter case the object was coated with haematite.

Pigments

Evidence of pigment use, mostly in the form of iron minerals, is extensive and begins in the order of 1.1 million years ago at such sites as Wonderwerk Cave (Beaumont, 2004a, 2011; Beaumont and Bednarik, 2013; Chazan et al., 2008) and Kathu Pan 1 (Beaumont, 2004b) in South Africa, and Kabwe in Zambia (McBrearty and Brooks, 2000). The Acheulian of Africa, Europe and southern Asia has yielded numerous examples of pigment use (Bednarik, 1992, 2003), and at one African site alone, Lion Cavern in Swaziland (Dart, 1969), over 1200 metric tonnes of specularite was mined during the Middle Stone Age.

Manuports

Objects transported by hominins and deposited in occupation sites, because of some outstanding characteristics, include rock crystals, fossil casts and unusually colored or shaped exotic stones. They are found in the Lower and Middle Pleistocene and have been reported from the three Old World continents. The earliest specimen is the red jaspilite cobble from Makapansgat Limeworks, South Africa, deposited in a dolomite cave about 2.95 million years ago (Bednarik, 1998; Dart, 1974). Transported for many kilometres to the site, the object was very probably collected due to pareidolic detection of its suggestive features, which presupposes apperceptive capability in the hominins concerned (Fig. 2).

Although it can be (and has been) argued that pigment could have been used for purely “utilitarian” tasks (in the great majority of ethnographic cases its use is of “symbolic” nature), other classes of exograms preserved from a period of three million years provide secure minimum information about the rise of exograms in hominin cognition. Only incredibly fortuitous circumstances have permitted the preservation of exogrammatical traces from the Pleistocene, and presumably only in exceptionally rare instances. It is obvious that today’s immense cultural complexity is entirely predicated on the use of exograms: each extant conspecific uses millions of them every day. Very little of the immense volume of transfer of knowledge among humans would be possible without systems of exograms, including those making up language, writing or other forms of communication, or externalized “memes”, or indeed any external manifestation the human brain refers to in constructing its social and cultural reality.

Discussion

The wholesale neglect of this important realization is attributable to the compartmentalization of exograms into diverse and supposedly unconnected entities, just as the recognition of the Pleistocene exograms has been hampered by subsuming palaeoart under “art”. Similarly, the confusion of symbols and exograms derives from neglecting their supervenience relationship. The symbol systems used by primatologists to communicate with apes are all humanly created, and the question arises whether such symbols could be defined as exograms. This issue appears to help define them, because the use of externally stored memory presupposes the ‘creation’ of exograms. Therefore the language



Fig. 2. Jaspilite cobble deposited in Makapansgat Limeworks Cave, South Africa, about 2.95 million years ago; oldest known manuport, demonstrating apperceptive capability in the hominins concerned.

boards and other communication devices of ethologists conveniently define the difference between symbols and exograms: clearly they use referents, but they do not constitute native or naturalized systems of external storage. On the other hand, exograms may not necessarily have referents, as they refer more typically to purely abstract concepts, whereas symbols by definition stand for other entities. Moreover, most symbols are shared with conspecifics, generally via culture, whereas there is a distinctive separation of personal exograms (not shared with conspecifics) and shared exograms (culturally determined).

Ultimately, the use of exograms is the principal difference between humans and other animals, now that the relevance of practically all others ever proposed has been rejected or downgraded. This apprehension is itself rather significant, but how does it connect to the atrophy the human brain has experienced since the accelerated neotenzionization of the species commenced around 40 ka ago? There is apparently complete acceptance of the view that, during this very period, the demands made on the brain increased markedly, as a result of greater technological, cultural and social complexity. Therefore the empirical reduction of brain size over the same period of time presents a significant paradox (Henneberg, 2004), which needs to be explained. To suggest that this reduction has been compensated for by improved interconnectivity, shorter inter-regional pathways connecting neuronal populations forming distinct brain regions, greater neuronal density, or other improved efficiencies in the patterns of anatomical connectivity is unconvincing (Brodmann, 1909; Jirsa and McIntosh, 2007; Sporns, 2010; Swanson, 2003), in view of the presumed massive increase in demands made on the human brain. Moreover, as noted above, this possibility would negate the justification for the preceding encephalization: if a smaller brain can underwrite greater intelligence, social complexity and cognition, why would evolution have saddled humans with the substantial metabolic, social and evolutionary cost of this large brain in the first place? Clearly something else has to be at work here.

The archaeological record may be unrepresentative and is certainly inchoate, but it does seem to indicate that utilization of exograms increased gradually over the course of the entire Pleistocene. It seems widely accepted that, beginning about 40 ka ago, there is a distinctive acceleration in this development. The relatively isolated, seemingly not always coherent earlier practices appear to coalesce into burgeoning systems based on exograms during the period called the Upper Palaeolithic in Eurasia. If these are indeed extracranial storage systems for amassing memory traces, it is to be expected that the biologically all-crucial brain volume then ceased to dictate the limits of cognition, memory and communication. No longer did the arms race determined by numbers of neurons and synapses govern boundaries and thresholds, but competence in employing and exploiting exograms became the primary selecting factor in maximizing cognitive fitness. Needless to say, this process is by its very nature autocatalytic, and its effects can be observed throughout present-day societies, being evident virtually everywhere. No human civilization for the past couple of million years could have functioned without exograms, and dependence upon them has increased exponentially. However, at some point in time this process has made the rapid atrophy of the human brain possible, which soon proceeded at a rate 37 times the previous long-term rate of encephalization. One would be hard-pressed to find an alternative explanation for this development, other than the hypothesis delegating much of the functions of the brain to the external memory bank provided by exograms. This is simply a way of restating that cultural functions overtook those of biology and evolution, taking human development onto a trajectory involving numerous other consequences, most of which are detrimental (Bednarik, 2008, 2011, 2012). The proposition that brain atrophy, neotenization and the rise of exograms are linked is readily testable: to refute it a more economical and simpler explanation needs to be presented.

This does not, however, clarify cause and effect of the process: is it human self-domestication or the declining need of brain power that is responsible for the reduction of cranial volume? Both factors are attributable to the rise of culture as the principal determinant of human development (Boyd and Richerson, 2005; Richerson and Boyd, 2005). The most probable explanation is that humans were rather fortunate that around the time their self-domestication affected their brain size, their burgeoning culture had rendered an explosion of extra-cranial storage possible. Thus the reduction in internal brain space could be tolerated without impairing functionality – in fact it even facilitated increasing cultural complexities. It then appears that if that alternative had not been available, the course of subsequent human history would have been very different. Indeed, the ascent of exograms defines human modernity (Bednarik, 2011).

Conclusion

This discussion paper makes no attempt to re-write hominin history; it differs little from the traditional view in its take on the empirical evidence or on the course of this history. Rather, it applies a different framework to the “archaeological record”, showing that there are alternatives to the currently favored explanation that, on reflection, seem more in keeping with science’s preference for austerity in rationalization. Instead of explaining the nature of contemporary humans by unlikely and unsubstantiated exoduses into supposedly vacant regions, or regions occupied by inferior people, the emphasis is on finding rational explanations for some of the most tantalizing paradoxes in recent hominin evolution. For instance why has natural selection allowed the establishment of thousands of genetic disorders, neuropathologies, and neurodegenerative conditions afflicting modern humans, an enigma neuroscience has found impossible to explain (see extensive debate in Keller and Miller, 2006). The replacement model, based as it is on genetic drift and natural selection, has no explanation for this, and for numerous other features of human modernity. It cannot, for instance, explain the loss of oestrus in humans, the genetic base of exclusive homosexuality, or more relevantly, the recent atrophy of the human brain. Indeed, there is a pronounced lack of coherent contemplation so far of the latter paradox.

The rapid decrease in cranial volume, seemingly proceeding at an exponentially increasing rate (Henneberg, 2004: Fig. 1), has indeed received very little attention. Here it is contended that it is related to the same issues that explain various other paradoxes concerning the last 40 ka of human history, that have either not been clarified or have been misinterpreted. The rapid neotenization humans experienced during this time, expounded popularly as demonstrating a replacement of all robust *Homo*

sapiens by a purported genetic strain of graciles unable to breed with other members of that species, is another effect of the processes collectively clarified by the domestication hypothesis (Bednarik, 2008). Here it has been shown that it also explains the mystery of the brain atrophy occurring at a time when the proliferation of cultural and social imperatives is thought to have demanded a significant increase in memory. Not only has unintended self-domestication resulted in great genetic burdens for modern humans, the cultural complexity that gave rise to it also provided a substitute for the need of more cranial space and brain power: extra-cranial memory encoded in exograms, the hallmark of human culture. Not only does this explanation clarify all these paradoxes; it is consistent with the empirical evidence currently available. Perhaps this evidence changes in the future, but as it stands the domestication hypothesis is the most parsimonious explanation for how humans became what they are today (Bednarik, 2008, 2011).

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