OLDOWAN CULTURE AND THE EVOLUTION OF ANTICIPATORY COGNITION

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Abstract: Anticipatory cognition, that is, the ability to mentally represent future needs, is a uniquely human trait that has arisen along the hominid line. We argue for the co-evolution of early anticipatory cognition and the Oldowan cultural niche. Following Plummer (2004), we identify the niche as consisting of stone tool manufacture, of transports over long ranges of tools as well as food and of the use of accumulation spots. Our main argument is that this niche promoted the selection for anticipatory cognition, in particular planning for future goals. Once established, anticipatory cognition opened up for further cultural developments, such as long ranging migration, division of labour, and advanced co-operation and communication, all of which one find evidence for in *Homo ergaster/erectus*.

1. INTRODUCTION

A distinctive feature of human thinking that contrasts with the cognition of other primates is our capacity to form mental representations of the distant future – humans can engage in "mental time travelling" (Suddendorf & Corballis, 1997; Suddendorf & Busby, 2003). We will call this general capacity *anticipatory cognition*. In particular, we shall focus on the capacity to plan for *future needs*, what we (following Gulz, 1991) call anticipatory planning, and its role in the evolution of humans. Existing evidence as regards planning in primates and other animals suggest that they can only plan for present needs (this is dubbed the Bischof-Kohler hypothesis by Suddendorf & Corballis, 1997). At the end of the article, we shall argue that anticipatory planning is needed for the evolution of human co-operation and social structuring as well as for language. This indicates that anticipatory cognition plays a key role in the evolutionary transition from the cognitive capacities we share with the apes to the thinking of humans.

From the point of view of evolutionary theory, the central question is: what has generated the capacity for anticipatory cognition in the hominid line? Our main thesis is that the cultural niche that was created by the use of Oldowan tools, including transport of tools and carcasses (Plummer, 2004), has lead to a selection for anticipatory cognition, and in particular anticipatory planning.

To substantiate this thesis, we will first discuss cultural niches and their role in explanations of human evolution. Secondly, some notions of cognitive representations will be introduced and the concept of anticipatory planning will be defined. Then we shall examine the evidence concerning tool transport in the Oldowan culture. A precursor for this may be a skill for throwing among hominids that is not found among other primates. We suggest that the Oldowan culture constitutes an expanding cultural niche and that a capacity for anticipatory cognition will be selected for in this niche.

As additional support for the general thesis we note that in *Homo ergaster/erectus* one finds several innovations that clearly depend on anticipatory planning. In the final section, we shall argue at that anticipatory cognition opens up for the evolution of human co-operation and social structuring, as well as for the evolution of symbolic communication.

Our main method consists of an interpretation of paleoanthropological and archaeological data from the perspective of cognitive science. We will consider three questions: (1) Why is *Homo sapiens* the only living species with a cognitive ability to reach in to the distant future, beyond the current drive state? (2) Approximately when did this ability emerge? (3) What are the consequences of this emergence?

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2. THE CONCEPT OF NICHE CONSTRUCTION

In this section, we present the notion of *niche construction* which is borrowed from evolutionary biology. In particular, we focus on the concept of a cultural niche.

Niche construction can be defined as the systematic changes that organisms bring about in their environments (Day, Laland & Odling-Smee, 2003). A wide variety of organisms construct parts of their environment: spiders making webs, birds building nests, beavers constructing dams and plants altering their chemical surroundings. Although the degree to which the environment is changed varies between different organisms, niche construction cannot be viewed as something exclusive for “higher” or complex organisms. Rather, it seems to be a commonplace phenomenon wherever life is found.

The most interesting part of niche construction is perhaps not the construction itself, but the evolutionary feedback that might be the result of it. Mathematical analyses based on population genetic models show that niche construction can make nontrivial differences to the evolutionary processes and it can also generate unusual evolutionary dynamics (see e.g. Laland, Odling-Smee & Feldman, 1996, 2001). There is a growing opinion that niche construction should be regarded as an evolutionary process in its own right (Day, Laland & Odling-Smee, 2003). Even though traits generated by niche construction are products of natural selection, they are not merely that, because such traits may themselves alter the selective pressures, often in a directed manner. Consequently, the traits generated by a niche can actually change the evolutionary dynamics. Another interesting consequence of niche construction is what is called ecological inheritance. This is characterized by offspring inheriting the altered ecology from its ancestors – an ecology with its own selective pressures. Implementing niche construction in evolutionary theory involves two kinds of modifying processes, natural selection and niche construction, as well as two kinds of descent, genetic and ecological inheritance (Day, Laland & Odling-Smee, 2003).

Culture is the most forceful medium in niche construction, because culturally transmitted traits spread much more rapidly than genetically transmitted traits do. On one hand, culture can create a very strong selection and thereby increase the rate of evolutionary changes. On the other hand, culture can buffer out particular natural selection pressures (Laland, Odling-Smee & Feldman, 2000). A cultural innovation, constituting a form of niche construction, can create a behavioural drive that accelerates evolution. The same innovation can create a niche that blocks natural selective pressures. For example, humans live in cold climates without having any major biological adaptations to cold, because they rely on the cultural niche created by clothes and external heat sources. The consequence is that the naked human body does not exhibit cold adapted traits to the extent that would be expected from a mammal living in a cold climate.

The hominids have presumably been the most cultural dependent species ever and thus the most powerful and flexible niche constructors (to various degrees, of course, and with *Homo sapiens* at the present extreme). A consequence of this is that the hominids should exhibit great evolutionary resistance to changes in the natural environment, but also be capable of far-reaching evolutionary change caused by some ground-breaking cultural innovation (Laland, Odling-Smee & Feldman, 2000). Such changes can make it intricate to establish the course of human cognitive evolution. The key point is that some of our major cognitive adaptations might not only be a result of new demands from a changing natural environment, but to a larger degree emerge from a highly constructed environment, including both social and artefactual elements. It is not sufficient to look at habitat, climate and other natural ecological factors, when trying to understand how humans evolved.

The study of hominid cultural traits inferred from the archaeological record or otherwise, generates new questions from the point of view of niche construction. What kind of environment does a certain culture constitute? What ecological inheritance is present in the culture? And, most important, what are the selective pressures that arise in this environment? Questions like these must be considered in connection with cultural niche construction. The general thesis is that the hominids themselves created a great deal of the selective pressures that eventually made us human.

In Section 4, we will adopt the niche construction view and analyze some of the cognitive implications of the earliest clearly identifiable hominid culture, the Oldowan culture – a culture that can be defined by the behaviours surrounding crude sharp edged stone tools. But before that, we must present certain aspects of human cognition.

3. Anticipatory cognition

3.1 Cued and detached representations

In order to understand the functions of most of the higher forms of cognition, one must rely on an analysis of how humans and other animals *represent* various things, in particular the surrounding world and its possibilities. There is an extensive debate in the literature on what is the appropriate meaning of ”representation” in this context (see e.g. Roitblat, 1982; Vauclair, 1990; Gärdenfors, 1996, 2003; and Grush, 1997). Here, we will not go into the intricacies of the debate, but only point out that there are different *kinds* of representations. We claim that in order to give an accurate analysis of many phenomena in animal and human cognition, it is necessary to distinguish between two kinds of mental representations: *cued* and *detached* (Gärdenfors, 1996, 2003).

A *cued* representation stands for something that is present in the current external situation of the representing individual. In general, the represented object need not be actually present in the actual situation, but it must have been triggered by something in a recent situation. Delayed responses, in the behaviourist's sense, are based on cued representations according to this characterization.

When, for example, a particular object is categorized as food, the animal will then act differently than if the same object had been categorized as a potential mate. We are not assuming that the individual is, in any sense, *aware* of the representation, only that there is some generalizing factor that determines its behaviour.

In contrast, *detached* representations may stand for objects or events that are neither present in the current situation nor directly triggered by some recent situation. A memory of something that can be evoked independently of the context where the memory was created would be an example of a detached representation. For example, consider a chimpanzee, who performs the following sequence of actions: walks away from a termite hill, breaks a twig, peels its leaves off to make a stick, returns to the termite hill, and uses the stick to “fish” for termites. This behaviour seems very difficult to explain unless it is assumed that the chimp has a detached representation of a stick and its use. A detached representation is something the individual can utilize regardless of whether what it represents is present or not.

A detached representation can even stand for something that does not exist at all. For example, our imaginative worlds are full of centaurs, unicorns, elves and trolls – about which we easily communicate although they do not truly correspond to any sensory impressions we have received. Being able to use a detached representation requires that one can *suppress* the sensations one has for the moment, otherwise they will come into conflict with the representation. That places new demands on mental capacities. The suppression of information is managed by the frontal lobe of the brain, which is the part that has expanded most rapidly during the evolution of the hominids. The frontal lobe is in charge of planning and fantasizing and the so-called “executive functions” of self-control (Hughes, Russell & Robbins, 1994).

We are not claiming that it is possible to draw a sharp line between cued and detached representations. However, we still believe that the rough distinction between the two major kinds of representations is instrumental in that it directs our attention to key features of the mental representations.

The different kinds of representation also connect to different kinds of memory. Tulving’s (1985) distinction between procedural, semantic and episodic memory can be associated with different levels of representations. An animal needs no representations to remember a procedure. It is sufficient to have responses that are connected to various kinds of conditioning. The procedural memory determines what action should be carried out when an organism receives a certain stimulus. The semantic memory, however, is tied to the categories that an organism has created. This requires at least cued representations. Semantic memory presents the world in a way that supports the selection of appropriate actions. Finally, episodic memory presumes detached representations and a personal identity that combines the individual episodes of memory. In order to think about a previous event, you have to be able to produce representations that are not bound to the current situation. Tulving (1993, p. 67) writes: “The owner of an episodic memory system is not only capable of remembering the temporal organization of otherwise unrelated events, but is also capable of mental time travel: such a person can transport at will into the personal past, as well as into the future, a feat not possible for other kinds of memory.” At the same time, you have to *suppress* the perceptions you have at the moment to avoid a conflict with the memory you have evoked (Glenberg, 1997). Tulving (1985) suggests that *Homo sapiens* is presently the only species that has episodic memory. This hypothesis has, however, been challenged by Schwarz and Evans (2001), who claim that also apes, in particular chimpanzees, have an episodic-like memory.

The collection of all detached representations of an organism (animal or human) and their interrelations will in this article be called *the inner world* of the individual. There is strong evidence that humans have richer inner worlds than other animals (Gärdenfors, 2003). Gomez (2004, p. 20) argues that the prolonged immaturity in the children of apes and in particular humans results in a greater flexibility in forming representations which in turn leads to greater cognitive and behavioural flexibility.

3.2 Two kinds of planning

The ability to envision various actions and their consequences is a necessary requirement for an animal to be capable of planning. Following Gulz (1991, p. 46), we employ the following criterion: An organism is planning its actions if it has a representation of a goal and a start situation and it is capable of generating a representation of partially ordered set of actions for itself for getting from start to goal. This criterion presupposes representations of (1) goal and start situations, (2) sequences of actions, and (3) the outcomes of actions. The representations of the actions must be detached, otherwise the organism has no choice. According to our characterization, planning therefore presupposes an inner world.

There are several clear cases of planning among primates and less clear cases in other species (see e. g. chapters 5, 7, 8 and 9 in Ellen & Thinus-Blanc, eds., 1987; pp. 58-61 in Gulz, 1991; Byrne, 1995; Suddendorf & Corballis, 1997; and Hauser, 2000). The termite-fishing chimpanzee mentioned earlier is one such example. In passing, it should be noted that this is an example of planned *tool making*.

The plans of apes and other animals depend on their current drive states: They plan because they are hungry or thirsty, tired or frightened. Oakley (1961 p. 187) notes that "Sultan, the chimpanzee observed by Kohler, was capable of improvising tools in certain situations. Tool making occurred only in the presence of a visible reward, and never without it. In the chimpanzee the mental range seems to be limited to present situations, with little conception of past or future." Kohler himself (1927, p. 272) wrote that "[the] time in which the chimpanzee lives is limited in past and future." More specifically, Bischof (1978) and Bischof-Kohler (1985) argue that animals other than humans cannot anticipate future needs or drive states. Their cognition is therefore bound to their present motivational state (see also Gulz, 1991). This hypothesis, which is called the Bischof-Kohler hypothesis (Suddendorf & Corballis, 1997), is supported by the current evidence concerning planning in non-human animals.

According to the Bischof-Kohler hypothesis, humans are the only extant animals that can plan for *future* needs. Gulz (1991, p. 55) calls planning for present needs *immediate planning* while planning for the future is called *anticipatory planning*. This is a special case of what has been called "mental time travelling" (Suddendorf & Corballis, 1997; Suddendorf & Busby, 2003). Humans can predict that they will be hungry tomorrow and save some food, and we can imagine that the winter will be cold, so we start building a shelter already in the summer. The crucial distinction is that for an individual to be capable of anticipatory planning it must have a detached representation of its *future needs*. In contrast, immediate planning only requires a cued representation of the current need.

The cognitive capacity of anticipatory planning is dependent on executive functions. One definition of this notion is: "'Executive function' is an umbrella term for the mental operations which enable an individual to disengage from the immediate context in order to guide behaviour by reference to mental models and future goals" (Hughes, Russell & Robbins, 1994, p. 477). Suddendorf & Corballis (1997) note: "Future need anticipation therefore might be only a special case of animals' general problem with simultaneously representing conflicting mental states." It is well known that the executive functions are controlled by the prefrontal cortex. Lesions to the prefrontal area lead to impaired goal-directed behaviour. Ingvar (1985) even calls this state a "lack of future."

There is nothing in the available evidence concerning animal planning, notwithstanding all its methodological problems, which suggests that any other genus than *Homo* has detached representations of their desires (see e.g. Whiten & Byrne, 1988, and their commentators). The cognition of other animals concerns here and now, while humans are both here and in the future. The squirrel or nuthatch that is gathering and storing food for the winter is not engaged in anticipatory planning because it is not planning at all. It has no *representation* of the winter, let alone its needs. The gathering behaviour is an innate complex behaviour pattern that is stereotypical without sensitivity to varying circumstances (cf. Gulz, 1991, p. 62).

Anticipatory planning is a component in a more general anticipatory cognition that is a hallmark of *Homo sapiens*. It also includes episodic memory and other aspects of "mental time travel" (Suddendorf & Corballi, 1997; Suddendorf & Busby, 2003) The central question of this article is what factors along the hominid line have created selective evolutionary forces that have resulted in anticipatory cognition in general (including episodic memory) and anticipatory planning in particular (also cf. Savage-Rumbaugh, 1994). In following sections, we shall argue that a cultural niche based on transport was established during the Oldowan culture. This niche then led to the co-evolution of transport and anticipatory planning. Once anticipatory planning had developed in the hominid minds, it opened up for further cultural achievements as we shall argue in Section 5.

4. THE CO-EVOLUTION OF TRANSPORT AND ANTICIPATORY PLANNING

4.1 A possible pre-Oldowan cultural niche

Before analyzing the Oldowan cultural niche, we will briefly speculate upon some possible earlier cultural traits that might have been important in the development of the Oldowan culture. Our point of departure will be bipedalism. We do not know when this feature appeared in evolution, but it was clearly present in the australopithecines. The key factor is that bipedalism frees your hands and arms for other activities than locomotion. We suggest that the free hands eventually resulted in a niche with its own selective pressures and ecological inheritance. This niche may have provided fertile ground for the innovation of stone tools, and, more importantly, for the evolution of a cultural niche based on anticipatory cognition. As Savage-Rumbaugh (1994, p. 23) puts it: "While eliminating the need to use the forelimbs for locomotion would certainly make object carriage easier, it was not the freeing of the hands that was critical to the emergence of frequent object carriage; rather it was the freeing of the mind."

Panger et al. (2002) argue that the morphology and the habitat of some of the hominids ancestral to *Homo* make it highly likely that tools were used well before the Oldowan. Tool cultures are also found in modern primate societies, in particular with chimpanzees (Whiten et al., 1999). Besides the more apparent primate tool uses such as nut cracking with stones or logs, or termite or honey extraction with twigs, we want to highlight some tool cultural traits that seem to fit hominids better than other primates and that could have played a part in the development of the Oldowan culture.

We suggest that hard precision throwing and transport of stones over long periods have been behaviours that were adaptive for the early hominids (as well as for later ones). The importance of throwing in human evolution has been considered by several authors in a variety of ways (e.g. Calvin, 1982, 1993; Savage-Rumbaugh, 1994; Bingham, 2000). It is not farfetched to assume that a hard precision throw was of vital importance for a small and clawless slow biped with reduced canines. Bipedalism makes you slow compared to quadruped running (the favoured locomotion of dangerous predators) and it also makes you less skilled in climbing. On the other hand, bipedalism in itself is a strong prerequisite for precision throwing. Markze (1996) notes that 50% of the speed in a throw comes from the trunk. To be able to make full use of the trunk in a throw, one needs stable hind limbs. Electromyographic observations of the *gluteus maximus* in a throwing human show the key role of this muscle (Markze, 1996). The bipedal morphology of hominids consequently made it possible for them to evolve a better hard precision throwing capacity than is found in other primates. A well-developed throwing behaviour was presumably present already in the hominid populations that created the Oldowan culture. We will return to the implications of this, but first we shall consider a certain hominid transporting behaviour that could also have been induced by hominid bipedalism.

Non-hominid primates sometimes transport their tools. For instance, chimpanzees transport nut cracking stones or sticks to termite hills. These transports are mostly limited to short distances and rarely exceed a few hundred metres (Boesch & Boesch-Acherman, 2000). Apes are quadrupeds, and it is awkward and energy consuming to use one of the limbs for transporting objects. There seems to be nothing to gain, no economy, in long distance transports, if you are built like an ape. For bipedal hominids, on the other hand, there is a lot to gain. Consequently, it is reasonable to assume that early hominids transported tools and/or throwing stones for longer distances than modern primates. There is strong evidence that hominids in the Oldowan culture were apt transporters and good at logistics, as we shall see later on, but it is also likely that earlier hominids had developed these capacities, albeit on a smaller scale.

Hominids who picked up stones of throwing size and carried them around in their whereabouts would increase their readiness and thereby their fitness, especially when they moved in environments with small amounts of visible stones of throwing size. This type of readiness is a well-established life-saver in modern military Special Forces units, as well as a known necessity among hunters all over the world. The closeness to the weapon makes all the difference because it is often a matter of seconds in getting the upper hand over the enemy or the prey. For example, if a hominid came under sudden attack from a big cat or a competitor this kind of readiness would be crucially advantageous. If the same hominids would stumble over a potential prey, the stone could do what the biped normally could not: chase down a fast running quadruped.

It is of course possible to imagine a whole range of items that where transported by pre-Oldowan hominids, but that they also transported stones of throwing size is supported by the inferences that can be made from observations of the sizes of the Oldowan tools and of the Oldowan tool making skills. Canell (2002) notes that Oldowan tools have about the same size and weight as the optimal throwing stone would have (under the assumption that two species or groups of different sizes existed then). Even modern humans working with stone samples, e.g. geologists, unconsciously prefer to pick up samples of optimal throwing size. This suggests an intimate relation with throwing of stones in our evolution. One also finds interesting details in how an Oldowan tool is crafted which imply the existence of a hard precision throwing behaviour. We therefore submit that stones of throwing size have been a part of the ecological heritage in pre-Oldowan hominid populations.

When comparing the hominid way of making stone tools with that of an ape, small but important differences become apparent. The language-trained bonobo (*Pan paniscus*) Kanzi showed some remarkable craftsmanship when making Olduwan tools, but he is not really at the cutting edge with the hominids (Toth et al, 1993, Schick et al, 1999). He seems to lack some of the precision and power control, which are two of the main components in a good throw. Savage-Rumbaugh (1994) points out that this lack is due to the stiffness in the wrists of African apes. A human can bend the wrist almost 90 degrees backward, whilst an ape only can produce a bend of a few degrees – a result of different locomotor adaptations. The human joint mobility makes it possible to snap the wrist in a throw, resulting in more precise aim and higher power. She also points out that “[a] similar wrist-snapping movement is critical to the fashioning of rock tools. In order to efficiently flake off large pieces of stone, the toolmaker must essentially engage in a “control throw” by snapping the wrist holding the hammer stone just before striking the core.” (1994, p. 48). Young (2003) notes that the human power and precision grip primarily seem to be adaptations to precision throws, and that they seemingly precede stone tool making.

Still, Kanzi is fully capable of producing sharp stone edges that are just or almost as useful and functional as the original Olduwan flakes. In line with this, we suggest that the hominids’ refined manner in making sharp edges is actually a by-product of the neurological and biomechanical adaptations for precision throwing.

One can even argue that if stone tool making was the evolutionary cause of certain motor skills, such as precision and focused power, then one should expect to find early stone tools exhibiting features of poorer craftsmanship. Until recently the common view has been that there existed some sort of “pre-Oldowan” industry, and that the earliest dated stone tools exhibits less developed traits. However, new careful analyses of some of the oldest Oldowan artefacts point to the contrary (e.g. de la Torre, 2004). The first knappers seem to have been as skilful as later tool makers. We suggest that the missing motor link is high precision throwing and not any as yet undiscovered pre-Oldowan sharp edged technology.

The presumed pre-Oldowan culture, with its throwing and transporting elements, does not imply any major cognitive adaptations compared to apes. However, it constitutes an environment, with optimal sized stones in the ecological heritage, that could rapidly develop into the Oldowan culture when certain new selective pressures arise.

4.2 The Oldowan cultural niche

The appearance of the first sharp edged stone tools in the archaeological record roughly coincides with a series of other relevant events in the human evolution. Ice sheets started to grow in the northern parts of the world, and Africa experienced deforestation and expanding savannas. The increased grasslands reduced the floral food resources for the hominids, as the savannah is only about half as productive as a tropical forest. On the other hand, the production of herbivores on the savannah is almost three times as high, yielding a markedly larger mammal biomass (Leonard & Robertson, 1997, 2000). These environmental changes resulted in selective pressures on the hominids that lead them to change their diet from predominantly vegetarian to more protein and fat based. The sharp stone edge appears to be a direct answer to this shift as even the earliest finds of Oldowan technology is associated with butchering (de Heinzelin et al., 1999; Semaw et al., 2003). It is also likely that the stone tools were used for woodworking and processing plant materials, as is indicated by a microwear analysis of 1.5 million year old Koobi Fora stone artefacts (Keeley & Toth 1981).

There is clear evidence that, already from the start, transport of the artefacts (at least the stone tools) was an important trait of this technology. Toth (1985) identifies three types of archaeological evidence of Oldowan tool transports: (1) direct evidence of raw material transport, (2) evidence that only some stages of flaking are represented at archaeological sites, and (3) evidence from refitting lithic materials.

The first line of evidence is based on tools found far from their geological sources. One of the oldest direct evidence of transporting was found at Lake Turkana where 2.3 mya old Oldowan tools have been transported about 1 km (Kibunja, 1994). There are several finds from Oldowai interpreted as tool transports: 2-3 km transports at 1.7-1.85 mya ago (Potts, 1984), 1.8 m.y.a. old transports for 10 km (Hay, 1976) and 13 km transports at the same age (Ohel, 1984). Bunn (1994) notes later tool transports with distances about 15-20 km undertaken at Koobi Fora 1.64 m.y.a. ago.

The second line derives from the predictable set of flake types that occur when making an Oldowan tool. By extensive experimentation in making replicas of Oldowan tools, Toth (1985) concluded that it is possible to create a classification system that reveals at what stage in the manufacturing process a certain flake was made. According to this system a high percentage of the later stages were represented at some Koobi Fora sites. The inference is that partially flaked stones were transported from another manufacturing location.

The third line of evidence comes from refitting studies. For example, in the effort of refitting flakes back to the original core at a Koobi Fora site, which had not undergone any serious fluvial disturbance, it was found that only about 15% were conjoinable to others. Again, this suggests transport of semi-manufactured stones. Despite these lines of evidence, it is still not clear whether the earliest transports were made in the same habitual manner as seem to be the case from 2 m.y.a. and on

(Plummer, 2004).

Another important and distinctive feature in the new increased meat eating lifestyle is the accumulation of tools and bones (hominid meal leftovers) at certain places in the plio-pleistocene landscape. Although these accumulations have been interpreted in numerous ways, some assumptions are fairly undisputed: both stone tools or their raw material and pieces of carcasses were transported to these locations from perhaps kilometres away (Plummer, 2004).

The main components of the Oldowan culture can thus be recognized as: (1) the manufacturing and use of stone tools; (2) the transport of artefacts (at least the stone tools); (3) the transport of pieces of carcasses; (4) and the use of accumulation spots. The most significant advantage of this culture is that it enabled a much wider exploitation of meat resources than is observed in any other primate species. The conglomerate of cultural and other environmental factors and their implications, behavioural and others, were causally intertwined in complex and intricate ways. This network is highly schematically depicted in Figure 1.

Today we can only identify very few traces of this causal network. Nevertheless, it seems fairly clear that the Oldowan culture was the main constituent in the highly constructed niche that the Oldowan hominids lived in. It is important to note that this niche created new strongly selective pressures. In the following two subsections, we will delineate some of the results of these pressures. Section 4.3 focuses on the major morphological changes in the hominids, which have been comparatively widely studied. In section 4.4 we will then look at the poorly investigated cognitive implications of the selective pressures.

4.3 Morphological adaptations to the Oldowan niche

Perhaps the most obvious signs of morphological traits that resulted from the pressures inflicted by the Oldowan niche are definitively found in *Homo ergaster/erectus* (*Homo habilis* exhibits some intermediate steps of these traits, suggesting this species to be the first constructor of the Oldowan niche). *Homo ergaster/erectus* was a long ranging species, fuelled by a high quality diet, and adapted to transporting fairly heavy burdens. The long legs, short broad trunk and short arms, in comparison to the predecessors, seem to be adaptations to endurant

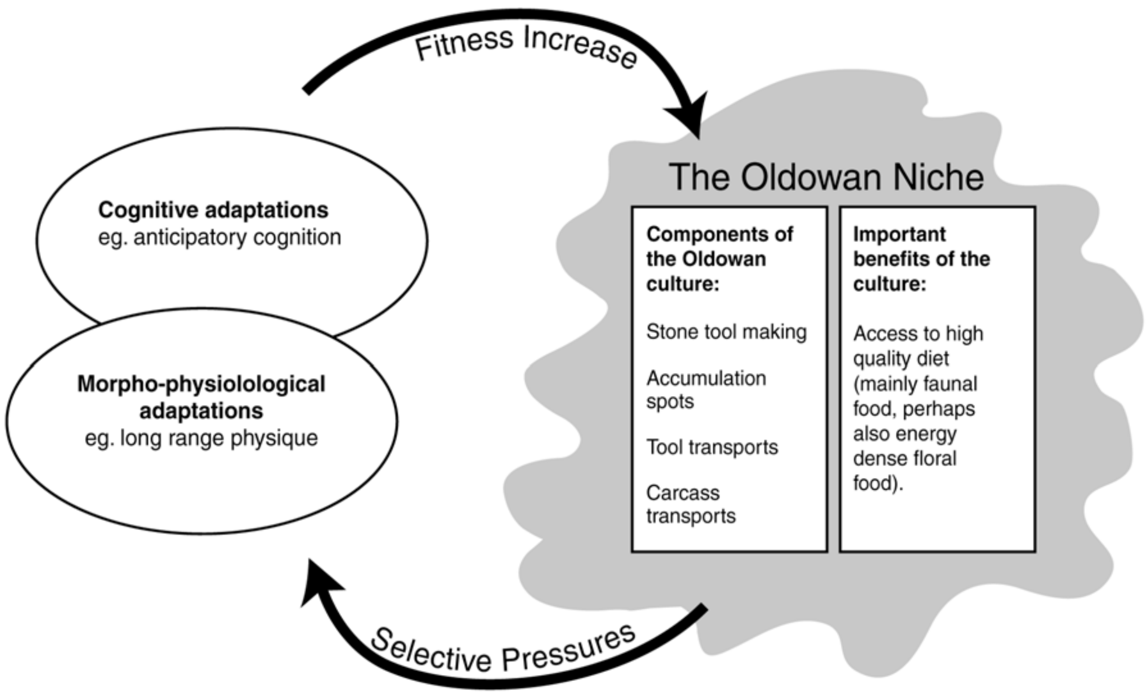

Figure 1
The Oldowan niche had its own selective pressures. Adaptations to these pressures increased the fitness within the niche, and the environment in the niche changed as a result of the adaptations. Consequently the niche should not be viewed as a completely static environment, rather as an ever changing entity with some few consistent focal points.

bipedalism, that is, long range walking or running (Preuschoft & Witte, 1991; Hilton & Meldrum, 2004). *Ergaster/erectus*'s gracile physique and more prominent stature gave this hominid a thermo-regular advantage (Wheeler, 1992), which implies a capability for long ranging day time excursions in hot open lands. Plummer (2004) suggests that there are several indications pointing towards a modern human thermoregulation, which mainly means sweating. This could very well have proven to be an advantage, since large predators are fairly inactive in the heat of the day. Furthermore, the proportions of the *ergaster*/*erectus* body made it far more efficient in carrying loads on the back or in the hands (Wang & Crompton, 2004). These adaptations presumably made the *ergaster/erectus* a better scavenger/hunter (as a primate), since it could patrol larger areas comparatively quickly in the day-time heat and efficiently carry pieces of carcasses back to the accumulation spots. Such a long range behaviour demands a lot more energy than living like an australopithecine, at least an increase with 40-45% and perhaps as much as 80-85% (Leonard & Robertson, 1997). This increase combined with the reduced jaws, teeth and guts and the enlarged brain of *ergaster/erectus* is a tell tale sign of a very high quality diet (with high caloric density and easily digestible). The larger meat intake is of course attributed to this quality rise. However, meat is quite literally only half the story: Aiello & Wells (2002) notes that no more than about 50% of the daily energy consumption could consist of animal proteins. After all hominids are omnivores. Gathering high quality plant food must also have been a crucial part of *ergaster/erectus* subsistence. Such gathering is part of the implications for the division of labour often attributed to *ergaster/erectus*. A division with probable further cognitive implications, as we, among other things, shall discuss in next subsection.

4.4 Anticipatory cognition as an adaptation to the Oldowan niche

Fossilized material is far from enough to create a complete and well-founded picture of the morphology and physiology of the early *ergaster/erectus*. There is even less tangible material when it comes to constructing models of their long gone cognition. Our argument is therefore to some extent based on theoretical considerations that we combine with the scarce "hard" evidence and the behavioural inferences made from it.

Firstly, we note that the modern *Homo sapiens* is the only extant species capable of anticipatory cognition. From this we conclude that anticipatory cognition evolved in the earliest sapiens or in some predecessor along the hominid lineage.

Secondly, we believe that many of the cognitive prerequisites for anticipatory planning are present in apes. As mentioned earlier, chimpanzees are capable of planning actions with a range of elements, and some researchers claim that they have something that could be interpreted as episodic memory. The crucial factor that separates them from anticipatory cognition is the capacity to detach their cognition from their current drive state. This capacity may in itself not have to depend on any major genetic reorganisation or largely different brain morphology. Following Byrne (2000) and other authors we assume that complex cognitive traits that are present in both *Homo sapiens* and apes were also present in the common ancestor. In brief, it is likely that the pre-Oldowan hominids were at the brink of anticipatory cognition and that certain selective pressures rapidly could bring about this form of cognition.

When considering the Oldowan niche and its inhabitants from this point of view, we want to give substance to the cognitive evolution that took place as an answer to the new selective pressures. *Ergaster/erectus*, who is a much closer relative to us than to any extant primate, exhibited a range of behaviours that is not seen in any other of the contemporary primates. *Homo sapiens* would rely on anticipatory cognition to perform such behaviours. Even though it might be possible to explain each of these *ergaster/erectus* behaviours in more minimalist terms than assuming anticipatory cognition, we believe that they are much more coherently explained on the basis of anticipatory cognition.

As stated earlier, we do not believe that the Oldowan niche initially required agents with anticipatory cognition. Rather we view the development of the Oldowan culture and of anticipatory cognition as a form of co-evolution. The Oldowan life style was in a way signified by an extension in time and space. For example, there were long delays between the acquisition and the use of the tool, as well as considerable geographical distances between the sources of tool raw material sources and killing sites. The fitness of the hominids in this niche would increase with adaptations for long ranging, as shown in the morphological remains. These morphological adaptations must also have been related to behavioural adaptations. We believe that the behavioural adaptations mainly were a result of an evolving anticipatory cognition – this form of cognition is long ranging in its character. There was energy to be saved and efficiency to be gained in this niche if anticipatory cognition would be used. Conversely, such adaptations would of course affect the cultural niche. To substantiate our claim that there existed selective pressures for anticipatory cognition in the Oldowan niche, and that it most likely arose in this niche, we will give some examples based on the behaviours that have been predicted for this culture.

Our first example considers the curated

technology (Toth, 1985) that is represented by the Oldowan culture. Plummer (2004) summarizes the curated characteristics as follows: "[…] Oldowan was not simply an expedient technology: the repeated carrying of artifacts for use at different points on the landscape may reflect pressure to curate or economize, based on a current or projected need for stone." There certainly seem to have existed projected needs within the Oldowan niche. It is not possible to know exactly where the next fresh kill will be found; it might be several kilometres away from nearest raw material source. Without sharp edged stone tools in the immediate vicinity, a carcass would loose much of its value for a hominid. Thousands of calories would be right under one's nose but still out of reach. The big predators and scavengers would probably not allow enough time for the hominids to locate the nearest tool source. Not to mention all the extra energy that would be lost in a non-planned search for tools. This problem could be solved by habitual stone carrying, very much like the one discussed in Section 4.1. However, just carrying tools is a strategy that lacks flexibility. If a hominid can envision which area it is going to patrol, then it can decide if it has to bring raw material for tools or not. Transporting something that would not be needed is uneconomic. First of all, energy is wasted in vain, and secondly it occupies space (one or two of the hands) that could be used for something that is needed, perhaps an ostrich egg filled with water when going into arid land. The strategy of accumulating stones of the preferred raw material in areas where no stones can be found is beneficial, since long periods of haphazard transports are avoided. This strategy becomes even more effective if one keeps track of the resources available in a given accumulation spot: not letting it run out of stones or not wasting energy by carrying stones to an already abundant supply. Anticipatory cognition would solve this task swiftly. Another aspect of Oldowan culture seems to be the saving of a tool (or a core) after it has been used once. It is needless to point out the great economy in such behaviour. With anticipatory cognition one "knows" that there will be a need for the tool in the future as well. Anticipatory cognition opens up a very flexible selectivity that can be used with high precision and efficiency depending on one's current imagined goal related to a future need.

Our second example of anticipatory thinking that had selective value concerns the division of labour. This form of anticipatory cognition could in fact be used to turn the group of hominids into a virtual Swiss army knife, which would benefit every individual within the group. A division of labour within the group could solve a multitude of needs at once. Some individuals might carry throwing stones, some might carry sharp edges and others could carry water or wooden tools. It is a way of optimizing the carrying resources of the group, which is probably already burdened with carrying infants. Such co-operation requires a shared goal outside the scope of the immediate drive state, and it is dependent on an advanced form of communication (we shall return to this topic in the following section).

Another form of division of labour associated with the *ergaster/erectus* is a sexual division in foraging. Aiello & Key (2002) note that the much larger body of *Homo erectus* females would have considerably increased the energy requirements during gestation and lactation (under the assumption that their reproductive schedules concurred with the australopithecines). The offspring would be very costly indeed. As a better explanation they propose that a shortening of the interbirth interval for *Homo erectus* would give a great reduction in cost per offspring and of course an increase in reproduction. However, this strategy implies that the females would need to invest more in daily care of the offspring.

Such an investment could only work if a system with a division of labour existed in the hominid group, because the female could not possibly have time to cover her and her children's energy expenditure by herself. Scavenging or hunting was arguably mainly a male concern. One of the simple reasons for this is that hominid children could not maintain the speed and endurance of the adults in the presumed patrolling activities, as children are less energy efficient (see e.g. Plummer, 2004) and of course slower and weaker. Children were most probably close to their mothers, who must have been somewhat more stationary due to lactating and weaning infants. And among other things, the bipedal foot of hominid infants (and the loss of bodily hair) makes it impossible for them to cling to their mothers. Unlike all other primates, the hominid mothers therefore had to use their arms to carry their babies (see e.g. Savage-Rumbaugh, 1994). Females must thus have been engaged in a "slower" foraging, such as gathering high quality plant food. This kind of division is a common foraging strategy in modern tropical foraging societies, where males provide most of the energy and protein to the diet (Kaplan et al, 2000).

The modern human form of hunting and gathering is deeply dependent on anticipatory cognition. The individual must in some sense be able to imagine other individuals currently outside his or her immediate sensory scope doing their part of the job. The strategy does not allow the individual an immediate consumption of all the obtained food, even if there is a drive state that signals hunger. Individuals must also at some times ignore high energy food and focus on their task, hunting or gathering (a standard procedure for most hunter-gather foragers), in order to achieve the main goal – a variable and nutritious meal. One could of course argue that the Oldowan males did not necessarily have to envision this meal when they brought back the meat. It could have been a question of attracting females. Such a scenario would however not rule out the selective value of anticipatory cognition. Sexual selection could even speed up the process. Males who were better at suppressing immediate drive states and thereby brought back larger amounts of food, could get a higher reproductive success.

The examples above are used to show that there might have been many reasons to develop anticipatory cognition within the Oldowan niche. Once the period of Acheulean tools is reached it is apparent that anticipatory cognition was used. We agree with Savage-Rumbaugh (1994) that the 45 minutes it takes to produce an Acheulean axe is a clear sign of anticipation beyond a current drive state. From our point of view it is also obvious that anticipatory cognition was present in the first hominid long distance migrates. The first migration out of Africa seems to have taken place at a very early stage of the history of *Homo ergaster/erectus*, around 1.7 m.y.a. Even if the new Transcaucasian habitat was somewhat similar to the east African savannah, there were of course differences, and in order to reach this new land a number of obstacles had to be overcome. The hominids did not only have to migrate over topographic barriers, but also get through the seasonality of the temperate belt when passing the Levantine corridor that connected Africa with Eurasia (Gabunia, Vekua & Lordkipanidze, 2000). The most reasonable account for this formidable migration is to ascribe the *ergaster/erectus* anticipatory cognition. In general, using anticipatory cognition appears be one of the most effective ways for a tropical species to cope with a temperate seasonal climate (it is achieved by billions of *Homo sapiens* every year).

Overall, it could be said that anticipatory cognition fits well with the lifestyle of the hunter/scavenger-gathering and highly energy consuming *ergaster/erectus*. Plummer (2004, p. 128): writes: "The emerging picture of *H. erectus* is of a creature that was large and wide-ranging, could efficiently transport burdens, had a high total energy expenditure, and ate a high-quality diet." Each of the behavioural features we have considered could perhaps be explained in more cognitively minimal terms, but this would not account for the broader picture and the flexibility of this species.

5. Further effects of anticipatory cognition: collaboration and symbolic communication

In this section, we present some further cultural developments that depend on anticipatory cognition. We will consider the consequences of collaboration, rituals, miming and the emergence of symbolic communication. These developments, except for possibly symbolic language have been associated with *Homo ergaster/erectus*.

5.1 Co-operation and rituals as signs of anticipatory planning

Humans as well as some animals co-operate in order to reach common goals. There are many ways of co-operating, some of which are not co-operation in the literal sense of the word. Among these one may count more or less instinctive co-ordination of behaviour, such as it emerges among termites building hills or honeybees gathering food. At the opposite side of the scale, we find human co-operation, depending on elaborate long-term planning and negotiations.

The hominid life on the savannah opened up for many new forms of co-operation for future goals. For example, Plummer (2004, p. 139) writes: "Given that body size often predicts rank in the carnivore guild, an individual *H. habilis* would likely not have fared well in a contest with many of its contemporary carnivores. Competition with large carnivores may have favored cohesive groups and co-ordinated group movements in *H. habilis*, co-operative behavior including group defense, diurnal foraging (as many large predators preferentially hunt at night) with both hunting and scavenging being practiced as the opportunities arose, and the ability (using stone tools) to rapidly dismember large carcasses so as to minimize time spent at death sites."

For many forms of co-operation among animals, it seems that representations are not needed. If the common goal is present in the actual environment, for example food to be eaten or an antagonist to be fought, the collaborators need not focus on a joint representation of it before acting. If, on the other hand, the goal is detached, i.e. distant in time or space, then a *common* representation of it must be produced before co-operative action can be taken. For example, building a common dwelling requires coordinated planning of how to obtain the building material and advanced collaboration in the construction. In general terms, co-operation about detached goals requires that *the inner worlds of the individuals be co-ordinated*.

To show the evolutionary importance of co-operation for future goals, Deacon (1997, pp. 385-401) suggests that the first form of symbolic communication is marriage agreements, that is, deliberate commitments to pair bonding. The ecological conditions of the early hominids made meat a prominent part of their diet. At the same time, a nursing female hominid, with a baby that is much more dependent on its mother than those of the other primates, cannot efficiently participate in hunting and scavenging. A female who cannot count on at least one male supplying her with meat, will suffer from a high probability of losing her children. On the other hand, a male who cannot be reasonably sure that he is the father of the children he is supporting, runs a serious risk of investing in the genes of other males. Thus both sexes have evolutionarily motivated reasons for establishing a long-term bond between woman and man.

Deacon (1997, p. 399) argues that for these reasons there was strong evolutionary pressure in hominid societies to establish relationships of exclusive sexual access. He says that such an exclusive sexual bond ”is a prescription for future behaviors.” Even if we do not know of any evidence that marriage agreements was the first form of symbolic communication, we still find this example important in the discussion of early anticipatory cognition. A detached pair-bonding agreement implicitly determines which future behaviours are allowed and not allowed. These expectations concerning future behaviour do not only include the pair, but also the other members of the social group who are supposed not to disturb the relation by cheating. Anybody who breaks the agreement risks punishment from the entire group. Thus in order to maintain such bonds, they must be linked to social sanctions. With the aid of some form of ritual, one can mark out a loyalty bond for the rest of the group and that the appropriate sanctions are now at function. It should also be noted that episodic memory is required to be able to *refer* to the established loyalty bond later on, by miming or by speech, and to remind group members of the sanctions (Atran, 2002, pp. 159-160).

The more advanced forms of co-operation make the individuals in a society mutually dependent on each other. As van Schaik et al. (1999, p. 726) point out, tolerance and gregariousness is beneficial for *learning*, which again is a factor that reinforces the tendency for co-operation. As indirect support for this, it has been shown that animals that risks to be attacked by conspecifics do not learn well (Fragaszy & Visalberghi, 1990).

5.3 Communication about future collaborative goals

Language is the tool by which agents can make their inner worlds known to each other. In previous articles (Brinck & Gärdenfors, 2003; Gärdenfors, 2004), it has been proposed that there is a strong connection between the evolution of anticipatory cognition and the evolution of symbolic communication. In brief, the argument is that symbolic language makes it possible to *co-operate about detached goals*.

Language is based on the use of representations as stand-ins for entities, actual or just imagined. Use of such representations replaces the use of environmental cues in communication. If somebody has an idea about a goal she wishes to attain, she can use language to communicate her thoughts. In this way, language makes it possible for us to share visions about the future.

Co-operation about detached goals would hardly be possible without advanced communication between the collaborators. A characteristic feature of animal communication is that it consists of signals, referring to what is present at the moment in the environment, be it food, danger or a mate. This form of signalling is not sufficient when non-present goals are to be communicated or negotiated. As a matter of fact, we do not see any way to explain how this can be done without evoking symbolic communication. Maybe an iconic system such as miming can solve some of the co-ordination problem (Zlatev, Persson & Gärdenfors, 2005), but co-operation concerning truly new goals can presumably only be achieved when arbitrary symbols are exploited in a creative manner.

It has been suggested that communication by iconic methods, for instance, by miming, constitutes an intermediary step between signaling and symbolic communication (Donald, 1991; Zlatev, Persson & Gärdenfors, 2005). This suggestion seems correct at least as concerns communication about the means to reach a goal. By using icons, one agent can show another how to act in order for the two of them to reach a common goal. Icons can work as an imperative, urging the agents to “Do like this!” (Brinck & Gärdenfors, 2003).

Communication by symbols is more intricate, because the meanings of the symbols are general and defined by interrelation. It has so far not been shown that apes can communicate in a fully symbolic way (Deacon, 1997; Tomasello, 1999). An important feature of the use of symbols in co-operation is that they can set the co-operators free from the goals that are available in the present environment. The detached goals and the means to reach them are picked out and externally shared through the symbolic communication. This kind of sharing gives humans an enormous advantage concerning co-operation in comparison to other species. We view this advantage as a strong evolutionary force behind the emergence of symbols. More precisely, we submit that there has been a co-evolution of co-operation about future goals and symbolic communication (cf. the "ratchet effect" discussed by Tomasello, 1999, pp. 37-40).

Thus it could be said that anticipatory cognition not only constitutes a part of the cognitive substrate necessary to symbolic communication (the ability to envision non-existing states detached from a current situation), it has also been a selective force for evolving symbolic communication (creating a need for communicating about non-existing states detached from a current situation).

6. CONCLUSION

Delineating the specifics of human cognitive evolution is a speculative endeavour. The problem we started out with is the question of why humans are the only extant species that exhibit anticipatory cognition. Given the scarcity of direct empirical evidence concerning the changes in the cognitive abilities of different hominids, an answer to the question must inevitably be based on some speculation. Our main method has been to establish connections between (1) anatomical factors, such as bipedalism, (2) ecological conditions, such as life of the savannah and (3) cultural factors, such as sharing of food with (4) evolutionary selective pressures on cognitive traits leading to anticipatory cognition.

We have argued for the co-evolution of early anticipatory planning and the Oldowan cultural niche that is based on transport over extended space and time. Our main argument has been that this niche promoted the evolution of anticipatory cognition, in particular planning for future goals, i.e. anticipatory planning. By depicting a pre-Oldowan cultural scenario, depending on stone throwing and transports, our goal has been to make it credible that ultimately morphological and physiological factors, and not major cognitive adaptations, led to the Oldowan culture. When the Oldowan culture was once established it constituted a prominent part of the environment for the hominids. This self made environment, or constructed niche, was not static. The niche constructing hominids responded to their created environment by biological adaptations, and in pace with these adaptations they altered the environment in accordance to their changing abilities.

However, there were some central and basic traits in the Oldowan culture that remained crucial over time: the crude sharp edged stone tool and its importance in meat acquisition. The behaviours connected with the tools and the foraging were signified by long range transports, and an extended time span between exploiting tool raw materials and consuming the meat (or other food items related to tool use).

It seems clear that the morpho-physiological long range adaptations exhibited in *Homo ergaster/erectus* were mainly adaptations to these behaviours. Anticipatory cognition can be viewed as a cognitive counterpart to such long range adaptations. The long ranging nature of the Oldowan culture is not the only thing that makes it probable that anticipatory cognition evolved during this period. The behaviours of the first migraters and the Aucheulean tool makers cannot be satisfactorily explained in other terms than by some form of anticipatory cognition. This makes us believe that anticipatory cognition began evolving in *Homo habilis* or early *ergaster/erectus* populations.

Anticipatory cognition is a key feature in the cognition of humans and is essential for behaviours identified as unique for our species. This cognitive trait is fundamental in cooperation for distant goals as well as for symbolic communication. We have argued that, anticipatory cognition created a need for a new form of communication in order to be able to cooperate for distant goals. The required form of communication is most likely symbolic since otherwise it would have been difficult to communicate about detached needs and goals.

The evolutionary relationships between cooperation, communication and anticipatory cognition itself are probably intertwined in complicated co-evolutionary processes. These relationships have been important for the evolution of fully fledged anticipatory cognition, and they must be further analyzed in order to get a better understanding of the evolution of human cognition. More work is also needed to provide a detailed account of the cognitive architecture of anticipatory cognition, which, among other things, would help us understand what intermediate forms of anticipatory cognition might look like.

In summary, we view the evolution of anticipatory cognition as a critical factor in hominid evolution. It is a *sine qua non* for several of the uniquely human traits and it has been a bottle-neck that then opens up for a rapid cultural development.

Almost a century ago, the French poet Paul Valéry wrote in one of his aphorisms a strangely close summary of the contents of this article:

Homo walks in upright position.
Mates in all seasons, face to face.
Has opposing thumb. Omnivore. Capable of attention, even to absent objects.
Under the name of thought, reflection, obsessions, etc., he can dream extensively when awake, combine his dreams with his perceptions, and from them extract plans for actions, co-ordinations of movements, a kind of reorganization of instincts, desires, etc. …
He modifies the environment. He collects, preserves, anticipates, innovates.
He has the means to reach …

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