Discovery of the Fourth Dimension: Mental Time Travel and Human Evolution

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Abstract

This article considers the role of mental time travel in human evolution. A central thesis is that other primates, although having memory and expectation, do not possess the same ability to live in the past or in the future. The first half of this paper argues that reconstructive access to the past (i.e. episodic memory) is dependent on other advanced cognitive capabilities (e.g. self-awareness and meta-representation) and focuses on the results of recent `theory of mind' research in order to evaluate the thesis. Mental simulation is the proposed underlying mechanism for the development of both mindreading and mental time travel. The second half contrasts flexible awareness of possible futures with other forms of `anticipatory behaviour' and reviews evidence about how far other primates may think ahead. The phylogenetic history of mental time travel and its adaptive and exaptive relationships to other features are discussed. Mental access to the fourth dimension is essential for many of the distinctive characteristics of our species.

Preface

"If martians have been observing the development of the blue-green planet called Earth, they would have noticed the extraordinary, exponentially growing changes during the last millennia. One component of this planet, the species Homo sapiens sapiens, would have been easily recognized by the martians as the cause of these changes. Even more astonishing to the hypothetical martians than the tremendous effects humans have on the environment, would have been the human capability to commit global suicide" (Suddendorf, 1992, p.4). Hence, martian scientists might ask themselves what distinguishes humans from all the other creatures this planet produced? Most of humans' closest relatives, the other great apes, continue to behave calmly. So, what enabled and motivated humans to change the face of the Earth?

These are the great questions that puzzled me, and many before me, for a long time. The last two years I have tried to research and evaluate our knowledge in respect to a potential answer that so far was mainly neglected. The answer I advocate in this thesis is that humans, unlike other animals, developed a mental access to the fourth dimension: our awareness of past and future. The argument comprises recent findings in cognitive psychology, comparative psychology, developmental psychology, evolutionary psychology and primatology, and touches on many neighbouring fields such as archaeology and neurophysiology. Most issues raised are worth separate essays, but in the light of the scope of this paper and the variety of issues relevant, many topics can be illuminated only briefly (and some could only be pointed out in form of footnotes). This may be the price one has to pay if one does not focus on a specific detail but rather tries to bring together interdisciplinary knowledge in pursuit of the `larger picture'.

This picture is nonetheless confined to the `mental time travel' aspect of human evolution and I would like to urge those who try to reconstruct an even broader picture of human evolution to include this aspect. The argument is written in article style and indeed, has been submitted for publication. Because I did not want to disrupt this theoretical contribution, I decided to add the preliminary results of a survey I started in April 1993 in form of an Appendix (A). Furthermore, in Appendix B I suggest an experimental paradigm that may be able to put some of the ensuing questions to test. Both Appendices (A & B) are a substantial part of the thesis work and I would like to encourage readers to go through those in addition to the main body.

Questions that were once philosophical are now beginning to yield to scientific inquiry, and I hope that, even if the material requires some mental effort, some of the excitement of this enterprise is conveyed in this thesis.

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Introduction

> We humans have long attributed to ourselves special qualities of mind, spirit or morality that are denied all other creatures. Religions seem to play a special role in this by bestowing uniquely upon us an immortal soul or by tracing our origins to some divine act of creation. [Corballis, 1991, p.3]

What is the essential difference between humans and other creatures on planet Earth? Even after the general acceptance of the theory of evolution, when humans acknowledged having common ancestors with all other species, we put ourselves at the top of the ladder, standing in solitary splendour far above all other species.

This conceit may of course be regarded as a `false consensus bias' (Ross, Green & House, 1977) created by western scholars who were raised under the influence of the Christian tradition, which perpetuates an unbridgeable gap separating humans from animals. There are, however, other perspectives and influential philosophical and religious traditions that emphasize the continuity rather than discontinuity of human evolution. Hinduism, for example, views animal and human minds as stages that differ in merely quantitative fashion in the continued progression towards Nirvana.

Features that the western scientific enterprise assumed to be uniquely human only a few years ago (e.g. symbolic thinking, tool use, self-awareness) have been shown to exist, at least to a degree, in nonhuman great apes, too (e.g. Greenfield & Savage-Rumbaugh, 1990; Goodall, 1986; Gallup, 1983)1. In order to uphold the belief in an unbridgeable gap separating humans from animals, researchers of the last decades have been continuously forced to pose increasingly more restrictive (or less elegant) definitions of humanity or of supposedly uniquely human qualities, such as language (Gibson, 1990). An example of this trend has to do with the one-time belief that only humans use tools. In the face of increasing evidence to the contrary, it was then proposed that only humans manufacture tools, and more recently still that only humans use tools to manufacture tools (e.g. Beck, 1980)2.

Recent evidence suggests that some great apes, in contrast to monkeys, may have at least a rudimentary3 `theory of mind' (Premack & Woodruff, 1978; Premack, 1988), may be able to use pedagogy in both laboratory (Fouts, Fouts & van Cantfort, 1989) and field (Boesch, 1991) contexts, may show empathy and compassion (Boesch, 1992), may be able to truly imitate (Byrne, in press; Meador, Rumbaugh, Pate & Bard, 1987), and may have the ability (possibly underlying all those above) to imagine other possible worlds (Byrne & Whiten, 1992). These `discoveries' reveal more and more a picture of apes as the `missing link' bridging the gap between the animal kingdom and humanity. One could be even tempted to re-locate this `gap', so that it separates the great apes, rather than only humans, from all other animals.

Nevertheless, it can still be argued that there is a substantial gap between humans and the other great apes, if only because of the extraordinary impact we have had on the environment. As Passingham (1982) puts it:

> Our species is unique because, in only 35000 years or so, we have revolutionized the face of the Earth. We have created entirely new environments for ourselves, have changed the lives of animals, and have the power to threaten the existence of life on our planet. [p.21]

The present article will elaborate on this `something extra' that the great ape `homo' exhibits. I expect that the debate about whether it constitutes a continuity or discontinuity in phylogeny will eventually become immaterial, in the way the nature-nurture debate turned out to be. Depending on the philosophical emphasis implicit in the theoretical filter through which one views it, one may classify human evolution either as a discontinuity or a continuity, although the two may not be mutually exclusive.

Apparent discontinuities or the impression of qualitative differences can result from continuous gradual changes in phylogeny, in the way that H2O changes `qualitatively' from ice to water to gas as temperature continuously and quantitatively increases. These types of changes might be best described by the term metamorphosis (Bischof, 1985). The crucial evolutionary concept of exaptation (e.g. Gould, 1991; Gould & Vbra, 1982) might have been the underpinning of such a metamorphotic change in human evolution: A gradually evolved adaptive feature may have had a variety of `side' characteristics that were not directly relevant to the survival of the organism, but at a later point in phylogeny these characteristics may have become the basis for new strains of adaptation. In their theory of "punctuated equilibrium" Eldredge and Gould (1972) argued that major phylogenetic changes may occur in short periods of time producing an apparent discontinuity in the fossil record and among living species. The seemingly qualitative differences between humans and other animals might have been the result of a metamorphotic change that gave new fitness value to a variety of phylogenetic older features. This may have rapidly changed humans some time during the last 5 to 8 million years, after the phylogenetic split from the line that led to the modern chimpanzees.

In this article I want to re-introduce into the debate an aspect of human thought, rather than morphology, whose phylogenetic emergence might have had such a profound significance that it could have been a prime mover in human evolution: the discovery of the dimension of time.

Wolfgang Koehler (1917/1927) anticipated with his work many of the `recent discoveries' about the mentality of apes. Contrary to the prevailing Zeitgeist, Koehler emphasized the relatively sophisticated mental capacities of chimpanzees, but he also noted an important limitation:

> `The time in which the chimpanzee lives' is limited in past and future" [Koehler, 1917/1927, p.272].

We humans, by contrast, seem to be able to concern ourselves with issues that are not limited in past or future. Events as remote as the crucifixion of Christ can be very important to us, and we even tackle questions about the extent of time itself by developing religious or scientific concepts like `genesis', `big bang' or `judgment day'. Indeed, most of what is written or talked about refers to something that has happened in the past or could happen in the future; the present appears to be just a brief segment passing from the future into the past. While life is always happening in this present, our cognition, emotion, motivation and behaviour is largely influenced by what we believe has happened or may happen. Humans can `mentally travel in time'; we can use our imaginations to represent events of past and future and reflect upon them. Clearly, animals have some sort of memory and expectations, but their ability to mentally travel in time may be significantly limited.

The human ability to mentally travel in time is central to the interpretation of human evolution that is presented here. In particular, I will argue that our ability to anticipate the future, based on our access to the past, has changed human motivation, emotion, cognition, and behaviour, and was one of the major forces that led us to change the very face of the Earth. Perhaps we need to improve this ability even more if we are to survive the rapid changes we have produced recently.

The purposes of this article are to highlight mental time travel as an important human condition, to determine whether it is uniquely human, to propose a possible underlying mechanism, to assess its phylogenetic and ontogenetic development and to discuss its adaptive or exaptive relationship to other human characteristics. First I discuss mental time travel into the past and then mental time travel into the future.

Mental Time Travel into the Past

It seems reasonable to argue that in order to imagine a past that lies before their own lifetimes, people must have evolved the means to represent (remember) events of their own past. Many scientists have argued for fundamental differences between animal and human memory (e.g. Aristotle; Bischof, 1985; Gardner, 1975 cited in Marshall, 1982; Marshall, 1982; Tulving, 1983). But since animals can obviously learn from past experiences, it might be thought that human and animal memory differ only in degree. However, research in different areas (e.g. psychology, philosophy, artificial intelligence; see Polster, Nadel & Schacter, 1991, for a recent historical review) suggests that memory consists of multiple systems that may be functionally and structurally distinct (although alternative views exist, see for example Roediger, 1990), and this raises the possibility that one or more of these memory systems may be an acquisition unique to humans.

A Uniquely Human Memory System?

Research on the phenomena of amnesia, in particular the extensive studies of the patient H.M., forced psychologists to distinguish between different kinds of memory, because one type of memory can be impaired while another continues to function normally. Despite his memory loss, H.M.'s behaviour can be influenced by the past without him being aware of it (see Ogden & Corkin, 1991, for a recent review). The spared learning or memory abilities, as reflected in learned skills, classical and operant conditioning, priming, habituation and sensitization, affect performance without affording an `image/picture of the past' (Koehler, 1917/1927), a `recollective experience' (Gardiner, 1991) or `access' to the experience that is affecting current performance (Zola-Morgan & Squire, 1990). While there is ample evidence that animals rely extensively on information stored in this implicit fashion, there is considerable debate about whether animals possess the memory systems that are impaired in global amnesia. These are semantic and episodic memory (see Ogden & Corkin, 1991; Squire, 1992). Tulving (1972, 1983), who proposed the dissociation between semantic and episodic memory, saw these as functionally separate although interacting systems. Semantic memory comprises context-free knowledge or facts about the world and episodic memory comprises personal experiences and events (Tulving, 1983). Consolidation of both kinds of information appears to be dependent on the hippocampus and related structures (Squire, 1992). Rats, monkeys and humans seem to have similar hippocampus-dependent memory systems (Squire, 1992), but this similarity might be due to a shared ability to store semantic facts, rather than episodes.

Ridley (1992) argued that semantic memory exists in animals such as vervet monkeys, because these animals apparently represent not-perceptually-present facts about their social world. The distress call of an isolated infant, for instance, leads the mother to look to her infant whereas other mothers look to the mother (see Cheney & Seyfarth, 1990, for further examples). Evidence for episodic memory, the memory of personal experiences associated with past points in time, seems to be more difficult to find for animals, and Tulving (1983) himself went so far as to suggest that episodic memory may be uniquely human.

This suggestion did not stay unchallenged, however. Olton (1984) and earlier Roitblat (1982) pointed out that animals display certain behaviour, as in a trial of a delayed conditioned-discrimination task, or in foraging where an animal must remember not to go to the same flower twice to obtain nectar, which indicates that "remnants" of a previous experience allow it to affect later behaviour. Thus, the animal "represents" a past event and, according to Olton (1984), therefore possesses episodic memory.

However, Dretske (1982) argued that this inference is not unambiguous. If event A leads to the change B in the cognitive apparatus of an animal and B affects behaviour C at a later point in time, then B does not necessarily carry any information about A itself, and may therefore not be a true representation of A. The mediator B might be `causal' rather than `informational'; "that is, that the memory trace of the stored event only contains instruction for future behavior, without any information that would permit the reconstruction of the past" (Tulving, 1984, p.258). The fact that animals can `recognize' objects that they have seen only once before could be a result of a feeling of familiarity rather than of a remembrance of that event (Ridley, 1992). In his reply to Olton's critique Tulving accepts that animals may have a form of episodic memory that serves at least as a causal mediator, and in fact Olton's examples meet many and violate none of the criteria Tulving (1983) laid out for episodic memory. However, Tulving maintains that animals may not be able to "mentally travel back in time to recollect and reminisce the way humans do" and illustrates his position by rhetorically asking "was Aristotle wrong when he said that, `Many animals have memory and are capable of instruction, but no other animal except man can recall the past at will'...?" (Tulving, 1984, p.258).

If one accepts Dretske (1982) and Tulving's (1984) argument that learning from single events does not constitute evidence for representations of the past, it appears as yet impossible to show that animals travel mentally into the past even if they actually do so. It is however possible to further analyze the possibility of mental time travel in animals indirectly by considering related mental capacities.

Mental Capacities and Mental Time Travel

Tulving (1985) argued that different kinds of consciousness characterize different memory systems. Procedural (here termed implicit) memory implies anoetic (nonknowing) consciousness, semantic memory implies noetic (knowing) consciousness, and episodic memory implies autonoetic (self-knowing) consciousness. Although it is not clear whether these types of consciousness are, as Tulving argued, properties of the memory systems themselves (Schacter, 1989, for example, argued for separate memory and consciousness modules), they appear to be interlinked. Episodic memory contains information about past states of one's self and of the world. On the one hand, in providing autobiographical information about one's own past, memory of past events (episodic memory) provides the basis for one's personal identity. On the other hand, in order to attribute representations to experiences of self at an earlier point in time one may need to be aware of one's self in the present (cf. Howe & Courage, 1993), an ability that only chimpanzees (e.g. Gallup, 1970), orangutans (e.g. Suarez & Gallup, 1981) and a gorilla (Patterson, 1991)4 have demonstrated through self-recognition in a mirror5. Monkeys and even elephants can learn how a mirror works, but, in contrast to the great apes, they cannot locate markings viewed in a mirror if these markings are on their own bodies (Gallup, 1983; Povinelli, 1989). If one cannot consciously (autonoetically) recognize the self in the present (e.g. in the mirror), how could one possibly recognize the self in the past? In order to understand that current mental images can represent one's own earlier experiences, one needs to have a concept of self that allows for such inferences. It might be objected that it is not necessary to postulate the need for metacognitions such as the inference that representations are experiences of the self in the past, because memories of past events could reveal themselves without them. But, as I will show in the following paragraphs, memory for past episodes, unlike memory for facts, does imply metacognitions in that it involves active reconstruction and attribution, and is therefore as much a function of the present as a record of the past.

The term memory is often associated with a fixed databank (e.g. library) but this metaphor appears to be more appropriate for semantic knowledge (memory for facts) than for episodic memory. In contrast to the retrieval of facts, retrieval of past episodes usually recodes (`updates') the stored information (Tulving, 1984)6. Retrieval of past episodes appears to be more than `opening and reading a file'; the past episodes need to be reconstructed.

Almost a century ago Freud (1895, cited in Marshall, 1982) noted that even memories that reveal themselves as images require a story grammar if remembrance is to be distinguished from random hallucinations. However, the storyline is often reconstructed on the basis of one's general knowledge rather than what actually happened (e.g. Bartlett, 1932) and may therefore not be part of the memory trace7.

The order of past events in time seems not to be a property of memory. After reviewing the evidence Friedman concluded recently that

> [i]n spite of the common intuition that chronology is a basic property of autobiographical memory, the research reviewed demonstrates that there is no single, natural temporal code in human memory. Instead, a chronological past depends on a process of active, repeated construction [Friedman, 1993, p.44]8.

The reconstruction of time and storyline presupposes that one is aware of the `pastness' of the current representations. In other words, in order to reconstruct episodes one needs to be able to make the basic distinction between representations of the past (memories) and representations of the present (e.g. hallucinations, perceptions). But even this basic quality appears not to be inherent in memory, that is, memories seem not to be marked as memories. On the one hand, there are plenty of examples of confabulation, the experience of remembering without the existence of corresponding memory representations (see, for example, Bowers & Hilgard, 1986). We frequently `remember' events that did not happen (or at least not in the way we recall them). On the other hand, it has been shown that "[h]aving - and even using - a memory representation of a prior event is not sufficient to insure the subjective experience of remembering" (Jacoby, Kelley & Dywan, 1989, p.417). A feeling of `pastness' appears not to be a property of the memory representation, but has to be inferred and attributed (or, in the case of confabulation, misattributed) to the current representation (Jacoby, Kelley & Dywan, 1989). However, it is this subjective experience of the `pastness' of representations, not the objective validity of memory (as usually investigated in human and animal research), on which the ability to mentally travel into one's own past rests. Thus, what Tulving (1983, 1984) called episodic memory is as much dependent on present mental abilities as on memory storage of the past. What appears to be required is a concept of self and the ability to form meta- or second-order representations of one's own knowledge.

In order to travel mentally back in time, i.e. to attribute representations to experiences of the self in the past and reconstruct these representations into episodes, one needs to have access to the content of one's own mind (cf. Ridley, 1992). In addition to the primary representation (e.g. I am in a park), one has to represent this representation as a memory. Other primary representations that are represented as memories (e.g. I go shopping and I play ball) can be reconstructed into a past episode (e.g. I was in a park, played ball and then went shopping) which may afford further metacognitions. The ability to voluntarily (selectively) choose what events of the past are internally generated is a characteristic of human mental time travel that even more strongly demands flexible access to one's own mind.

The Mentality of Primates

Do animals have an awareness about the contents of their own minds? Cheney and Seyfarth (1990) argue that monkeys do not recognize and represent their own knowledge. Monkeys do not entertain metacognitions of their own states of mind. Just as people with `blindsight' do not know (are not consciously aware) that they have vision, monkeys may not know what they know, or even that they know (e.g. Gallup, 1983; Humphrey, 1986). Since the subjective experience of remembering seems not to be evoked by the memory trace itself, some animals may have representations of past events without the awareness (knowing, representing) that these representations are past experiences and consequently without the possibility to actively reconstruct these representations into narrative episodes.

But how can we know whether or not animals form second-order representations of their own mental states? We can only infer from observable behaviour. Behavioural available only for chimpanzees and perhaps the other great apes (Whiten and Byrne, 1991). This evidence comprises observations indicating behaviour such as pretend based on the ability to form meta-representations.

The question whether or not animals can attribute mental states such as remembering to themselves might be best assessed by examining the growing body of data concerning the attribution of mental states to others (cf. next section). Since Premack and Woodruff's (1978) original article on whether chimpanzees have a `theory of mind', research on animals' and children's conceptions of mind has boomed. I will review some of the research results that are important for mental time travel.

A `complete' theory of mind, such as that possessed by adult humans, is expressed by being able to attribute mental states to one's self (e.g. do I desire, intend, believe or, according to the previous argument, remember X?) and to others (e.g. does she desire or believe X or Y?) even when there is a discrepancy between one's own and other's knowledge (Cheney & Seyfarth, 1990). A complete theory of mind does not evolve in a single step, whether in phylogeny or in ontogeny, but is better described by gradual differences between species and between developmental stages. The ostrich that buries its head in the sand is apparently intellectually unable to take the visual perspective of others. However, Kummer, for example, observed a female baboon apparently hiding parts of her body (i.e. her hands that were grooming a subadult male) from the male leader, implying that she was able to mentally take the male's visual perspective (Kummer, 1990, record 56 in Byrne & Whiten, 1990). This does not necessarily imply an attribution of a mental state resulting from seeing. But an understanding of that another's visual perspective differs from one's own might be viewed as a phylogenetic step into that direction (cf. Whiten, 1991).

There appears to be little evidence indicating that monkeys attribute mental states, i.e. that they are aware of others' or their own intentions, beliefs or knowledge (Cheney & Seyfarth, 1990). Rhesus monkeys, for example, fail to comprehend what another individual knows as a result of seeing. They choose randomly between the advice of those trainers who saw the baiting of one of several containers that were invisible to them and those who could not have seen it (Povinelli, Parks & Novak, 1991). Chimpanzees, however, learn to pick the individual who can help solve the task (Povinelli, Nelson & Boysen, 1990; Premack, 1988). Besides understanding visual perspective in this case it appears necessary to attribute resulting states of mind (knowledge).

Similar discrepancies between the performance of chimpanzees and monkeys in the realms of deception (Byrne & Whiten, 1990, 1992), teaching (Boesch, 1991; Fouts et al., 1989) and imitation (Byrne, in press; Meador et al., 1987) may also be due to chimpanzees' superior skills in attributing mental states (Byrne, in press; Cheney & Seyfarth, 1990). Imitation, for example, is not evident in monkeys in spite of the popular belief that monkeys are notorious imitators. Recent reviews attribute monkeys' social learning to `lower level' mechanisms such as stimulus enhancement and social facilitation, while they accept the evidence for `true' imitation in great apes (Byrne, in press; Meador, et al., 1987). Monkeys may not truly imitate because they cannot impute motives (Cheney & Seyfarth, 1990) and because they may not be able to mentally take other's roles (Byrne, in press). In a cooperation task devised by Povinelli, Parks and Novak (1992) monkeys learned their part without gaining knowledge about the contingent role of the other participant. This can be inferred from the observation that in a role-reversal condition the monkeys did not show positive transfer effects from their prior experience in the other role. By contrast, chimpanzees were able to assume the other's role when they were reversed (Povinelli, Nelson & Boysen, 1992).

These and other observations substantiate the view that only chimpanzees (and perhaps the other great apes) have some meta-representational understanding of, or awareness about, the nature of mind (see Suddendorf, 1993, for a comprehensive review of the evidence). Sceptical reviews (e.g. Heyes, 1993) nevertheless maintain that none of the recent efforts has provided convincing evidence for mental state attribution in animals. Heyes (1993) argues that the observed behaviour of apes could be explained by learning processes that do not entail the attribution of mental states. If Heyes is right, then there would be no reason to believe that any animal can reconstruct past episodes, because no species has provided evidence for the required awareness about contents of their own or other minds. But the consistent discrepancy between the performances of monkeys and great apes on varied measures has convinced many scholars that our closest relatives seem superior at attributing mental states, rather than merely at learning (e.g. Byrne & Whiten, 1992; Cheney & Seyfarth, 1990; Povinelli, 1993; Premack, 1988; Suddendorf, 1993).

Yet, the consistent discrepancy between the performances of great apes and adult humans also ensures that even if chimpanzees can make attributions, these attributions are limited in a number of respects (Premack, 1988). There is experimental evidence suggesting that chimpanzees, in contrast to most other animals, can understand that others may differ in what they see (Premack, 1988), what they intend and desire (Premack & Woodruff, 1978) and what they know (Povinelli, Nelson & Boysen, 1990). However, there is no evidence suggesting that chimpanzees can simultaneously represent their own knowledge and different knowledge of others (see Cheney & Seyfarth, 1990; Premack, 1988). The understanding of false beliefs (see Wimmer & Perner, 1983) seems to indicate a marked conceptual shift in children's (three and a half to four years) understanding of mind (e.g. Gopnik, 1993; Wellman, 1991; see below). Chimpanzees have not provided evidence for reaching this level of mental attribution, but investigations are scant (see Suddendorf, 1993, for a review). As yet, we have to assume that chimpanzees cannot represent others' false beliefs, i.e. they cannot represent knowledge that is in opposition to their own (Premack, 1988, Premack & Dasser, 1991; Whiten, 1992).

Knowing Yourself and Knowing Others

If we assume that apes do have some ability to attribute mental states, may the deficits in mindreading capacity that are nonetheless apparent bear any constraining impact on their potential mental time travelling ability? I will risk a speculation that an inability to represent mental states opposed to one's own present mental states applies not only to the mental states of others, but also to one's own earlier mental states. This inference is empirically supported by recent findings in child psychology.

In human development two, three and four-year-olds progressively master the attribution of desires, then beliefs, and finally false beliefs (i.e. simultaneously representing knowledge that is contrary to their own) (see, for example, Gopnik, 1993; Wellman, 1991; Whiten, 1991; Wimmer & Perner, 1983). Consistent with the above speculation, the acquisition of attributing opposing mental states to others coincides with, or follows, the acquisition of attributing opposing mental states to one's self in the past (Gopnik, 1993). Three-year-olds fail to understand that their current knowledge, for example that there are pencils and not smarties in the candy box, may not be available to others and wrongly predict that another child believes pencils to be in the candy box (Perner, Leekam & Wimmer, 1987). Asked what they themselves believed to be in the candy box before they were shown, they apparently fail to remember their own previous false belief and say that they originally thought pencils were in the box (Gopnik & Astington, 1988). In contrast to changes in belief, changes in the physical world were remembered by the subjects. Children younger than four years seem to have problems remembering information referring to an opposing past state of themselves as much as they fail to represent contrary mental states of others. This appears to be as true for desires as for the later understanding of intentions and beliefs. Having eaten enough to satiate a desire, still one third of three-year-olds reported not having been hungry before: after eating four portions of mousse the children insisted that they had not had a desire for the mousse before (Gopnik, 1993). Full understanding of opposing-to-own-present mental states of others or past self (of desires, intentions and beliefs) is not reached before the average age of three and a half to four years.

The inference, then, is that if chimpanzees cannot attribute mental states to others that oppose their own, then they should not be able to attribute past mental states to themselves that oppose their present ones. We have seen that recent findings in developmental psychology, while not providing proof, do support this idea. However, would this inability restrict chimpanzees' ability to mentally re-experience past episodes? Does this inability restrict three-year olds' episodic memory?

While implicit memory (e.g. conditioning, priming) appears to be functional very early in infancy, most studies indicate that memory for past episodes develops between age three and four (see Pillemer & White, 1989 for a review). Two and a half year olds may recall some fragments of remote past events, but only between the ages of three and four do children seem to begin to mentally travel into their past, i.e. to mentally reconstruct past episodes as organized narratives. Around the same age (between three and four, Loftus, 1993; Pillemer & White, 1989; Sheingold & Tenny, 1982) childhood amnesia begins to cease. That is, adults' accessible memory for past episodes usually begins from that point9.

At around the same time children acquire gradually the abilities to mentally reconstruct past episodes and to attribute mental states to others and to themselves. This may not be mere coincidence. Children who fail to recall their opposing-to-present past mental states may not have acquired a fully established episodic memory system because past episodes are defined by the past state of the world and the past state of self. Although the children seem to some extent to be able to remember past states of the world, they are apparently unable to recall their own past mental states, or at least those aspects of their past mental states that are contradictory to the present one. A full picture of a past episode, however, requires that one represents one's former states of mind (e.g. desires, intentions and beliefs) in order to understand and, more fundamentally, reconstruct the past interaction of self and the world.

That children have difficulties with the essential self-referencing aspect of episodic memory is further substantiated by the finding that three-year-olds have problems recalling the source of their own current knowledge (Gopnik & Graf, 1988; O'Neill & Gopnik, 1991). Although it may have happened only minutes ago, they apparently fail to reconstruct the episode during which they have acquired their current knowledge. A fully-fledged episodic memory system that allows for mental time travel back to (or, reconstruction of) the experience of self at a past point in time demands the ability to represent opposing-to-present mental states. Only at the age of three and a half to four years does the child fully master this, and only then may it therefore establish an episodic memory system comparable to the adult human one. Later still, between four and eight years, the child acquires an explicit knowledge about the culturally dependent time patterns (e.g. weeks, months, years) that assist the structuring of one's own past experiences (Friedman, 1991, 1992).

If chimpanzees cannot represent opposing-to-present mental states of their past selves, one may conclude that chimpanzees cannot have a fully established episodic memory system. While they may have an elementary memory for past events of the world comparable to that in children under three and a half years, the reconstruction of one's own past experiences requires the representation of opposing-to-present mental states. Without such reconstruction mental time travel into one's own past is drastically limited.

A Model for the Development of Mental Time Travel and Mindreading

Because of the hypothesized link between mindreading and mental time travel I will propose a model for mental time travel that is based on one of the explanatory concepts that have been put forward for the development of `theory of mind'. Simulation theory is a model proposed for children's mindreading development (Gordon, 1986; Harris, 1991; Humphrey, 1986; Johnson, 1988), and it may also serve as a conceptualization for mental time travel. According to this model the child does not hold an actual `theory' of mind but acquires knowledge of another person's mind by internally simulating that person's situation (i.e. his or her self-world constellation)10. This idea is based on evidence that two- to three-year-olds can imagine having a mental state (e.g. belief or desire) that they do not have and that they can imagine different worlds (Harris, 1991). Both abilities appear to be evident in the development of children's pretend play. During early childhood children improve their ability to reason from pretend premises (see Harris, 1991) which appears necessary for more advanced mindreading based on the analogy from imagined to real. Harris (1991) postulates that imagined events are produced against a background of default settings which correspond to the current state of self and of the world. Between two and four years of age the child learns to become flexible and accurate in altering the default settings in order to imagine what it would be like being in somebody else's position. The child has to change the default setting of the state of the world (as known to the child) to the state of the world as known to the other and the intentional stance of self to the intentional stance of the other in order to make a correct simulation of the self-world constellation of the other.

According to this approach, the typical failures of younger children result from an insufficient ability to set aside their own current knowledge of the state of the world and/or to detach from their own intentional stance (Goldman, 1993; Harris, 1993). Their own present states interfere with the simulation. Escaping from the influence of one's own mental states is learned first in respect to intentional stance and then in respect to knowledge and belief. By age four the child is able to accurately simulate the mind-world relationship of others. Only later still, I suggest, may these simulation processes lead to the formation of an actual theory of mind, i.e. a semantic set of rules that describe the nature of mind and that allow for understanding and prediction of another's mind and action without requiring an internal simulation. The ability of mental perspective taking and simulation is, however, not lost to adult humans. While we can quickly infer that someone is jealous, based on our knowledge about the circumstances and our semantic theory of the nature of minds, we can also try to imagine what it would be like being in the other's position. Such a simulated `episodic' process may result in better, more empathic understanding and better prediction of the other person's feelings, thoughts and actions.

The ontogeny (and perhaps phylogeny) of our access to our own past might be quite similar to the development of mindreading outlined above. The mental reconstruction of past episodes may also be based on using one's imagination to represent other possible worlds and states of self. A semantic concept (theory) of the past may develop only later in life. Instead, children may first have to learn to mentally simulate (reconstruct) past episodes. Instead of imagining what it would be like, one may simulate what it was like being in a specific situation. The reconstruction of past episodes may be understood as an internal simulation of past states of the world and of the self. This requires the basic capacity to attribute current representations to experiences of one's self at a past point in time, i.e. to recognize them as memories. Both processes are fostered in human development by the guidance of parents who usually ask for and support the verbal report (reconstruction) of past episodes. However, as for the mindreading capacity, children have to acquire the ability to accurately alter default settings, i.e. to set aside their current mental state (intentional stance to and knowledge about the world) when attempting to simulate past episodes11. Only at about age four may they be able to mentally travel back in time and simulate (re-experience) their own past state and the state of the world as it was known to the past self. Later still, this ability to re-experience (re-present) past episodes may result in an abstract understanding of the past which may allow for quick access to relevant information of past episodes without involving internal simulation and re-experiencing of the complex episode. As with mindreading, the earlier system of simulation remains functional in later life. We can remember that we have seen Paul this afternoon without simulating the past episode, and we can also travel mentally into the past, `picture' the situation, reminisce (re-experience) the encounter and empathize with our own or Paul's position. Instead of proposing a sharp distinction between the systems it may be more reasonable to view them as two extremes of a continuum whereby the more abstract conscious access grew out of the ability to mentally simulate past episodes12.

Can other animals use mental simulation for the reconstruction of past episodes? Chimpanzees (and perhaps the other great apes) fulfil the mental simulation prerequisite of being able to imagine other possible worlds (Byrne & Whiten, 1992). In contrast to monkeys, chimpanzees seem to be self-aware and appear to engage in `true' pretence, i.e. they form second-order representations about the world (Whiten & Byrne, 1991). Reasoning in this imagined world appears to be possible for chimpanzees and proper transference between real and imagined world also appears to occur. In order to solve Koehler's (1917/1927) raking problem by insight the chimpanzee Sultan seemed to form a mental representation of the situation, manipulate components in his imagination until he hit upon a solution, and then enact the solution in the real world. Chimpanzees seem to be able to attribute at least some mental states to others (Premack, 1988), to imitate (Meador et al., 1987) and to take other's roles (Povinelli, Nelson & Boysen, 1992), which may mean that they can use mental simulation processes. Perhaps chimpanzees are only limited by the `small' but, according to the outlined model, significant step of escaping their present state of mind in order to fully travel mentally into their own past and reminisce the way we do. I have argued above that chimpanzees' presumed inability to simultaneously represent opposing-to-own mental states of others may also indicate their inability to represent opposing-to-present mental states of their own past, and in this respect they may resemble three-year-old children13. A completely functional episodic memory system may require the ability to detach from the present, to attribute representations to the past and to use the imagination to reconstruct them into episodes with a storyline for the interaction of both, states of the world and states of self. Awareness of and access to the contents of the dimension of time may be strongly dependent on the full development of all mental abilities involved in such a system. An overview of the model is provided by table 1.

Table 1. Proposed Development of Mindreading and Mental Time Travel into One's Own Past

Mental stage		Ontogeny	Phylogeny
2nd-order representation self-awareness imagine other possible worlds		2 years[a]	great apes gorilla?
Attribution of mental states but interference of own present state in simulation	reconstruction of past events but interference of own present state in simulation	3 years	great apes?
attribution of mental states; simulation without interference	time travel into past; simulation without interference	4 years	homo erectus?[b]
abstract theory of mind	abstract concept of past	5 years onwards	homo sapiens

[a] age is not a causal agent but allows for roughly averaged categorization
[b] see section `when did mental time travel emerge' below

Why Travel Mentally into the Past?

What adaptive advantage could it have to represent one's former state of mind in the context of past events, i.e. to mentally travel back in time, if phylogenetic older forms of memory already allow for learning from a single event? We humans seem to care for our memory of past events as we do for a personal treasure, as expressed by the phrase: no one can take away your memories. These memories seem to be valued for their own sake. We can tell stories about our past, which certainly has the adaptive advantage of transmitting knowledge to others who do not have to experience those events themselves in order to learn from them. However, this advantage could only have evolved after the emergence of language and is of benefit mainly to the receiver. It appears more reasonable to search for selective advantages in the individual actually doing these time travels. In fact, we do not merely repeat past situations mentally, we also reflect on them, which constitutes a significant advantage in that it permits us to learn over and over again from a single experience and thereby to increase semantic knowledge. One picture may contain information requiring thousands of words to describe, and similarly one episode may contain thousands of semantic facts that may only become accessible if one can repeatedly look at it, either in reality or in imagination.

It is clear that a superior semantic knowledge about the world (e.g. facts about the physical, chemical and biological reality) was necessary for our species to change the world in the way it has (e.g. through technology, agriculture, science etc.). Some scholars have taken this as evidence for the idea that semantic memory must have evolved, whether in phylogeny or in ontogeny, after the evolution of episodic memory (e.g. Donald, 1991; Seamon, 1984). However, other animals appear to possess semantic memory (see above, p.8), which supports Tulving's (1983, 1984, 1985) perspective that episodic memory must have evolved later. Nevertheless this development of a memory for past events may have had the great adaptive advantage of boosting the older semantic memory system. The ability to mentally travel back in time, to simulate past experiences, enables the individual to extract far more semantic knowledge then could have been extracted at the moment of the experience itself. Episodic memory potentiates the access to information utilizable for the generation of abstract theories. Conversely, Kinsbourne and Wood (1975, cited in Kinsbourne, 1989) showed that the absence of episodic memory slows down the acquisition of new knowledge. Using one's imagination to reconstruct episodes of the past is an evolutionary catalyst that boosts the ability to acquire sophisticated semantic knowledge. Causal chains can be analyzed by putting (reconstructing) an event in broader contexts, relationships and rules can be extracted and the same (simulation) system can be used to change aspects, permitting the individual to test alternatives without having to face real-life consequences14.

Although these abilities clearly increase the fitness of the organism, they may not have evolved for these reasons. In recent years the idea that intelligence or even consciousness has emerged in order to deal with social problems has become popular (e.g. Byrne & Whiten, 1988; Humphrey, 1976, 1986; Jolly, 1966). This hypothesis of so-called `Machiavellian intelligence' (Byrne & Whiten, 1988; de Waal, 1982) suggests that the need to become a good natural psychologist was the selective pressure that produced intelligence in primates. Clearly, if one knows what is on the mind of another individual, one is better at predicting and manipulating behaviour, at cooperating and planning, and at imitating and teaching. If the Machiavellian intelligence hypothesis is correct, then our `self intelligence', our knowledge of present and past self, might be an exaptation: it may have emerged from the ability to understand others. Humphrey (1986) argued along these lines when he claimed that the human desire to gather a variety of experiences emerged because it allows us to understand others in similar situations. But searching for a functional or temporal order in the interdependent complexity of evolution is difficult. A selective pressure that would favour social intelligence would have inevitably favoured self intelligence, but the reverse pattern may equally be true. Social and self intelligence seem inextricably interwoven. Chimpanzees that have been reared in social isolation seem not to be able to recognize themselves in a mirror (Gallup, McClure, Hill & Bundy, 1971), but if one can recognize one's self in a mirror, every conspecific may, at least to a degree, appear to be a mirror image of one's self (Bischof, 1978). The ability to understand others and one's (past) self probably co-evolved. But whether or not one ability emerged merely as a by-product of the other remains debatable.

Regardless of whether the origins of mental time travel into one's own past are adaptational or exaptational, once evolved, it provided the basis for a definition of one's personal identity. The imagination can be used to re-present and re-analyze the past and based on (or extrapolated from) this past it may also be used to pre-present change, was necessary for the evolution of a consciousness like ours (Ingvar, 1985;

Popper & Eccles, 1977), and has had a possibly metamorphotic impact on many and varied aspects of life.

But another important ability is deeply involved in this evolutionary process. It is the most sophisticated tool humans have developed for reading the minds of others and expressing one's own: language. It is difficult to disentangle the evolutionary sequence of reading the minds of others, mental time travel and language. All appear to be interdependent. In ontogeny, early language training seems to precede the emergence of the other abilities and may indeed facilitate internal meta-representation and enhance narrative reconstruction of past episodes. However, there is a reason why language probably emerged late in the phylogenetic sequence. The crucial aspect of human language is its infinite flexibility (e.g. Corballis, 1991). In order to think or talk with infinite flexibility humans must have something of infinite flexibility to think or talk about. The ability to mentally travel in time may have provided just that, creating mental access to the virtually unlimited content of the fourth dimension and therefore an open-endedness of thought that required an open-endedness of language for adequate expression.

Summary

The question whether or not animals can mentally travel back into their own past cannot be answered directly, because in the absence of introspection or language we can infer only from observable behaviour what underlying mental mechanism may be involved. Animals can learn from single events, but this is not sufficient evidence for the existence of the ability to conjure up episodes of the past. Animals may have limited access to their past, not because they lack the necessary capacity to store information, but because of insufficient cognitive abilities.

Remembering past episodes seems to involve active reconstructive processes. Memory representations appear not to be `marked' as memories; instead, their role needs to be inferred. Mental time travel into one's own past appears to require meta-representations and access to the content of one's own mind. Currently available data suggest that only the great apes have such mental capacities. The same picture emerges when one considers the interdependency between episodic memory and self-awareness: only the great apes (with the possible exception of gorillas) seem to be able to recognize themselves in a mirror. Monkeys fall short on both accounts, leaving the great apes as the most likely, if not only, candidates for potentially being able to mentally travel in time the way we do.

Nevertheless, even the great apes may suffer cognitive limitations, especially with respect to `theory of mind', that may prevent mental time travel. "There is very little evidence that chimpanzees recognize a discrepancy between their own states of mind and the states of mind of others", write Cheney and Seyfarth (1990, p. 254). Chimpanzees' failure to solve tasks that demand the simultaneous representation of opposing-to-present states of mind (of knowledge and belief) may indicate that they are unable to represent their own past states of mind if those are opposed to their present ones. This also appears to be the case for children under the age of four. Only after this is overcome, may it be fully possible to travel mentally into one's own past.

Drawing from simulation theory of mindreading (e.g. Harris, 1991), I suggested that mental time travel might be understood as a reconstruction of memory traces into episodes that takes place in the imagination of the individual. An ability to set aside the current state of mind would be necessary for the simulation of past episodes.

While chimpanzees seem to fulfil most cognitive prerequisites for mental simulation, they may not be able to escape the influence of the present mental state, which may hinder the establishment of a fully fledged episodic memory system. Further research may prove this wrong, but if not, and if Koehler (1917/1927) is right in his opinion that even chimpanzees' access to time is limited, then we might infer that mental time travel emerged after the phylogenetic split from apes, and was a critical factor in human evolution.

Mental Time Travel into the Future

In Greek mythology it was Prometheus who stole fire from heaven for the use of humans. "The name Prometheus literally means foresight, the ability to look ahead and in imagination to experience events that lie in the future" (Coan, 1987, p.44). So, according to the ancient Greeks, it was foresight that gave us some of the powers of the gods: the ability to see, to create, to control; the power that make us stand between the worlds of the animals and those of the gods. Does this ancient wisdom bear a grain of truth for the processes that determined the course of human evolution?

Among the adaptative advantages of developing the ability to travel mentally into the past I briefly mentioned that this ability also provides the basis for the ability to look into the future. This might have been a crucial consequence indeed. Predicting the future is a fundamental human capacity that needs to be considered by any theory attempting to illuminate the reasons for the distinct impact our species has had on planet Earth.

The most crucial questions we can ask, according to Humphrey, are:

> "Where have we come from? What are we? Where are we going? ... They are not really separate questions, but one big question taken in three bites. For only by understanding where we have come from can we make sense of what we are; only by understanding what we are can we make sense of where we are going" [Humphrey, 1986, p. 174].

The dependency of an understanding of future on an understanding of past and present is obvious: unlike the past and present, the future is a pure figment of our imagination. Mental states of past self and present others are attributed on the basis of actual stimuli (memory traces and perceptions), but attribution of future mental states is not a reaction to stimuli from the future, but is extrapolated from past and present. The same applies to representations of the world. The future has to be voluntarily imagined. Animals who lack the ability to reconstruct past episodes may also lack the ability to simulate future ones.

The level of understanding past and present determines the possible level of understanding the future. Non-conscious effects of the past, as produced by classical conditioning, can result in same-level anticipations of future (e.g. Pavlov's dogs salivated before meat powder was present). Conscious awareness of past episodes, however, can result in an awareness of potential future episodes. Mental time travel into the future may be achieved through extrapolation from similar past episodes (prediction by analogy) or, more important for the understanding of humans' extraordinary impact on the world over the last 10,000 years, through the application of semantic knowledge (prediction by theory) about the laws that govern nature. As with the development of mindreading and mental time travel into the past, the more abstract theory-based predictions may derive from the more basic ability to mentally simulate future episodes.

`Instinctual' versus `Intelligent' Anticipatory Behaviour

It is highly adaptive for an organism to be able to act not only in order to ensure present survival, but also in order to increase future survival chances. Anticipations have an apparent value for survival: if one knows what will happen one can act now in order to prevent harm or maximize profit. Anticipatory behaviour, however, can result from underlying mechanisms other than mental time travel (see also Appendix A). Learning (e.g. operant conditioning) is inherently prospective, but the future need not to be mentally represented by the individual. Similarly, insight-free instincts, such as hibernation, are another way organisms adapt a priori to recurring environmental changes (e.g. seasons) without the necessity for individual representation of future situations. Hibernators prepare for the winter even if they have not experienced that season before. The relatively inflexible anticipatory behaviour and its occurrence in only narrow contexts appears to distinguish what is labelled instinctual from what is labelled intelligent.

However, this dichotomy may be another qualitative distinction that may be viewed as a metamorphosis deriving from mere gradual differences. Recently, Gibson (1990) has argued that intelligence and instinct may be viewed as the two ends of one continuum of `mental constructional ability'. Based on connectionist models of the interconnectivity to the degree of hierachicalization of behaviour and therefore to the degree of flexibility that determines how instinctual or intelligent behaviour appears to be. In this perspective, the relatively inflexible and context-specific anticipatory behaviours of relatively small-brained hibernators are at the one end of the continuum of mental constructional ability, while the flexible, context-independent mental time travels of adult humans represent the other end. The constructional capacity to mentally simulate, or `picture', future events seems not to be required for anticipatory behaviour such as the hoarding of nuts by squirrels. Even the apparently foresightful behaviour of satiated leopards wedging half-eaten carcases in a tree does not require the representation of future hunger and feast, because it is a typical behaviour for members of that species and evolved as an adaptive behaviour for specific circumstances (F. Reynolds, personal communication, June 19, 1993).

Cheney and Seyfarth (1990) refer to a kind of "laser beam" intelligence that animals often display in a single domain but not in others. This inability to apply the knowledge possessed in one domain to contextually different problems might be due to an inaccessibility of the knowledge. It may be the awareness about knowledge, knowing that and what one knows - or in short, metacognition - that allows us to apply our knowledge to different domains in a flexible and generative manner (cf. Cheney & Seyfarth, 1990).

The ability to form meta-representations of one's own knowledge might be a development at one end of Gibson's `mental constructional ability' continuum, like a metamorphosis, resulting in flexible behaviour of a qualitatively new kind. As mentioned earlier, evidence for some form of such second-order representations is as yet available only for the great apes (Cheney & Seyfarth, 1990; Suddendorf, 1993; Whiten & Byrne, 1991). Mental time travel, however, whether into the past or into the future, requires this ability.

The use of one's imagination to mentally simulate future situations may require the same, and perhaps even more, cognitive abilities as mental simulation of one's past. In contrast to monkeys, great apes have provided evidence for the advanced cognitive features of second-order representation, imagination of other possible worlds, self-awareness and mindreading (which all appear interlinked). Great apes may therefore have the basic cognitive capacities required for mental simulation. Instead of imagining what it was like (as in simulation of past episodes) or what it would be like (as in mindreading) the simulation process may also be used to answer what it will be like being in a future situation. As for the other two applications of the mental simulator, it appears necessary for the individual to detach from the current mental state in order to imagine other states (of others, past self or future self) that may be opposed to the present one. Mental simulation of the future may be restricted in chimpanzees by their seeming inability to represent opposing-to-present future mental states and, additionally, by their limited access to past experiences which may limit the ability to infer future states of the world and self.

Despite these potential limitations, great apes' advanced cognitive abilities should allow for flexible problem solving with an eye to the future. In fact, Doehl (1970) showed that the chimpanzee Julia was able to look several steps ahead in a sequential problem-solving task. Julia had to choose between two keys in a transparent box which opened further boxes with keys until arriving at the final box containing either a food reward or nothing. Only by choosing the right key in the beginning was reward obtainable. Julia learned to act not by chance but by determining the route leading to the reward before choosing the initial key. Each trial was of course a different arrangement of keys and boxes so that simple chaining explanations can be ruled out. Julia was able to look five steps ahead in pursuit of her final goal.

The different tool cultures of chimpanzees provide further examples of `forethought'. The chimpanzees at Gombe, for example, manufacture tools at one place to use them later for termite fishing at another place out of sight (Goodall, 1986). In that a branch is trimmed for use as a probe, such behaviour may be based on the high `mental constructional ability' of second-order representation. Whiten and Byrne (1991) argue that besides the primary perception of the branch as a branch, the individual has to generate a meta-representation of it as a probe. Similarly to these observations in the field, the experimental observation of Sultan's problem solving by insight (Koehler, 1917/1927; see above, p.28) seems to indicate that chimpanzees can use their imagination to mentally construct (`picture') possible future realities.

Anticipating Near versus Remote Futures

Despite this evidence for chimpanzees' capacity to imagine the future, Koehler (1917/1927) argued that it was restricted. He suggested that it is "of theoretical importance that the clearest consideration of a future event occurs when the anticipated event is a planned act of the animal itself" (Koehler, 1917/1927, p. 272). The reason for this has to do with the motivational connection between the animal at present and the anticipated event. Clearly, Sultan imagined `the future' as an attempt to get the bananas that could satisfy his present hunger. Similarly, Julia's performance was driven by her desire for the food reward and the Gombe chimpanzees' manufacture of sticks is motivated by an appetite for termites. However complex these anticipations are, they are concerned with a relatively near future. Koehler viewed this as the `dynamic essence of drive behaviour' and as belonging to the present; the anticipations do not go beyond the actual context of one behavioural unit or gestalt. In other words, one could say that animals appear to be bound to the present. This notion is expressed in many writings about the restrictedness of animal thought compared with that of humans. Recently, Donald wrote for example that apes' "behavior, complex as it is, seems unreflective, concrete and situation bound" (Donald, 1991, p. 199). And Stebbins (1982) and Eccles (1989) refer to `time-binding', i.e. simultaneous access to past and future, as a unique human feature. Bischof (1978, 1985) and Bischof-Koehler (1985) make this point more explicit and, based on Koehler's (1917/1927) writings, suggest a limit to the extent to which animals can represent the future. They claim that animals cannot anticipate future needs or drive states and are therefore bound to a present that is defined by their current motivational state. Only humans, they argue, have acquired the ability to imagine a remote future that lies beyond the current needs. I will call this idea the Bischof-Koehler hypothesis (this name refers to all three researchers involved: Wolfgang Koehler (1917/1927), Norbert Bischof (1978; 1985) and Doris Bischof-Koehler (1985)).

None of these authors provided a clear definition of drive or need, whether anticipated or current. They seem to rely on a common sense understanding of the terms. A review of the long debate about motivation, drives and needs goes beyond the scope of this paper. However, Bischof (1985) illustrates his point with the example of the homeostatic motive, thirst. When an animal is thirsty it tries to find a way to get something to drink: perception is focused on key stimuli that indicate access to water (e.g. certain plants that grow only close to lakes and rivers), memory is searched, and so on. To begin these procedures animals must first experience the thirst; humans need not. While a full-bellied lion is no threat to nearby zebras, a full-bellied human may well be. Clearly, humans anticipate future needs very often as expressed in that we collect (buy) food even if we are not hungry or in that we carry (possess) tools, even if we do not need them to satisfy any current needs, because we can anticipate their usefulness for the satisfaction of future needs. Business, for instance, is to a great extent dependent on anticipations of one's own and others' future needs.

The Bischof-Koehler hypothesis appears to be consistent with the idea, outlined above, that animals may be unable to escape the influence of the present mental state. While chimpanzees fulfil most of the cognitive requirements necessary to use the setting aside their own current mental state in order to imagine opposing-to-present future (past) mental states. The emphasis that the Bischof-Koehler hypothesis places on the representation of future needs is justifiable. What adaptive advantage would there be in developing the capacity to imagine remote futures, if this forethought is conferred to serve only the present needs? If all one cares about is related to the current needs because one cannot imagine future ones (or cannot set aside the present one), what aid does one receive from imaginations of remote futures? Only if one can realize that one will have different future needs does it appear to make sense to invest in further capacities to represent aspects of remote futures. While many animals may have concurrent drives and needs with varying degrees of urgency, anticipating future needs appears to be special. This ability seems crucial for the evolution of `unlimited' mental time travel.

However, chimpanzees appear to have problems with representing opposing-to-own mental states of knowledge and belief, but not necessarily with the attribution of contrary desires and intentions. Chimpanzees can attribute desires and intentions to others (Woodruff & Premack, 1978), but it is not clear if they can do so when these states actually oppose their own current state. In order to demonstrate this, one might seek evidence that completely satiated chimpanzees, for example, can attribute hunger to others (but see also the experiment suggested in Appendix B). If chimpanzees can attribute opposing-to-present states of needs to others, then problems with setting aside the current state of needs could hardly account for the postulated inability to represent own future needs. Rather than being caused by an inability to simultaneously represent opposing (future) needs, chimpanzees' limited access to a remote future may be due to their limited access to their past. In order to mentally infer future states of the world and self, one has to extrapolate from one's knowledge of the past. The voluntary imagination of future needs evoked by an imagined remote future environment may demand more access to the past (e.g what environmental circumstances produce(d) what needs) than chimpanzees possess.

Can Apes Travel Mentally into Remote Futures? Reviewing the Evidence

Although Griffin (1978) pointed 15 years ago to the importance of acquiring knowledge about animals' sense of a remote future and urged cognitive ethologists to specifically study this realm, as yet little has been published on the topic. The few experimental investigations of animal forethought are generally concerned with the ability to anticipate near futures (e.g. Washburn & Rumbaugh, 1992). As yet we need to rely on anecdotal data in order to assess the validity of the Bischof-Koehler hypothesis.

When Jane Goodall (1986) asked to what extent chimpanzees can plan ahead, she chose an example of a male chimpanzee called Satan: "[w]hen Satan followed a female in estrus until she nested, then slept close beside her, was he planning the early morning getaway? Or did he simply take advantage, each time, of the favorable circumstances he found himself in the morning?" (Goodall, 1986, p.588). No matter what the answer, it seems to be apparent that Satan, even if he had planned the situation, was acting according to his present sexual drive. The anecdote would therefore constitute a single, although extended, entity of `dynamic drive behaviour'; that is, it would still not extend into the `future' in Koehler's sense.

Bischof (1985) points to a general evolutionary pattern progressively increasing the gap between drive and action. Great apes display quite extensive gaps. They are able to postpone the immediate enactment of their current drive, producing the intention to receive gratification at a future point in time. De Waal (1982), for example, reported an instance that took place in the Arnhem Zoo. The researchers hid grapefruits in the chimpanzee enclosure by burying them in sand. Once outside, the chimpanzees searched enthusiastically but unsuccessfully for the hidden treat, although several, including Dandy, passed over the spot. Only later in the afternoon did it become apparent that not all chimpanzees had failed to find the spot. Unnoticed by the others, Dandy went straight to the hiding place, dug up the fruits and enjoyed the treat having avoided competition. Other examples of this kind can be found in Byrne and Whiten's (1990) database of tactical deception in primates. However, while postponing the enactment of a current drive may be a necessary prerequisite and a step towards future-need anticipation and consideration, it is not equivalent.

Chimpanzees have been observed carrying stones over long distances to open nuts at a place where no suitable `stone tools' can be found (Boesch & Boesch, 1984). However, even this extreme instance of apparent forethought seems to be induced by the current drive. "What is imagined is the resonance of current needs in a future environment" (translated from Bischof, 1985, p. 541). The chimpanzees that pick up the stones and carry them seem to do this to satisfy the already present motive of having an appetite for these special nuts. Thus, it could be argued that the future environment can be anticipated, but only with the inducement of the current drive, which remains unchanged and outlines the instance as one behavioural unit.

As yet, only one reported anecdote appears to suggest that chimpanzees may anticipate future needs:

> It is November and the days are becoming colder. On this particular morning Franje collects all the straw from her cage (subgoal) and takes it with her under her arm so that she can make a nice warm nest for herself outside (goal). Franje does not do this in reaction to the cold, but before she can have actually felt how cold it is outside. [de Waal, 1982, p.192]

Apparently, the chimpanzee Franje anticipated the future coldness and the resulting future desire or need for warmth. But since the above citation is the entire information published about this case, many question marks remain. As with many other anecdotes, alternative, more parsimonious, explanations cannot be ruled out and are indeed plausible. Experimental research is needed (in Appendix B I propose a possible experimental paradigm). A single anecdote, in contrast to a single proven case, cannot falsify the Bischof-Koehler hypothesis, i.e. that animals are present or situation-bound because they cannot anticipate own future needs.

However, absence of evidence for future-need anticipations in animals is not equivalent to evidence for absence. The Bischof-Koehler hypothesis appears to be congruent with our current knowledge about animals (see Appendix A for the results of a survey of animal foresight). But the Zeitgeist of science in the first 70 years of this century did not allow much anecdotal evidence for animal intelligence (such as forethought) to surface and experimental studies did not focus on `mentalist' concepts. While the widespread and relatively uncritical use of anecdotes led 19th-century scientists to radically overestimate the mentality of animals (Lindsay, 1880, for example, concluded that animals engage in criminal activities and commit suicide, cited in Bernstein, 1988), most 20th-century scientists appear to have made the systematic bias of underestimating animals' cognitive capacities. `Lloyd Morgan's canon' destroyed the acceptability of the anecdotal method and the emergence of `the principle of parsimony' demanded that one should attribute the behaviour of an animal to no higher, or more complex, level of mental ability than is strictly necessary. It remains debatable, however, whether our decision about what constitutes higher and what constitutes lower is correct (cf. Griffin, 1981; Suddendorf, 1993). To find data that could potentially falsify the Bischof-Koehler hypothesis among the database deriving from this period appears unlikely even on a priori grounds. However, the research climate is changing. Speculations about the evolution of mental abilities in recent studies (e.g. Cheney and Seyfarth's study on vervet monkeys) seem to place more emphasis on what level of mental ability is optimal rather than what level is minimal (Figueredo, 1992). And the anecdotal method has been successfully reintroduced for studying primate deception (Whiten & Byrne, 1988; Byrne & Whiten, 1990, 1992), a phenomenon completely ignored under the earlier paradigm. Instead of naive overestimation of animal mentality without experimental evidence and instead of underestimation of animal mentality by depriving us of valuable anecdotes (the phenomenon of infanticide, despite its social and evolutionary importance, was unrecognized until anecdotes were `accepted'), we now seem to be entering a phase of more balanced inquiry. Experimental studies have shown many advanced mental abilities to exist in animals (see above, p.2, 3, 15-19) and systematic gathering of anecdotal observations enriches the realms of further inquiry (see Appendix A).

Before discussing the adaptive advantages of mental time travel into the future yet another type of apparent forethought needs to be mentioned.

> It often happens that human beings discover the goals of their behaviour only in retrospect. During adolescence, for example, we stand up against our parents, provoking and challenging them. Later we may explain this behaviour by saying, `I wanted my independence', but remember that we did not start the generation conflict with this motive explicitly in mind. It was an unnamed, unconscious motive. [de Waal, 1982, p.193]

De Waal put forward this example as a possible explanation for the strategic intelligence displayed by the ex-alpha male Yeroen of the Arnhem chimpanzee colony. After losing his alpha position to Luit, Yeroen cooperated with the third male Nikkie which eventually brought Yeroen, as Nikkie's right hand, back to power. This success occurred months later after being initially negative. Not all behaviour that turns out to be smart in retrospect was necessarily intended with the future goal in mind.

Similar explanations could account for apparently forethoughtful behaviour such as the acquisition of mental maps for future use. Gorillas and chimpanzees seem to acquire an extensive knowledge about their territory, permitting the individual to take the shortest route to desired fruiting trees or, in the case of chimpanzees of the Tai forest, to stones for opening nuts (C.E.G. Tutin, personal communication, June 25, 1993; Boesch & Boesch, 1984). Whether this knowledge is acquired with intention, that is, having in mind the usefulness of this knowledge for the future, is questionable, however. Many animals learn more than would be actually necessary for current demands. Learning as such is inextricably interwoven with control and anticipation15. Information is stored for future use. Indeed, animals may store information for future use only; not for the reconstruction of the past (see above, p.7-36). It is a well known fact that rats, for example, learn where food is hidden in a maze even if they are not hungry. Being hungry a day later, they go straight to the food when being put into the maze. This so-called latent learning requires that the rats have acquired a mental map for potential future use. There is no reason, however, to assume that the rats have mentally travelled into the future, anticipated the potential future hunger and decided that it is worth remembering where the food was placed. Neither is there evidence that the mental maps acquired by apes require such forethoughtful mental processes. In spite of their advanced mental capacities, chimpanzees have as yet not provided evidence for awareness about remote futures (cf. Appendix A).

It may therefore be conjectured that only humans can mentally travel in time in a virtually unlimited way.

Why Travel Mentally into the Future?

As outlined in the previous sections, organisms evolved a variety of means to enable them to act in ways that increase future fitness. Mostly innate, species- and domain-specific, anticipatory behaviour and basically all forms of memory and learning are of this kind. While all great apes may have developed the mental constructional ability to meta-represent their own knowledge, i.e. to know what they know, only humans may have discovered a new dimension of knowledge (time) that they are aware of. What adaptive advantage could it have to evolve mental time travel into the future additionally to the phylogenetic older forms of `considering' the future? In the following I will only touch on some of the crucial consequences. Outstanding among those potential advantages is the individual flexibility of anticipations and the consequential increased degree of flexibility and generativity of behaviour.

In contrast to phylogenetic earlier mechanisms, mental representation of possible futures allows for anticipation of virtually anything and for flexible adaptation of current behaviour in consideration of this future. The fitness of this new mechanism depends mainly on the accuracy of relevant mental predictions. Mental simulation of likely futures can be achieved by extrapolating similar past episodes, by generating and applying heuristics and, at perhaps the most sophisticated and recent level, by induction or deduction of actual theories about the world (including the mind). In short, it depends on one's access to the past and the knowledge one has been able to extract about the `laws' of nature, such as causal relations. The immediate fitness value of mental time travels into the future is the increased degree of flexibility in the ability to act now for the future. Once on this phylogenetic track, strong selective pressure favours better anticipation of the future, i.e. better acquisition of experience and knowledge and its utilization for prediction, and better manipulation of the future (see below).

In this process, behaviour became more and more dependent on what is mentally represented. Apes may to some degree read the minds of others in order to predict and manipulate behaviour, but for humans, with their mental access to time, this becomes essential. Although the behaviourists tried, human behaviour can often not be understood or predicted without considering what is on the individual's mind. In particular, one has to take into account that human behaviour can be driven by intentions that derive from mentally represented goals that lie in the remote future, well beyond the satisfaction of the current needs. Understanding and prediction of human behaviour is further hampered by the obscure complexity of the not-directly-observable mental world of social interaction. A far more sophisticated `Machiavellian intelligence' emerged to deal with these problems: a narrative mind able to understand and predict the world in an event-filled rather than abstract time (cf. Carrithers, 1991). First of all, however, new mechanisms of motivation must have emerged with mental time travel.

Classic theories of motivation, generalized to animals and humans, emphasized innate forces and learned stimulus-dependent factors. With mental time travel into remote futures humans acquired a quite different set of influential factors. The anticipation of future needs, as pointed out above, might have been a milestone in evolution. Simulating future environment-need constellations (e.g. a dry area will evoke thirst) can affect current motivation and behaviour (e.g. one may decide to carry water when walking into a particular area) even when this is contradictory to the present environment-need constellation (e.g. plenty of water and no thirst) (cf.

Bischof, 1985). With mental time travel into the future a third component of motivation needs to be considered because imagined future needs can be converted into current motivators. Long-term goals can be generated and current behaviour can be adjusted to serve these aims.

To make these processes functional within the cognitive apparatus, I postulate the emergence of a cognitive motive organizer, or CMO, which fulfils two phylogenetically new tasks: (1) to represent most likely and significant anticipations and/or remember relevant earlier anticipations (cf. `memory of the future', Ingvar, 1985) and (2) to evaluate and coordinate these anticipations and the current environment-need constellation. New and differentially weighted motives can be generated and complexly organized. In recent years motivation theorists have come to appreciate the importance of humans' concern about the future. Bandura (1991) summarized those studies and theories of motivation that include cognitive motivators (expectancy-value, goal and attribution theory). He concluded that "[c]ognitive regulation of motivation relies extensively on an anticipatory proactive system rather than simply on a reactive negative feedback system" (Bandura, 1991, p.150). Earlier he pointed out that "even in the so-called biological motivators, human behavior is extensively activated and regulated by anticipatory and generative cognitive mechanisms rather than simply impelled by biological urges" (Bandura, 1991, p.70).

This proactive anticipatory system, or CMO, demands an executive and decision-making authority. This may be the origins of what we believe to be our `freedom of will'. Our intentions, motives and goals appear, at least to a degree, to be up to us. Animal behaviour is driven by innate, learned or homoeostatic factors which may not be under the voluntary control of the individual because the organism cannot represent alternative future drives. In contrast, the CMO allows humans to alter and even create new motives based on access to the future. Individuals became responsible for their own drive management16. An intrinsic by-product of this new element of choice is that one may be `wrong' in one's decisions. This, of course, is the fundamental basis of morality. Instead of being driven, humans can put themselves in the driver's seat, having to take responsibility for their own intentions and actions. Nature let one of its creatures off the leash, as it were.

However, perceived control, whether the control is real or not, is a dimension of reinforcement for humans and animals. But mental time travel results in a new kind of potential control over one's own destiny. This refers not only to one's intentions and goals but also to one's influence upon the future. Humans must have inevitably learned that their future anticipations are based on guesses and inferences, not on clairvoyance. On the one hand, better predictions may be achieved through greater knowledge, but on the other hand they may also be achieved through greater control of the future. Attempting to direct the future through proactive manipulation appears to be a natural consequence of an awareness about possible futures. The perceived control may be achieved through `religious' or `natural' technologies (see Festinger, 1983)17. The required generativity and flexibility, perhaps underlying both technology and language (Corballis, 1991; Greenfield, 1991), could only have been achieved through mental access to the infinite content of the dimension of time.

All these processes that I have touched on are, of course, far more complex than could thoroughly be discussed in this paper and involve many factors that are multidimensionally interconnected (see also Bischof, 1985; Suddendorf, 1992). However, it should have become clear that our awareness of time is deeply involved in many crucial human developments. The scientific neglect of this important human capacity needs to be overcome if we ever want to understand our nature, our evolution and our development. A final important consequence remains to be discussed, which will clearly illustrate the importance of our awareness of time for ourselves.

As Humphrey (1986) pointed out, the crucial questions of where we come from, what we are and where we are going are essentially one. Only with an awareness about time can we ask these questions and perhaps find answers, through which we can define our personal identity. In addition to the self-awareness displayed at present in other great apes, humans can form a concept of self over time. Although fundamental psychological and physical changes take place in our individual development from infancy to old age our capacity for mental time travel allows us to view any of these stages as part of our personal identity. Furthermore, this self experiences a certain control over its own drive management, by being the authority that is making decisions about goals and, if necessary, even about overriding the basic instincts (e.g. hunger in strike or fasting) in pursuit of these goals. Our impression of `freedom of will' and our personal identity over time are consequences of mental time travel that have profoundly affected the human ego.

Mental time travel into an unrestrictedly remote future must have confronted humans with what according to Freud is the most frightening of all conceivable facts: one's inevitable death. The perception of continuity of one's personal identity over time might have resulted in the belief in a continuing identity after death: a continuing `soul', whether in heaven or hell, in this world or another, in the same body or in a different one. This belief may be applied, not only to those who can form such mental concepts (i.e. humans; discontinuity philosophy), but also to those who cannot (i.e. all living beings; continuity philosophy). To deal with the insecurity and lack of control about one's destiny after death, socially shared after-life concepts may have emerged: the core of religions. Goals and needs that lie beyond one's own lifetime were anticipated. The ancient Egyptians or Chinese, for example, believed in the after-life need for goods while people who believe in heaven and hell may anticipate the need to have a `clean slate'. Current life became strongly affected by the answers to the inevitable questions mental time travel provoked. I agree with Gould (1991) that a single exaptive argument for the origin of religions cannot explain all multifaced and complex aspects of the evolution of these institutions, but the emergence of the ability to become aware about time and one's personal future surely played a fundamental role.

When human's mental horizon broadened by the dimension of time, the course of human evolution changed significantly. Changes in behaviour, cognition, motivation and emotion must have taken place, justifying the simplifying label `prime mover'.

When did Mental Time Travel Emerge?

In order to investigate the history of a living organism or of some of its characteristics, one can use information about currently living species and about remains and artifacts from the past. Recent advances in genetics have changed our concept about the relationship of today's species. In particular for many it was surprising that, in spite of the apparent differences, humans and chimpanzees (Pan troglodytes) seem to be genetically more closely related than chimpanzees and gorillas (Gorilla gorilla) (Miyamoto, Slightom & Goodman, 1987; Gibbons, 1990)18.

The common ancestors of humans and chimpanzees lived about 5 to 8 million years ago. Since the human-ape branch grew out of the primate tree some 30 million years ago, humans share about 22-25 million years of evolution with chimpanzees that humans and chimps do not share with monkeys. It should therefore not surprise that in many respects chimpanzees differ more from monkeys than they differ from us. However, the reviewed evidence suggests that chimpanzees do not share the apparently important human capacity of unrestricted mental time travel and one may therefore conjecture that this characteristic developed after the phylogenetic split from chimpanzees19. What evidence do we have about the emergence of mental time travel in the last 5 to 8 million years of evolution?

The archaeological record provides us only with limited and selected information about human evolution. Important cognitive developments, such as mental time travel, often do not manifest in physical evidence. We are therefore likely to commit type II errors in our archaeological analysis; that is, we are likely to accept the null hypothesis that our forebears did not possess some cognitive ability when in fact they did. Conversely, the likelihood of committing type I errors, i.e. to reject the null hypothesis and accept the hypothesis that some cognitive ability was present, even though it was not, is reduced. However, type I errors are also likely because of possible misinterpretations of the few data that we have. With these considerations in mind, let us now consider the evidence for mental time travel in our ancestors.

Stone tools - perhaps merely due to their durability - are the oldest known artifacts and have often been viewed as the earliest evidence for real humans (this is why Leakey labelled the 1.8-million-year-old body remains `Homo habilis' or `handy man' in contrast to the australopithecines). However, the oldest stone tools, the so-called Oldowan tools (datings vary from 2.4 to 1.6 million years old), associated with Homo habilis20, seem to be within the competence of modern chimpanzees (Wynn & McGrew, 1989; see also Toth et al., 1993) and the stone tool culture of tai chimpanzees (e.g. Boesch & Boesch, 1984), although not involving manufacture of stone tools, has been evaluated as representing a similar state of development (Wynn & McGrew, 1989). The production of an Oldowan tool may require some mental picture of the finished product and the use to which it will be put, but is not convincing evidence for mental time travel beyond the current needs because it might have been manufactured merely as a means to satisfy a current drive (just as appears to be the case for the tai chimpanzees). Although we may commit a type II error, current evidence does not support the idea that mental time travel beyond the current drive was present in H. habilis, even though the capacity to think ahead might have improved.

Evidence for mental time travel into a remote future is more convincing for Homo erectus. With the emergence of H. erectus (about 1.6 million years ago) a more sophisticated, so-called Acheulian, tool culture occurred. One of these tools was the biface handaxe whose production included a somewhat symmetrical removing of flakes from two sides of the stone core so that the tool became sharper and more pointed. The manufacture of costly bifacial stone tools leads one to assume that they were not intended for one time use only, but were kept for future use, which would imply that the manufacturer has anticipated future needs for which this tool might be helpful. In turn, the anticipation of multiple future uses could have been an incentive for the more time-consuming manufacture of more sophisticated, versatile and long-lasting tools. However, H. erectus' Acheulian tool kit showed little further refinement for over a million years. Perhaps H. erectus represents an intermediate stage of the evolution of mental time travel, in that simulation of future and past episodes was possible, but the generation of abstract semantic concepts and theories from this knowledge was still in its infancy (see table 1. above).

The earliest evidence for a consequential increase in flexibility and generativity is not stone tools, but the fact that about one million years ago H. erectus migrated from Africa to various parts of the Old World. While migrations are generally nothing unusual, this one appears to be different because H. erectus moved into very distinct environments and quickly adapted to very diverse climates. Instead of slow morphological adaptation (e.g. in size and fur, etc) H. erectus must have been able to manufacture an adequate ecological niche in alien ecological conditions that originally could not meet human needs (e.g. eventually through use of fire). Our ancestors must have analyzed past experiences and predicted future environment-need constellations in order to respond with flexibility to varying demands and with the generativity necessary to alter the environment to meet their (future) needs.

With Homo sapiens neandertalensis (between 100,000-35,000 years ago) there is the first evidence for unrestricted mental time travel even beyond death. Burials and `bear cult' indicate early attempts to deal with the questions mental time travel inevitably confronts us with.

Finally modern humans (Homo sapiens sapiens) left clear evidence for the use of abstract semantic knowledge and theories about the world in the so-called `evolutionary explosion' (35,000-10,000 years ago) of technology and art. This again increased exponentially with the invention of external symbolic memory storage (cf. Donald, 1991) six to four thousand years ago, enhancing accumulation of and access to knowledge about the world (including records of the past and prophecies about the future). Recent revolutions in science, technology and information processing and transfer mark a further step in the evolution of humans' ability to understand and manipulate the world.

Over the last 2 million years human brain size has increased (encephalization), indicating the increasing importance of the cognitive apparatus for survival and reproductive success. The limbic system, a brain structure concerned with basic needs which forms a major part of the brain in most mammals, became much less prominent in humans as indicated by its reduced size relative to the whole cortex. This corresponds with the view (discussed above) that with mental time travel humans achieved extended cognitive control over their own drive management. One structure that appears to be critical for these `higher' cognitive functions is the prefrontal cortex which is reciprocally connected to the limbic regions and to sensory association areas and appears to be responsible for the generation of action schemes and the temporal organization of behaviour (Fuster, 1989; Ingvar, 1985). The `regio frontralis' constitutes 3.5% of the cat cortex, 17% of the chimpanzee cortex and 29% of the human cortex (Brodmann, 1912, cited in Fuster, 1989). The prefrontal cortex in humans appears to be essential for mental time travel and some of its above discussed `by-products'. The inability to consider the future appears to arise from lesions only to this area of the brain (Fuster, 1989, Ingvar, 1985). New and goal-directed behaviour, especially if based on deliberation and choice, is often severely impaired (Fuster, 1989). Ingvar (1985) refers to a `lack of future'; behaviour is dominated by present needs and stimuli, the here and now. Resulting symptoms of prefrontal lesions may be lack of ambition, apathy, unawareness of behavioural consequences and moral values (Ingvar, 1985); effectively cancelling the advances induced by the emergence of mental time travel. The late development of the prefrontal cortex in phylogeny (and its late functional commitment and myelination in ontogeny), supports the view that this area is involved in higher mental functions, of which the time aspect may be of crucial importance.

The last two million years have witnessed the progressive sophistication of a human weapon that no other animal can yet beat: a brain that can potentially anticipate, alter and react to whatever might happen in the future.

Summary

Organisms have developed a variety of means enabling them to act now for the future. Only the great apes, however, may have developed an awareness flexible, context-independent manner. Such mental time travel in which the imagination is used to simulate possible future scenarios may, nonetheless, be limited in great apes. The reviewed evidence does not support the idea that chimpanzees can mentally travel into a remote, virtually unlimited, future the way we can and frequently do. According to the Bischof-Koehler hypothesis the extent of ape forethought is limited by an inability to imagine future drives or needs.

In the archaeological record the first evidence for future-need anticipation is associated with Homo erectus and unlimited forethought, even beyond death, can be inferred from artifacts associated with Homo sapiens. As with the proposed development of mindreading and mental time travel into the past, mental time travel into the future might have gradually developed from simulated-episodic to more abstract-theoretical levels. The `mental world' and the underlying cognitive apparatus, involving particularly the prefrontal cortex, became increasingly important. Aspects of human's mental make-up, ranging from motivation to self-perception, changed accordingly. Mental time travel is a fundamental feature of the human mind; without it, technology, language, morality and religion could not have evolved the way they did. It seems that the ancient Greeks were right: it was indeed Prometheus (foresight) who brought about the changes that made us appear to stand between the worlds of the animals and those of the gods.

Concluding Comments

The reviewed evidence suggests that unrestricted mental time travel is a characteristic unique to humans. The discovery of the fourth dimension was probably a process of the last two million years, but each human has to re-discover it in childhood. Mental simulation may be the underlying mechanism responsible for our success. Given the essential status of mental time travel for many other cognitive functions, science may need to devote more attention to this human capacity if we ever want to understand the human mind, its evolution and development.

Appendix A

A Survey of Animal Foresight:

A preliminary investigation of whether or not
the Bischof-Koehler hypothesis
is consistent with current knowledge about primates

Introduction

The Bischof-Koehler hypothesis, which states that

Animals cannot anticipate their own future states of need or drive,

is difficult to test empirically. Indeed it is impossible to demonstrate unequivocally that it is true, because any animal at any point in time may anticipate a future need and consequently all animals would need to be tested all the time. One can only attempt to falsify the hypothesis (cf. Popper, 1934). The first step in such an attempt is to review the studies that have been done. The few published investigations focusing explicitly on primate foresight do not oppose the thesis in that they do not show that an animal anticipated future needs. It is possible, however, that there are unpublished phenomena known to workers in the field that are unknown to those outside the field of primatology. Therefore, the best and perhaps the only way of examining whether the Bischof-Koehler hypothesis is consistent with current knowledge is to ask those scientists who study primates (and other species) whether they have observed or know of any behaviour that may contradict the claim. And so I did.

Byrne and Whiten (1987, 1990, 1992) used a similar research strategy to collect information about an aspect of primates that had previously not been studied anecdotes (Byrne & Whiten, 1990) is an important accumulation of otherwise neglected knowledge that led to the establishment of tactical deception as a phenomenon of primate behaviour. Similarly, I thought, a survey on animal foresight might update the database on which to assess the Bischof-Koehler hypothesis by accumulating information that has not previously been brought together. If the survey does not reveal evidence of foresight to refute the hypothesis, the conjecture that it is consistent with current knowledge becomes firmer. Furthermore, the survey may help extending current knowledge by accumulating anecdotes relevant to the topic. If further anecdotes of the kind of de Waal's observation of Franje (1982, see above, p.49) were to amass, it would threaten the hypothesis. At least it would call (and perhaps set the stage) for perhaps more conclusive experimental inquiries. A collection of anecdotes alone, however, may not provide a decisive answer to the question about the validity of the hypothesis (cf. Heyes, 1993). Nonetheless, as some respondents attested (e.g. Byrne, Tutin), the survey appears to be the only feasible way of approaching the issue at this initial stage.

There are some essential differences between the gathering of anecdotes in Whiten and Byrne's (e.g 1988) exemplary study on tactical deception and the current search for anecdotes concerning the anticipation of future states of drive or need. Tactical deception is a phenomenon that can be defined in behavioural terms (e.g. Whiten & Byrne, 1988). By contrast, mental time travel, drive or need and anticipated drive or need are not directly observable. As pointed out above, Bischof (1985) and Bischof-

Koehler (1985) failed to provide a definition of what constitutes a drive or need. Since the scientific community has not been able to agree upon a common definition, it is not surprising that Rowell and Harcourt complain about this state of affairs in response to my request. The other respondents appear to have relied on their common sense understanding of the terms. In addition to the problem that drives cannot be observed directly, the possibility of concurrent multiple drives with different degrees of urgency and of interruption of drive behaviour complicate the issue. Only experimental manipulations may be able to control these factors at least to a degree. Indeed, in Appendix B I will propose an experimental design that may solve these problems by controlling current and future drives. While Byrne and Whiten (e.g. 1991) used those anecdotes that met their own definition for inferences about possible underlying mental processes and capabilities, the current survey relies on inferences that the observers themselves make as to what constitutes evidence of future-need anticipation21. Consequently, without a clear behavioural definition, the study can only be explorative in its nature. Contributed anecdotes can only be observations of anticipatory behaviour that the respondent deems may entail mental representation of a future state of drive or need.

Anticipatory behaviour may be defined as any behaviour that becomes meaningful only in consideration of events that follow it. In this sense nest building among birds is an anticipatory behaviour because this activity only makes sense in the light of future breeding. This does not imply, though, that the actor (the bird) is aware or holds a mental representation of the future event. Indeed, anticipatory behaviour may or may not be based on forethought and forethought may or may not manifest in anticipatory behaviour. In the absence of language, mental processes such as forethought can only be inferred. Such inferences should be guided by a comparison of the specific features that characterize different possible underlying mechanisms for anticipatory behaviour. I will briefly rehearse the different mechanisms discussed above:

1) Learning

Mechanisms of learning are mechanisms that can underlie anticipatory behaviour because learning as such makes sense only in the light of future use. In classical conditioning, for example, the effectiveness of a CS (conditioned stimulus) is mainly dependent upon its quality as a reliable predictor of the UCS (unconditioned stimulus). Time itself may even serve as a CS; that is, a dog may be conditioned to salivate prior to the appearance of food that is presented at regular intervals. Similarly, operant conditioning (law of effect) implies some form of expectancy of rewards or punishments. Explanations of anticipatory behaviour based on learning require that the animal has had past experiences with the same or sufficiently similar situations. Other conditions relevant to this kind of underlying mechanism of anticipatory behaviour are described in the findings amassed by behaviourists.

2) Instinct

Anticipatory behaviour can result from genetically controlled mechanisms. Such instinctual behaviour may not require any past experience (e.g. in the case of hibernation), although the inherent aspects may need environmental input and may be altered through this. Instinctual anticipatory behaviours should be universal or at least common among members of the species. The behaviour can be expected to be stereotypical (apart from learned modifications) and fixed to a particular domain. In experiments the behaviour may be provoked through the presentation of isolated particular releasing factors.

3) Coincidence

This category is not really related to an underlying mechanism of anticipatory behaviour but rather comprises those behaviours that may in retrospect look anticipatory, but whose functional origin was not related to the future events. Behaviour may turn out to be useful by sheer coincidence. Such coincidences may, through mechanisms of category 1 or 4, become actual anticipatory behaviours.

4) Representation of the future

Many human anticipatory behaviours are based on mental representation of possible future events (mental time travel). While learning and instinct may be involved neither can alone nor in combination explain resulting behaviour. Behaviour based on insight may be characterized through its transferability, flexibility and generativity. Past experience with the situation may not be necessary and the resulting behaviour may not be shared with other conspecifics (Mental time travel is individual cognition and thus one can expect interindividually different resulting behaviour). Only anticipatory behaviour that is based on mental time travel is relevant to the Bischof-Koehler hypothesis.

The dissociation of possible underlying mechanism for anticipatory behaviour cannot be conclusive if based solely on anecdotal evidence. In addition, it has to be conjectured that in many cases more than just one mechanism is involved (e.g. a combination of learning and instinct) or the mechanisms are not as clear cut as they seem (see Gibson, 1990 and discussion above, p.40, 41). With all these limitations and restrictions in mind the current survey should be viewed as a preliminary study of evidence that potentially could refute the Bischof-Koehler hypothesis.

Having pointed out some of the difficulties and weaknesses as well as the aims and potentials of the survey, I will now proceed to describe the survey and what it revealed.

Method

The Request

In the initial stage of the survey (June 1993) the following letter was send to 73 researchers:

XXX...

XXX...

Dear X

I am a graduate student at the University of Waikato working under the supervision of Prof. Mike C. Corballis at the University of Auckland, and would greatly appreciate your help.

A SURVEY OF ANIMAL FORESIGHT

In 1917 Koehler wrote that " `the time in which the chimpanzee lives' is limited in past and future" (Koehler, 1917/1927, p.272). Bischof (1985) claims that an animal's anticipatory behavior is always connected to the current drive (need). The ability to represent a future beyond the context of the current drive might be a crucial feature in the development of homo.

Following discussion with Richard Byrne, I decided to adopt Whiten and Byrne's (1988) research strategy of collecting unpublished (anecdotal and experimental) data from experts in order to explore the null-hypothesis: animals cannot anticipate (pre-present) future environment-need constellations independent of the context of the current drive (need).

Apparently, humans can extrapolate themselves into an imagined future and can anticipate what needs they will have. For example, even when we are not thirsty we can anticipate our future thirst and we can act a priori in order to secure the fulfilment of the future need by, for instance, carrying water when walking through waterless areas.

I would be very grateful if you could send me any observational (anecdotal) or experimental data that may indicate that any animal (please specify by giving binominal names) has been able to anticipate its own future needs in this way, or, if you do not have such data, a note stating this for each species you are studying. You may add "negative evidence", i.e. clear cases of animals not anticipating beyond their current drive although such anticipations would have been beneficial.

If you are conducting experimental research, it would be of specific interest to me to receive data about success or failure in attempts to let the animal perform tasks that require anticipations of future needs, or attempts to teach the animal concepts (e.g. symbols that refer to an extended future) which imply such knowledge.

Some "foresight" behavior, such as manufacture of sticks at one place for later use for termite fishing at another out of sight place (e.g. Goodall, 1986), does not constitute future-need anticipations as long as the preparatory behavior and the consummatory act are in the context of the current drive.

If you have any data which may refute the null-hypothesis please specify the following:

- how did you know that the animal has cognitively anticipated future needs?
- Is it possible, from your knowledge of the species, that reasons other than future pre-presentation could account for that behavior?
- Was the behavior that led to your inference observed more than once? If so, please give each record fully, or, if observed many times, please give a representative instance in detail and summarize the frequency and pattern.
- Do you have any evidence relevant to the ontogeny or phylogeny of that behavior?
- How long (approximately) had you been observing the behavior of these animals at the time of the instance(s)?
- Please give as many details as you can on experimental data.

Please note that:

If there are any constraints, such as copyright, on the use to which I may put the data, please tell me.

If you consider that your contribution includes any original ideas of your own, and you would like this to be acknowledged, please make this clear.

My intention is to complete a catalogue of records, and acknowledge their sources. However, if you do not wish your identity to be revealed in this way, please tell me.

All contributors will be acknowledged in any ensuing publication and I would be pleased to send a copy of the complete catalogue of records to anyone who requests it.

Please supply as much information and comment that you care to add!

With kind regards

Thomas Suddendorf

In a second attempt, three months later, I asked for more anecdotes via the e-mail news group Primate Talk. This second request was slightly altered in that I included de Waal's (1982) anecdote of the chimpanzee Franje (see above, p.49) in order to provided the researchers with a clearer idea of what kind of evidence would be relevant.

The Informants

In the initial study 73 researchers were personally contacted. Four categories of potential informants were targeted: Primatologists, the researchers who conducted projects attempting to teach `language' to great apes, comparative psychologists (ape-human) and researchers of non-primate species (dolphins & parrots).

57 primatologists were selected from the membership list of the International Primatological Society (kindly provided by Richard Byrne, April, 1993). The selection was guided by criteria such as experience in the field and expertise in cognitive and behavioural aspects, rather than physiology, distribution or conservation. These criteria were chosen in order to reach those experts most likely to be able to contribute relevant and reliable data. For each major taxa specialists were contacted.

Representatives of all seven major `ape-language projects' received the request letter. Furthermore, five well-known comparative psychologists specializing in ape's cognitive capacities and four researchers pioneering in the study of dolphin and parrot intelligence were personally contacted.

The second survey conducted via the Primate Talk network could potentially have reached up to 600 mainly American primatologists who subscribe to this newsgroup.

Results

The results are presented in the form of numbered records. A record comprises a particular contribution by one respondent.

Primatologists

Only three records derived from the second survey and these are incorporated in the presentation of the results of the primatologists who were personnally contacted. This presentation is structured according to taxa following the example of Byrne and Whiten (1990).

STREPSIRHINI

Lemur catta

1. Observer: A. Jolly

I don't actually think I could provide any [foresight anecdote] for lemurs.

HAPLORHINI

PLATYRRHINI [new world monkeys]

Callithrix argentata

2. Observer: H. Buchanan-Smith

No incident seen. [175 hours on three family groups in captivity]

Cebulla pygmaea

3. Observer: C.T. Snowdon

Pygmy marmosets and other species of marmosets have dental adaptations that allow them to excavate holes in the bark of trees to extract plant exudate. In the course of a four month field study in the Peruvian Amazon in 1978 I made extensive observations on a group of pygmy marmosets, and noted that they generally went to one of their sap trees soon after arising each morning. Their last actions at night before retiring to a sleeping site were to excavate at the tree. I have personally interpreted this as anticipatory behavior-- that is sap doesn't run out immediately, and holes have to be excavated in advance, so at least the digging of sap holes could be called anticipatory behavior. However, I have no data on whether digging holes was ever done without the animals at the same time feeding on holes that already contained sap. These are the smallest monkeys in the world (ca. 90-100 g) and they have a high metabolic rate requiring feeding immediately before sleeping each night and immediately upon arising. Thus I cannot argue that the hole digging was ever done when food motivation was not present or when feeding opportunities were not present. The closest I could come to having marmosets fit your definition was that toward the end of the study, they used the two sap sources less and less frequently and began digging holes in other nearby trees. The excavation of the first holes in a new tree is independent of food being present, but I'm not sure how I could ever argue that there was an absence of food motivation while the animals dug holes.

Saguinus labiatus

4. Observer: H. Buchanan-Smith

No incident seen. [500 hours on pairs and families in captivity]

Saguinus fuscicollis

5. Observer: H. Buchanan-Smith

Saguinus oedipus

6. Observer: H. Buchanan-Smith

No incident seen. [200 hours on family group in captivity]

CATARRHINI

Cercopithecoidea [old world monkeys]

Cercopithecus mitis

7. Observer: T.E. Rowell

I don't have any anecdotal evidence of "foresight", [and frankly I cannot imagine any anecdote which could possibly provide what you are looking for.]

Macaca fascicularis

8. Observer: M. Cords

No incident reported. Does caching behavior in rodents and birds count as potential evidence of foresight? (Although I suspect we agree that it need not indicate mental representation of the future.)

9. Observer: F. Burton

No incident reported. At best, the future exists as a goal currently held. Seen after the fact, it appears that a non-human primate has developed a complex strategy over time to effect purpose: there is no doubt that this is what actually occurs. Rather, the memories evoked by an immediate image prompt the animal to perform. Thus, in political machinations, the monkey acts today for an outcome or goal that is prospective; but the moment of its occurrence is always the present. (Burton, 1993, p.44)

Papio hamadryas

10. Observer: H. Kummer

No incident reported [Kummer forwarded the request to a colleague (Hemelrijke) who studies chimpanzees, because evidence concerning anticipatory behaviour is to be expected to come from apes (Hemelrijke).]

11. Observer: S. Zuckerman Negative evidence

F. Reynolds contributed the observation by S. Zuckerman (1932) of the introduction of an equal number of male and female baboons to Monkey Hill in London Zoo. In their natural habitat hamadryas live in harem groups with surplus males moving around separately and not part of the breeding group. Since the less dominant males could not get away in captive conditions, the story of Monkey Hill was total carnage as males competed to round up and hold onto as many females as possible, eventually destroying the colony completely. If the male baboons had been able to bring reason and foresight to their predicament, they could have shared out the females equally and amicably.

Hominoidea

Pongo pygmaeus

12. Observer: A. Russon

As far as I can see, they [orangutans] don't [think ahead] a whole lot. Of the incidents I can think of, forethought only shows at the level of a few minutes from now or so. [But then you know, if you don't really look it's amazing what you miss.]

Gorilla gorilla

13. Observer: A.H. Harcourt

Not aware of anything that you might want to term anticipation, [but then I'm not at all sure what would count as anticipation in your mind].

14. Observer: C.E.G. Tutin

We have been studying wild gorillas...at Lope in Gabon since 1984. It is strikingly clear that they monitor the `behavior' of trees in the same way that we do and have a perfect understanding of the link between flowers and fruit. For example, they so often arrive at a fig tree just as the fruit ripens and this is impressive as trees fruit asynchronously and at irregular intervals. It's very hard to prove all this but it's so clear when we spend time in the forest and try to guess where the apes will be by studying trees. It's painfully clear to us that the apes are a lot more skilled than we are! Lowland gorillas eat fruit of at least 120 species and there is great variability in fruiting patterns but information on tree phenology is gathered, stored and processed and they go unerringly to the right place at the right time- sometimes travelling several kilometres to isolated trees. May be this doesn't qualify as sceptics would argue that they wonder randomly driven by the current drive of hunger but there's food all over the place yet they go to their favourite food and must use foresight to work out the daily travel routes.

Pan troglodytes

15. Observer: R.W. Wrangham

I can think of no data from my observations of chimpanzees Pan troglodytes that falls into your category of foresight. [several thousands of hours at Gombe, Tansania and Kibale, Uganda]

16. Observer: C.K. Hemelrijk

I must admit that I do not remember such instances.

17. Observer: R.W. Byrne

Byrne and Byrne (1988) reported that a group of chimpanzees surrounded a cave in which a leopard and its infant had hid. The group made excited noises and one old male, after several unsuccessful attempts, lunged into the cave once more and emerged with a very small leopard cub in his hand (p.24). The chimpanzee group inspected, beat, bit and eventually killed the cub in a process that took some forty minutes. However, they did not eat it but groom the body. This behaviour makes sense if one considers that a potential future predator had been terminated. But did the chimpanzees have had this in mind when they began their extraordinary siege? Apart from this and perhaps the chimpanzee war anecdotes I cannot think of anything that may contradict the Bischof-Koehler hypothesis. Indeed, considering current knowledge, I believe the assumption is on firm ground. [verbal communication, April, 1993]

The `Ape-Language' Projects

Premack and Miles failed to respond, and the Gardners, Patterson and Savage-Rumbaugh excused themselves because of too heavy a workload. However, Savage-Rumbaugh pointed out that she has anecdotes regarding anticipation of and communication about future needs and kindly forwarded my request to her collaborator K. Brakke.

18. Observer: K. Brakke [project Austin, Kanzi, Panbanisha & Panzee ?]

We have raised the apes (to date three Pan pansicus and one Pan troglodytes) from infancy in an environment that closely resembles that of a human child..... we do not have a symbol that indicates future tense....Certainly, the language learning process itself appears to involve some anticipatory capacity. One of the functions of language is to provide a means of predicting (or negotiating) what is going to happen....the apes appear able to take in anticipatory information and act accordingly, even if what we end up doing is not what they "want" to do. In this sense, they seem able to "predict" things that don't arise from their current "drive". They also seem to be able to "put off" their drive if we tell them we will take care of it "later" -- they seem to have some sense of "later" versus "no" if we decide not to pursue their wishes at the moment.

19. Observer: K. Brakke [project Kanzi]

Kanzi of his own accord has started helping us clean out his enclosure in the evenings by pushing food scraps out of tight corners and into the drain canal. This expedites the cleaning process and lets us move on to the next step of the evening routine which may be distribution of blankets or bowls of crushed ice (a favorite evening treat). Kanzi is probably helping because he wants his ice or blankets, but he is clearly understanding that those events do not come about until cleaning is completed and is acting to facilitate something that is not directly related to his sleep or thirst "drive". Similarly, several of our apes will finish their computer tasks so that they can go play chase afterwards.

20. Observer: R. Fouts [project Tatu]

We have had only two examples of this [sense of time] and they were two years and nine months apart.... We make it a general rule here to celebrate all birthdays and holidays...We always get the [Christmas] tree and decorate it on the weekend following the Thursday of Thanksgiving....the Christmas tree is a favourite topic of conversation with the chimpanzees, and they refer to it with a sign combination they devised - CANDY TREE....On the Friday following Thanksgiving in 1989 it began to snow outside, and it was on this occasion that Tatu asked the following question:`CANDY TREE?' This impressed us a great deal because it could be interpreted that Tatu not only remembered the Christmas tree but also knew that this was the season for it, which is temporal perception. However, we were also aware that this was but a single observation of this type of behaviour, and it was not until August 1991 that we made a second observation of a similar instance of behaviour. As mentioned, we also celebrate all the birthdays each year. We have two birthdays right next to each other: Debbi Fouts' birthday is on the first of August and Dar's is on the second. This year we celebrated Debbi's birthday with treats and birthday songs as usual. Later that day, in the afternoon, Tatu asked `DAR ICE CREAM?' Ice cream is often part of the birthday celebrations, and it appears that Tatu may have been aware of what came after Debbi's birthday.
(Fouts & Fouts, 1993, p. 38)

21. Observer: R. Fouts [project Washoe] negative evidence

Arnold Chamove remembered that R. Fouts told him a few years ago that he tried to teach words referring to the future to Washoe. This was unsuccessful; Washoe did not seem to understand. To my request for verification of this report Roger Fouts wrote: In regard to Arnold's citation that we taught Washoe signs for the future are technically incorrect. What we did do was use signs indicating the future around her, none of which we have observed her to acquire. So we did not intentionally try to teach her any of these signs.

22. Observer: H. Terrace [project Nim Chimpsky]

I am unable to provide any positive incidences of animal foresight that show autonomy from a "current drive" or preparatory behavior for a consummatory act.

Comparative Psychologists

None of the five comparative experts replied to the request.

Researchers of Non-Primate Species

Dolphins

23. Observer: D.A. Helweg

I cannot think of any incident in which dolphins provide evidence for anticipations of future needs. The special conditions of marine observation make the investigation of such issues difficult. (verbal communication, July, 1993)

24. Observer: L.M. Herman

I am sorry, but I have no reprints relevant to your request.

Parrots

25. Observer: I.M. Pepperberg

I have read your letter concerning animal foresight and have passed it around my laboratory. The conclusion that my students and I have reached is that, given your criteria for foresight, no examples exist for animals and probably not even for young children.

These records are the result of all responses received until December the 10th 1993.

Discussion

None of the respondents pointed to an established piece of knowledge that clearly falsifies the Bischof-Koehler hypothesis. However, five respondents contributed observations of anticipatory behaviour that they deemed may be relevant. The ensuing six records are individually discussed in order of presentation. While anecdotes in principal may not falsify the hypothesis, they may shed light on the trustworthiness of the claim we call Bischof-Koehler hypothesis.

Snowdon provided the only potential evidence for new world monkeys (record 6). The sap extraction phenomenon is based on prior excavation of holes in the bark of trees. The initial digging of holes is an anticipatory behaviour because it becomes meaningful only in relation to future sap extraction. This does not require that the animal be aware about the meaning of the behaviour or that the animal have a mental picture of the future. Snowdon himself pointed out that this observation does not constitute evidence for future-need anticipation. Since the behaviour is shared among many individuals and the behaviour has an apparent (learning) history, explanations based on learned or inherent factors seem likely. On the other hand flexibility, generativity or transferability are not reported and there is consequently no support for an explanation based on mental time travel. This is not to say that we can exclude the possibility that the marmosets do indeed anticipate their future hunger, but because of plausible alternative explanations we cannot consider this observation as evidence against the Bischof-Koehler hypothesis.

While no potential evidence has been contributed for old world monkeys, five records pertain to the behaviour of apes. Tutin provided the only one for Gorillas (record 14). The phenomenon of gorillas appearing to arrive at trees that have ripe fruit seems to involve forethought and perhaps even future-need anticipation. Indeed, Tutin is convinced that gorillas can anticipate future needs. The existence of mental maps has been evidenced for chimpanzees (Boesch & Boesch, 1984) and may well exist in gorillas, too (see discussion above, p.52, 53). Tutin's claim that apes may have a temporal map in addition to a spatial one is, however, a suggestion that has not been evidenced but is based on the personal impression that the gorillas go unerringly to the right place at the right time.

But is this a planned behaviour or does it only appear that way in the eyes of the observer? Tutin informs us that lowland gorillas eat fruit of at least 120 species. The likelihood of encountering a favourite fruiting tree independent of where one chooses to travel might be higher than Tutin assumes. Tutin tries to dismiss this "sceptic's" interpretation by pointing out that there is food all over the place, yet the apes go to their favourite food. But how can we know this? We can only decide what their favourite fruit of the day is when we observe them eating it. I agree with Tutin that apes have more than plain hunger, they have appetite. They may prefer X over Y but after enough of X they may develop some desire for Y (cf. Premack's principal, Premack, 1959). So, if they have an appetite for bananas, say, they may go to places where there are banana trees (with the help of their spatial memory). If they see some other ripe fruit on the way, say a fruiting fig tree, they may or may not change their minds (depending on their need for nutrition and the evaluation of that food in comparison to other available food) and eat those. This may not involve any anticipation of future needs and may be partly the reason why the researchers often fail to predict the whereabouts of the gorillas by studying trees.

The interesting point of Tutin's contribution is not the claim about a planned daily travel route, but rather the possibility that the apes actually study trees to predict when the fruit will be eatable. If that is the case it may mean that they anticipate the future appetite for these fruits. Alternatively, however, just as it is probably the case in the acquisition of mental maps in rodents (see above, p.53), the information might be gathered and stored without the future need in mind. Nevertheless, it would certainly be valuable to study explicitly whether apes can form temporal maps, especially in relation to events that occur asynchronously and at irregular intervals, such as the ripening of fruit on a fig tree.

As yet, however, as Tutin admits, the potential alternative explanations do not allow this contribution to be considered as strong evidence against the Bischof-Koehler hypothesis. It is to be hoped, though, that this research programme will be picked up soon. Perhaps gorillas do intentionally study trees whose fruit they fancy. Indeed, it could be argued that in circumstances of food shortage such an ability would be favoured by natural selection. This might even be the selective pressure that supported the development of mental time travel in early hominids.

Byrne contributed an extraordinary observation of chimpanzees stealing a leopard cub from its mother and killing it (record 17). The question of whether or not the chimpanzees had in mind that they were terminating a future predator cannot be answered. It is difficult to think of alternative explanations for this remarkable behaviour. However, the chimpanzees themselves seem not to have been sure about what they were doing. Their behaviour was inconsistent and discrepant: the killing of the cub was a long process and not a determined action and the same animals who dropped the cub from trees investigated and groomed the body (an expression of affection). An explanation of this anecdote based on collective anticipation and reasoning is consistent with the observation, but requires a far more elaborate understanding of time then has previously been considered. Alternatively, the behaviour might have been driven by an unconscious motive, similar to de Waal's (1982, see above, p.52) explanation of Luid's strategic politics, or it may have had nothing to do with the future at all. Byrne himself favoured these alternative explanations and agreed that there is no convincing evidence for future-need anticipation in animals.

The last three records derived from chimpanzees involved in the `ape-language' projects. Brakke (record 18) points out that the acquisition of language inherently provides a means of predicting what is going to happen. The chimpanzees appear to understand a difference between the answers "later" and "no". This, however, can be readily explained in terms of operant conditioning: the stimulus "later" results in delayed reinforcement and the stimulus "no" is not followed by reinforcement. Such a discrimination problem should be expected to be solvable by chimpanzees and does not require the involvement of future-need anticipation. Indeed, it is debatable whether the ape's `language' performance itself is anything but problem solving (cf. debate in Griffin, 1981)

The second observation contributed by Brakke (record 19) also appears to be best explained in terms of learned behavioural contingencies. Kanzi helps to clean his enclosure to get the reward (crushed ice or blankets) more quickly. And the computer tasks are finished in order to receive the reward of free play. Although these behaviours can involve representations of the future, we do not have any information box.

If these records are the data Savage-Rumbaugh referred to as evidence for future-need anticipation, then she misunderstood the request. These records do not contradict the Bischof-Koehler hypothesis.

Fouts reports two instances (record 20) that may indicate a sense of time. The chimpanzee Tatu signed two `sentences' that seem to refer to an event that is about to happen (the following day). Although it is possible that these questions (CANDY TREE?; DAR ICE CREAM?) were asked by chance, it appears reasonable to assume that they do indeed refer to the future event. This is, however, a long way from arguing that this confirms a sense of time. A concept of abstract time and temporal associations (category 1 above) are quite different. Tatu might have learned the association between two events (Thanksgiving and Candy Tree; Debbi's celebration day and Dar's celebration day). This is an astonishing feat of learning, since the trials occur only at yearly intervals. Yet, the events are apparently very special and emotionally loaded, so that it is not so surprising that only a few trials over a long period (years) are sufficient to establish the association. It is a pity that Fouts could not report a subsequent conversation with Tatu which may have illuminated what exactly was on his mind when he was asking these questions.

While some very interesting anecdotes have been contributed, none resembles the kind of behaviour displayed by Franje (de Waal, 1982). The expected substantiation of de Waal's anecdotal evidence did not happen. Instead, two records (11 & 21) comprise `negative evidence'.

It is interesting to note that the `ape-language' projects have apparently not resulted in the apes acquiring words for the future (or future tense), although, at least in Fouts' laboratory (record 21), such signs are used by the researchers interacting with the apes. Such negative evidence may not be very definitive. Indeed, it does not have much epistemological value because we can only falsify but not verify the hypothesis. This pitfall becomes even clearer when we consider the other negative evidence contributed by Reynolds (record 11). She pointed to the observations of Zuckerman (1932). Reynolds remarks that reason and foresight could have prevented the disastrous self-destruction following the introduction of equal numbers of male and female baboons to Monkey Hill at London Zoo. Even so, it does not follow that the catastrophe evidences the absence of reason and foresight. We humans evidently have the ability to travel mentally in time and to reason along rational lines, yet we engage in wars and self-destructive activities that fly in the face of rational thought and foresight. In short, absence of evidence is not evidence for absence. Even thousands of records of negative evidence substantiating the hypothesis would be overturned with the acceptance of the validity of one positive record.

Nevertheless, it is relevant to consider the numerical distribution of the responses. It has to be conjectured, though, that many of the contacted researchers who are not aware of any positive evidence did not reply for that very reason.

In contrast to the 5 respondents whose contributions were discussed above, 15 respondents wrote to state that they are not aware of any evidence that may contradict the Bischof-Koehler hypothesis. The experts on lemurs, old world monkeys, dolphins and parrots22 all declared this. Apart from Snowdon's observation of marmosets (record 3, see discussion above) this is also true for new world monkeys. Thus, the most questionable issue remains the potential ability of apes. But even here, the four respondents who contributed observations are opposed by five researchers who state that in spite of their long experience in observing apes they are not aware of anything that could support the view that apes anticipate future states of drive or need. Contrary to Tutin's (and Savage-Rumbaugh's) statements, three respondents (Burton, Byrne & Pepperberg) clearly expressed their belief that the Bischof-Koehler hypothesis is consistent with current knowledge. Frances Burton, with her published statement: "At best, the future exists as a goal currently held" (1993, p.44; record 9) did in effect paraphrase the writings of Koehler (1917/1927), Bischof (1978, 1985) and Bischof-Koehler (1985).

Concluding Comments

Although the majority of respondents wrote to attest to absence of evidence, the survey does not (and cannot in principal) verify the Bischof-Koehler hypothesis. On the other hand, the few records potentially contradicting the hypothesis are not strong enough to falsify it. Suggestive anecdotes were not substantiated by further observations of similar behaviour (e.g. of the Franje type). While most of the contributed observations of anticipatory behaviour can easily be explained in other terms than future-need anticipation, some leave us puzzled (notably Byrne's record: 17). Tutin's account (record 14), it is to be hoped, will result in specific inquiries in the possibility of the existence of temporal maps in apes. In the absence of such research, the results of this preliminary survey substantiate the claim that the Bischof-Koehler hypothesis is consistent with current knowledge. The most important outcome of this project (the records as well as the discussions with experts) has been the reassurance that I, without personal experience in primatology, have not overlooked a realm that shows future-need anticipation in non-human primates. Indeed, until there is evidence to the contrary, parsimony demands that we accept the Bischof-Koehler hypothesis.

However, further research is necessary. In the light of limited numbers of responses, more records need to be compiled. In fact, the survey is continuing23. While this may result in a more comprehensive database on primate forethought, experimental research is also needed in order to attempt falsification of the hypothesis. In Appendix B I will outline an experimental paradigm that may provide proof for future-need anticipation.

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Those respondents requesting the resulting catalogue received a copy of this paper.

Appendix B

An experimental paradigm for the investigation of future-need anticipation

Introduction

In order to test the Bischof-Koehler hypothesis one has to provide the subjects with the opportunity to anticipate future states of drive or need. This requires not only that we set the stage for possible anticipation, but also that we arrange to observe this in a way that excludes alternative explanations. We need access to, or control over, mental states which are usually not directly observable or measurable, viz. forethought, drive/need and anticipated drive/need. The operationalization can be based on the following criteria.

Mental time travel can be dissociated from other reasons for anticipatory behaviour on the basis of specific characteristics (see Appendix A above). Learning explanations (category 1) can be excluded if the subjects are not given the opportunity to learn the anticipatory behaviour; that is, only success in the first trial of the experimental situation can be used to dismiss learning explanations. Instinctual explanations (category 2) can be dismissed if the subjects are confronted with a novel task that does not involve behaviour that is typical for the species. Anticipatory behaviour that is the product of sheer coincidence (category 4) can be excluded on statistical grounds; that is, many subjects may need to be tested or many alternative options need to be provided. Finally, variations of the original experiment may be able to show flexibility, generativity and transferability, which would substantiate a mental time travel explanation.

Homoeostatic needs (e.g. hunger, thirst) may be controllable through manipulation of the input factors. These needs can be assumed to be fulfilled in conditions where plenty of food and drink are available. Deprivation of essential factors brings the homoeostatic system out of balance and inevitably results in increasing need for this factor (e.g. liquid). The ethical problem and distress associated with deprivation might be reduced by short term deprivation with concurrent drive enhancers (e.g. salty food produces thirst more quickly).

Future needs can be created by controlling what is going to happen (e.g. salty food and drink deprivation). But it is necessary to provide the subject with means by which they can predict these need-evoking circumstances. Regular occurrence of the same procedure or distinct cues can provide the subjects with these means.

The following experimental paradigm is designed to fulfil all of the criteria outlined above.

Suggested Experiment

On a regular basis subjects are brought into room A for a certain amount of time until moved into room B. Both rooms are reserved for pretraining and experimental condition only. In the pretraining condition the subject in room A will have its needs taken care of (e.g. plenty of drinks). Before moving on to room B the subject is given the choice between several items (e.g. toys, but no drinks) of which it can take one into room B. In room B the subject is deprived from any liquid but given a salty treat (e.g. potato chips). Several measures may need to be taken in order to determine when a sufficient level of thirst is achieved. This procedure has to be repeated on a regular basis, and/or with distinct room cues (e.g. blue room A and green room B) for a certain period.

The experimental condition is the introduction of a familiar drink container among the items from which the subjects can choose in room A before going into room B. To avoid interference of a novelty factor resulting in the preference of the drink, all items in the experimental condition may be new. The question is whether the subjects tend to choose the drink item at more than a chance level. This can be shown by comparing the results with a control condition in which the drink is offered among other items, while the controls are not subject to drink deprivation in room B. If a significant number of, for example, chimpanzee subjects choose the drink item on the first trial of the experimental condition it is reasonable to argue that they anticipated the future thirst. Explanations in terms of learning, instinct and coincidence can be dismissed. And since in room A all needs are taken care of (e.g. plenty of drinks) the possibility of an already present drive can be rejected.

The test only has epistemological value if its outcome is positive. If the subjects fail to choose the drink item other explanations then absence of the capability to anticipate future needs are possible. A positive outcome, however, would falsify the Bischof-Koehler hypothesis because future-need anticipation would have been demonstrated.

The potential of this paradigm is not limited to testing this hypothesis. Besides using apes and monkeys as subjects, it would be interesting to test children. The question of when children become able to anticipate future needs could be addressed. This may become very important for future research because it could provide the empirical means of studying the development of humans' cognitive motive organizer (CMO, see above, p.56, 57; and Suddendorf, 1992). When do humans become able to decide about their current motivation, rather than being driven by whatever motive is present? When do we begin to travel mentally into the future and develop a `freedom of will' that enables us to suppress current drives and needs in favour of goals that lie in the remote future? Beginning with this proposed experimental design many critical questions raised in this paper could be addressed empirically.

Extrapolating from the current knowledge discussed above it has to be conjectured that apes, monkeys and children younger than three and a half years will fail to pass the test. But experiments are done to add facts, whether expected or not, to our theories.

Appendix C

Epilogue

I would like to add a few final words to this research. A problem many people have with biological or evolutionary accounts of human nature is the fact that evolutionary arguments have often been abused as a justification for the status quo (e.g. in the areas of sexism, racism and any kind of discrimination). Humans are, however, not merely governed by nature (e.g. drives) but can, through access to the fourth dimension, make decisions about the future based on moral and ethic considerations.

Examining the difference between humans and animals might be misunderstood as trying to justify human superiority. In fact, however, my intention is quite the opposite. Recent research strongly supports Darwin's idea of a continuity of mental experience (even though metamorphotic quantum leaps may create a different impression). The other great apes are most likely aware of the mental world (cf. Suddendorf, 1993). Genetic research suggests that we are more closely related to chimpanzees than chimpanzees are to gorillas (Gibbons, 1990). And even the social behaviour of apes appears to mirror human behaviour more closely than had been expected a few years ago. De Waal (1989), for example, noted that bonobos have a human-like sex life (face to face sexual intercourse, lesbian and gay interactions) and Goodall (e.g. 1986) was the first to report chimpanzee wars.

In the light of increasing evidence for animal intelligence and similarities between the other great apes and ourselves, it is the search for the small but significant changes that caused us to appear so different that fascinates me. Instead of attributing the difference between humans and animals to some divine origin, rational scientific approaches begin to unwrap the myths that distort our self-image. But science can hardly slip out of the dilemma of providing arguments for moral issues and of evaluating something as good or bad even if there is no scientific backup for this. In respect to evolution, Festinger (1983) pointed out, for example, that there is no useful English word to describe the sequence through the millennia without a connotation of better or worse. To a certain degree, evolution is like a Rorschach test, as Mike Corballis put it to me. The observer, just as much as the picture, determines what he or she sees. So I am perhaps overemphasizing the mental time travel aspect of human evolution. But for two reasons I feel quite happy about that. First, this aspect has been widely neglected and needs to be brought back into the discussion. Second, whether or not the discovery of the fourth dimension was a prime mover in human evolution, the time aspect of our thinking is certainly a crucial part of the way we are today.

So my interpretation is that, with awareness of time, humans are the only species that can change and destroy the Earth and the only species that can experience the moral responsibility to do something about it. I want to point out explicitly that these proposals are no justification for human's moral right to exploit animals or nature, but to the contrary, in my opinion, it gives us the moral responsibility to channel our impact in a way that protects the future of our planet and of all those creatures that do not even know what tomorrow is.

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Notes

1 Most of the animal research that is elaborated in this paper is focused on primates although the pioneering work of scholars like Herman on dolphins and Pepperberg on parrots may surprise the scientific community with evidence for novel intelligence in non-primate species. However, for a discussion of human evolution the study of our closest relatives appears to be primarily important.

2 However, since the production and use of early human stone tools (i.e. Oldowan tools) are within the competence of chimpanzees, even this latest definition of human's unique capacity to use tools can be disputed (e.g. Wynn & McGrew, 1989; see also Toth, Schick, Savage-Rumbaugh, Sevik & Rumbaugh, 1993, for the performances of a bonobo in recent investigations on semi-guided stone tool production).

3 The term rudimentary in evolutionary biology refers to features that were once fully developed but have since degenerated (e.g. human body hair can be viewed as a rudiment of fur). However, many scholars have used the term in the sense of `not fully developed' or `elementary' without implying that the feature was once fully developed. Although the term loses a major aspect of its specific meaning, I adopt the more general use of the term rudimentary without implying anything about the phylogeny of the feature.

4 The fact that as yet only one home-reared gorilla has proven to us the ability of self-recognition in a mirror, has provoked much speculation. Povinelli (1993) argued recently that gorillas might have lost the ability of self-recognition and that Patterson's gorilla (Koko) does perform well on the mirror task only because the experimenters' intervention (instruction in American Sign Language and other tutoring) resulted in the expression of an apparently lost ancestral psychological trait. This speculation rests on the assumption that since orangutans display self-recognition, the common ancestor of the great apes must have evolved the capacity for self-recognition (i.e. the feature is homologous in present day apes). An alternative explanation would be that this ability emerged independently (analogous through convergence) in orangutans and humans and chimpanzees, while not in gorillas. However, it may also be that all gorillas have the potential ability but our experimental techniques have as yet failed to show this in other individuals than Koko.

5 It has been argued that self-awareness may exist in different degrees in different animals (e.g. Cheney & Seyfarth, 1990). The fact that vervet monkeys, for example, recognize their own rank in social hierarchies or that baboons yawn less often when among conspecifics (but not when alone) if they have rotten teeth, may be interpreted as representing some form of self-awareness. However, the ability to recognize one's own visual image may be understood as representing a qualitatively different stage of self-awareness; a metamorphosis at one end of a continuum of degrees of self-awareness.

6 H.M. can recall some episodes from about 16 years before the operation which led to his amnesia. However, these stories are highly stereotyped. He is apparently unable to `update' these memories (Ogden & Corkin, 1991). He recalls them, like semantic knowledge, without any further reconstruction.

7 Such reconstructions may demand cognitive abilities that animals lack. Gardner (1975, cited in Marshall, 1982), for example, argued that only a language-possessing species has the semantic ability to structure event memories into a history. However, the tendency to view all higher abilities of the human mind as secondary properties or by-products of the evolution of language has been criticized (e.g. Premack, 1988).

Indeed, I will argue below that the ability to mentally travel in time might have been necessary for the evolution of language, although the question of which came first is a difficult one and may constitute a chicken-and-egg problem.

8 A similar finding has been reported for memory of dream events. Active reconstruction of the chronology of dream events results in an order that often differs from the sequence revealed through spontaneous report/retrieval (Foulkes & Schmidt, 1982).

9 Usher and Neisser (1993) reported recently that some important events of early life (hospitalization and birth of a sibling) are remembered by adult subjects even if they were only two years old at the time of the event. Loftus (1993), however, argues that this finding should not change our assumptions about the termination of childhood amnesia which generally begins between age three and four.

10 Other scholars advocate, however, that young children do hold an actual `theory' of mind. Gopnik (1993), for example, argues that children may have a `Gibsonian theory of mind': they hold the theory that the real thing in the world is directly transferred into the representation of it in the mind. Current data do not allow for a conclusive decision between `theory theories' and `simulation theories'.

11 Kinsbourne (1989) argued similarly that Korsakoff patients' amnesia may be the result of their difficulties in escaping from the influence of the present mental state and the state of the world. He showed that the amnesics are "tied to the episode that happens to be" (Kinsbourne, 1989, p.184). Recapturing previous experiences appears impossible if one cannot detach from the present one. The patients' inability to envisage a future is congruent with the explanation that escaping the control of the present state is impossible; this will be discussed in the next section.

12 This appears to be a general pattern of cognitive development. Studies on children's conversation with adults, for example, have shown that children's responses shift gradually from an anecdotal (episodic) to an abstract psychological level between

13 This would be consistent with Premack's (1988) rule of thumb that states that what three and a half year olds cannot do cannot be done by chimpanzees. Such an assumption does not imply that chimpanzees are developmentally arrested children (cf. Povinelli, 1993). Species-specific differences in mental capacities surely exist. A three and a half year old child will not, for example, outperform chimpanzees on mental map tasks. However, if we are to investigate whether chimpanzees have the human ability to mentally travel in time it is reasonable to ask whether chimpanzees master the steps that humans have to master in their process of acquiring that ability.

14 These mental processes can themselves be stored in memory, mainly as semantics or separate mental episodes, but sometimes as part of the event that has been reflected upon. Later reconstructions of that event may therefore be different (see reconstruction above) which can, for example, cause problems with the reliability of eye-witnesses in court. The fact that suggestive questions can have impact on memory reconstruction is well known (e.g. Loftus & Loftus, 1975).

15 Learned helplessness (Seligman, 1975) is a result of breaking this contingency.

16 The ease by which humans can create new motives and needs becomes most apparent in today's world of advertisement. Needs can be suggested. We can not only achieve a certain control over our own needs, but we can also attempt to control the needs of others.

17 Festinger (1983) argued that humans tried (and still try) to control just about everything. Only in retrospect may we distinguish between `natural' and `religious' technologies; for early humans they were probably the same: e.g. making fire and making rain.

18 The debate about how close humans and chimpanzees are genetically continues (Gibbons, 1990) and will not settle until mapping of both species' genetic code is completed.

19 Even if evidence for chimpanzee's mental time travel into remote futures were to accumulate, mental time travel might still have been a prime mover in human evolution that first emerged after the phylogenetic split from chimpanzees. Just as it is inappropriate to generalize directly from our knowledge of contemporary hunter-gatherers to the life of say Homo erectus, so it may be faulty to generalize from the cognitive abilities of contemporary chimpanzees to what distinguished early homo from its chimp relative. Indeed, present-day chimpanzees, like humans, have had about 5 to 8 million years of evolution since our common ancestors developed into distinct species. While chimpanzees in the Tai forest have developed a culture that uses stones as hammer and anvil, other chimpanzee groups have not and it would be inappropriate to assume that chimpanzees four million years ago did have such a stone tool culture. This could mean that some human-like characteristics (such as mental time travel) are present in rudimentary form in modern chimpanzees, but are relatively recent acquisitions that are analogous and not homologous to the human feature. Premack (1983) argued, for example, that the cognitive ability to use relational distinctions may only emerge in chimpanzees with language training and the intervention of the human species.

20 The oldest stone tools may also be attributed to a transitional form from australopithecus and homo because the dating of these tools seems to be earlier than that of Homo habilis.

21 Harcourt and Rowell, for example, stated that they could not imagine what kind of observation is relevant. This led to the inclusion of the Franje anecdote in the second request.

22 The focus of this study was on primates because of their relevance to theories of human evolution. The few researchers of non-primate species have been contacted mainly out of personal interest but also because Bischof (1985) and Bischof-Koehler (1985) did not restrict their hypothesis to primates. However, I have to admit that the title `a survey of non-human primate foresight' rather than animal foresight would have been more appropriate and was indeed adopted in the second survey conducted via Primate Talk.

23 The request is published in the January 1994 edition of the Laboratory Primate Newsletter and in an article submitted for pubication I ask readers to contribute more observations. Furthermore, I plan to attend at the XVth congress of the International Primatological Society in Bali August 1994 at which I intend to collect and discuss data directly with the primatologists.

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