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Cognitive Cladistics and the Relativity of Spatial Cognition

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Cognitive Cladistics and the Relativity of Spatial Cognition

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to my families

to Gary Allen

Dankwoord

I am sitting at my desk. The music is just not quite too loud to bear. Almost done. It was quite a ride this dissertation-thing. One day you can't get into acting school and ten years later you are writing the last few lines of a dissertation in Psychology. Or was it Psychology? Anyway, this is the opportunity to repay some of the hands who helped me walk, run and trip when I needed to.

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Leipzig, 14 November 2006

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Introduction

Cognitive psychology has been centrally concerned with the nature of human cognition and its ontogenetic development. It has largely treated this process as the emergence of a universal cognitive structure from innate sources. In this dissertation I try to give empirical access to these postulated inherited sources and assess their pliability in the face of the process of cognitive development and cross-cultural variation. The investigated cognitive domain is spatial cognition, which has been extensively studied in adults, infants and animals alike and therefore offers a solid platform for discussion. So the two central questions guiding this thesis are:

- 1. Are there inherited defaults for spatial cognition in humans?**
- 2. If so, are they affected by uniquely human capacities such as language?**

In **chapter 2**, using a basic spatial memory task, I first contrast the skills of all the extant great apes¹ including 1-year old human infants. Results show that all non-human great apes and 1-year old human infants exhibit a preference for place over feature strategies for spatial memory². I will argue that this suggests the common ancestor of all great apes had the same preference. Further tests revealed the reverse preference in 3-year old human children. Thus, the continuity between our species and the other great apes is masked during early human ontogeny. Increasing language proficiency and the accompanying rapid enculturation are discussed as possible explanations for the change in strategy-preference.

Language and culture facilitate flexible adaptations to varying ecologies, enabling humans to inhabit a vast repertoire of environments. So if language and culture vary across humans, and if language and culture can restructure our inherited predispositions in early development (chapter 2), mature cognition should also vary between cultural communities³. **Chapter 3** addresses

¹For more details on the tested non-human species, see Appendix 6.2.1

²For more details on the the terms and definitions of this thesis, see Appendix 6.1

³For more details on the the different tested cultural communities, see Appendix 6.2.2

the question if variability across languages might result in cognitive variability across their speakers. Dutch and Namibian elementary school children were compared using a spatial reconstruction task. The two cultures differ in the way they predominantly express spatial relations in language. Three experiments investigated cognitive strategy preferences across different levels of task-complexity and instruction. Data show a correlation between dominant linguistic spatial frames of reference and performance patterns in a non-linguistic spatial memory task. When instructed to use their respective non-habitual cognitive strategy, participants were not easily able to switch between strategies and their attempts to do so decreased their performance levels. The possibility that language might play a role in inducing stable preferences in cognitive strategy is discussed.

On the one hand, all humans inherit cognitive predispositions from an evolutionary ancestor (chapter 2). On the other hand, human cognition is variably adaptable to cultural circumstance (chapter 3). Although these two statements could be seen to contradict each other, I argue in **chapter 4** that they need not be. First, the same two cultural groups as in chapter 3 are compared on their cognition for spatial relations. As before the two cultural groups diverge, parallel to linguistic coding strategies. Furthermore, mature non-human great apes were tested with the very same spatial task to establish the inherited primate baseline. Results show that human culture can override even the basic cognitive preferences we inherited from our common ancestor with the other great apes. In conclusion I propose a model for human cognition that has a rich, inherited primate basis, which may be masked by language and culture, predicting differential human performance in the conditions where culture overrides an inherited default strategy.

We will only be in a position to appreciate the distinctive hallmarks of human cognition when we understand both the **continuities** and **discontinuities** within *Homo sapiens* and across all the extant members of our immediate phylogenetic family, the Hominidae.

1.1 Continuities

“Curiously enough, the only thing that went through the mind of the bowl of petunias as it fell was ‘Oh no, not again’. Many people have speculated that if we knew exactly why the bowl of petunias had thought that, we would know a lot more about the nature of the universe than we do now.”

(Douglas Adams, A hitchhikers guide to the galaxy)

Are there inherited cognitive defaults for spatial cognition in humans? How would we know? Different approaches have been taken to unearth inherited structures of human cognitive architecture. Here I will give abridged accounts of the two most prominent research strategies, mention some of their pitfalls and finally describe the methodology of this thesis.

1.1.1 The developmental approach:

How low can you go?

The *developmental approach* to the quest for the inherited mental defaults is in essence to test cognitive abilities early in infancy, before children have had a feasible chance to acquire them other than by genetic endowment. The study of human cognitive development has made immense methodological advances especially in the last 20 years. For example recent habituation paradigms allow testing below the threshold of early developmental studies based on object choice or qualitative observation. In these studies children are presented with a long series of stimuli, which share a particular dimension until the infant is ‘bored’. Then a new stimulus is presented which breaks the established dimensional match. Different measures such as gazing behaviour, sucking rate or brain potentials can be used to test the infants surprise, indicating they are sensitive to the tested dimension. As a result of this and other methodological advances, younger and younger infants have been attributed with more and more complex cognitive skills (Carey, 1985; Keil, 1989). Already right after birth infants recognize abstract drawings of human faces among other stimuli (M. Johnson & Morton, 1991), at 5 months they

understand simple addition and subtraction of hidden objects (Wynn, 1992) and by 6 months infants display a rudimentary sense of number (Xu & Spelke, 2000). These and many more similar findings fuelled the general suspicion in mainstream cognitive psychology that at least some basic cognitive functions are hardwired in humans from birth. The existence and nature of the innate endowment is still a major topic in the field (Carey & Spelke, 1996; Carey, 2004; Tooby & Cosmides, 1992; Cosmides & Tooby, 1994; Elman et al., 1996; Fodor, 1983; Karmiloff-Smith, 1992; Spelke & Newport, 1998; Tomasello, 2003).

The developmental approach in my view suffers at least two limitations: (1) Higher cognitive components develop in parallel with more fundamental functions such as sensory- and motor-abilities. And those in turn put restraints on psychological methodology. Preferential looking paradigms are of no use, if the infant has not mastered control of gazing behaviour. Every method will have its lower age-boundary, imposed by one or the other developmental constraint, which may be unrelated to the cognitive ability under investigation. What do we conclude about the time before we gained access to an infants mind? We simply cannot know if an infant did have a sense of number before 6 months of age until we test a 5 month old. This criticism is obvious and many researchers demonstrate awareness of the limitations it poses on their conclusions (Hood, Carey, & Prasada, 2000; S. P. Johnson, 2003). But there is a further constraint of the developmental approach which is slightly less obvious. (2) Many cognitive abilities develop relatively late. For example relational thought, including the ability to understand from a set of trials that defining object properties might not lie in the object itself, but in its relations to other objects. A simple relational rule might be that the correct choice is the object with the same size relationship to the other objects in a set as a previously observed choice (If I pick the largest, you should pick the largest). Children successfully infer such a rule from feedback and apply it successfully from roughly 4 years of age onwards (Rattermann & Gentner, 1998). At 4 years infants also walk,

talk and go to school (at least in some countries). They have had plenty of time to acquire relational thought by other means than inheritance. So for example, in chapter 4, where relational spatial concepts are at stake, it makes no sense to look at human infants. But do we have to conclude that there are no inherited preconditions for relational thought? Spatial relations between objects provide basic framing structures for the encoding of events (Burgess, 2002) and relational thought in general forms the basis for propositional structure, predication, understanding analogy and metaphor (Gentner, 2003; Tomasello, 2003). Relational learning is central to human cognition, so there is reason to suspect an inherited substrate. I want to argue that there is no a priori reason to exclude the possibility of inherited preconditions in late-blooming cognitive domains. But since they develop later in life, there is no infant data available to shed light on such inherited predispositions. The developmental approach is insufficient. Several researchers, some already in the early days of Psychology (Köhler, 1921), have come to the same conclusion and turned to a different source of information to complement the developmental approach: Non-human animals (Call, 2003; Hauser & Spelke, 2004; Langer, 2001; Tomasello, 2000).

1.1.2 The comparative approach: Reconstructing evolutionary history

For current purposes, inherited traits should be seen as part of the evolutionary endowment of the species. That endowment is either a unique adaptation which has occurred in human prehistory or it was passed on to us by an evolutionary ancestor. How far back in evolutionary time this endowment can be traced depends of course on the trait. The argument here concerns those cognitive traits which are not uniquely human, which comprise the majority of human basic cognitive abilities. So in this sense, inherited cognitive preconditions are passed on to us by an evolutionary ancestor. The problem with evolutionary ancestors as a source of information is that they are

all dead. To avoid this problem, psychologists have turned to the next best alternative: Extant phylogenetic relatives.

The *comparative approach* to the quest for the inherited human mental defaults is in essence to infer cognitive abilities in an evolutionary ancestor to *Homo sapiens*. Any cognitive ability, which is part of a shared repertoire between two related species, might be part of the evolutionary inheritance ever since their last common ancestor. This argument was accessibly outlined by Richard Byrne (1995). In his formulation he made clear the limits and restrictions to this approach, part of which I will build on in further arguments below. Following the comparative approach, humans have been compared to capuchin monkeys (Brosnan & Waal, 2003), tamarins (Miller, Dibble, & Hauser, 2001), and chimpanzees (Povinelli, Boysen, & Nelson, 1990; Warneken & Tomasello, 2006) to name but a few. And indeed continuities between humans and our phylogenetic cousins are striking. Not only do other primates display understanding of faces (Tomonaga et al., 2004), distinctiveness of hidden objects (Hauser, MacNeilage, & Ware, 1996) and number (Hauser & Carey, 2003), they also display ‘human-like’ abilities in more complex cognitive tasks such as perspective taking (Hare, Call, & Tomasello, 2001; Liebal, Pika, Call, & Tomasello, 2004) and cooperation (Melis, Hare, & Tomasello, 2006). Without questioning the great progress the inclusion of primate data has brought towards the quest for the inherited defaults of human cognition, I would like to raise some concerns which lead me to the more systematic approach adapted in this thesis. I will argue that comparing new world monkeys to humans provides little evidence about the mental properties of their common ancestor. I will also argue that comparing chimpanzees to humans is generally more dependable when making a statement about human ancestors, but that other, ideally larger combinations of species might be even more powerful. To make the argument accessible we have to take a short detour into the evolutionary history of *Homo sapiens* and our taxonomic relationships to other primates.

1.1.3 Cognitive cladistics:

Reading the mind of the common ancestor

Taxonomy is a nested classification of groups or ‘taxa’ (Greek, singular: taxon) based on some form of similarity. The only way in which an animal could be a member of two groups is if one included the other. For example, humans are primates and primates are animals. So it would be correct to say humans are primates and animals. The smallest taxon is usually the *species* (a group of potentially interbreeding individuals). Species are grouped into *genera* (Greek, singular: genus). Genera are then grouped into *families*, families into *orders*, orders into *classes*, classes into *phyla* (Greek, singular: Phylum) and finally phyla into *kingdoms*. Evolutionary taxonomy, or cladistics, is the classification of species in such a way that it correctly reflects evolutionary history. A valid grouping or ‘*clade*’ within evolutionary taxonomy is a group of species with a common ancestor that is not ancestral to any other species (*monophyletic* group). The currently most common, but by far not the only measure of similarity in cladistics is molecular structure and function (Enard & Pääbo, 2004). Figure 1.1 presents a tentative evolutionary taxonomy of our own order: The primates. While classic cladistics usually analyzes similarity of traits across species to infer their relationship-status, one can also invert the argument. Based on any reliable set of taxonomic relations of living species we can reconstruct states of the common ancestor. The argument goes as follows: If a certain trait exists in all taxa of a clade, the trait must have been present in their common ancestor. This logic would only fail us if the same trait had evolved independently several times within the same clade. This phenomenon is called convergent evolution or *homoplasy*. The chance that homoplasy accounts for a shared trait within a clade can be decreased following a simple rule: Compare as many species with common inheritance as possible. Every added related species displaying the same trait decreases the likelihood of an independent evolution of the same trait in all of them. So in essence we can follow two maxims: *Com-*

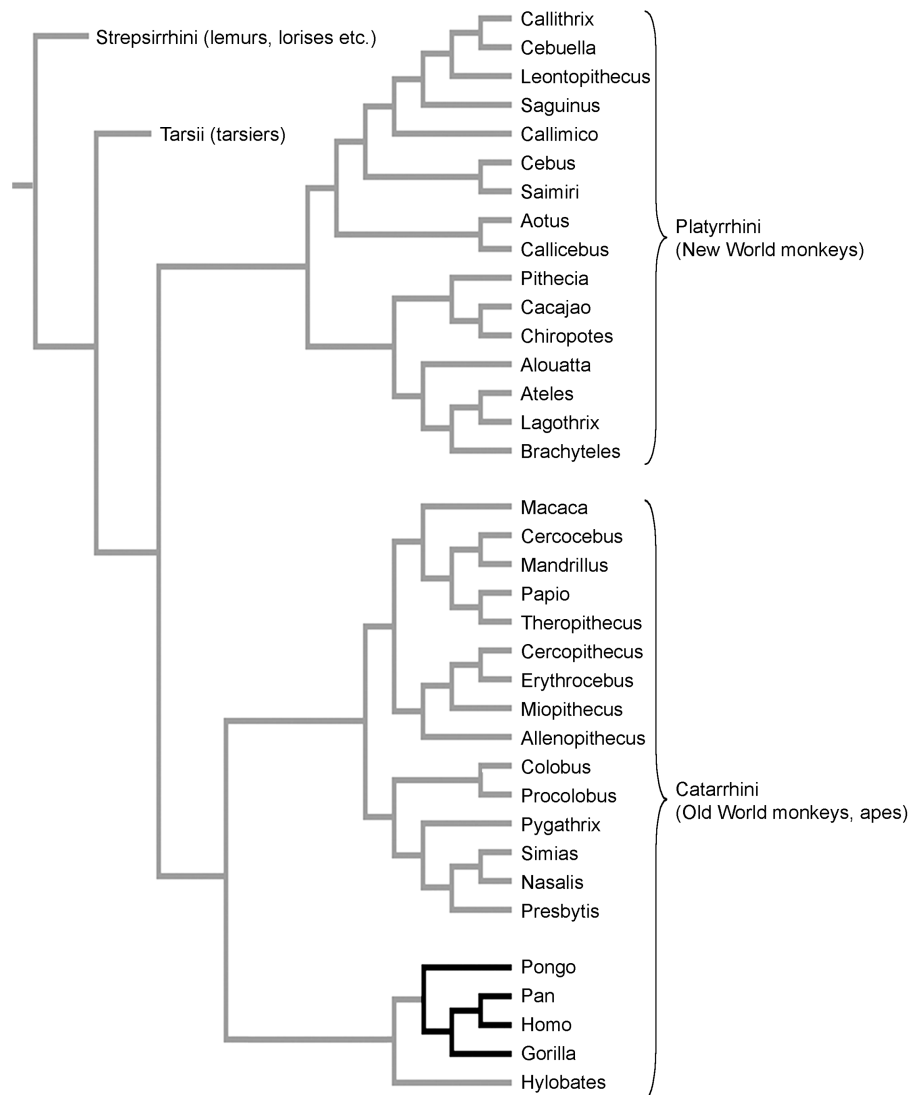


Figure 1.1: Taxonomic tree of the order *primates* (based on the ‘Tree of Life’ project: <http://tolweb.org/tree>)

pleteness and *extensiveness*. Ideally one would compare all extant species (completeness) of a maximally large taxonomic group (extensiveness) with a single common ancestor. From this general rule we can create a scale on which we can compare studies on the power with which they allow inferences concerning the common ancestor of the tested species based on the taxonomic relationships of those species. The division of animals into species is constantly debated and always changing. Therefore I will use genera instead of species for this scale, as they are less controversial (Figure 1.1). So let n be the number of tested genera and N be the total number of extant genera sharing the same common ancestor as all members of n . If we now put them in a very simple relationship and give it a name (inferential power index = *IPI*) it might help us to design a maximally powerful study for our purposes.

$$IPI = \frac{n^2}{N} \quad (1.1)$$

IPI varies from 0 to n , where increasing numbers would indicate a higher inferential power. This measure can be nothing but a rule of thumb to support the argument on which I rest this thesis. If it was to serve a more general purpose it should also include the average number of individuals tested for each genus and a measure for the variability of the tested trait within the genera.⁴ However, for now it will suffice.

Let us turn back to the comparative approach and make clear the unsystematic way in which it is practiced for the purposes of cognitive psychology. Table 1.1 lists some recent studies making inferences about the common ancestor of different samples of primate species. I argued before that by comparing humans to for example tamarins, little to no knowledge can be gained about the last common ancestor of the two. Thirty-four other genera share the same common ancestor as humans and tamarins (see Figure 1.1). According to the two maxims above, Miller et al. (2001) (see Table 1.1) can

⁴These kinds of measures exist (Ronquist, 2004), but are too complex and detailed for the current purpose.

Table 1.1: Prominent recent studies making inferences about the common ancestor of different samples of primate species. The *IPi* (inferential power index) represents the relative power of the inference.

Reference	Tested genera	Conclusion	<i>IPi</i>
Brosnan et al. (2003) <i>Nature</i>	<i>Cebus</i> (capuchin)	“Monkeys refused to participate if they witnessed a conspecific obtain a more attractive reward for equal effort. . . These reactions support an early evolutionary origin of inequity aversion.” (p. 297)	0.03
Miller et al. (2001) <i>Nature Neuroscience</i>	<i>Saguinus</i> (tamarin) <i>Homo</i> (human)	“Given the phylogenetic relatedness of humans and cotton-top tamarins, these results suggest that the neural mechanisms mediating auditory continuity may have evolved in a common ancestor at least 40 million years ago. . . and possibly earlier.” (p.784)	0.11
Whiten et al. (2005) <i>Nature</i>	<i>Pan</i> (chimpanzee)	“Our data. . . demonstrate a clear capacity for the cultural transmission of alternative technologies among apes. These results suggest an ancient origin for the conformist cultural propensities so evident in humans.” (p. 739)	0.5
Warneken et al. (2006) <i>Science</i>	<i>Pan</i> (chimpanzee) <i>Homo</i> (human)	“However, our nearest primate relatives show some skills and motivations in this direction as well, and this suggests that the common ancestor to chimpanzees and humans already possessed some tendency to help. . . .” (p.1301)	2.0
Bräuer et al. (2005) <i>Journal of Comparative Psychology</i>	<i>Pongo</i> (orangutan) <i>Gorilla</i> (gorilla) <i>Pan</i> (chimpanzee)	“These results. . . suggest that apes have an appreciation of what others can and cannot see. Since all great apes display those skills it is conceivable that they were also present in their common ancestor.” (p.153)	2.25

claim neither completeness, nor extensiveness. To make a believable argument about the existence of a trait in the common ancestor between humans and tamarins, we would need to consider at least 10 ($IPI = 2.9$) other genera with the same ancestor. I also argued before that comparing chimpanzees and humans (e.g., Warneken & Tomasello, 2006) is a more informative approach, but can still be improved. This approach is more informative because *Homo* (represented by humans) and *Pan* (represented by chimpanzees) are the only two extant genera descending from a single common ancestor who lived roughly 5-6 million years ago. Therefore these studies can claim completeness but nevertheless only present a small sample-size of tested genera. The likelihood that the trait in question independently evolved since the last common ancestor in just two species is obviously higher than the same trait coinciding in let's say a complete clade including ten genera.

There is one final concern I would like to raise considering the standard comparative approach. All of the studies mentioned above, and to my knowledge all comparative studies on evolution of the human mind have compared abilities across species. These results are always subject to a trivial counter-argument: All tests are devised by humans. For that simple reason, tasks are most likely posed in ways that are intuitive to humans but not necessarily to other species. Even if we managed to create a test, which is intuitive to chimpanzees, it might for the same reason not be intuitive to gorillas or tamarins. Therefore all differences in ability can be dismissed by claiming that experiments are just not well enough adapted to suit all tested species. Of course this problem increases with the number of tested species (n).

Instead of attempting to solve the problem as others have (Povinelli, Bering, & Giambrone, 2000; Hare & Tomasello, 2004), it can be circumvented by testing preferences instead of abilities. The tasks presented in chapters 2 and 4 of this thesis can easily be solved by all tested genera, but allow for different alternative interpretations and therefore different strategies that can be adopted to solve them. If the tested genera now differ in their preferred choice of strategy, differences cannot be due to lack of ability. If the genera

share a preference for one particular strategy over another (hence are quicker to learn it and/or better at applying it in comparison to another), we are able to make a very strong argument for the existence of that preference in the shared common ancestor, avoiding discussion about fair tests of ability.

In summary, any study comparing cognitive preferences between all extant genera of great apes (*Pongo*, *Gorilla*, *Pan* and *Homo*) would score an *IPI* of 4 and be a powerful approach to the quest for the inherited cognitive defaults in humans. Chapters 2 and 4 of this thesis will be based on this combination of data.

1.2 Discontinuities

“It is of course perfectly natural to assume that everyone else is having a far better time than you. Human beings have a phrase ‘The other man’s grass is always greener’, which describes this phenomenon. The Sheltenack race had a similar phrase, but since their planet is somewhat eccentric botanically speaking, the best they could manage was ‘The other Sheltenack’s jupleberry shrub is always a more mauvey shade of pinky russet’ and so the expression soon fell into disuse ... and the Sheltenacks had little option but to become terribly happy and contented with their lot - much to the surprise of everyone in the galaxy, who had not realized that the best way not to be unhappy was not to have a word for it.”

(Douglas Adams, A hitchhikers guide to the galaxy)

Do inherited cognitive defaults vary across ontogeny? Do they vary across cultures? Some cognitive defaults are common amongst the great apes ever since their last common ancestor. However, they might still be affected by cognitive or other factors that are unique to the human species. For example language has been argued to be a driving force of cognitive change and cultural adaptation in humans (Dennet, 1991; Levinson, 2003a; Lucy, 1992; Vygotsky, 1962). The present thesis investigates the possibility that even inherited cognitive predisposition might be affected by human language.

There is a long standing debate in the cognitive sciences wether language can affect other cognitive functions. Put provocatively, the question is whether language changes the way we think. The question is not if language can transmit information, which in turn might change the way we think about things. Language can inform or misinform, encourage or dishearten. As Bloom and Keil put it: “This is what language is *for*.” (2001, p.354; emphasis original). The more interesting question is if language shapes thought in any way other than by means of the information it conveys. Does the structure of language - be it syntactic, morphological, semantic or otherwise - influence the structure of other cognitive processes such as for example representing, categorizing, remembering and reasoning (Bloom & Keil, 2001; Papafragou, Massey, & Gleitman, 2002)?

Many interesting commonsense questions arise from entertaining the idea that language might shape thought: Imagine having been raised without a

language, as a wild-child. Would your thoughts be very different from your thoughts now? Do animals think in other ways than we do? Do speakers of different languages think differently? There is a simple answer to these questions, which represents the mainstream in most cognitive sciences: “In our view the answer to these questions tends to be no.” (Papafragou et al., 2002, p.54). “Does language have a dramatic influence on thought in some other way than through communication? Probably not.” (Bloom & Keil, 2001, p.364). One simply cannot say what one cannot already think. Language codes pre-existing cognitive concepts and therefore cognition takes the lead in human development (Langer, 2001; Gleitman & Papafragou, 2005; Fodor, 1985). Learning a first language then means to learn how to translate the universal language of thought into a form that can be communicated to others (Pinker, 1994; Fodor, 1975). Hence all humans think alike, irrespective of the language they speak (Fodor, 1985; Papafragou et al., 2002). In short, the widespread position in cognitive science is that (1) human conceptual structure is relatively constant across cultures, (2) conceptual structure and semantic structure are tightly coupled, and (3) therefore neither cognition nor semantics vary substantially across humans. Following this line of reasoning, inherited cognitive defaults could not be changed through language.

The alternative position, namely that language might impact other cognitive functions, is held in different flavours and intensities. Some argue for a general effect of language, which results in cognitive differences between speakers of any language and other animals without a comparable semi-otic system (Vygotsky, 1962; Carruthers, 2002; Deacon, 1997; Dennet, 1991; Spelke, 2003). The second account argues for a specific effect of languages, which results in cognitive differences between speakers of different languages (Whorf, 1956; Gumperz & Levinson, 1996; Gentner, 2003; Levinson, 2003a; Lucy, 1992).

1.2.1 General effects of language

“Perhaps the kind of mind you get when you add language to it is so different from the kind of mind you can have without language that calling them both minds is a mistake.”

(Dennet, 1996, p.17)

The world presents itself quite differently to various species by virtue of their varying sensory capacities including neural functions for organizing, storing and manipulating incoming information. The question here is if, in similar ways, the availability and use of language might fundamentally alter the vision humans hold of their world relative to other species. The acquisition of language is one of the major events in early human development. Coeval with different levels of language mastery are substantial changes in other cognitive domains. The tightly interweaved developmental trajectory of linguistic concepts and non-linguistic cognitive abilities has led many researchers to believe the two to be correlated and most likely even causally related. However there is a sharp divide amongst scientists as to which of the two human capacities, language or cognition, might take the lead. Early on, Vygotsky, Bruner and others argued that language allows for the translation of experience into a more symbolic form, enabling cognitive processing of remotely or arbitrarily related experiences even in their complete absence (Bruner, 1964; Vygotsky, 1962), creating intellectual possibilities that are orders of magnitude beyond any non-symbolic cognitive system. They showed for example that symbolic and relational rules are more easily learned by children with internalized speech than by younger children without internal language (Bruner, 1964) or non-human primates (Kendler & Kendler, 1962). Versions of this original view are still held in the current literature, although in different varieties: Some believe that language is an integral part of concept formation (Gentner, 2003; Xu, 2002) and that this formation happens stepwise as specific linguistic concepts aid acquisition of their cognitive counterparts at different points during child development. For example, language facilitates object individuation through naming already at around 1 year of age (Xu, 2002; Xu,

Cote, & Baker, 2005), while some parts of relational language are only proficiently used and aid relational thought around 4 years of age (Rattermann & Gentner, 1998; Gentner, 2003; Loewenstein & Gentner, 2005). Others believe that cognitive concepts are innately pre-defined in children, but that the combinatorial structure of natural language allows for new combinations between these pre-existing concepts (Spelke, 2003; Carruthers, 2002). This combination of existing sources of information gives access to new sets of information beyond the abilities of non-linguistic animals. The resulting functional architecture, emerging under the impact of natural language, is more than the sum of its parts.

So if cognition is dramatically restructured after the first year of life, be it through concept formation or conceptual recombination, what happens to the inherited cognitive defaults we might identify using the cognitive cladistics approach? Are these phylogenetic endowments essential to our species and therefore rigid and conservative? Or alternatively, are even these inherited cognitive structures subject to uniquely human processes in ontogeny? This question is approached experimentally in chapter 2 by testing all extant non-human great ape species and human infants before (1-year old) and after (3-years old) this proposed major period of cognitive change.

1.2.2 Specific effects of languages

"The thing is: I *hate* relativism. I hate relativism more than I hate anything else, excepting, maybe, fibreglass powerboats. "

(Fodor, 1985, p.5, emphasis original)

At this point it is important to consider that language in fact varies. Syntax as well as semantics differ greatly between human communities. Spoken languages may have anywhere between 11 and 141 distinct phonemes (Maddieson, 1984). Languages may or may not use constituent structure to encode grammatical relations (Austin & Bresnan, 1996; Levinson, 1987), so they might or might not have syntactic constraints on word order. Languages may

or may not make use of basic word class distinctions, such as adjective or adverb. Some languages express aspect, some don't; some have seven tenses, others have none; some force marking of honorability for each noun-phrase, some do not and so on and so forth (Levinson, 2003a). But languages don't only vary in their syntactic structure. They also have been documented to vary in basic semantic domains such as colour (Brown & Lenneberg, 1954), landscape (Burenhult, in preparation), the body (Majid, Enfield, & Staden, 2006), motion (Talmy, 1975) and space (Levinson & Wilkins, 2006). The combination of these facts with a (post-)Vygotskian approach leads to the following consideration: If language-structure impacts cognition during human development and if additionally language-structure varies across cultural communities, mature cognition should also vary between cultures. The proposal that variability across languages might result in cognitive variability across their speakers was most prominently articulated by Whorf (1956) and is therefore often referred to as the 'Whorf-' or 'Sapir-Whorf-hypothesis'. The central argument starts with the fact that each language has only a finite number of devices at its disposal to refer to an infinite variety of experience. Thus, languages, for the purpose of speech, somehow need to condense and chunk experience by classifying things as 'the same' which are in many ways quite different. These classifications are not arbitrary, but are based on meaningful criteria, which might in turn vary across languages. Any language then provides its speakers with ready-made structures of experience, which serve as grooves to guide thought (Lucy & Wertsch, 1987). Given the cross-linguistic variations in conceptual domains mentioned above, the system of categories each language provides is not a common, universally shared system, but one peculiar to the individual language. In short, Whorf (1956) argued that (1) languages vary in their semantic partitioning of experience, (2) linguistic categories are used as guides for habitual thought, and (3) therefore speakers of different languages will categorize their world differently. Attempting to interpret experience, speakers will intuitively use the categories provided by their language, without usually being aware of it.

This does not mean that language categories, in Whorf's view, blind speakers to an obvious reality, but that they suggest associations, which might not necessarily be entailed by objective experience.

In the last few years, linguistic relativity has had something of a renaissance (Bowerman & Levinson, 2001; Hunt & Agnoli, 1991; Gumperz & Levinson, 1996; Gentner & Goldin-Meadow, 2003). To date, cross-cultural effects that can be predicted by language differences have been found for example in the cognitive processing of colour (Roberson, Davies, & Davidoff, 2000), number (Gordon, 2004; Pica, Lemer, Izard, & Dehaene, 2004), time (Boroditsky, 2001) and space (Levinson & Brown, 1994; Mishra & Dasen, 2005; Neumann & Widlok, 1996; Pederson et al., 1998; Wassmann & Dasen, 1998). However, none of these claims are uncontroversial and opposition is broad and outspoken (Fodor, 1985; Bloom & Keil, 2001; Li & Gleitman, 2002; Gleitman & Papafragou, 2005). The Whorfian hypothesis is still perceived by many as a nuisance, relentlessly entertained by stubborn rebels for a hopeless cause (Fodor, 1985).

There might be several reasons for the strong reluctance shown towards linguistic relativity within cognitive psychology. Firstly, linguistic relativity is often falsely equated with 'linguistic determinism', which states that some languages absolutely close off their speakers from parts of perceptual experience. These claims did not stand up to experimental investigation (Heider, 1972), resulting in extreme scepticism about the possibility of any influence of language on thought (Clark & Clark, 1977; Devitt & Sterelny, 1987; Pinker, 1994), and still serve as a straw-man for opponents of milder forms of linguistic relativity (Li, Abarbanell, & Papafragou, 2005). Secondly, some argue that linguistic relativity opens the door to ethnical relativism and racist arguments. Finally, cognitive psychologists might fear that accepting linguistic relativity will effectively undermine their scientific conduct. In the field of cognitive psychology, it is standard procedure to recruit students from psychology undergraduate classes and, based on their performance, make inferences about the human mind, relying on the assumption that people are

people (Gergen, 1973; Sears, 1986; Medin & Atran, 2004; Norenzayan & Heine, 2005). The idea that speakers of different languages might vary in their proficiency to discriminate green and blue, 7 and 8, or right and left puts strains on the generalizability of experimental results using very restricted populations.

The currently most successful research strategy used to test the linguistic relativity is a hybrid of linguistic typology and cognitive psychology. First, different languages are compared on their syntactic or semantic features using elicitation tasks. If there is variability between languages in a particular domain, non-linguistic cognitive tasks are designed which tap into this domain. Differences between communities on the cognitive task, which parallel the linguistic differences, would indicate a correlation between language and thought. To show that language is the causal factor driving this relationship, many linguistic communities need to be compared to see if language is the most reliable predictor among other alternatives such as ecology, subsistence or industrialization. By now more than 20 cultures have been compared on their habitual linguistic constructions to describe spatial relations and their habitual cognitive strategies (Levinson, 2003b; Majid, Bowerman, Kita, Haun, & Levinson, 2004). The comparison revealed that none of the alternative factors determine usage patterns in spatial descriptions across languages (Majid et al., 2004). Since none of the alternative factors by themselves seem to determine linguistic preferences, they are unlikely candidates for intervening variables affecting both language and cognition. However, the controversy is far from resolved (Li et al., 2005). Chapter 3 compares two cultures which differ in the way they predominantly express spatial relations in language and investigate the stability of differences in habitual spatial cognition between the two cultural communities. Chapter 4 combines the approaches of chapter 2 and 3 and uses cognitive cladistics to reveal inherited predispositions in human spatial relational cognition and, at the same time tests whether behaviour in the very same paradigm used for non-human great apes will vary across cultures. With the present findings, based on phylogenetic,

ontogenetic and cross-cultural contrasts, I hope to open up the prospects of a systematic evolutionary psychology based on the cladistics of cognitive preferences and abilities and their comparison across human cultures.

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Evolutionary psychology of spatial representations

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2.1 Abstract

Comparatively little is known about the inherited primate background underlying human cognition, the human cognitive wild type. Yet it is possible to trace the evolution of human cognitive abilities and tendencies by contrasting the skills of our nearest cousins, not just chimpanzees, but all the extant great apes, thus showing what we are likely to have inherited from the common ancestor (Byrne, 1995). By looking at human infants early in cognitive development, we can also obtain insights into native cognitive biases in our species (Hespos & Spelke, 2004). Here we focus on spatial memory, a central cognitive domain. We show, first, that all non-human great apes and 1-year old human infants exhibit a preference for place over feature strategies for spatial memory. This suggests the common ancestor of all great apes had the same preference. We then examine 3-year old human children, and find that this preference reverses. Thus, the continuity between our species and the other great apes is masked early in human ontogeny. These findings, based on both phylogenetic and ontogenetic contrasts, open up the prospect of a systematic evolutionary psychology based on the cladistics of cognitive preferences.

2.2 Introduction

All species feeding upon dispersed resources in space and time need to remember locations and know how to find them. There are two main strategies for remembering object-location: Using object-features vs. place as defined by a spatial frame of reference. Earlier studies have examined the use of place and feature cues in a range of species from goldfish to pigeons, humans to rats. In tasks which allow the subject species to freely combine both kinds of cues, all tested species seem able to use both kinds according to circumstance, although some seem able to combine both more readily than others. However, in tasks which oppose the two kinds of cues, some species prefer place- [e.g., fish (Vargas & Lopez, 2005; Bitterman, 1965), lizards (Day, Ismail, & Wilczynski, 2003), rats (Cheng, 1986; Morris, Hagan, & Rawlins,

1986)) while others predominantly use feature-based strategies (e.g. toads (Williams, 1967), chicks (Vallortigara, Zanforlin, & Pasti, 1990), human children (Allen, 1999)]. No studies however have systematically tracked these preferences across the phylogenetic tree. Here we investigated a complete family, systematically examining this particular cognitive preference across all the extant genera in the Hominidae (see Figure A.1), including humans at two different ontogenetic phases.

2.3 Experiment

To examine spatial memory strategy across the Hominidae, we compared the performance of all four non-human great apes (apes henceforth), pre-linguistic human infants (1-year olds) and human children (3-year olds). We used a simple object search task in which subjects had to choose between using a place- or feature-based strategy.

Methods

Participants Twenty-five apes of four different species belonging to all three non-human great ape genera Pongo: 5 orangutans (*Pongo pygmaeus*), Gorilla: 4 Gorillas (*Gorilla gorilla*) and Pan: 5 Bonobos (*Pan paniscus*) and 11 chimpanzees (*Pan troglodytes*) - were tested with this apparatus. There were 9 males and 16 females ranging from 5 to 32 years of age. All apes were housed at the Wolfgang Köhler Primate Research Center at Leipzig Zoo (Germany). They were living in social groups with conspecifics and had access to indoor and outdoor areas. During testing, the apes were fed according to their daily routine four times a day on a diet of fruit, vegetables and monkey chow; water was at their disposal at all times.

In addition, we tested twenty-six 3-year olds with a mean age of 42 months (*range*: 38-46 months, $M = 42.3$; $SD = 1.9$) in local kindergartens. Twenty-six human infants approximately 1 year old with a mean age of 54 weeks (*range*: 52-56 weeks; $M = 54.3$; $SD = 1.3$) were recruited from the local

community. In the two groups there were 12 girls and 14 boys each. All children were native German speakers of normal ability range and came from mixed socio-economic backgrounds.

Setup An imitation hollow stone, an imitation birds nest and a hollow piece of wood were used as containers. All were approximately 15 cm wide and placed on a plastic plank (70 x 40 cm) separated by 20 cm centre to centre. An opaque plastic screen (70 x 40 cm) or a dark curtain was used as an occluder. Apes received grapes or slices of banana as rewards whereas children received small toy animals that they collected in a bag and returned at the end of the session. The toys used as rewards with 1-year olds were slightly bigger than those for older children to avoid risk of swallowing.

Procedure An experimenter (E) distributed three containers open side up on a table. All three containers had distinct rich featural attributes. Subjects observed while E produced the reward and inverted all the containers, so that one of the containers hid the reward. The apparatus was then occluded, and two of the containers were switched out of sight of the participant. In the FEATURE condition the reward moved with the distinctive container, in the PLACE condition the reward remained in its original place, now under a different container. The place and feature conditions were administered in two consecutive blocks for each individual, counterbalanced for order across subjects. The transition between the two blocks was unmarked that is, the strategy that had yielded rewards in the prior block suddenly no longer did, while the alternative strategy was now the winning one. Randomly interleaved within both blocks were control-trials in which all containers stayed in their original location (the NO SWITCH condition). After these manipulations (appr. 7 sec after presentation), the occluder was raised, and the subject chose one of the three containers (no correction allowed), and got the reward, if any, under it (Figure 2.1). All subjects were verbally encouraged for a correct choice and children that did not immediately produce a response were prompted with the words: "Can you find it? Show me!". There were no other verbal instructions.

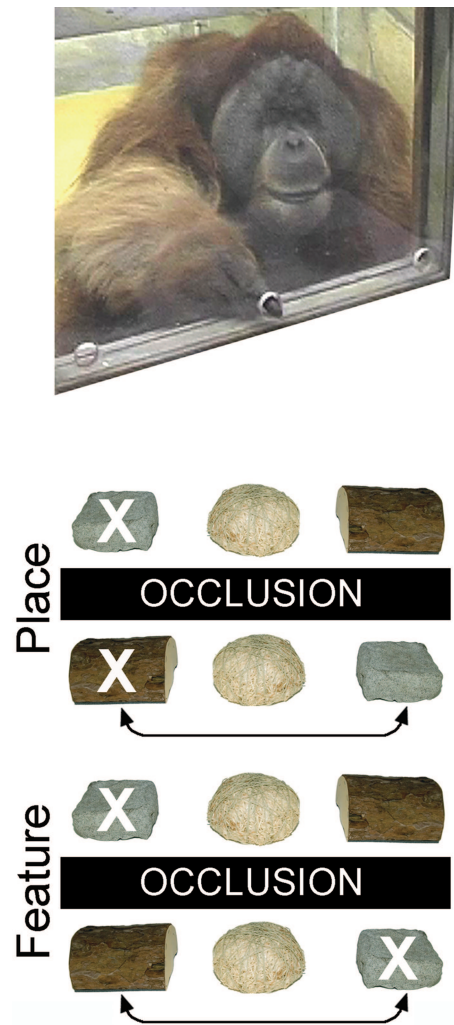


Figure 2.1: (Top) Adult orangutan male performing the task. (Bottom) Experimental conditions. The 'X' indicates the hidden reward before and after occlusion. PLACE: During occlusion the experimenter (E) switches two containers while the reward stays in its original location. FEATURE: E again switches two containers during occlusion but moves the reward with its container.

For older children and apes, each block was composed of 6 trials of one of the two test-conditions (place or feature) and 3 no-switch trials. Thus, subjects received 9 trials per block in two consecutive blocks for a total of 18 trials. We had to modify the procedure for younger children because pilot testing had revealed that they presented a strong bias to choose the middle position (Call, 2001). To avoid this problem, we removed the central cup from the setup. As a result they received 4 trials per block in the two-container setup (2 place trials, 2 feature trials, + 2 no-switch trials each). We videotaped all trials and scored the container selected by subjects. Some trials were excluded from analysis on one or more of the following grounds: (a) The response was blocked from view on video; (b) The subjects left their hands close to one of the response places during occlusion, thereby predisposing a place-type response (1.9 % of all trials excluded in total); (c) Three 3-year olds were excluded because they performed at least one block without a single correct no-switch trial while one additional 3-year old was excluded due to experimenter error; (d) Six 1-year olds were excluded because they did not complete all trials. The sets of subjects reported above are the final sets, after exclusions.

Results

Comparing the average number of correct trials, we first analyzed the differences among ape genera. A mixed ANOVA with condition (*place / feature / no-switch*) as within-subject factor and genera (*Pongo / Gorilla / Pan*) as a between-subject factor revealed significant main effects for condition ($F(2,44) = 17.78, P < 0.001$) and genus ($F(2,21) = 3.73, P < 0.05$). There was no significant condition x genus interaction ($F(4,44) = 1.325$). No simple post-hoc comparisons between genera reached significance. In tendency *Pan* ($M = 64.9; SE = 2.5$) outperformed *Gorilla* ($M = 52.9; SE = 5.0$) and *Pongo* ($M = 54.0; SE = 4.5$). Since we could not detect any differential preferences for one strategy over the other between genera we collapsed all apes for further analysis. (Table 2.1) presents the percentage of correct trials in the three conditions for the remaining three groups).

Table 2.1: Mean percentage (\pm SD) of correct trials in the three experimental conditions (Place / Feature / No Switch) for each of the three subject-groups.

	Place		Feature		No Switch	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
3-year olds	30.9	24.7	50.9	32.0	75.6	15.8
1-year olds	71.2	25.2	46.2	28.0	72.1	20.4
Apes	60.4	27.5	35.7	16.8	86.0	17.8

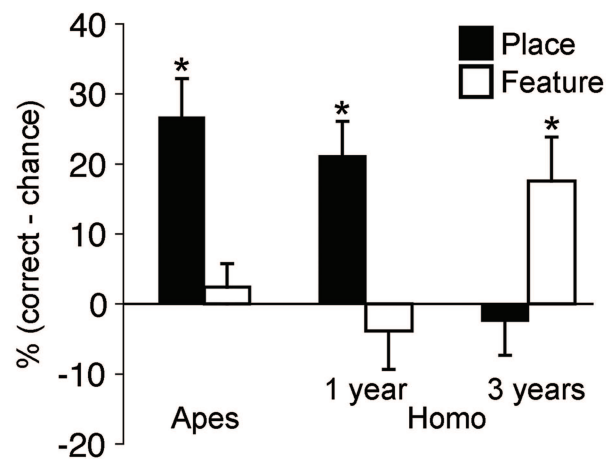


Figure 2.2: Mean percent correct (\pm SE) for the place and feature conditions only. Means are adjusted for the respective chance levels of the different subject groups: 33.33% for 3-year old human children and apes (1 out of 3 containers) and 50% for 1-year old human infants (1 out of 2 containers). Conditions marked with ‘*’ were significantly different from chance in one-sample *t*-tests. Unmarked bars were not significantly different from chance.

A mixed ANOVA (condition (*place / feature / no-switch*) x order (*place first / feature first*)) conducted for each group (apes, 1-year olds, 3-year olds) separately, revealed a significant main effect of condition in all three groups (apes: $F(2,46) = 34.30$; $P < 0.001$; 1-year olds: $F(2,48) = 7.90$, $P < 0.01$; 3-year olds: $F(2,48) = 18.23$, $P < 0.001$). However, the three subject groups differed in their strategy preferences (Figure 2.2). Both 1-year olds and apes performed better when the food stayed in the same location regardless of the movement of the container (i.e., in the place condition) than when it moved with its container (both $P < 0.01$, paired t -tests). For 1-year olds, a one-sample t -test against chance ($chance = 0.50$) revealed that subjects were significantly above chance in all conditions ($P < 0.001$) except feature ($P > 0.4$). The same pattern was detected in apes: A one-sample t -test against chance ($chance = 0.33$) revealed that subjects were significantly above chance in all conditions ($P < 0.001$) except feature ($P > 0.4$). In contrast, 3-year olds performed better at retrieving the reward when it moved with the container (i.e., in the feature condition) than when it stayed in its place ($P < 0.05$, paired t -test). For 3-year olds, a one-sample t -test against chance ($chance = 0.33$) revealed that subjects were significantly above chance ($P < 0.01$) in all conditions except place ($P > 0.5$). The p -values in all simple comparisons between the conditions reported here and in the main text were calculated and alpha-level corrected using a Bonferroni-Holm post-hoc test. Figure 2.2 presents a summary score obtained after subtracting the respective chance levels for percent correct scores in the place and feature conditions.

A more detailed analysis looked at subjects' choice of strategy rather than their correct performance. We classified the subjects' choices as place-based, feature-based or errors (i.e. neither the selected location nor the container had been rewarded before occlusion). An analysis of choices at switch-trial 'one' revealed that distributions match the error data. Distribution of first-choice-strategy in older children differed significantly from that of 1-year olds (Fisher-exact-test, $P < .001$) and apes (Fisher exact test, $P < .001$) which were in turn very similar to each other (Fisher-exact-test, $P > .5$). While 3 year-old children tend to use a feature strategy on their very first switch-trial, apes and 1-year olds initially chose place (Figure 2.3). Overall, the



Figure 2.3: Percentage of subjects choosing to use either place or feature cues to retrieve the reward on trial 1 of the experiment (before receiving any feedback).

performance of young human infants and all other hominid genera showed a similar pattern, which differed substantially from that observed in older human children, who preferred to use feature rather than place information.

Since the data on children had shown that age had an effect on the propensity to select place over feature, we also analyzed this aspect for nonhuman apes. We calculated the percentage of switch trials in which subjects chose based on place compared to feature. Figure 2.4 presents the percentage of trials in which subjects chose place over feature. There was a significant increase with age in the tendency to focus on place information ($r = 0.62$, $n = 25$, $P = 0.001$). Subjects below 14 years of age selected place over feature on average in 52.5% of the trials whereas this figure increased to 76.5% of the trials for animals older than 14 years of age. There was no significant relation between age and the percentage of errors committed by subjects ($r = 0.05$, $n = 25$, $P = 0.80$). Although the age range in which we investigated children and apes was not the same, the data suggest that human infants and apes come initially to spatial tasks with the same place bias, but they diverge in opposite directions, towards the feature strategy in the case of children, and towards greater consistency in the use of place in the case of apes.

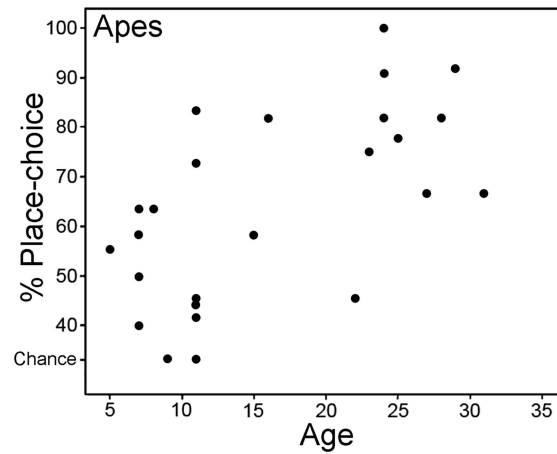


Figure 2.4: Scatterplot displaying the relationship between the percentage of trials in which a subject chose place over feature and the subjects age for all apes.

2.4 Discussion

Apes of four different species belonging to all three non-human great ape genera Pongo: orangutans (*Pongo pygmaeus*), Gorilla: gorillas (*Gorilla gorilla*) and Pan: bonobos (*Pan paniscus*) and chimpanzees (*Pan troglodytes*) - were tested in this study. In addition, human prelinguistic infants between 12-13 months and 3-year olds were tested. We show that all non-human great ape genera share a preference for locating things in space in terms of abstract place or position rather than in terms of the features of a container object. Indeed, the continuities between human and ape spatial cognition are striking: Apes and humans show similar ontogenetic development across the Piagetian stages up to stage 6 (Antinucci, 1989), commit similar errors (Call, 2001), and can cope with a variety of object displacements (Tomasello & Call, 1997; Beran, Beran, & Menzel, 2005; Barth & Call, in press). Here we have shown that at 1 year of age, humans exhibit just the same biases in spatial cognition found in all other genera of the family (Figure 2.5). The standard method of comparative cognition thus suggests a common phylogenetic inheritance of a preference for place-based spatial strategies from the ancestor shared by all four genera. Object-location memory is a central cognitive

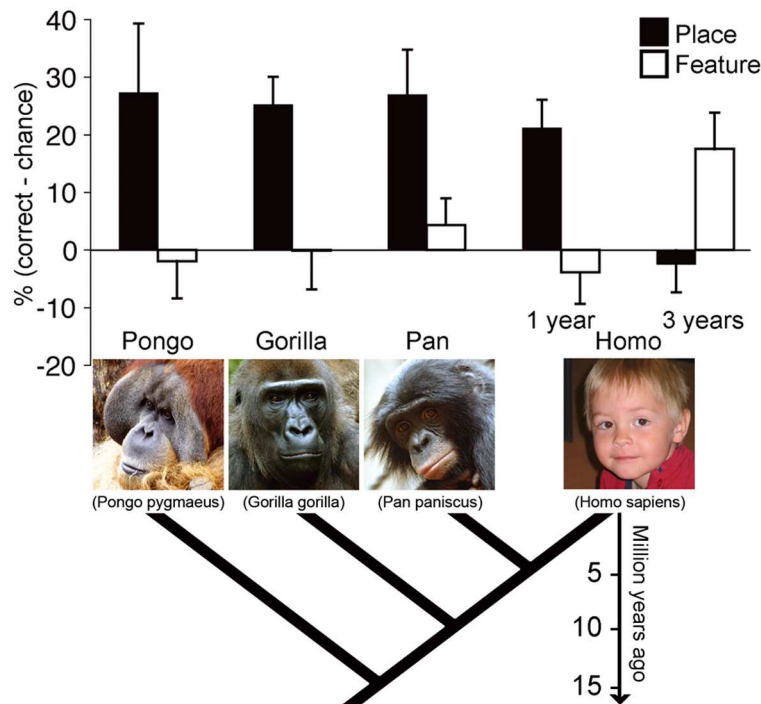


Figure 2.5: Mean percent correct (\pm SE) for the place and feature conditions for all ape genera and human 1- and 3-year old children. Means are adjusted for the respective chance levels of the different subject groups (see Fig. 2.2). No statistics were computed for the separate non-human genera because of relatively small sample sizes in some of the groups. Qualitatively, *Pongo*, *Gorilla* and *Pan* as well as 1-year old human infants all display a similar pattern. In contrast, 3-year old infants show the opposite preference. Below is the phylogenetic tree displaying the evolutionary relationships between the four Hominid genera (*Pongo*, *Gorilla*, *Pan*, *Homo*).

function underlying more complex foraging behaviour. Hence, this finding is of considerable interest for the interpretation of the fossil record – it suggests, dominantly place-based foraging strategies in the common ancestor of the Hominidae, which may thus have foraged in rather different ways than modern human hunter-gatherers: Place-based strategies are highly effective while foraging within a stable territory; feature-based strategies are advantageous while foraging in novel environments (e.g., finding mushrooms close to trees of a particular species). Thus strategy preferences might indicate foraging and lifestyle preferences. Through a comparative analysis of cognition across a complete phylogenetic clade, we have been able to reconstruct behavioural preferences in our common ancestor which cannot be found directly in the fossil record.

We also find that human infants share the same cognitive preference as apes, but this changes into a preference for features during early human ontogeny. Why should three-year old children differ in their preferred spatial strategy from human infants and other great apes? One possibility is that 1-year old human infants (as well as apes) lack certain cognitive abilities, needed to solve a feature-based search task [e.g. response inhibition (Diamond & Doar, 1989) or exhaustive search strategies (Perlmutter et al., 1981)], which excel after the first year of life. However in previous experiments various animal species (Bitterman, 1965; Meador, Rumbaugh, Pate, & Bard, 1987) and human infants (Bremner, 1978; Bushnell, McKenzie, Lawrence, & Connell, 1995) demonstrated the ability to use feature cues to retrieve hidden targets. In fact all of our subject groups tended to improve on their dispreferred strategy at least when it was rewarded in the first block of trials (Figure 2.6). Alternatively, the preference for place over feature cues for spatial memory in 1-year olds and apes might not be due to a lack of ability to solve the feature condition, but to a proclivity to use place- over feature-based strategies whenever available. In that case, the switch in humans would be due to reconstructive events in human ontogeny between the first and the third years, which re-weight preferences, not create abilities. Clearly this is a period where much happens in cognitive development. Maybe most prominently, infants are inducted into social life through the acquisition of

interpersonal skills (Flavell, 1999), such as for example increasing understanding of others' mental states and the acquisition of spoken language, the combination of which open up the full affordances of human culture (Tomasello, 2003). Language in particular has long been argued to play a reconstructive role in human cognitive development (Vygotsky, 1962; Bruner, 1964; Gentner, 2003; Spelke, 2003; Xu, 2002). Indeed, the first words learnt by German children are nouns (Gentner, 1982), and nouns specifically name bundles of object features, thus making featural specificity prominent. In fact, previous research has shown naming to draw attention to featural distinctions between objects in young infants (Xu, 2002; Xu, Cote, & Baker, 2005). Further experimentation would be needed to demonstrate a causal role for language for the present task, e.g. by examining infants of the same age but different language capacities. What the present data tells us is that the 'wild type' in our family exhibits a proclivity for place over feature in spatial tasks, and that humans reverse this early in childhood.

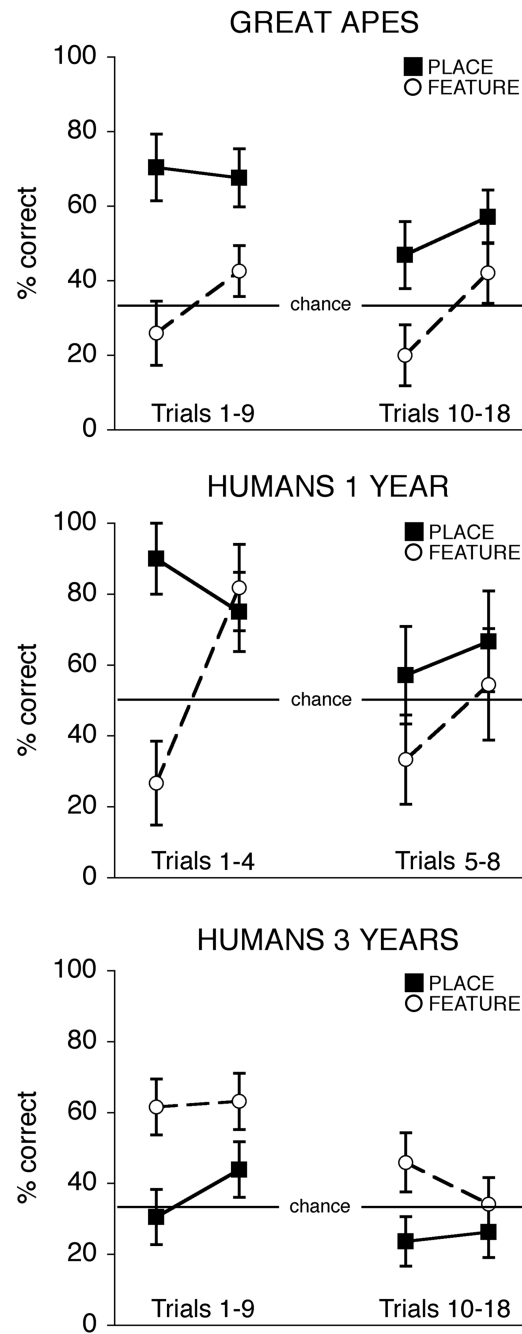


Figure 2.6: Mean percent correct (\pm SE) for the first and second half of trials in each block for the place and feature conditions only. Means are adjusted for the respective chance levels of the different subject groups: 33.33% for 3-year old human children and apes (1 out of 3 containers) and 50% for 1-year-old human infants (1 out of 2 containers).

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Covariation of spatial language and cognition

A version of this chapter has been submitted as D.B.M. Haun, C.J. Rapold, G. Janzen & S.C. Levinson (submitted). Right might be wrong where West is right: Spatial language and cognition covary across cultures.

3.1 Abstract

Here we explore cross-cultural variation in spatial cognition by comparing Dutch and Namibian elementary school children in a spatial reconstruction task. The two cultures differ in the way they predominantly express spatial relations in language. In three experiments we investigate cognitive strategy preferences across different levels of task-complexity and instruction. Our data show a correlation between dominant linguistic spatial frames of reference and performance patterns in non-linguistic spatial memory tasks. This correlation is fully robust already by age 8 and stable across an increase of complexity in the spatial array. When instructed to use their respective non-habitual cognitive strategy, participants were not easily able to switch between strategies and their attempts to do so decreased their performance levels. In the light of the current debate on cross-cultural variability of spatial cognition, we suggest that language can play a role in inducing stable preferences in cognitive strategy.

3.2 Introduction

There has been much controversy over what effect language has on other cognitive functions. Some presume that basic concepts, such as space or number, are ontogenetically antecedent to language, which merely expresses prior conceptual understanding and therefore cannot change it (Fodor, 1975; Gleitman & Papafragou, 2005; Pinker, 1994). Others claim that language can greatly facilitate mental processing (Dennet, 1991; Vygotsky, 1962), and make available cognitive adaptations to specific social environments (Levinson, 2003; Lucy, 1992). The latter position holds that cognitive concepts may be derived from language and that at least parts of the conceptual space in a speaker's mind are restructured by exposure to language (Brown & Lenneberg, 1954; Gentner, 2003; Whorf, 1956). Cross-cultural variation in language provides a natural laboratory to test these claims. To date, cross-cultural effects predicted by language differences have been found for example in the cognitive processing of colour (Roberson, Davies, & Davidoff, 2000), number (Gordon,

2004; Pica, Lemer, Izard, & Dehaene, 2004) and time (Boroditsky, 2001). Space, another central cognitive domain, has been an arena of controversy (Levinson, Kita, Haun, & Rasch, 2002; Li & Gleitman, 2002; Pederson et al., 1998). Spatial language varies across cultures (Pederson et al., 1998). The controversial question is whether these differences in spatial language correlate with similar variations in spatial cognition. Despite evidence documenting these correlations (Mishra & Dasen, 2005; Neumann & Widlok, 1996; Pederson et al., 1998; Wassmann & Dasen, 1998), the controversy is still far from resolved. In this paper, we first extract from the literature the considerations that have led some researchers to disregard available data and assume spatial cognition to be cross-culturally universal. The literature suggests some methodological adjustments, which we then apply in a set of experiments conducted in two cultures, reported in the second half of the paper.

3.2.1 Schooling & Context

Comparing cognition across cultures, especially when comparing industrialized and indigenous populations, brings with it the difficulty of controlling for formal education (Mishra & Dasen, 2005) and testing context (Li & Gleitman, 2002). A good solution is to focus on elementary school children: they have not yet diverged in educational level to the extent that their parents have. In the experiments below we therefore compare two populations of elementary school children who are both exposed to standard schooling in their first language, testing situations, writing-systems and English. Both populations were tested outdoors next to their school buildings, which were of similar size and both oriented along an East-West axis. Both populations received video instructions in their first languages.

3.2.2 Frames of Reference distinctions

Underlying linguistic descriptions of spatial arrays are coordinate systems or frames of reference (FoR). They serve to specify the directional relationship



DUTCH

Twee	Personen	die	naast	elkaar	
Two	persons	deict.dem.	next-to	recipr.pron.	
staan.	Die	ene	kijkt	naar	links
stand-3p	deict.dem.	one	look-3s	towards	left
die	andere	kijkt	naar	rechts.	
deict.dem.	other	look-3s	towards	right	

‘Two people standing next to each other.
One of them is looking left, the other one
is looking right.’

HAI||OM

Photo-s-a	ta	ge	go	uu,
picture-3sf-OBL	1s	DECL	REC.PAST	3pm.OBL
/gam	khoe-ga	uu-hâ,	o-b	
two	person-3pm.obl	take-be.located	then-3sm	
ge	/gui-b-a	sore-=gâ-s-a	!oa	
DECL	one-3sm-OBL	sun-enter-3sf-OBL	towards	
garu,	/gui-b-a	/gam-b-a	!oa	garu.
walk	one-3sm-OBL	warm-3sm-OBL	towards	walk

‘I have a photo, it has two men, and one of them
walks towards the west (lit. where the sun goes in).
one of them walks to the east (lit. the warmth).’

DECL	declarative	p	plural
f	feminine gender	REC	recent (past) tense
m	masculine gender	s	singular
OBL	oblique case	deict.dem.	deictic demonstrative
recipr.pron.	Reciprocal pronoun		

Figure 3.1: Transcript of a Dutch and a ≠Akhoe Hai||om speaker, describing a photograph to another participant in a director/matcher task. In these tasks, two speakers hold two identical sets of photographs. Without seeing each other, the ‘director’ describes one of the pictures, while the ‘matcher’ attempts to find the corresponding photograph in his own set. Below the original texts are an interlinear transcript and the free translation into English.

between objects, in reference to a shared spatial anchor (Levelt, 1996; Talmy, 1983). Extensive field research in over 20 languages, analyzing natural and elicited conversation, revealed a threefold distinction of systems (Levinson, 2003): European languages such as English predominantly use a *Relative*, viewpoint-dependent FoR with terms like front, back, left and right: “The ball is to the left of the tree (from my point of view)”. Some languages, for example Malaysian Jahai, predominantly use a coordinate system that makes reference to facets of objects - an *Intrinsic* FoR: “The tree is at the front of the house”. Other languages, like Guugu Yimithirr (Australia), predominantly use a third, so-called *Absolute* FoR, in which linguistic descriptions use cardinal-direction type systems such as our North-South-East-West - “Theres an ant by your southern leg” (Figure 3.1).

Many cognitive psychologists however, operate with a two-way distinction between FoRs: egocentric vs. allocentric. While egocentric (body-centered) strategies, essentially match properties of Relative linguistic constructions, allocentric (world-centered) responses collapse use of Absolute cardinal directions and Intrinsic strategies using local landmarks.

This three- vs. two dimensions mismatch poses a problem for the investigation of the relationship between language and cognition and has led to systematic misunderstandings (Levinson et al., 2002; Li & Gleitman, 2002). For example, initial investigations suggested that speakers of Absolute languages prefer allocentric to egocentric spatial strategies (Neumann & Widlok, 1996; Pederson et al., 1998; Wassmann & Dasen, 1998). Participants were asked to memorize spatial arrays; they were then rotated 180° before being asked to reconstruct them. As a result, the space formerly to their left is now to their right (north and south of course remain the same). In this way body-centered (egocentric) responses can only be discriminated from others using any environmental axis (allocentric) (Figure 3.2A). So in principle Absolute speakers could have been producing Intrinsic rather than Absolute behavioral responses, allowing a mismatch between spatial language and cognition.

Here, we factor out all three FoRs by using a 90° rotation of subjects instead of 180°. We also moved subjects to the opposite side of a salient local landmark so that reference to a local landmark as opposed to Absolute

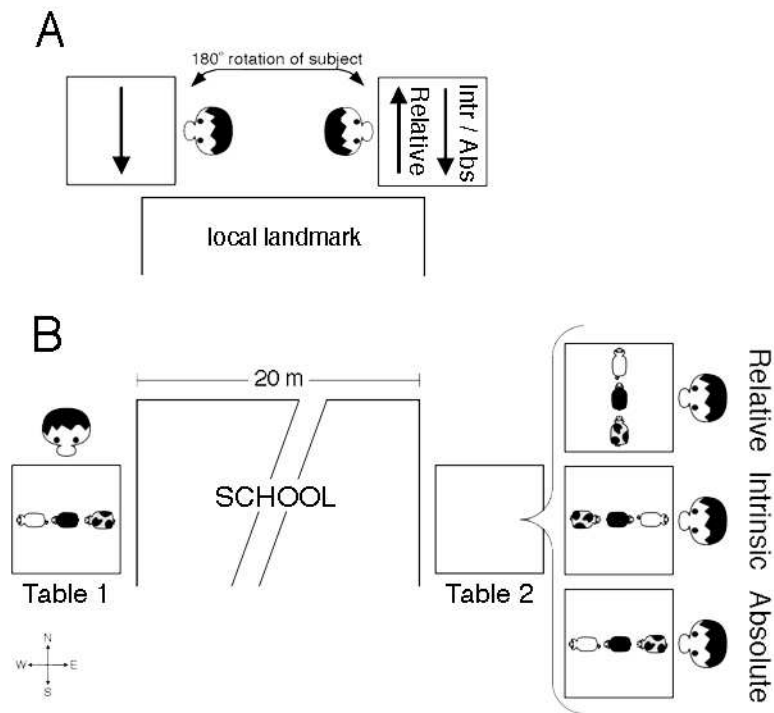


Figure 3.2: **A:** Basic experimental setup in previous studies. Subjects are presented with a spatial array, then rotated 180° degrees and asked to reproduce it on a different table. In this setup, Intrinsic (arrow towards a local landmark) and Absolute (south) responses are indistinguishable. **B:** Schematic experimental setup for the current study (both in Millingen (The Netherlands) and Farm 6 (Namibia)). Subjects are presented with a spatial array on table 1, then rotated 90° and asked to reproduce it on table 2. In this setup, all three frames of reference are distinguishable.

coordinates like North would become apparent (Figure 3.2B). Participants could now mentally code the same toy as either being left, east or towards the landmark of another toy, and the type of coding is, after rotation, transparent to the investigators. This paradigm matches three behavioral response categories to the three existing linguistic FoRs, thereby allowing for a closer investigation of the relationship between linguistic usage and cognitive coding.

3.2.3 Task-complexity

Previous designs have tended to use very simple sets of stimuli (usually 2-3 objects at a time) to allow for detection of preferences in strategy choice. But given a simple task, perhaps participants are free to solve it whichever way they like in line with local cultural norms or behavioral preferences, while underlyingly the set of options and the cognitive biases are invariant (Li, Abarbanell, & Papafragou, 2005; Li & Gleitman, 2002). Thus, many cognitive scientists have argued, following Kant (1768), that spatial cognition is fundamentally Relative (Halligan, Fink, Marshall, & Vallar, 2003; Miller & Johnson-Liard, 1976). However, if cultural compliance requires Absolute spatial strategies, the individual might achieve these by momentarily overriding their natural tendencies consulting additional strategies such as sub-vocal rehearsal (Munnich & Landau, 2003). Following this reasoning, one might predict that, the harder the task, the less speakers might be able to follow cultural norms. As a result, participants might fall back onto a cross-culturally shared natural tendency. In the following experiments, we investigate this by increasing complexity of the array to see if it affects strategy preference. Besides increasing task-demand, a complex array also minimizes possible confounding effects of sub-vocal rehearsal in a non-linguistic task for the following reason: Spatial language follows a pair-wise figure-ground structure (Talmy, 1983), in which arrays of objects are described in pairs of two, until all possible combinations are satisfied. Doubling the number of items in an array does not simply result in double the necessary linguistic units, but causes a combinatorial explosion. The more complex the linguistic encoding becomes, the less suitable a sub-vocal linguistic strategy becomes for memory encoding.

3.2.4 Instructions

In earlier studies (and Experiments 1 and 2), instructions were deliberately kept general (they were of the kind ‘make the array again’), so that subjects would use whatever preferred strategy comes naturally to them. But given

an ambiguous task, subjects might do whatever they find culturally appropriate, which might drive the observed cross-cultural variation instead of the proposed cognitive preferences (Li et al., 2005; Newcombe & Huttenlocher, 2000). If so, unambiguous instructions should easily sway participants to alter their behavior. To test this we chose two cultural communities, which have all three FoRs potentially available in their languages and differ only in their usage patterns - Dutch and ∇ Akhoe Hai||om, as described below. In experiment 3 below we instructed children of both communities in their first language to use the FoR they do not habitually use. If cross-cultural differences are merely varying interpretations of open tasks, and all cognitive options are equally available, an instruction should easily produce opposite response patterns.

3.3 Experiments

The following experiments were run in two culturally distinct populations, Dutch and Hai||om. The Dutch participants came from a rural setting in the Netherlands. Dutch speakers predominantly use Relative spatial relational descriptions, but also deploy Intrinsic constructions. Cardinal directions are sometimes used for large-scale spatial reference (Amsterdam is north of The Hague) but never for tabletop space. The ∇ Akhoe Hai||om (Hai||om for short) are a cultural group of hunter-gatherers living in the savannah of Northern Namibia. Their language is part of the Khoekhoe cluster within the Central Khoisan language family. Besides a dominant Absolute system, speakers have an Intrinsic and a rarely used Relative system with left-right-front-behind terms (Widlok, 1997).¹

Experiment 1 was designed to replicate earlier findings using a simple spatial array and unspecified instructions. Experiment 2 was designed to investigate the effects of task difficulty, to see if strategy preferences changed using a complex spatial array and unspecified instructions. In Experiment 3

¹An ethnographic description of the Hai||om can be found in Widlok (1999) and on <http://www.mpi.nl/DOBES/projects/akhoe>

Table 3.1: Percentage distributions of strategy choice in Dutch and Hai||om in simple array trials without instructions (Experiment 1), complex array trials without instructions (Experiment 2) and complex array trials with instructions to use the non-preferred strategy (Experiment 3).

	Experiment 1 simple Array free		Experiment 2 complex Array free		Experiment 3 complex Array instructed	
	Dutch	Hai om	Dutch	Hai om	Dutch	Hai om
Frames of Reference						
Relative	91.67	0.00	100.00	0.00	41.67	16.67
Intrinsic	0.00	15.00	0.00	0.00	8.33	33.33
Absolute	1.67	85.00	0.00	100.00	25.00	50.00
Other	6.67	0.00	0.00	0.00	25.00	0.00

we test whether participants are easily able to adopt any strategy to remember a complex spatial array when given clearly specified instructions (Table 3.1).

3.3.1 Experiment 1

Experiment 1 was designed to investigate whether two cultures that vary in their usage of linguistic expressions of spatial relations also, given unspecified instructions, vary in their preferential cognitive coding of simple spatial arrays, and whether potential cognitive preferences parallel the linguistic preferences.

Methods

Participants Our sample consisted of 12 children from each of the Dutch and the Hai||om communities. The Dutch children (6 males, 6 females; *mean-age* = 8;7 years, *range* = 8-9 years, *SD* = 6 months) were recruited from St. Martinus School, Millingen aan de Rijn. Hai||om children (8 males, 4 females; *mean-age* = 8;7 years, *range* = 7-11 years, *SD* = 1;4 years) were recruited

from |Khomxa Khoeda Primary School. All participants received rewards for participation and teachers and parents gave their informed consent.²

Setup The task involved memorizing a spatial array, and then reconstructing it at a different location. In both cultures, two tables were placed on opposite sides of the school building, a salient, familiar environmental landmark. A spatial array of toys was placed on table 1. Participants were always facing South during memorization and were then guided around the North side of the school to table 2 for reconstruction. Here, they were positioned facing West, and thereby rotated 90° relative to their orientation at table 1. Participants' spatial reconstructions of the array of toys were categorized into one of four potential response categories:

1. *Relative*: The toys were placed maintaining their spatial relations relative to the participants viewpoint.
2. *Intrinsic*: The toys were placed maintaining their spatial relations to the environmental landmark (school building).
3. *Absolute*: The toys were placed maintaining their spatial relations to cardinal directions.
4. *Other*: The toys were placed not maintaining any of the spatial relationships of categories 1-3.

Procedure Participants were given a video-instruction in their first language, which stated that an array of toys would be placed on a table and that they were to pay attention, as these would be removed and they would have to “make it again later”. A row of three out of four laterally symmetrical toy animals (cow / pig / horse / sheep) was placed on table 1, all facing either right or left of the participant (Figure 3.3A). The direction and identity of

²The experimenter was the first author, a bilingual German/English speaker. He interfaced with the teachers in both communities in English and with children through native-speaker video-instructions.

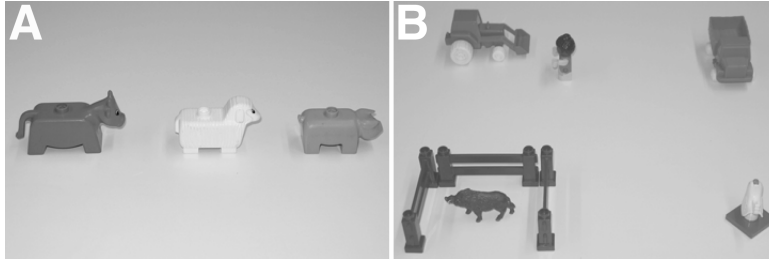


Figure 3.3: Simple (A) and complex (B) array of toys used as stimuli in both communities.

the animals were counterbalanced and randomized across participants. After participants indicated that they had memorized the setup, the experimenter removed the animals. In the first trial all four animals were simply placed back in a pile in the middle of the same table (table 1) after a short delay. All participants rebuilt the array correctly on the first attempt, picking the right subset of animals and orienting them correctly. In the following five trials, participants were guided to table 2 for their response. There, four animals were again piled on the table. Responses were recorded on paper and by photograph. Directional alignment of animals on each trial was coded according to the four potential response categories. The experimenter never gave any differential feedback. At the end of every trial, the participants were guided back to table 1.

Results

The array-internal order of animals was used as an indicator of general performance. Participants made few errors (% erroneous trials: *Median* = 0.0; *min* = 0.0; *max* = 40.0). Analyzing the directional alignment of animals on all trials, the populations differed significantly in their strategies (Fisher-exact, $p < .0001$; all Fisher-exact tests were performed on frequencies, but descriptive statistics are reported in percentages). While Dutch participants mainly used a Relative FoR to reconstruct the animals (91.67% of all trials across all subjects) the Hai||om population mainly produced Absolute responses (85%) (Table 3.1).

Discussion

The children of the two cultures varied in their preferred cognitive strategy for solving this spatial relational reconstruction task, with their preference matching the preferred mode of description in the language (Widlöck, 1997).

3.3.2 Experiment 2

To test if task-complexity would affect strategy preference, we presented participants with a second, more complex array of toys, consisting of six instead of three objects placed in a two-dimensional plane. If the difference reported in experiment 1 is due to flexible processing of an overly simple task, populations should differ less in their solutions to a more difficult task.

Method

Participants & Setup Participants and setup were identical in all experiments, which were conducted one right after the other.

Procedure Participants were shown one of three different complex arrays including six toys (see example Figure 3.3B) without additional instructions. Order of complex arrays across experiments 2 and 3 was counterbalanced across subjects. After they indicated that they had memorized the array, it was removed and the experimenter guided them along the school building to table 2 to reconstruct the array there (FREE). Responses were recorded on paper and by photograph.

Across a 90° observer-rotation, transformations within a Relative, Intrinsic or an Absolute FoR result in three different correct solutions (for simple examples see Figure 3.2 B). Childrens responses were compared to the three correct solutions in the three different FoRs. Differences between the correct solutions and the constructed arrays, in either position or orientation, were scored as errors. Children could make maximally 6 orientation- and 5 position errors (the pig was always in the sty). Their performance was

analyzed relative to the maximum number of 11 errors (%-possible-errors). Whichever FoR was the closest fit (lowest error-score) to their response was counted as their choice of strategy. This lowest error score was also used as a measure of performance and later compared to experiment 3. Any response with 2/3 or more of possible errors in any FoR was scored ‘Other’.

Results

Reconstructing the complex array, performance was worse than in experiment 1 (% possible errors: *Median* = 18.18, *min* = 0.0, *max* = 63.64). The populations once again differed significantly in the distribution of strategy choices (Fisher-exact, $p < .0001$). Dutch participants exclusively used a Relative FoR to reconstruct the animals (100% of all subjects), while the Hai||om population exclusively produced Absolute responses (100% of all subjects) in the FREE-condition (Table 3.1).

Discussion

In experiment 2 we used a more complex spatial array to increase task demand and reduce any possible effects of sub-vocal rehearsal. Cognitive preferences were unchanged when participants were free to choose strategy. We did not detect any trend towards a shared, underlying ‘natural FoR in any direction, as might have been predicted as task complexity increases. We conclude that cross-cultural preferences are stable even in harder tasks.

3.3.3 Experiment 3

In this experiment we instructed children of both communities in their first language to use the FoR they do not habitually use, but which is nevertheless conventionally codable in their language. If cross-cultural differences are merely varying interpretations of unspecified instructions, a clear instruction should easily reverse response patterns.

Methods

Participants & Setup Participants and setup were identical in all experiments, which were conducted one right after the other.

Procedure Participants saw a video instruction in their first language, which told them to use their non-habitual FoR. Dutch subjects were instructed to place, say, the Western objects back on the Western side of the array, when they reconstruct it. Hai||om children were told to place, say, the rightmost objects back on the right-hand side of the array, when they reconstruct it. Both instructions were recorded by native speakers of Dutch and Hai||om. We made sure the instructions were clear by getting feedback from independent bilingual consultants of both communities. After viewing the instructions participants underwent an brief training procedure in which two toys were placed on table 1. Then the experimenter removed them and subjects were rotated 90 around the same table. Now they were asked to reconstruct the mini-array following the instructions they had just received. When they mastered this test, they were again oriented South and presented with a complex array. Before removing the toys, the experimenter asked the participants to indicate which of the toys were on the Western side (Dutch) or the right side (Hai||om). If they failed, the experimenter named all four directions for them. After moving to table 2, subjects were again asked to indicate the axes of the instructed FoR in their new position and orientation. In case of failure the experimenter again labeled the sides correctly. They were then given the toys and asked to reconstruct the scene (INSTRUCTED). Responses were recorded on paper and by photograph.

Childrens strategy choices were assessed in the same way as in experiment 2. To measure their ability to follow the instructions, we compared childrens responses to the instructed correct responses, i.e. Absolute for Dutch and Relative for Hai||om children. Differences in orientation and position of the objects between the correct and the reconstructed array were scored as errors.

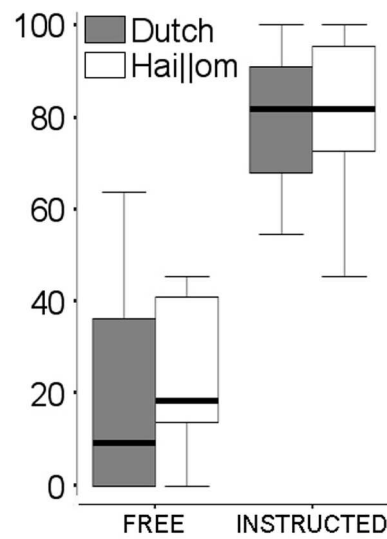


Figure 3.4: Boxplot of error-scores in Dutch and Hai||om in Complex-Array trials without (free) and with instructions (instructed). The height of the box represents the interquartile range of the sample. The black lines are the sample medians. Whiskers extend to the minimum and maximum of the samples. Descriptives statistics error-scores: Dutch: FREE: *Median* = 9.09, *min* = 0.0, *max* = 63.64; INSTRUCTED: *Median* = 81.82, *min* = 18.18, *max* = 100.00 Hai||om: FREE: *Median* = 18.18, *min* = 0.0, *max* = 45.46; INSTRUCTED: *Median* = 81.82, *min* = 45.45, *max* = 100.00.

Results

To see if instructions had an effect, we compared distribution of choices between Experiment 2 in which participants could freely choose strategy (FREE) and the instructed experiment 3 (INSTRUCTED) in both communities. Dutch (Fisher-exact, $p < .01$) and Hai||om (Fisher-exact, $p < .05$) showed significantly different distribution of response types following the instructions (Table 3.1).

To test whether the instructions changed subjects performance, we compared FREE and INSTRUCTED trials within and across populations. Both populations performed significantly worse in the instructed condition than in the free condition. (Wilcoxon-test: Dutch: $Z(N = 12) = -2.83$; $p < .05$; Hai||om: $Z(N = 12) = -3.06$; $p < .01$). Moreover, Hai||om children, freely choosing to respond in an Absolute FoR, outperformed Dutch children following Absolute instructions (Mann-Whitney-U-test: $U = 5.00$; $p < .0005$). Similarly, Dutch children, freely choosing to respond in a Relative FoR, outperformed Hai||om children following Relative instructions (Mann-Whitney-U-test: $U = 2.00$; $p < .0005$). In all tests on error-scores, p -values were corrected for multiple comparisons (Bonferroni). Descriptive statistics are reported in Figure 3.4.

Discussion

Only around half of the subjects displayed an attempt to adapt their behavior, and only one fifth of them successfully changed to a previously dis-preferred strategy. Participants were not easily able to switch strategy on demand, and their attempts to do so decreased their performance significantly in both groups there were at least four times as many errors. In other words, despite understanding the instructions, children struggled to reproduce the array using a strategy which they cognitively disprefer, and which is only infrequently used in their language (Widlok, 1997). This was true even though the instructed strategy was preferred by the other group, and therefore not harder per se. We conclude that cross-cultural preferences are not easily overcome.

3.4 Conclusions

We have here investigated cross-cultural differences in spatial cognition and their correlation with language differences by comparing two populations of elementary-school children in carefully matched experimental setups.

Our task extended the commonly used, two-way distinction between possible FoR strategies (egocentric-allocentric) to a three-way distinction (Relative-Intrinsic-Absolute) and thereby matched behavioral response-options to the threefold discrimination of FoRs in natural language. Our data show a correlation between the linguistic strategy dominant in the language and the cognitive strategy used to process spatial relations. This correlation is fully robust by age 8. The cross-linguistic differences were stable across an increase of complexity in the spatial array, a manipulation designed to increase task difficulty and at the same time reduce the efficiency of sub-vocal rehearsal. We found no evidence for a common, underlying natural tendency towards any FoR across the two communities. Using their own first language, we also instructed speakers of both communities to use their non-habitual cognitive strategy. Participants were not easily able to switch strategy on demand, and their attempts to do so decreased their performance significantly. Dutch children struggled to reproduce the array so that it preserved the cardinal directions of the original stimulus, while Hai||om children struggled to reproduce the array so that Relative right/left/front/back constancies were preserved.

The human brain supports Relative, Intrinsic and Absolute spatial cognition (Burgess, Donnett, Jeffery, & O' Keefe, 1999). Therefore linguistic effects on cognition in this domain can never be a matter of capacity, but only of preference and proficiency. The question at stake is not what people can or cannot think, given a language preference, but rather about the kind of cognitive coding they will use by default, and the ease or difficulty with which other coding systems can be adopted. Of course correlations between linguistic usage patterns and cognitive proficiency might be caused by a third intervening variable that affects both. But a comparison of the environment, dwelling and subsistence-mode of over 20 cultural communities revealed that

none of these factors determine usage patterns in spatial descriptions across languages (Majid, Bowerman, Kita, Haun, & Levinson, 2004). Since none of these factors by themselves seem to determine linguistic preferences, we consider them unlikely candidates for intervening variables affecting both language and cognition. Instead we suggest that in order to be a functioning member of a linguistic group, one has to communicate using the conventional semantic concepts and categories. To achieve this, non-linguistic cognitive representations need to be aligned to support the locally preferred linguistic categories. Over time, language will induce expertise effects in the non-linguistic cognition that supports its use. There are several established cognitive processes such as perceptual tuning (Goldstone, 1998), representational redescription (Karmiloff-Smith, 1992), chunking through lexical packaging (Miller, 1956), and structure-mapping (Gentner, 2003) that could account for linguistic effects on non-linguistic representations, which in turn can have effects on the kinds of computations carried out by the cognitive architecture (Bowerman & Levinson, 2001; Majid et al., 2004). Our results therefore suggest that language can play a role in inducing strong, stable preferences in cognitive strategy, and that these culture-specific preferences are already in place by middle childhood. It follows that linguistic diversity goes hand in hand with cognitive diversity, and a cross-cultural perspective on human cognition should play a central part in understanding how variable adult cognition is built from a common cognitive foundation.

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Cognitive cladistics and cultural override

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4.1 Abstract

Current approaches to human cognition often take a strong nativist stance based on Western adult performance, backed up where possible by neonate and infant research, and almost never by comparative research across the Hominidae. But recent research suggests considerable cross-cultural differences in cognitive strategies, including relational thinking, a domain where infant research is impossible due to lack of cognitive maturation. Here we apply the same paradigm across children and adults of two cultures and across all non-human great ape genera. We find that both child and adult spatial cognition systematically varies with language and culture, but that nevertheless there is a clear inherited bias for one spatial strategy in the great apes. It is reasonable to conclude, we argue, that language and culture mask the native tendencies in our species. This cladistic approach suggests that the correct perspective on human cognition is neither nativist uniformitarian nor ‘blank slate’ but recognizes the powerful impact that language and culture can have on our shared primate cognitive biases.

4.2 Introduction

Cognitive psychology has been centrally concerned with the nature of human adult cognition and its development from infancy. It has largely treated this as the emergence of a universal cognitive structure from innate sources that can be glimpsed in infancy. Many of these processes have been traditionally thought to be discontinuous with our nearest primate cousins. This picture needs correcting in two main directions. First, adult cognitive strategies diverge according to expertise and culture in some quite fundamental domains like color (Roberson, Davies, & Davidoff, 2000), number (Gordon, 2004; Pica, Lemer, Izard, & Dehaene, 2004) or spatial cognition (Levinson & Brown, 1994; Chua, Boland, & Nisbett, 2005; Neumann & Widlok, 1996; Pederson et al., 1998). Language seems to play an important role in this divergent specialization of the intellect. Innate biases are thus masked by cultural and linguistic divergence. Although neonate and infant research might throw

light on these biases, many cognitive abilities - for example those involved in relational reasoning - are not fully developed before cultural effects take hold. Second, continuities with our primate cousins should be presumed, and efforts should be made to track them (Barth & Call, in press; Byrne, 1995; Hauser & Spelke, 2004). The overall picture that then emerges is, we argue, one in which human infants inherit many of the same cognitive preferences and biases as our primate cousins, but then go on to build cognitive structures which may diverge in variable ways from this primate base under the influence of language and culture (Vygotsky, 1962).

In this paper we focus on the cognition of spatial relations, which shares the relational characteristics of many higher cognitive processes (Gentner, 2003). First, in part 1, we explore human cognition for spatial relations in two cultures, examining both adults and children. As predicted by earlier work, we find major divergence in the two cultural groups, parallel to linguistic coding strategies. Such a result is compatible with a ‘blank-slate’ view of human cognition, but it need not imply it. Spatial cognition is vital to all foraging species and is served by phylogenetically conservative neural systems (Burgess, Donnett, Jeffery, & O’Keefe, 1999), so there are good reasons to suppose an inherited substrate. The standard approach would be to look for preferences in human infants, but relational thinking is a domain where it is difficult or impossible to acquire insight into innate biases by infant research, for the relevant cognitive skills do not mature till well after children learn language, and with it all the baggage of culture. In experiments 2 and 3 we therefore, additionally to European preschool children, look at mature apes of all the other great ape genera to establish the inherited primate baseline and moreover gain insight into the evolutionary history of spatial cognition.

4.3 Cross-cultural variation

Spatial relations provide basic framing structures for the encoding of events (Burgess, 2002) and relational thought forms the basis for propositional structure, predication, understanding analogy and metaphor (Gentner, 2003; To-

masello, 2003). Therefore spatial memory, and the relational learning it requires, is central to human cognition. Children acquire relational thought relatively late in ontogeny coeval with the acquisition of the relevant linguistic expressions (Loewenstein & Gentner, 2005; Gentner, 2003). Because of this co-emergence of cognitive and linguistic concepts of spatial relations in children, it has been argued that the ontogeny of relational thought is tightly interweaved with, or might even be dependent on, relational language (Gentner, 2003).

Spatial relational language follows coordinate systems or frames of reference (FoR for short), which serve to specify the directional relationships between objects in space, in reference to a shared referential anchor (Levelt, 1996). Extensive field research in over 20 languages, analyzing natural and elicited conversation, has revealed that in language just three FoRs seem to be employed, but that languages vary in the repertoire they code and also in the habitual usage of FoRs (Levinson, 2003). Some languages use a Relative, viewpoint-dependent FoR with terms like front, back, left and right: “The ball is to the left of the tree” (from my point of view). Some languages utilize an Intrinsic FoR, which makes reference to faceted objects “The ball is at the front of the house”. Some languages use a third, so-called Absolute FoR in which linguistic descriptions use cardinal-direction type systems such as our North-South-East-West: “The hot water is in the northern tap”. While Relative constructions are predominant in European languages, the Absolute FoR is dominant for example in several indigenous languages of Australia, Papua New Guinea, South-, Middle- and North America, Nepal, India, Siberia, and South-West Africa (Levinson, 2003; Majid, Bowerman, Kita, Haun, & Levinson, 2004).

Continuing investigations into the cognition of speakers of Absolute languages suggest that they prefer Absolute (world-centred) to Relative (body-centred) strategies in simple non-linguistic spatial memory tasks, while the reverse is found in European speakers of predominantly Relative languages such as English or Dutch (Levinson & Brown, 1994; Mishra & Dasen, 2005; Neumann & Widlok, 1996; Pederson et al., 1998; Wassmann & Dasen, 1998) for critique see (Bloom & Keil, 2001; Li & Gleitman, 2002). In other words,

language difference covaries with differences in cognitive strategy for non-linguistic tasks.

Here we investigate spatial relational learning in two distinct cultural communities: a Dutch village representing a typical western European, post-industrial culture and ǀAkhoe Hai||om , a Khoisan hunter-gatherer community in Namibia. Both Dutch and ǀAkhoe Hai||om (Hai||om for short) languages make at least residual use of all three FoRs in natural conversation. However, they differ in their language usage patterns. Speakers of Dutch almost exclusively use Relative constructions to describe small-scale spatial relations (Pederson et al., 1998; Levinson, 2003). Hai||om speakers in principle have a Relative FoR available but they almost always use Absolute spatial descriptions (Widlok, 1997).¹ In experiment 1, we tested children at the age of approximate emergence of the relevant spatial relational terms [7-11 years of age; (Brown & Levinson, 2000; Piaget, 1928)] in a feedback-learning paradigm, with minimal verbal instructions to minimize cross-culturally variant translations and interpretations (Bloom & Keil, 2001). We also tested adults in both cultures to see if differences were not only initial variations of an emerging cognitive skill, but actually stable across the lifespan. On the basis of earlier results (Levinson, 2003), we predicted that consultants from the two distinct cultures which vary in their linguistic expression of spatial relations would also vary in their habitual cognitive coding of spatial relations

¹Germany and The Netherlands are post-industrial Western-European nations with a mixed rural and urban lifestyle, inhabiting a densely populated landscape. German and Dutch speakers predominantly use Relative spatial relational descriptions but also deploy Intrinsic constructions. Cardinal directions are only ever used for large-scale spatial reference (Amsterdam is north of The Hague) but never for tabletop space. The research sites for the present paper are a village called Millingen aan de Rijn with roughly 6000 inhabitants and Leipzig, a German city with roughly 500000 inhabitants. The Hai||om are a group of hunter-gatherers living in the savannah of Northern Namibia. Their language is part of the Khoekhoe cluster within the Central Khoisan language family. Despite political and economical marginalization and loss of their traditional hunting and gathering land to farmers, many aspects of Hai||om traditional culture have been maintained, including healing trance dances, hunting magic, a lunar calendar and an Absolute linguistic system for spatial relations. Besides the dominant Absolute system in the language, the speakers have an Intrinsic and a rarely used Relative system with left-right-front-behind terms (Widlok, 1997). The research site for the present paper is a camp called Farm 6 in Mangetti West, with some 200 Hai||om. An ethnographic description of the Hai||om can be found in (Widlok, 1999).

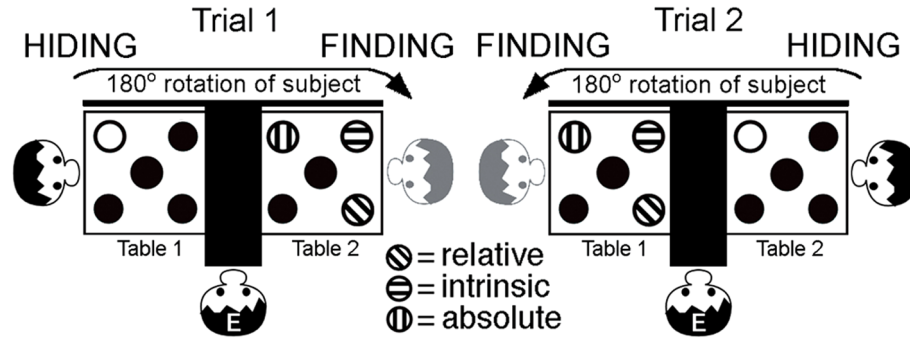


Figure 4.1: Experiment 1: Experimental setup in two consecutive example trials. Ten exactly identical cups were placed on two tables (5 each). Participants were watching while a target was hidden under the cup depicted as white (HIDING). Then they moved to the other table and indicated where they thought a second target might be hidden (FINDING). The three differently striped cups show the different contingencies rewarded in the three consecutive blocks of trials.

and that cognitive preferences would match the linguistic preference. Hence, Dutch speakers should prefer Relative to Absolute cognitive strategies while Hai||om speakers should show the reverse pattern.

4.3.1 Experiment 1

We used a non-linguistic spatial relational learning paradigm to test if the preferred linguistic FoR in a given language would predict the preferred cognitive strategy. As subjects, we used four groups: Dutch children and adults, and Hai||om children and adults.

Methods

Participants The sample consisted of 12 adults and 12 children from both the Dutch and the Hai||om communities. (Dutch adults: 6 male, 6 female, *mean age* = 23 years 1 months, *range* = 18-34 years, *SD* = 4 years 6 months; Hai||om adults: 3 male, 9 female, *mean age* = 21 years 10 months, *range* = 15-40 years, *SD* = 6 years 7 months; Dutch children: 8 male, 4 female,

mean age = 8 years 6 months, *range* = 8-10 years, *SD* = 9 months; Hai||om children: 8 male, 4 female, *mean age* = 8 years 10 months, *range* = 7-11 years, *SD* = 1 year 7 months). All 48 volunteers received rewards for participation and teachers and parents gave their informed consent for Dutch and Hai||om children.

Setup Two small tables were placed next to each other with a solid opaque screen in-between to separate them visually. Five identical cups were placed on each table in a dice-five constellation (Figure 4.1). The setups varied only slightly in size across groups. All participants but three Hai||om adults were tested in similar indoor contexts. The three adults were tested outdoors close to their home village. The experimenters were the first and second author. They interfaced with the teachers in both communities in English and with participants through native-speaker video instructions.

Procedure Participants were instructed in their first language to find a hidden target when prompted.² At the beginning of a session, the participant was positioned in front of table 1 facing the screen. They watched an experimenter (E) place a target under one of the five cups (HIDING). Then they were directed over to table 2, again facing the screen, so shifting their orientation 180°. Here they were prompted to indicate the cup under which they judged the target would be found (FINDING). After their response E turned over their cup of choice and, in case of an incorrect choice (choosing any cup without a hidden target), the correct cup to allow volunteers to adjust their behavior to maximize hit rate. We scored the container selected by subjects based on videotapes and/or in situ notes. Trial 2 started with a new HIDING at table 2 after which participants moved back to table 1 for FINDING. This procedure was iterated for a total of 30 trials (3 blocks of 10). After two correct responses with the target in the central position as a training criterion, targets were hidden following three rules (Figure 4.1):

²Instructions: “Here you see a set of cups on a table. You will watch Daniel hide this block under one of them. Then you will go to another table with another set of cups, where you can search for a block. The game is to find the hidden block.” (abbreviated translation into English).

1. *Relative* condition: The hiding and finding cups maintained position Relative to the viewpoint of the participant. If the HIDING cup was close to her on her left hand side the FINDING cup was again the close one on the left hand side after she rotated into her new position at the other table.
2. *Intrinsic* condition: The hiding and finding cups maintained position in relation to a salient landmark between the two tables, namely the screen or E. If the HIDING cup was for example the one diagonally across from E, the FINDING cup was again diagonally across from E after the participant rotated into her new position at the other table.
3. *Absolute* condition: The hiding and finding cups maintained position Relative to the larger, surrounding environment. If the HIDING cup was the north-western cup, the FINDING cup was again the north-western one after the participant rotated into her new position at the other table.

Figure 4.1 makes clear the distinct position of the FINDING cup in each condition. The three different conditions were administered to each individual in three consecutive blocks of 10 randomized trials, counterbalanced for order across subjects. The transition between the blocks was unmarked - thus the prior winning strategy no longer worked, and a new one had to be learnt. Randomly intermixed within all three blocks were 2 trials each, in which the middle cup was the FINDING cup (Middle-condition). In these Middle-trials all three rules lead to the same solution. Participants that did not at least perform 50% correct on Middle-trials (cup in central position) were excluded from the final analysis. In all side-trials (all but the middle-condition), participants had a 2/5 chance to pick a FINDING cup, which was not related to the HIDING-cup following any of the three rules mentioned above (Relative, Intrinsic and Absolute). Subjects who did so not significantly below chance level (binomial test: less than 6 errors out of 24 trials) were also excluded from the final analysis.

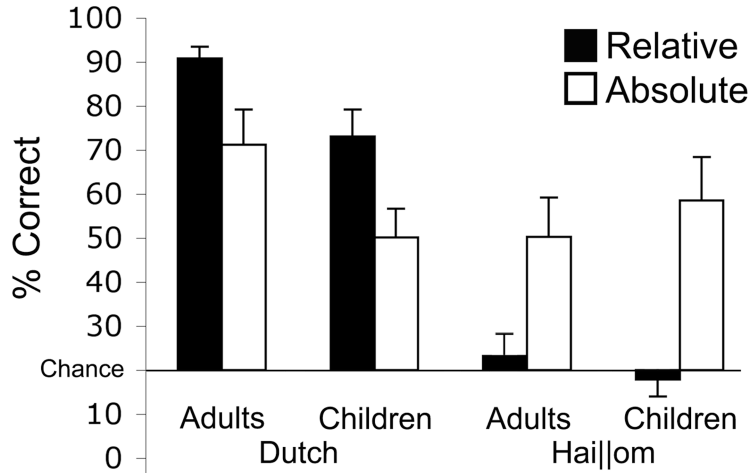


Figure 4.2: Mean percent correct (\pm SE) for the Relative and Absolute conditions for both Adults and children in the Dutch and Hai||om communities. Means are plotted against chance level (20 %, 1 out of 5 cups).

Results

We conducted a mixed ANOVA with the within-subject-factor condition (*Relative / Intrinsic / Absolute / Middle*) and the between-subject-factors language (*Dutch / Hai||om*) and age-group (*adults / children*). Analysis revealed a main effect of condition ($F(3,132) = 38.13, P < .001$; % correct: Relative: $M = 51.27, SD = 5.1$; Intrinsic: $M = 51.31, SD = 4.3$; Absolute: $M = 57.57, SD = 4.3$; Middle: $M = 93.75, SD = 2.1$). Bonferroni Holm post-hoc test showed that overall subjects performed better in the middle condition than in any other (Relative vs. Intrinsic: $t(47) = -.01, P > .05$; Intrinsic vs. Absolute: $t(47) = -.99, P > .05$; Absolute vs. middle: $t(47) = -7.52, P < .01$).

We also found a main effect of language ($F(1,44) = 65.48, P < .001$; Dutch: $M = 76.58, SD = 8.1$; Hai||om: $M = 50.37, SD = 14.4$). Dutch outperformed Namibian participants, most likely due to more advanced formal schooling. We found no significant effect for age-group ($P = .08$).

The ANOVA also revealed an interaction of condition x language ($F(3,132) = 14.23, P < .001$; Dutch: Relative: $M = 82.0, SD = 18.4$; Intrinsic: $M =$

64.4, $SD = 25.6$; Absolute: $M = 60.7$, $SD = 26.9$; Middle: $M = 99.3$, $SD = 3.5$; Hai||om: Relative: $M = 20.6$, $SD = 16.0$; Intrinsic: $M = 38.3$, $SD = 28.6$; Absolute: $M = 54.4$, $SD = 32.1$; Middle: $M = 88.2$, $SD = 19.3$). For the condition \times language interaction, we predicted a priori that the preferred linguistic FoRs would also constitute the preferred cognitive strategy in comparison to the infrequently used one. So Dutch subjects should perform better in the Relative than in the Absolute condition and the reverse should be true for the Hai||om. Bonferroni-Holm post-hoc tests indeed reveal this to be the case (Dutch: Relative vs. Absolute: $t(23) = 3.76$, $P < .01$; Hai||om: Relative vs. Absolute: $t(23) = -4.08$, $P < .01$) (Figure 4.2).

Discussion

In this experiment, we trained three response-options in a spatial relational learning task, which match the threefold Relative-Intrinsic-Absolute discrimination of FoRs in natural language. Our data show a correlation between the habitual linguistic strategy and the preferred cognitive strategies to process spatial relations: both children and adults were more accurate (made less errors) and were faster to learn the FINDING pattern that matched the FoR dominant in their language. This correlation is fully robust by age 8 and persists into adulthood. In sum, Dutch and Hai||om subjects varied in their preferred cognitive strategy to solve a spatial relational learning task and their preference matched the preferred mode of description in their respective language. Clearly, human cognitive competence encompasses all three FoRs, and indeed special neurocognitive systems seem to support each of them (Burgess et al., 1999). Cross-cultural differences in spatial cognition therefore concern preference and proficiency, not absolute ability. Many things might hypothetically fuel cross-cultural variation of spatial cognition in this sense. Several potential sources have been proposed, such as group-cohesion or lifestyle (Li & Gleitman, 2002), context (Gallistel, 2002; Li & Gleitman, 2002), and language (Levinson, 2003; Majid et al., 2004). The largest and strongest body of evidence supports the latter theory (Levinson & Brown, 1994; Levinson, Kita, Haun, & Rasch, 2002; Mishra & Dasen, 2005; Pederson et al., 1998; Neumann & Widlok, 1996; Wassmann & Dasen, 1998), which

proposes that cognitive categories and concepts are not necessarily universal, but potentially variable and seem to align with cross-linguistically variable semantics. To communicate about space, in a way appropriate within a linguistic community, cognitive representations need to be aligned with habitual linguistic categories so that information is coded appropriately for later linguistic use. Like other expertise effects, frequent use of a particular language will train the cognitive system in the necessary underlying processing. Whatever the right combination of factors might be that ultimately explains the variation of spatial strategies across human groups, it will, in one way or the other, be part of what we loosely call ‘culture’. However, cultural variation in cognition does not of course exclude a rich inherited basis, even in the variables in question. It is therefore reasonable to ask what the input or cognitive default is in this domain for humans. Is the default spatial relational strategy unset (the ‘blank slate’ view), or is it preset but malleable enough to be overridden by cultural preferences?

4.4 Phylogenetic inheritance

Since relational cognition only fully develops late in ontogeny, there is no infant data which can shed light on a default strategy preference. There is, however, an alternative source of information from comparative cognitive science (Byrne, 1995): If all genera of a phylogenetic family (in our case the Hominidae) exhibit the same behavioral tendencies or cognitive biases, this suggests inheritance from the common ancestor shared by all genera (in our case *Pongo*, *Gorilla*, *Pan* & *Homo*; Figure A.1). It is also reasonable to assume that any such tendencies shared by all non-human great ape genera and any human population is most likely part of the primate inheritance shared by all humans. In this second part of the paper we apply this cladistic reasoning to investigate inherited preferences for coding spatial relations in FoRs.

There has been a great deal of speculation about the inherited structure of spatial relational thought. Immanuel Kant argued that the human

body provides the source of our basic intuitions about the nature of space (Kant, 1768). In agreement, many cognitive scientists hold the assumption that spatial cognition is fundamentally Relative or egocentric [(Miller & Johnson-Liard, 1976; Halligan, Fink, Marshall, & Vallar, 2003; Wang & Spelke, 2002); but see (Burgess, Spiers, & Paleologou, 2004; Waller & Hodgson, in press)]. However, there are some reasons to doubt this. It is true that young infants initially, before they are fully mobile agents, display a quite inflexible Relative bias (Bremner, 1978). But as soon as they have become proficiently mobile and competent navigators [around 16 months of age (Acredolo, 1988)], they successfully use non-Relative cognitive strategies. If the two types of strategies are immediately compared, English-speaking children, at least between 3 and roughly 5 years of age, are better at non-Relative strategies than at Relative ones (Allen, 1999; Nardini, Burgess, Breckenridge, & Atkinson, in press). Moreover, children learning an Absolute language acquire the relevant linguistic expressions at least as early as children learning a Relative language (Johnston, 1988; Piaget, 1928; Brown & Levinson, 2000; Leon, 1994; Wassmann & Dasen, 1998).

Relevant data from other species is sparse - there is only scant evidence for a preference for Relative vs. non-Relative cognitive strategies, although what there is mostly suggests a non-Relative advantage [Chimpanzee (Menzel, 1973); rats (Ray & Heyes, 2002); cats (Fiset & Dore, 1996); but see dogs (Fiset, Gagnon, & Beaulieu, 2000) and a gorilla infant (Visalberghi, 1984)]. However, none of these experiments, infant or animal, used a strictly relational paradigm. . Since prior research suggests that, at least 4-year olds (Gentner, 2003) and chimpanzees, can process relational information (Kuhlmeier, Boysen, & Mukobi, 1999; Oden, Thompson, & Premack, 1990) we set out, in experiment 2 and 3, to determine whether there is a background preference for Relative or non-Relative coding of spatial relations through all great ape genera to see if they share a cognitive ‘wild-type inherited from a common ancestor.

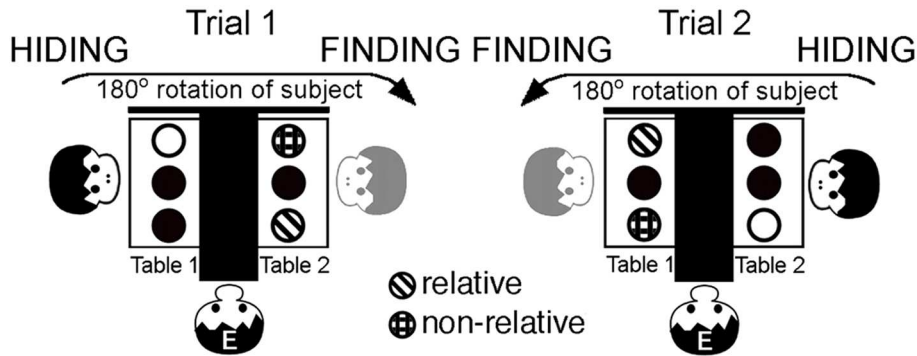


Figure 4.3: Experiment 2: Experimental setup in two consecutive example trials. Six exactly identical cups are placed on two tables (3 each). Participants are watching while a target is hidden under the cup depicted as white (HIDING). Then they move to the other table and indicate where they think a second target might be hidden (FINDING). The two differently striped cups show the different contingencies rewarded in one of two consecutive blocks of trials.

4.4.1 Experiment 2

This experiment is precisely analogous to experiment 1, conducted on adults and children in two communities.

Methods

Participants the final sample included 12 German preschool-children (6 male 6 female, mean age = 4 years 10 months, range = 4 years 10 months - 4 years 11 months), 3 orangutans (*Pongo pygmaeus*), 2 gorillas (*Gorilla gorilla*), 3 bonobos (*Pan paniscus*) and 5 chimpanzees (*Pan troglodytes*) participated in this experiment. Amongst non-human great apes, there were 4 males and 9 females ranging from 8 to 28 years of age ($M = 14.17$ years; $SD = 6.76$ years). All apes were housed at the Wolfgang Köhler Primate Research Center at Zoo Leipzig (Germany). They lived in social groups with conspecifics and had access to indoor and outdoor areas. During testing, the apes were fed according to their daily routine four times a day on a diet of fruit, vegetables and monkey chow; water was at their disposal at all times.

Setup The setup was similar to experiment 1 with the exception that the number of cups on each table was reduced to 3 (see procedure). The cups were arranged equidistant in a straight line from left to right of the participant (Figure 4.3). The experimenter was the first author. There were no instructions beyond the request to move to the other table and an invitation to search.

Procedure To adapt it to the shorter attention span of our non-human participants, and because of their known limitations with respect to abstract reasoning (Call, 2004), we have simplified the conditions as follows. In contrast to experiment 1 the Intrinsic and Absolute conditions are collapsed (Figure 4.3). The three identical cups in a straight line only offer two alternative strategies: The Relative one and a non-Relative one, which could be based on either Intrinsic or Absolute cues. The two conditions were administered in two consecutive blocks of 12 randomized trials for each individual, counterbalanced for order across subjects. The transition between the blocks was unmarked, as before. Randomly intermixed within blocks were 4 trials each in which the middle cup was the FINDING cup (Middle-condition). In these Middle-trials both rules lead to the same solution. Participants that did not at least perform 50 % correct on Middle-trials (cup in central position) were excluded from the final analysis (3 excluded). In all side-trials (all but the middle-condition), participants had a 1/3 chance to pick a FINDING cup, which was not related to the HIDING-cup following a Relative or non-Relative rule. Subjects who did so 50% of the time or more were also excluded from the final analysis (8 excluded).

Results

We used a mixed ANOVA to analyze the effect of the within-subject factor condition (*Relative / non-Relative / Middle*) and the between-subject factor genus (*Pongo / Gorilla / Pan / Homo*) on the percentage of trials in which subjects found the reward.

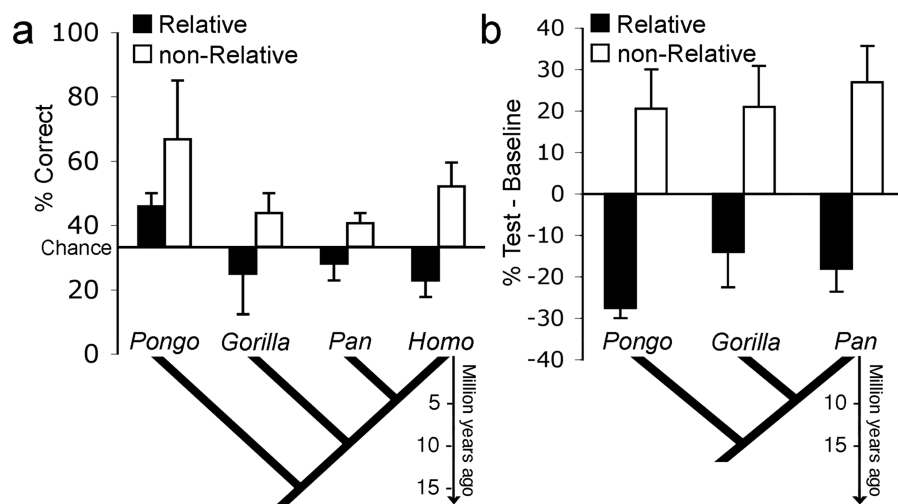


Figure 4.4: **a**: Experiment 2: Mean percent correct (\pm SE) for the Relative and non-Relative conditions for all great ape genera. Means are plotted against chance levels (33 %, 1 out of 3 cups) and mapped to the taxonomic tree below (see also Figure A.1). **b**: Experiment 3: Difference in choice of Relative and non-Relative cups between Baseline and Test-trials, mapped to the taxonomic tree below (see Figure A.1).

The ANOVA revealed a significant main effect of condition ($F(2,42) = 13.96$; $P < .001$; Relative: $M = 27.5$, $SD = 16.5$; non-Relative: $M = 49.5$, $SD = 21.8$; Middle: $M = 67.0$, $SD = 21.0$).

The planned simple comparison between the Relative and non-Relative conditions was conducted using a paired sample t -test and the P -value corrected for multiple comparisons according to Bonferroni-Holm. Apes performed better when the finding-container maintained the hiding-container's spatial relations to the surrounding environment than to the participants' own body-axis (Relative vs. non-Relative: $t(24) = 4.07$; $P < .001$). We detected no significant main effect of genus ($P = .67$) and no interaction ($P < .25$). Trends in the descriptive statistics show a similar pattern across all ape-groups (Figure 4.4a).

Discussion

Processing small-scale spatial relations between objects, apes deploy environmental layout more readily than self. Despite common expectations, this data indicate that Hominid spatial cognition is at least not always primarily egocentric.

4.4.2 Experiment 3

Although experiment 2 shows that apes are able to solve spatial relational tasks, their performance was at a low level. Previous literature has shown that abstract rules in general put considerable constraints on great apes' performance (Call, 2004). In experiment 3 we used the identical setup to experiment 2 but used a design in which there is no necessity for complex abstract rule learning.

Methods

Participants The final sample included 2 orangutans (*Pongo pygmaeus*), 5 gorillas (*Gorilla gorilla*), 4 bonobos (*Pan paniscus*) and 6 chimpanzees (*Pan troglodytes*). There were 6 males and 11 females ranging from 8 to

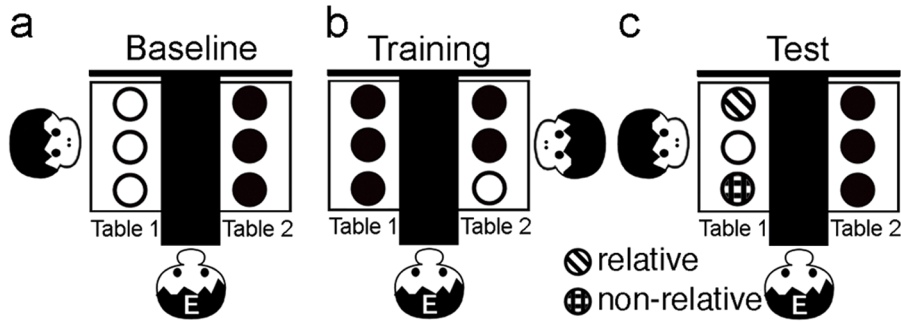


Figure 4.5: Setup and procedure in Experiment 3: When the animal entered the testing room it was directed to table 1. Here it had 10 trials in which all three cups were rewarded (a: Baseline). Then the animal was directed to table 2 and the experimenter started rewarding only one of the three cups until the animal would pick this particular cup 10 out of 12 times in a row (b: Training). When the animal hit criterion it was directed back to table 1 and again chose 10 times with all three cups rewarded in all trials (c: Test). We compared choice distributions between Test- and Baseline-trials.

29 years of age ($M = 14.88$ years; $SD = 7.88$ years). All apes were part of the same population described above. Of the original sample 4 animals were excluded because they chose the same cup $\geq 90\%$ of all trials across all sessions and 1 animal due to experimenter error. If in the TRAINING section of a session (see Procedure), an animal did not choose the training-cup 10 out of 12 times in a row within 60 trials, the session was terminated and excluded from the analysis. Of a total of 51 sessions 4 had to be excluded due to a failed criterion and 3 due to experimenter error.

Setup The setup was the same as in experiment 2. The experimenter was the first author.

Procedure We induced a strong spatial response bias for one of three identical cups by training apes to pick one particular cup from a lateral array of three. We then investigated how this response bias would manifest itself when the subject is rotated 180° . Suppose the training induces an expectation of reward under the leftmost cup. When the animal is rotated,

if the bias has been conceived of in egocentric terms, it should choose the leftmost cup; if on the other hand the animal has conceived of the array using allocentric coordinates, it should choose the rightmost cup (Figure 4.5c). In this way, rather than learn an abstract rule, the animal simply had to express its interpretation of the training bias.

Every animal went through three test-sessions on three different days. When the animal entered the testing room it was directed to table 1 (Figure 4.5). Here it had 10 trials in which all three cups were rewarded (Baseline, Figure 4.5a). We recorded the distribution of choices across the three containers. We scored the container selected by subjects based on videotapes and/or in situ notes. After the initial 10 trials the ape was directed to table 2, where again for 10 trials all three cups were rewarded to avoid two different game-contexts for the two tables. Then still at table 2, E started rewarding only one of the three identical cups for all trials to come, until the animal would pick this particular cup 10 out of 12 times in a row (Training, Figure 4.5b). Every animal participated in one session for each of the three potential ‘training-cups’ on table 2. The order of sessions was counterbalanced across subjects. When the ape hit criterion (10 of 12 correct choices in a row) it was directed back to table 1, thus undergoing 180° rotation, and again chose 10 times with all three cups rewarded in all trials (Test, Figure 4.5c). Again we recorded the distribution of choices across the containers.

Results

For statistical analysis we subtracted Baseline from Test choice-percentages for each cup to isolate effects of Training. As a manipulation-control, we first analyzed the session in which the middle cup was the training-cup on table 2 (Middle-sessions). If any training bias translated from table 2 back to table 1, the percentage of trials in which animals pick the middle cup should increase from baseline to test trials in Middle-sessions and therefore $\text{Test} - \text{Baseline} > 0$. A one-sample *t*-test against zero revealed a significant increase in percentage of middle cup choices on table 1 after it was repeatedly rewarded on table 2 ($t(14) = 4.17$; $P < .001$; $M = 22.00$; $SD = 20.42$).

To further see if apes preferred a particular strategy we analyzed sessions in which one of the Side cups was rewarded during training on table 2 (Side-sessions). We subtracted percentage of choices on Baseline- from those on Test-trials for those cups, which either preserved the Relative or the non-Relative characteristics of the trained cup. We computed the average value across the two Side-sessions and conducted a mixed ANOVA with the within subject factor FoR (*Relative* / *non-Relative*) and the between-subject factor genus (*Pongo* / *Gorilla* / *Pan*). The ANOVA revealed a main effect of FoR ($F(1,13) = 11.1$; $P < .01$; Relative: $M = -15.63$; $SD = 22.9$; non-Relative: $M = 21.25$; $SD = 17.5$), no main effect of genus ($P = .74$) and no interaction ($P = .86$). Post-hoc one-sample t -test against zero (Bonferroni-Holm-corrected) revealed that animals chose the Relative cup significantly less in Test than in Baseline trials ($t(15) = -2.73$; $P < .005$), while they chose the non-Relative cup significantly more often in Test- than in Baseline-trials ($t(15) = 4.87$; $P < .001$). This combination of results indicates a non-Relative translation of response bias. Trends in the descriptive statistics show a similar pattern across all genera (Figure 4.4b).

Discussion

Experiment 3 replicated great apes' preference to use environmental cues in contrast to self in a less demanding task. Taken experiment 2 and 3 together, all great ape genera prefer to process spatial relations based on environmental cues and not self. The standard methods of comparative cognition thus suggest a common phylogenetic inheritance of a preference for non-Relative spatial strategies from the ancestor shared by all four existing genera of Hominidae (*Pongo*, *Gorilla*, *Pan* and *Homo*). Based on this result we argue that at least for small-scale spatial relations, the inherited cognitive mode of operation is not, as argued by Kant and others, egocentric, but preferably deploys environmental cues as common reference between objects.

4.5 Conclusions

In this paper we combine research on intra-human variability and inter-Hominidae continuities to understand human cognition in its roots and variability. We compared humans with different cultural backgrounds and non-human great apes in a domain, spatial relations, accessible and highly relevant to all tested species. Experiment 1 showed that human spatial relational learning varies cross-culturally and that habitual cognitive preferences covary with habitual usage patterns in natural spatial language. This correlation is fully robust by age 8 and persists in adulthood.

In experiment 2 and 3 we tracked the functional signature of spatial relational learning through all great ape genera, i.e. right across the whole Hominidae family including representatives of Pongo, Gorilla, Pan and Homo (European 4-year olds). All genera prefer environment- to self-centred processing of spatial relations. The standard methods of comparative cognitive science suggest a common phylogenetic inheritance of a preference for environmental or allocentric over egocentric spatial strategies from the ancestor shared by all four genera. This conclusion upsets the Kantian assumption of the priority of egocentric spatial reasoning, but it does so on firm empirical grounds.

This inherited bias towards the allocentric coding of spatial relations, can be overridden by cultural preferences, as in our own Western preference for egocentric or Relative spatial coding. This override is not a rare or typically European phenomenon. Relative languages have been documented in industrial and indigenous cultures all over the globe (Majid et al., 2004), including for example the speakers of Kgalagadi, a Bantu language, who live a mere few hundred kilometers from the Hai||om language area (Neumann & Widlok, 1996). Nevertheless, overriding the bias might be expected to incur some costs - thus the theory makes predictions about the relatively greater difficulty of acquiring a predominantly egocentric coding system. First, some individuals might be expected to have some special difficulties - *prima facie* evidence comes from lifelong difficulties with 'left' and 'right' that some adults evidence (Elze, 1926). Second, the relevant linguistic spa-

tial relational constructions may be expected to be learnt later by children. Again, the evidence suggests this is correct: children in cultures where Absolute coding is predominant, seem to master this as early as 4, and certainly by 7 years of age (Wassmann & Dasen, 1998; Brown & Levinson, 2000; Leon, 1994), while children in Relative coding cultures do not seem to master full use of left/right systems till around 11 (Piaget, 1928).

The model for human cognition that we propose then has a rich, inherited primate basis, which may be masked by language and culture. Our primary access to these underlying defaults is through the study of our nearest primate cousins. The model does not suppose that language and culture can necessarily build cognitive structures entirely *de novo* - in the domain of spatial relations at least, all three frames of reference have clear neural substrates [Relative: posterior parietal cortex (Cohen & Andersen, 2002); Intrinsic: supplementary eye-fields (Olson & Gettner, 1995); Absolute: hippocampus and entorhinal cortex (O'Keefe & Burgess, 1996; Hafting, Fyhn, Molden, Moser, & Moser, 2005)], and these perhaps exhaust the available alternatives. The model makes predictions about differential human performance in the conditions where culture overrides an inherited default strategy. It places cladistic reasoning at the heart of an evolutionary psychology. We hope this perspective will supercede the very limited rhetoric of the controversies (Duchaine, Cosmides, & Tooby, 2001; Pinker, 1994, 2002; Tooby & Cosmides, 1992) which pit a simple nativist account of human cognition, admitting no cross-cultural variation, against a naive 'blank-slate' approach, which admits no strong phylogenetic inheritance behind human cognition.

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General Discussion

At the beginning of this thesis it was argued that in order to appreciate the distinctive hallmarks of human cognition we need to understand both the continuities and discontinuities within *Homo sapiens* and across all Hominidae. In an attempt to gain some insight into both, continuities and discontinuities, three chapters were presented contrasting great ape species (chapters 2 and 4), humans of different age groups (chapters 2 and 4) and humans with different cultural backgrounds (chapters 3 and 4). Findings of each experiment were presented and discussed within each chapter. The beginning of each of the following sections will provide in italics summarizing theses, expressing the general findings about continuities and discontinuities across species, age and cultures, reported in this dissertation. The body of the sections places these findings in the context of current theory and suggests directions for further research.

5.1 Continuities

Are there inherited defaults for spatial cognition in humans?

By ways of taxonomically informed cross-species comparisons we can reconstruct the cognitive architecture of their common ancestor. The ancestral cognitive predispositions are inherited by all extant species, representing a cognitive ‘wildtype’. The cognitive wildtype for spatial cognition in all great apes, including humans, preferentially deploys place over feature cues to retrieve hidden targets and environmental cues over self to code spatial relations.

The present thesis demonstrates an experimental approach to the inherited defaults of human spatial cognition and reveals a first glimpse at their structure and flexibility. There is a long standing discussion in developmental psychology as to whether cognitive capacities are hardwired in human brains at birth, and if yes, how many there are, which ones and to what extent they are predetermined (Elman et al., 1996; Fodor, 1985; Karmiloff-Smith, 1992; Gopnik & Meltzoff, 1997; Cosmides & Tooby, 1994; Pinker, 2002; Newcombe, 2002). The currently more prominent theoretical camp, nativism (Spelke, 2003; Cosmides & Tooby, 1994; Pinker, 1994, 2002),

claims that humans are born with a set of genetically controlled, informationally encapsulated processing units (modules), and preset developmental programs, which unfold throughout ontogeny (Fodor, 1975, 1985; Spelke & Newport, 1998). Hence, cognitive structure is universal across humans and experience irrelevant for cognitive development (Spelke, 2003). The innate modular structure of human cognition changes during ontogeny in two ways: Either through new, previously dormant modules coming online (Fodor, 1985; Scholl & Leslie, 1999) or through the combination of modularly processed information by means of combinatorial semantics (Hermer & Spelke, 1996; Spelke, 2003; Carruthers, 2002). In opposition, empiricists (Elman et al., 1996; Karmiloff-Smith, 1992; Newcombe, 2002) claim that humans are born with a set of general multi-purpose cognitive mechanisms, which potentially subserve a multitude of functions. These mechanisms react to the environment of the developing child, adapting to the surrounding problem space. To the extent that all humans are faced with almost identical problems during ontogeny (language, locomotion, gravity, support, etc.), cognitive structure may be expected to be universal across humans (Brown, 2004).

Challenges to both schools of thinking have taken several forms in the past, being either based on overarching theoretical arguments (Gopnik & Meltzoff, 1997; Karmiloff-Smith, 1992; Cosmides & Tooby, 1994; Pinker, 2002) or methodological critiques of specific empirical findings (Bogartz, Shinskey, & Speaker, 1997; Learmonth, Nadel, & Newcombe, 2002; Vargas & Lopez, 2005; Mix, 2002; Hespos & Spelke, 2004). As a result it becomes clear that nativism and empiricism are two extreme ends of a theoretical continuum and of great value as points of departure for empirical discussion. The truth, however, as it does so often, lies somewhere in between these two accounts. Human development must partly rely on both: Inherited pre-specifications and environment; Nature and Nurture. And most empiricists (Elman et al., 1996; Newcombe, 2002), and a little more reluctantly nativists as well (Spelke, 2003; Carruthers, 2002) will agree to an interactionist account of some form. But what form? The problem with the interactionist position is that the proposed interactions are either too trivial to be of any major interest or too complex to be empirically testable (Elman et al., 1996).

This is one of the points where this thesis will hopefully contribute to the field, by demonstrating the need for a controlled comparison of species and age groups in order to get a better handle on the inherited structure of human cognition. Chapters 2 and 4 presented data from all genera of our phylogenetic family (*Pongo*, *Gorilla*, *Pan* & *Homo*) and showed that they share behavioural preferences on spatial memory tasks. Since all genera exhibit the same behavioral tendencies or cognitive biases, this suggests inheritance from the common ancestor shared by all genera. Any such tendencies shared by all non-human great ape genera and any human population are most likely part of the primate inheritance shared by all humans and therefore part of the inherited predispositions of the human mind. In the case of spatial cognition, there seem to be inherited preferences in humans. However, claiming something to be ‘inherited’, does not explain how it comes about. From the data at hand, it is impossible to tell if it is an actual genetically coded cognitive preference, or the inevitable outcome of an interaction between genes and environment during the first few months of human ontogeny. So inherited defaults, revealed by means of cognitive cladistics, do not necessarily support either nativist or empiricist theories. In fact, genetic control and environmental influence are not necessarily contradictory mechanisms at all. Epigenetic developmental phenomena, meaning factors influencing cell-fate which are not coded in the DNA, are well documented in Biology. But these epigenetic effects might in turn be triggered by genetically coded mechanisms. Genes may partially set up environmental (e.g., chemical) gradients that then channel further cell development. In a similar way, environmental stimuli may channel the particular course of cognitive development. The empirical task ahead is not to attempt to prove one theoretical extreme or the other, but to explore these complex interactions and understand how they constrain outcomes.

In the future, cognitive cladistics should be applied to similar data-sets to scope other cognitive domains such as causality, social learning or symbolic thought, in order to slowly carve out a more complete picture of the human cognitive wildtype. However, the power of the cognitive cladistics approach does not end with the detection of common cognition, but maybe even more

interesting, it can detect outliers. By comparing a complete and extensive set of species with common ancestry, one of the tested species might turn out to diverge from the majority. Species might have undergone special evolutionary adaptations, unique to their evolutionary past, and distinct from those of the other members of the family. The resulting cognitive abilities and preferences are unique to this species amongst its relatives. We can ask questions such as: Which cognitive abilities make chimpanzees chimpanzee, orangutans orangutan and humans human? The most common approach to find out what's uniquely human, has been to compare human children to chimpanzees. But how do we know that any given difference is not uniquely chimpanzee, while humans share their version of the trait with the rest of the great apes? Controlled cognitive cladistics will not only be able to tell us who shares what with whom, but also who doesn't.

5.2 Discontinuities

Are inherited defaults for spatial cognition in humans affected by uniquely human capacities such as language?

Language, in one way or the other might reorganize inherited cognitive predispositions in early human ontogeny. Language might also introduce cognitive diversity. Human cognition is not always universal. Not even all those parts we inherit from our evolutionary ancestors.

Chapter 1 posed the question whether uniquely human cognitive abilities, such as language, could mould or restructure our inherited cognitive predispositions. Chapter 2 compared children before and after the critical period of language acquisition. While young infants share the cognitive preferences of the other great apes, older children show the opposite preference. It seems that the human cognitive wildtype can be restructured, in this case even inverted, during this critical phase of human ontogeny. Both, nativists and empiricists have discussed similar effects. For example, in two recent overview papers (Newcombe, 2002; Spelke, 2003), one by a nativist (Spelke, 2003) argued that the combinatorial semantics of natural language can recombine

information processed in innate modules, while the other, by an empiricist (Newcombe, 2002) argued that any experience (and this must logically include language exposure) might be part of the environmental influence on innate general multi-purpose cognitive mechanisms. So both authors conceded, directly or indirectly, that language might affect development, however, both authors assume these effects on cognition to be universal across humans, because all human children acquire language (Spelke, 2003; Newcombe, 2002). This deduction, I argue, is not necessarily valid. While it is true that all normally developing children will acquire language and therefore some general effects of language on thought might be universal to humans, languages vary in their structure and content and might impose specific effects on thought which might then result in cognitive diversity across cultures.

Chapters 3 and 4 presented data from two extremely different human cultural groups: Dutch and Hai||om. The two groups differed profoundly in their cognitive preferences for processing spatial relations. While Dutch subjects preferred to use themselves as a spatial anchor point, Hai||om adults and children preferred to use a cardinal-direction type system. This difference resembles the habitual linguistic coding prevalent in the two languages. The cross-cultural differences in cognitive preferences persisted across an increase of task-demand and were not easily overcome by subjects at will. Both above-mentioned review-papers (Spelke, 2003; Newcombe, 2002) underestimate the variability of human cognition, although they do so for completely different reasons. Spelke (2003) assumes human cognition to be universal because it is the result of a universal, predetermined development from universal innate sources. Newcombe (2002) argues that human cognition is universal because it is the inevitable outcome of the interaction between a flexible organism and a universal environment. In contrast to both accounts, the present data show that variable adult cognition rests on a common inherited foundation responsive to variable environments. In chapter 4 I propose a model, which assumes strong inherited biases and preferences in human cognition and the abilities to override those to adapt to cultural specifications. Even in a domain such as spatial cognition, where there exists an inherited primate wildtype in humans, culture, mediated by language, can overpower

predispositions. Culture allows fast adaptations to variable ecologies and these adaptations include the redistribution of cognitive preferences. In the coming years this model should be fleshed out by answering some questions such as: Can culture override the wildtype in other cognitive domains? Does the wildtype still exist in culturally ‘reformed’ adults, or is the override thorough and permanent? Are the abilities that are needed to override cognitive predispositions uniquely human?

As well as cognitive cladistics, cross-cultural psychology yields additional power not brought to bear in this thesis. While chapters 3 and 4 only demonstrated differences between cultural groups, cross-cultural comparisons might also reveal commonalities and even universals. What constitutes universality is not very well defined in cognitive psychology, for the simple reason that psychologists tend to assume universality of their findings in the first place. The documentation of cognitive diversity, such as in chapter 3 and 4 poses a theoretical challenge to that assumption and an even greater empirical challenge to cognitive psychology as a whole. In fact, many psychological functions that were assumed to be universal turned out not to be: Memory for and categorization of focal colours (Roberson, Davies, & Davidoff, 2000; Roberson, Davidoff, Davies, & Shapiro, 2004), category-based inductive reasoning (Bailenson, Shum, Atran, Medin, & Coley, 2002), (Medin & Atran, 2004), perceptual illusions (Segall, Campbell, & Herskovits, 1963), eye-movements in scene-perception (Chua, Boland, & Nisbett, 2005), temporal concepts (Boroditsky, 2001), numerical reasoning (Pica, Lemer, Izard, & Dehaene, 2004; Gordon, 2004), spatial reasoning (Levinson, 2003), preferred decisions in the ultimatum game (Henrich et al., 2005), independent self-concepts (Markus & Kitayama, 1999), the similarity-attraction effect (Heine & Renshaw, 2002), the fundamental attribution error (Choi, Nisbett, & Norenzayan, 1999), the prevalence of major depression (Weissman et al., 1996), noun bias in language learning (Tardif, 1996), and moral reasoning (Miller & Bersoff, 1992). This list is not by any means exhaustive [for more see: Norenzayan & Heine, (2005)]. The abundance of cognitive non-universals and the minimal amount of experimentally established universal cognitive functions [e.g., quantity sense (Dehaene, 1997); geometrical

intuition (Dehaene, Izard, Pica, & Spelke, 2006)] should make cognitive science step back and consider what kind of cross-cultural evidence is needed to empirically establish a human universal (Norenzayan & Heine, 2005).

The question what makes humans human has always played centre-court in all cognitive sciences. Very recently the European Community has established major funding schemes under the label “What does it mean to be human?”. To a cognitive psychologist this question roughly translates like this: What are the mental characteristics that differentiate human cognition from that of other animals in ways that allow for characteristically human behaviour? Considering continuities and discontinuities, we can already say something about the answer to that question, which should narrow down our search-grid: Whatever those mental characteristics are, they have to be uniquely human amongst the great apes and universal to all humans. In other words: If we decide a mental characteristic is definitional to being human, any other ape that has it would be ‘human’, and any human that doesn’t have it would not be ‘human’. While universality is hardly ever considered, uniqueness has been investigated, most informatively, by comparing human and chimpanzee behaviour, leading to manifold proposals of uniquely human characteristics: Teaching (Gergely & Csibra, in press), shared intentionality (Tomasello, Carpenter, Call, Behne, & Moll, 2005), cooperative temperament (Hare & Tomasello, 2005), understanding of unobservable object properties (Vonk & Povinelli, in press), symbolic thought (Dennet, 1991; Deacon, 1997), and relational thought (Gentner, 2003), to just name a few. But at the end of the day, only careful, taxonomically informed comparisons across all great apes will tell us what is and what isn’t uniquely human. And similarly, only extensive anthropologically and linguistically informed comparisons across human cultures will tell us what is and what isn’t universally human.

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Appendix

A.1 Terminology

A.1.1 Place vs Feature

There are two main strategies for coding object-location: Using place (“I will be waiting for you just north of the exit”) vs. using object-features (“I’ll be waiting for you in the red car”).

Place The Place strategy assumes a stable relationship between a target and the surface. So in a scene with several movable objects supported by a single surface, the location of any object will be defined relative to the surface. Other objects in the scene are irrelevant.

Feature The Feature strategy assumes a stable relationship between a target and it’s closely surrounding (potentially movable) objects. So in a scene with several movable objects supported by a single surface, the location of any object will be defined relative to one or more other objects which are identified by means of their perceptual features. The surface is irrelevant.

A.1.2 Spatial Frames of Reference

Linguistic Frames of Reference

Underlying linguistic descriptions of spatial arrays are coordinate systems or frames of reference (FoR). They serve to specify the directional relationship between objects, in reference to a shared spatial anchor. A system of three different kinds of reference systems emerged from analyzing natural and elicited conversation in over 20 languages at the Max Planck Institute for Psycholinguists (Levinson, 2003):

Relative Spatial Frame of Reference A Relative FoR describes a figure (F) to ground (G) relative to a presupposed viewpoint (V) outside both F and G. V must be centered on an observer. Relative FoR descriptions are

always ternary.

“The ball is to the left of the tree (from my point of view).”

Intrinsic Spatial Frame of Reference An Intrinsic FoR describes a figure (F) to ground (G) relative to a coordinate system centered in an ‘inherent feature’ of G. G must be a faceted object. Intrinsic FoR descriptions are always binary.

“The tree is at the front of the house.”

Absolute Spatial Frame of Reference An Absolute FoR describes a figure (F) to ground (G) relative to a coordinate system anchored to fixed, potentially non-visible bearings centered in G. Absolute FoR descriptions are always binary.

“Theres an ant by your southern leg.”

Cognitive Frames of Reference

Relating this distinction to a non-linguistic cognitive distinction is a difficult task. Many systems of classification exist in Cognitive Psychology but most only feature two different FoRs (e.g. Egocentric vs. Allocentric). From a cognitive perspective the three linguistic FoRs differ most clearly in which types of origin they dominantly use for their respective coordinate systems. Relative constructions dominantly use observers as origin, Intrinsic constructions use faceted objects and Absolute constructions use axes inherent in the larger surroundings. Indeed, these are frequency patterns, not clear-cut distinctions. It is quite possible to for example use an observer as origin in an Intrinsic construction (“The tree is at my front.”). But, to the best of my knowledge, these are the exceptions. For reasons of parsimony, this thesis uses the linguistic terminology to refer to the cognitive strategies as well:

Relative (Cognitive) Frames of Reference A Relative cognitive FoR relates objects within a coordinate system originating in the observer, using the body axes as directional references (often called egocentric).

Intrinsic (Cognitive) Frames of Reference An Intrinsic cognitive FoR relates objects within a coordinate system originating in a faceted object, using its axes as directional references (often called object-centered).

Absolute (Cognitive) Frames of Reference An Absolute cognitive FoR relates objects within a coordinate system originating in the structure of the larger surrounding, using its axes as directional references (often called geocentric).

A.2 Populations

A.2.1 Non-human populations

All non-human great apes observed in the course of this thesis are captive animals housed in the Wolfgang Köhler Primate Research Center in Leipzig, Germany. The Center operates within the context of the Leipzig Zoo and employs fourteen zoo keepers who provide routine animal care including feeding, cleaning, and enrichment. The breeding program at the zoo is framed within the global strategy of the European Endangered Species Program (EEP). All apes live in social groups with con-specifics and have access to large indoor and outdoor areas. During the studies reported in this thesis all apes were fed three times a day on a diet of fruit, vegetables, monkey-chow and occasionally meat. In addition, each season apes receive special foodstuffs (e.g., chestnuts) that the keepers hide in certain areas of the enclosure to promote natural foraging activities; other opportunities for special foraging activities (e.g., at artificial termite mounds) are also made available on a regular basis. Participation in study sessions was optional for all animals. In cooperation with the zoo, the Wolfgang Köhler Primate Research Center supports efforts to conserve great apes, both in the wild and in captivity. Due to habitat destruction through logging and hunting for meat or pets, all great ape species except the chimpanzee are endangered species according to the 2006 IUCN Red List of Threatened Species.

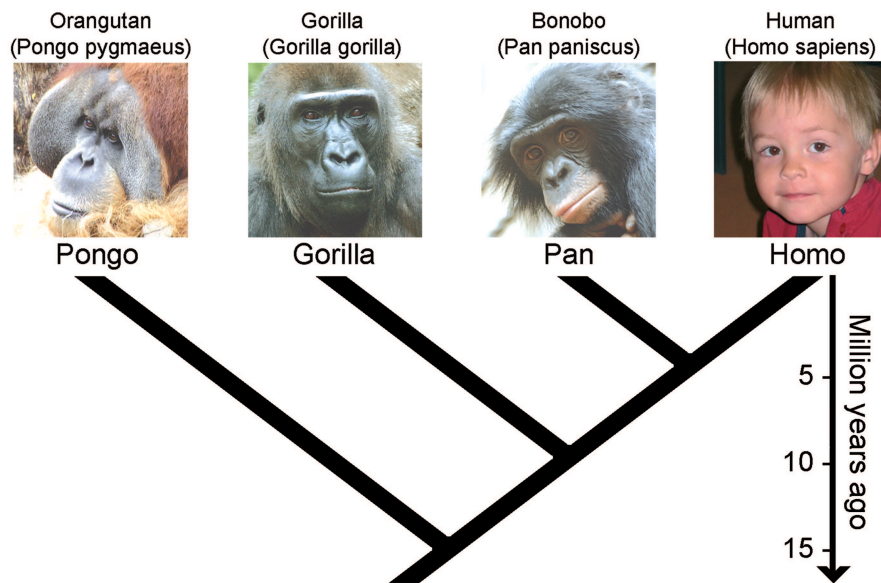


Figure A.1: Phylogenetic tree displaying the evolutionary relationships between the four extant Hominid genera (*Pongo*, *Gorilla*, *Pan*, *Homo*). The photographs display individuals of four representative species. All five extant species of Hominids participated in research reported in this thesis: Orangutan (*Pongo pygmaeus*), gorilla (*Gorilla gorilla*), bonobo (*Pan paniscus*), chimpanzee (*Pan troglodytes*) and human (*Homo sapiens*). Here I assume a taxonomy based on monophyletic groups. In this framework Hominidae include all the great apes including humans but not the Hylobatidae or small apes. Further information about non-human great ape species can amongst others be found in the following sources: (Macdonald, 2001; Call & Tomasello, 2007).

Orangutans (*Pongo pygmaeus*)

- Taxonomy

Orangutans diverged from the human lineage approximately 12-15 million years ago and therefore represent the great ape most distally related to humans. According to some, the orangutan populations on the islands of Sumatra and Borneo represent two distinct species. However, this taxonomic split is disputed in the literature. Although the two groups are genetically and morphologically different, both Bornean and Sumatran orangutans readily breed and produce fertile offspring in captivity. Furthermore, the behavioral repertoire of Bornean and Sumatran orangutans is basically identical. I will make no distinction between the two groups in this thesis.

- Morphology

Orangutans have coarse, long hair that varies from orange to brown in adults. They are characterized by a strong sexual dimorphism. Males are for example twice as heavy as females. In addition, there are two different sexually mature male morphs that are distinguished by both morphological features and behavioral traits. Fully developed or 'flanged' males display a number of secondary sexual characteristics, such as wide cheek pads, longer hair, and a large laryngeal sac. Unflanged males are about the same size as adult females and do not show these secondary sexual features, but they are sexually fully mature and able to sire offspring. Infants' are born with pink faces that darken with age.

- Behavior and Ecology

Orangutans represent the only Asian species of great ape and live exclusively in restricted areas on the islands of Sumatra and Borneo. Orangutans inhabit primary rain forests up to an altitude 1500m. The orangutan population density varies between 2 to 7 individuals per km^2 . They are mainly arboreal and feed on fruit, leaves, bark and animal prey. The small food patches in Bornean forests, which cannot feed more than one orangutan, force the animals to limit their social

interactions: The male is solitary and his territory overlaps the territory of several separate females traveling with their offspring. Thus, the semi-solitary social organization of orangutans can be described as an individual-based fission-fusion system that is highly variable over space and time. The adult male's long call attracts estrous females for mating. Unflanged males might forcibly rape females. Every night, orangutans construct a new leaf nest by braking branches of trees to form a platform. They may also construct leaf shelters to protect themselves from rain. The low population densities and large homeranges of orangutans require extended and undisturbed forest formations.

- Group Size: 1-5
- Average Body Weight: ♀: 40kg; ♂: 80kg
- Average Life Span: 59 years
- Average Neocortex Ratio¹: 3.14
- Estimated Wild Population²: 45 000

Gorillas (*Gorilla gorilla*)

- Taxonomy

Gorillas diverged from the human lineage approximately 7-10 million years ago. Within the Hominidae, they are as genetically distant from chimpanzees as they are from humans. In some current taxonomies, gorillas are classified as two species; western gorillas *Gorilla gorilla* and eastern gorillas *Gorilla beringei*. However the split into two different species is debated and related issues unresolved. Genetically the two groups are not different enough to justify the split and we know too little especially about western gorilla's behaviour in the wild to base the separation into two species on behavioural differences (as is done

¹The neocortex ratio is the ratio between neocortical volume and the volume of the rest of the brain. The average human neocortex ratio for example is 4.02 (Aiello & Dunbar, 1993). In comparison, spotted hyenas (*Crocuta crocuta*), have an average neocortex ratio of 1.94, one of the highest amongst carnivores (Dunbar & Bever, 1998).

²Source: UNEP (United Nations Environment Programme)

with Chimpanzees and Bonobos). In this thesis I will not differentiate between the two groups.

- Morphology

Gorillas are the largest and the most sexually dimorphic of all extant primate species. Gorilla pelage color varies from black over brown to gray. Adult males have an enlarged sagittal crest and a silvery color on the back that extends to the rump and thighs. Each gorilla has a unique nose pattern allowing for individual identification, not dissimilar to human fingerprints.

- Ecology and Behavior

Gorillas occur in two widely separated regions of Central Africa: One in the west and one in the east and they are found in a variety of forest habitats including primary low land rainforest, secondary forest, swamp forest, marshy clearings, and even dense alpine forest up to an altitude of 3000m. Gorillas are mainly terrestrial quadrupedal knuckle walkers and build new ground nest for sleeping every night. Depending on the season Western lowland gorillas feed on fruit, seeds, stems, piths and insects. They usually live in singlemale multifemale groups, but larger groups might host several silverback males.

- Group Size: 3-21
- Average Body Weight: ♀: 72kg; ♂: 170kg
- Average Life Span: 50 years
- Average Neocortex Ratio: 3.25
- Estimated Wild Population: 98 000

Bonobos (*Pan paniscus*)

- Taxonomy

Bonobos belong to the great ape clade together with orangutans, humans, chimpanzees, and gorillas. Bonobos and chimpanzees are humans' closest living relatives. Current estimates suggest that humans

shared a common ancestor with chimpanzees and bonobos around 5-7 million years ago. Bonobos along with common chimpanzees (*Pan troglodytes*), belong to the genus *Pan*. Their last common ancestor lived around 1.2 to 2.7 million years ago.

- Morphology

Bonobos are less sexually dimorphic than the other great apes. They are black and may turn gray with age. Bonobos are sometimes called pygmy- or dwarf chimpanzees, but these labels are misleading since bonobos are not actually smaller than chimpanzees, but merely have a more slender build than their close relatives. The face is black from birth, and the hair seems to be parted on top of the head. Adult males and females have over-proportionally large primary genitalia.

- Ecology and Behaviour

Bonobos inhabit the lowland rainforest of the Congo basin in the Democratic Republic of Congo. They are mixed arboreal and terrestrial foragers. They mainly knuckle-walk quadrupedally but they also occasionally walk bipedally. Bonobos feed on fruit leaves, herbs truffles, honey and small animal prey. They live in large multimale multifemale fission-fusion groups. In contrast to the more patrilineal society of chimpanzees, the society of bonobos centers around the adult females. Males establish dominance relationships with each other, but aggression is generally less intense than in chimpanzees, and conflicts are often settled in non-agonistic ways. Bonobos often engage in sexual behaviour that has no reproductive value for conception, including male and female homosexual interactions. Bonobos build new tree nest for sleeping every night.

- Group Size: 50-200
- Average Body Weight: ♀: 31kg; ♂: 39kg
- Average Life Span: 40 years
- Average Neocortex Ratio: 3.15
- Estimated Wild Population: 15 000

Chimpanzees (*Pan troglodytes*)

- Taxonomy

Chimpanzees and Bonobos are humans' closest living relatives. Current estimates suggest that humans shared a common ancestor with chimpanzees and bonobos around 5 to 7 million years ago. Likewise, chimpanzees shared a common ancestor with bonobos between 1.2 and 2.7 million years ago.

- Morphology

Chimpanzees are covered by black hair although some individuals turn grey with age in some areas of their body. Both genders often have a short white beard. The ears are prominent. Infants have pink to brown facial skin that darkens with age. Chimpanzees show a modest sexual dimorphism with males being slightly larger than females.

- Ecology and Behaviour

Chimpanzees inhabit dry woodland savannahs, grasslands and forests up to an altitude of 3000m all throughout equatorial Africa. They are mixed arboreal and terrestrial foragers. While on the ground they mainly knuckle walk quadrupedally but occasionally also walk bipedally. Chimpanzees feed on fruit leaves, herbs truffles, honey and animal prey including other primates. They live in large multimale multifemale fission-fusion groups with a stable dominance structure in which males are dominant over females. In the wild, chimpanzees, more than other non-human great apes, modify objects in their environment as tools for termite fishing, ant dipping, sponging water, hammers and anvils. Both infanticide and cannibalism have been reported in wild Chimpanzees. Humans still quite extensively hunt Chimpanzees for food and pets and while invasive medical research is forbidden on all great apes in Europe, US American medical research laboratories still hold more than 1000 Chimpanzees for invasive experimentation.

- Group Size: 10-100

- Average Body Weight: ♀: 31kg; ♂: 39kg

- Average Life Span: 53 years
- Average Neocortex Ratio: 3.15
- Estimated Wild Population: at least 175 000

A.2.2 Human populations

Europeans

The Netherlands and Germany are post-industrial Western-European nations with a mixed rural and urban lifestyle, inhabiting a densely populated landscape. In this thesis, European children under the age of 5 (chapters 2 and 4) were recruited in Leipzig, Germany, a city with approximately 500000 inhabitants. European children above 5 years of age (chapters 3 and 4) were recruited in Millingen aan de Rijn, a Dutch village with approximately 6000 inhabitants. All children were from mixed socio-economic backgrounds. The European adult population consisted mainly of university undergraduate students attending Radboud University, Nijmegen, the Netherlands.

ǀAkhoe Hai||om

The ǀAkhoe Hai||om are a group of (recent former) hunter-gatherers living in the savannah of Northern Namibia, roughly between the Omuramba Owambo river and the Angolan border. Their language, ǀAkhoe Hai||om, is part of the Khoekhoe cluster within the Khoisan language family. In comparison with the majority of people living in southern Africa, most speakers of ǀAkhoe Hai||om have maintained an unusual cultural profile including healing trance dances, hunting magic, a lunar calendar and the use of a landscape-term system for spatial orientation. As with all people considered to be ‘San’ or ‘Bushmen’, the ǀAkhoe Hai||om are politically and economically marginalized and their language has a low reputation. Their traditional hunting and gathering land has been under threat for the last 60 years at least and has increasingly been claimed by Bantu people or white Africans as farmland. As a result, the nomadic lifestyle of the ǀAkhoe Hai||om is under serious

threat and many ǀAkhoe Hai||om now find a living as farmhands on farms in their former homeland. The research reported in this thesis was conducted at a farm settlement commonly called “Farm 6” in Mangetti West, a government-owned farm set up to host ǀAkhoe Hai||om fleeing from the war of independence that was ravaging their Northern territories. With some 200 ǀAkhoe Hai||om, Farm 6 is the largest concentration of ǀAkhoe Hai||om where they are in the majority. There is now a lower primary school at Farm 6 with grades 1 through 5, with about 60 children attending out of a population of 90 potential pupils. The languages of instruction are English and Khoekhoegowab, the only standardised variety of the Khoekhoe cluster.

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Summary

Approximately 70 000 years ago, *Homo sapiens sapiens* was on the brink of extinction. The effective population consisted of roughly 4000 individuals. A mere 50 000 years later, *Homo sapiens sapiens* is the only remaining species of the genus *Homo* and after another 20 000 years 6 Billion *Homo sapiens sapiens* populate every possible corner of the planet across a variety of habitats unmatched by any other mammal species. Of course we are by far not the only survivors of that time. Every animal roaming earth today in one way or the other successfully adapted to its particular evolutionary pressures. Among those animals are very close relatives of the *Homo* lineage: The other great apes. But somehow the evolutionary path and the current behavioural patterns of *Homo sapiens sapiens* seem quite different even from our nearest living cousins. So what was it? What did *Homo sapiens sapiens* have that other *Homo* didn't? Was it sheer luck? Or were these 4000 individuals different in a way that ensured their survival? The conviction seems to be that they were indeed special and that their speciality was not their strength, or durability, but their cognitive abilities. *Sapiens sapiens* was the better thinker.

In the effort to understand our origins and place amongst the other animals we ask questions such as: What were the cognitive structures of our common ancestors? Are there inherited cognitive defaults in humans? If so, which ones are evolutionarily old, and which ones are recent innovations? Does 'inherited' mean immune to ontogenetic factors? From a scientists perspective, the biggest problem with these questions is that cognition does not fossilize. Paleoanthropologists have inferred cognitive abilities based on skull shape and handcrafted artifacts but the available information is only

distantly related to the actual phenomenon of interest: cognition. In this dissertation I try to create an additional and slightly more direct empirical access to inherited cognitive structures in humans and assess their vulnerability to ontogenetic factors such as cognitive maturation and cross-cultural variation.

The goal of this thesis is in essence to infer cognitive abilities in an evolutionary ancestor to *Homo sapiens sapiens*. Any cognitive ability, which is part of a shared repertoire between related species, is likely to be part of the evolutionary inheritance ever since their last common ancestor. Following a similar approach, humans have been compared to capuchin monkeys, tamarins, and chimpanzees to name but a few. And indeed continuities between humans and our phylogenetic cousins are striking. Not only do other primates display understanding of faces, distinctiveness of hidden objects and number, they also display ‘human-like’ abilities in more complex cognitive tasks such as perspective taking and cooperation. But comparisons between humans and one other, maybe even distantly related primate, as interesting as it might be, will not tell us anything about an evolutionary ancestor to humans. To put it bluntly: *Chimpanzees are not a human ancestor*. Neither is any other living primate. Evolution is not a stepwise process in which organisms moved closer and closer to the human state. Every living animal is the momentary result of a long evolutionary history. Chimpanzees are as far removed in evolutionary time from their last common ancestor with humans, as humans are. With that in mind, we can still use a comparative approach to gain information about our evolutionary ancestors, as long as we are careful about who we compare with whom. The argument goes as follows: If a certain trait exists in all species of a close phylogenetic family (clade), the trait must have been present in their common ancestor. Ideally one would compare *all* extant species of a *maximally large* family with a single common ancestor. The great apes are such a close family of species with a common ancestor (Hominidae). Today 5 Hominid species are still in existence: Orangutans, Gorillas, Bonobos, Chimpanzees and Humans. If all these species shared a particular cognitive preference or ability, it is most likely part of the evolutionary inheritance of the family at least ever since their last common

ancestor, and therefore also an evolutionarily old, inherited cognitive default in humans.

The investigated cognitive domain in this thesis is spatial cognition, more specifically spatial memory strategies and concepts of how objects are ‘organized’ in space (spatial relations). Across three experiments I compared all 4 species of non-human great apes, and humans of 4 different age-groups and 2 different cultures on their preferences in these cognitive abilities.

In **chapter 2**, using a basic spatial memory task, I first contrast the skills of all the extant great apes including 1-year old human infants. Results show that all non-human great apes and 1-year old human infants exhibit the same preference for a particular memory strategy. This suggests the common ancestor of all great apes had the same preference. Further tests revealed the reverse preference in 3-year old human children. Thus, the continuity between our species and the other great apes is masked during early human ontogeny. Increasing language proficiency and the accompanying rapid enculturation are discussed as possible explanations for the change in strategy-preference.

Language and culture facilitate flexible adaptations to varying ecologies, enabling humans to inhabit a vast repertoire of environments. So if language and culture vary across humans, and if language and culture can restructure our inherited predispositions in early development (chapter 2), mature cognition might also vary between cultural communities. **Chapter 3** addresses the question if variability across languages might result in cognitive variability across their speakers. Dutch and Namibian elementary school children were compared using a spatial reconstruction task. The two cultures differ in the way they predominantly express spatial relations in language. Three experiments investigated cognitive strategy preferences across different levels of task-complexity and instruction. Data show a correlation between dominant linguistic expressions and preference patterns in a non-linguistic cognitive task. When instructed to use their respective non-habitual cognitive strategy, participants were not easily able to switch between strategies and their attempts to do so decreased their performance levels. The possibility that language might play a role in inducing stable preferences in cognitive strategy is discussed.

On the one hand, all humans inherit cognitive predispositions from an evolutionary ancestor (chapter 2). On the other hand, human cognition is variably adaptable to cultural circumstance (chapter 3). Although these two statements could be seen to contradict each other, I argue in **chapter 4** that they need not be. First, the same two cultural groups as in chapter 3 are compared on their cognition for spatial relations. As before the two cultural groups diverge, parallel to linguistic coding strategies. Furthermore, mature non-human great apes were tested with the very same spatial task to establish the inherited primate baseline. Results show that human culture can override even the basic cognitive preferences we inherited from our common ancestor with the other great apes. In conclusion I propose a model for human cognition that has a rich, inherited primate basis, which may be masked by language and culture, predicting differential human performance in the conditions where culture overrides an inherited default strategy.

We will only be in a position to appreciate the distinctive hallmarks of human cognition when we understand both the continuities and discontinuities within *Homo sapiens* and across all the extant members of our immediate phylogenetic family, the Hominidae.

Samenvatting

Ongeveer 70 000 jaar geleden stond *Homo sapiens sapiens* op het punt van uitsterven. De effectieve populatie bestond uit ruwweg 4000 individuen. Niet meer dan 50 000 jaar later is *Homo sapiens sapiens* de enig overgebleven soort van het geslacht *Homo* en nog 20 000 jaar later bewonen 6 miljard *Homo sapiens sapiens* alle mogelijke uithoeken van onze planeet, verspreid over een verscheidenheid aan habitats, hierin ongevenaard door welke andere soort zoogdier dan ook. Natuurlijk zijn we bij lange na niet de enige overlevenden uit die tijd. Elk dier dat vandaag de dag over de aarde zwerft heeft zich op de een of andere wijze met succes aangepast aan zijn specifieke evolutionaire problemen. Onder die dieren bevinden zich nauwe verwanten van het geslacht *Homo*: de andere grote apen. Maar op de een of andere manier lijken de evolutionaire ontwikkeling en de huidige gedragspatronen van de *Homo sapiens sapiens* behoorlijk verschillend van zelfs onze meest verwante neven en nichten. Dus wat was het? Wat had *Homo sapiens sapiens* dat de andere *Homo* niet hadden? Was het puur toeval? Of waren deze 4000 personen op een zodanige wijze verschillend van de anderen, dat dit hun overleving garandeerde? Men lijkt ervan overtuigd te zijn, dat ze inderdaad bijzonder waren en dat hun bijzonderheid niet in hun kracht of fysieke uithoudingsvermogen lag, maar in hun cognitieve vermogens. *Sapiens sapiens* was de betere denker.

Als we onze herkomst en plaats tussen de andere dieren willen begrijpen, stellen we vragen als: wat waren de cognitieve structuren van onze gemeenschappelijke voorouders? Heeft de mens gerfde cognitieve standaard eigenschappen? En zo ja, welke hiervan zijn in evolutionair opzicht oud, en welke zijn recente vernieuwingen? Betekent 'gerfd' immuun voor ontogenetische

factoren? Vanuit het perspectief van een wetenschapper is het grootste probleem bij deze kwesties dat cognitie niet in fossielen terug te vinden is. Paleoantropologen hebben cognitieve vermogens herleid uit schedelvormen en handgemaakte artefacten, maar de beschikbare informatie is slechts indirect gerelateerd aan het verschijnsel waarin we genteresseerd zijn: cognitie. In deze dissertatie probeer ik een directere empirische toegang te krijgen tot gerfde cognitieve structuren van de mens en de kwetsbaarheid ervan te bepalen voor ontogenetische factoren, zoals cognitieve rijpheid en interculturele variatie.

Een belangrijk doel van dit proefschrift is om uit de cognitieve vermogens van *Homo sapiens sapiens* en zijn evolutionair naaste verwanten de cognitieve vermogens van een gedeelde evolutionaire voorouder af te leiden. Elk cognitief vermogen dat wordt gedeeld door verwante soorten maakt waarschijnlijk deel uit van de evolutionaire overerving sinds hun laatste gemeenschappelijke voorouder. Met een dergelijke benadering zijn mensen vergeleken met kapucijnapen, tamarins en chimpansees, om er slechts een aantal te noemen. En inderdaad is de samenhang tussen mensen en onze fylogenetische neven en nichten opvallend. Andere primaten hebben niet alleen herkenning van gezichtsuitdrukking, objectpermanentie, en het onderscheiden van getallen, ze vertonen ook 'menselijke' vermogens bij meer complexe cognitieve taken, zoals het innemen van een perspectief en van samenwerking. Maar vergelijkingen tussen mensen en een andere, misschien zelfs ver verwante primate, hoe interessant ze ook zijn, zeggen nog niets over een evolutionaire voorouder van de mens. Om het simpel te zeggen: *de chimpansee is geen voorouder van de mens*. Net zo min als welke andere levende primate dan ook. Evolutie is geen stapsgewijs proces waarbij organismen steeds meer de menselijke levensvorm zijn gaan benaderen. Elk levend dier is het tijdelijke resultaat van een lange evolutionaire geschiedenis. Chimpansees zijn in evolutionaire tijd net zo ver verwijderd van hun laatste gemeenschappelijke voorouder met de mens als de mens dat zelf is. Met deze wetenschap in ons achterhoofd kunnen we nog steeds een vergelijkende benadering gebruiken om informatie te krijgen over onze evolutionaire voorouders, zolang we ons bewust blijven van wie we met wie vergelijken. De redenering luidt als volgt: als

een bepaald kenmerk bij alle soorten van een nauw verwante fylogenetische familie (clade) voorkomt, moet dat kenmerk aanwezig geweest zijn bij hun gemeenschappelijke voorouder. Idealiter zou men alle nog bestaande soorten van een zo groot mogelijke familie vergelijken met een enkele gemeenschappelijke voorouder. De grote apen zijn zo'n nauw verwante familie van soorten met een gemeenschappelijke voorouder (Hominidae). Vandaag de dag zijn er nog vijf soorten Hominiden in leven: Orang-oetangs, Gorillas, Bonobos, Chimpansees en de Mens. Als al deze soorten een bepaalde cognitieve voorkeur of een cognitief vermogen zouden delen, dan behoort deze zeer waarschijnlijk tot de evolutionaire overerving van de familie (tenminste sinds hun laatste gemeenschappelijke voorouder) en dan zou het daardoor ook een evolutionair oude, erfde cognitieve standardeigenschap van de mens zijn.

Het cognitieve domein dat in dit proefschrift wordt onderzocht is ruimtelijke cognitie, en meer specifiek, ruimtelijke geheugenstrategieën en concepten van ruimtelijke relaties. In drie experimenten heb ik alle vier de soorten niet-menselijke grote apen, en mensen uit vier verschillende leeftijdsgroepen en uit twee verschillende culturen vergeleken ten aanzien van hun voorkeuren binnen deze cognitieve vermogens.

In **hoofdstuk 2** vergelijk ik eerst door middel van een elementaire ruimtelijke geheugentaak de vaardigheden van alle tegenwoordig nog levende grote apen en 1 jaar oude mensenkinderen. De resultaten laten zien dat alle niet-menselijke grote apen en 1 jaar oude mensenkinderen dezelfde voorkeuren vertonen voor een bepaalde geheugenstrategie. Dit doet vermoeden dat de gemeenschappelijke voorouder van alle grote apen dezelfde voorkeur had. Uit andere tests kwam naar voren, dat 3 jaar oude mensenkinderen juist een tegenovergestelde voorkeur hadden. Zo wordt de continuïteit tussen onze soort en de andere grote apen verhuld tijdens de vroege menselijke ontogenese. Toenemende taalbeheersing en de daarmee gepaard gaande snelle culturalisatie worden besproken als mogelijke verklaringen voor de verandering van voorkeursstrategie.

Taal en cultuur vergemakkelijken een flexibele aanpassing aan verschillende ecosystemen, waardoor het mogelijk wordt voor de mens om een uitgebreid scala aan milieus te bewonen. Dus als taal en cultuur tussen mensen

verschillen, en als taal en cultuur onze gerfde aanleg in de vroege ontwikkeling kan herstructureren (hoofdstuk 2), dan zou de volgroeide cognitie tussen culturele gemeenschappen ook kunnen variëren. **Hoofdstuk 3** behandelt de vraag of verschillen tussen talen cognitieve verschillen tussen haar sprekers tot gevolg kan hebben. Nederlandse en Namibische kleuterschoolkinderen zijn vergeleken in het toepassen van een ruimtelijke reconstructietaak. De twee culturen verschillen op de manier waarin ze ruimtelijke relaties in taal uitdrukken. Drie experimenten onderzochten de cognitieve voorkeursstrategie bij verschillende culturen, niveaus van taakcomplexiteit, en instructie. De data laten een correlatie zien tussen de in een cultuur gebruikelijke taalkundige uitdrukkingen en voorkeurspatronen in een niet-talige cognitieve taak. Wanneer de deelnemers genstrueerd werden om hun niet-gebruikelijke cognitieve strategie te gebruiken, kostte het hen moeite om te veranderen van strategie, en hun pogingen om dat te doen deed hun prestatieniveau afnemen. De mogelijkheid wordt besproken dat taal een rol zou spelen in het veroorzaken van stabiele voorkeuren voor een bepaalde cognitieve strategie.

Enerzijds erven alle mensen hun cognitieve aanleg van een evolutionaire voorouder (hoofdstuk 2). Anderzijds is menselijke cognitie aanpasbaar aan culturele omstandigheden (hoofdstuk 3). Hoewel deze twee stellingen tegenstrijdig lijken, bepleit ik in **Hoofdstuk 4** dat dit niet zo hoeft te zijn. Eerst worden dezelfde twee culturele groepen als in hoofdstuk 3 vergeleken wat betreft hun cognitie voor ruimtelijke relaties. Opnieuw lopen de twee culturele groepen uiteen, parallel met hun taalkundige coderingsstrategieën. Verder werden volwassen niet-menselijke grote apen met dezelfde ruimtelijke taak getest om de gerfde primate baseline vast te stellen. Uit de resultaten blijkt dat de menselijke cultuur zelfs de cognitieve basisvoorkeuren die we met de andere grote apen van onze gemeenschappelijke voorouder geërfd hebben, teniet kan doen. Tot besluit stel ik een model van de menselijke cognitie voor met een rijke, van de primaten geërfd basis, die door taal en cultuur verhuld kan worden, en die andere menselijke prestaties voorspelt in omstandigheden waar de cultuur een geërfd standaardstrategie onderdrukt en door een andere vervangt.

We zullen alleen in staat zijn de onderscheidende kenmerken van de

menselijke cognitie te waarderen als we zowel de continueiteiten als de discontinuiteiten binnen *Homo sapiens sapiens* en tussen alle bestaande leden van onze directe fylogenetische familie, de Homonidae, begrijpen.

Curriculum Vitae

Daniel Haun was born in 1977 in Bad Kreuznach, Germany. He studied Psychology at the University of Trier, Germany, specialized in Experimental Psychology under supervision of Gary Allen at the University of South Carolina, Columbia and graduated in 2002. Later that year, he obtained a PhD stipend from the Max Planck Society for the Advancement of Science and was jointly appointed to the Language & Cognition Group at the Max Planck Institute for Psycholinguistics and the F.C. Donders Centre for Cognitive Neuroimaging in Nijmegen, The Netherlands. In 2003 he was awarded a Marie-Curie stipend to spend one year under supervision of Neil Burgess at the Institute of Cognitive Neuroscience, University College London, UK. He currently holds position as member of scientific staff at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany. From July 2007 on he will be a lecturer in Psychology at the University of Portsmouth, UK.

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