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Plasticity of human spatial cognition: Spatial language and cognition covary across cultures

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ABSTRACT

The present paper explores cross-cultural variation in spatial cognition by comparing spatial reconstruction tasks by Dutch and Namibian elementary school children. These two communities differ in the way they predominantly express spatial relations in language. Four experiments investigate 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 non-linguistic spatial memory tasks. This correlation is shown to be 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 impaired their performance. These results indicate a difference not only in preference but also in competence and suggest that spatial language and non-linguistic preferences and competences in spatial cognition are systematically aligned across human populations.

1. Introduction

Questions about the plasticity of human cognition are central in cognitive science. How much individual variation is there in fundamental cognitive concepts and processes, and how much is this variation due to ontogenetic plasticity in human cognition? Given shared experiences within cultural groups but different sets of experiences between them, do we see population level differences in human cognition? Prominent in this context, is the issue of language differences and what they imply about possible differences in human conceptualization and expertise on a population level (Gentner & Goldin-Meadow, 2003; Levinson, 2003). There are around 7000 human natural languages and they differ in fundamental ways both in their form (sound systems, syntax) and their lexical inventories (the concepts coded in language) (Evans & Levinson, 2009).

The consequences of these linguistic coding differences have been hotly debated. One school of thought, following Fodor (1975), predicts little or no cognitive effects: there is a prelinguistic 'language of mind' that harbors all attainable human concepts, which a language selects from (Fodor, 1975; Gleitman & Papafragou, 2005; Pinker, 1994). Another line of thought claims that language gives rise to the concepts we use, or that at least the packaging can greatly facilitate mental processing (Dennet, 1991; Vygotsky, 1962), and make available cognitive adaptations to specific cultural environments (Levinson, 2003; Lucy, 1992). It may do this for example by 'coding' (Brown & Lenneberg, 1954), by 'recoding' (Miller, 1956), by providing relational concepts (Brown & Lenneberg, 1954; Gentner &

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Goldin-Meadow, 2003; Whorf, 1956). The resulting prediction of this latter perspective is that language differences imply cognitive differences.

Cross-linguistic variation provides a natural laboratory to test some of these different predictions. Even in just the last decade there has been considerable empirical work in a number of domains describing language-specific effects on cognition: for example color (Roberson, Davies, & Davidoff, 2000), number (Gordon, 2004; Pica, Lemer, Izard, & Dehaene, 2004), space (Haun, Rapold, Call, Janzen, & Levinson, 2006; Haun & Rapold, 2009; Levinson & Wilkins, 2006; Majid, Bowerman, Kita, Haun, & Levinson, 2004; Mishra & Dasen, 2005; Pederson et al., 1998) and time (Boroditsky, 2001). The conclusions vary across domains – for example, with respect to color (currently the best explored perceptual domain) recent results show on the one hand language-determined categories and linguistic effects on perceptual categories, and on the other universal constraints on color naming and language-independent category effects (see Regier and Kay (2009) for review).

The spatial domain has been intensively examined but has proved particularly controversial. It is incontrovertible that major cultural differences exist in the linguistic coding of space (Levinson, 2006; Pederson et al., 1998), and in the coding of major frames of reference in particular. Of special interest has been whether languages that primarily code different frames of reference would predict different non-linguistic spatial coding in their speakers. A considerable body of experimental evidence, based on cross-cultural comparison, suggests that the language one speaks indeed coincides with the frames of reference in which spatial memory and inference preferably operate (Haun & Rapold, 2009; Haun et al., 2006; Levinson, Kita, Haun, & Rasch, 2002; Mishra & Dasen, 2005; Pederson et al., 1998; Wassmann & Dasen, 1998). Nevertheless, doubt has been cast on these results from a number of different directions, both methodological and conceptual (Li, Abarbanell, & Papafragou, 2005; Li & Gleitman, 2002).

This paper attempts to resolve some of the issues in the spatial domain, along the following lines. First, we review the conceptual and methodological sticking points that have obstructed a clear consensus on the facts: (i) What are the relevant frame of reference distinctions, and how can we experimentally distinguish their use? (ii) Are the findings indicative of *preference* for one frame of reference, or about *ability* to operate in different frames of reference? (iii) How sensitive are the results to instructions that push either preference or ability? (iv) How sensitive are the results to task complexity, for example, does greater task complexity induce a reversion to a non-cultural, innate preference? (v) How can we control for orthogonal differences in subject populations and testing conditions?

Second, we report a series of experiments that were designed to address these issues by attending to each of these points. Here we first discuss the issues one by one, and explain how the experiments were designed to focus on them.

1.1. 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 between objects, in reference to a shared spatial anchor (Levelt, 1984; Talmy, 1983). Extensive field research in over 20 languages, analyzing natural and elicited conversation, has revealed a threefold distinction between frames of reference encoded in language (Levinson, 2003), as illustrated in Fig. 1: (i) *Relative frame of reference:* a ternary, 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)". In most European languages, this is the predominant frame in which people talk about locations and directions. (ii) *Intrinsic frame of reference*: a binary, viewpoint-independent relation, which specifies directions from a named facet of a reference object ("The garden is at the back of the building"). This is the main secondary frame in European languages, but in some languages (e.g. Mopan) it is the primary frame. These two FoRs are not always distinguishable in every utterance. Note the ambiguity of e.g. "The cat is in front of the truck" – on the intrinsic reading it is at the facet we call the front, on the relative reading it is between the speaker and the truck, and thus can be at its side. (iii) *Absolute frame of reference*: a binary relation between a reference object and a landmark using a system of fixed angles (e.g. north/south/east/west), as in "The lake is north of the town". This system is used in European languages normally only for geographic scale locations and directions, not e.g. for describing the location of things on a table – but many languages use it as the main FoR on all scales.

It is not a trivial task to map these linguistic distinction to related cognitive systems and previous attempts have resulted in much confusion (Levinson et al., 2002; Li &

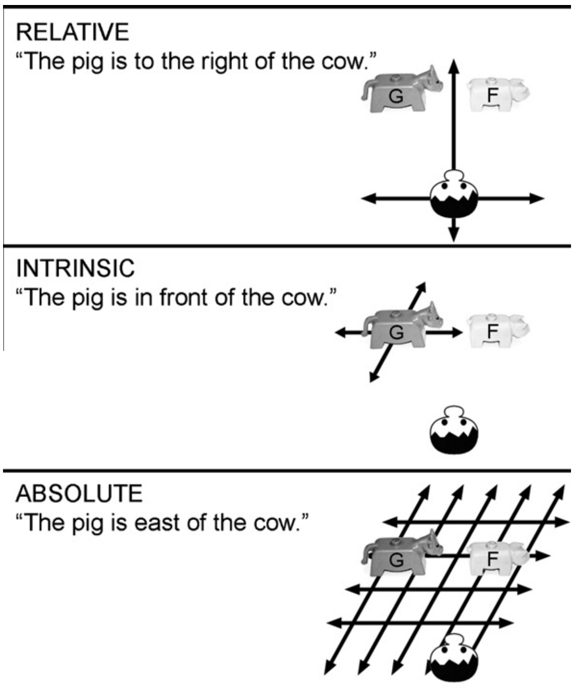

Fig. 1. Distinctions between three linguistic frames of reference.

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Gleitman, 2002). The most common division is to distinguish between egocentric cognitive FoRs, with coordinate systems centered in the agent and allocentric cognitive FoRs with coordinate systems centered in anything else (Burgess, 2006). The latter might include for example faceted objects as well the geometric layout of the environment. This distinction coincides with another interesting feature of FoRs being either view-dependent (coordinates change under rotation of ego) or view-independent (coordinates are stable under rotation of ego). Another way to categorize systems is to group cognitive FoRs with coordinate systems centered in movable objects (object-centered) and distinguish them from cognitive FoRs centered in unmovable features of the environment (geocentric) (Gallistel, 1990). Effectively crosscutting across these two frameworks, we will here adopt a three-way distinction of cognitive systems taking into consideration the most commonly used anchors in the three linguistic FoRs, namely ego in the relative FoR, faceted objects in the intrinsic FoR and the geometry of the larger environment in the absolute FoR. Hence, we distinguish egocentric, object-centered and geocentric cognitive systems.

The most common tool to discriminate between individuals' cognitive FoR preferences are array reconstruction tasks. In such tasks participants are asked to memorize an array of objects. These objects are subsequently removed and the participant is rotated and/or moved in space. Then participants are required to reconstruct the memorized array. Different movements of the participant between memorization and recall can be used to provoke distinguishable response patterns. For example, one way to explore egocentric from non-egocentric (object-centered or geocentric) cognitive strategies is to rotate the subject 180° between stimulus and response (Brown & Levinson, 1993; Levinson, 1997): if I memorize a row of animals as heading right, after a 180° rotation I'll arrange them

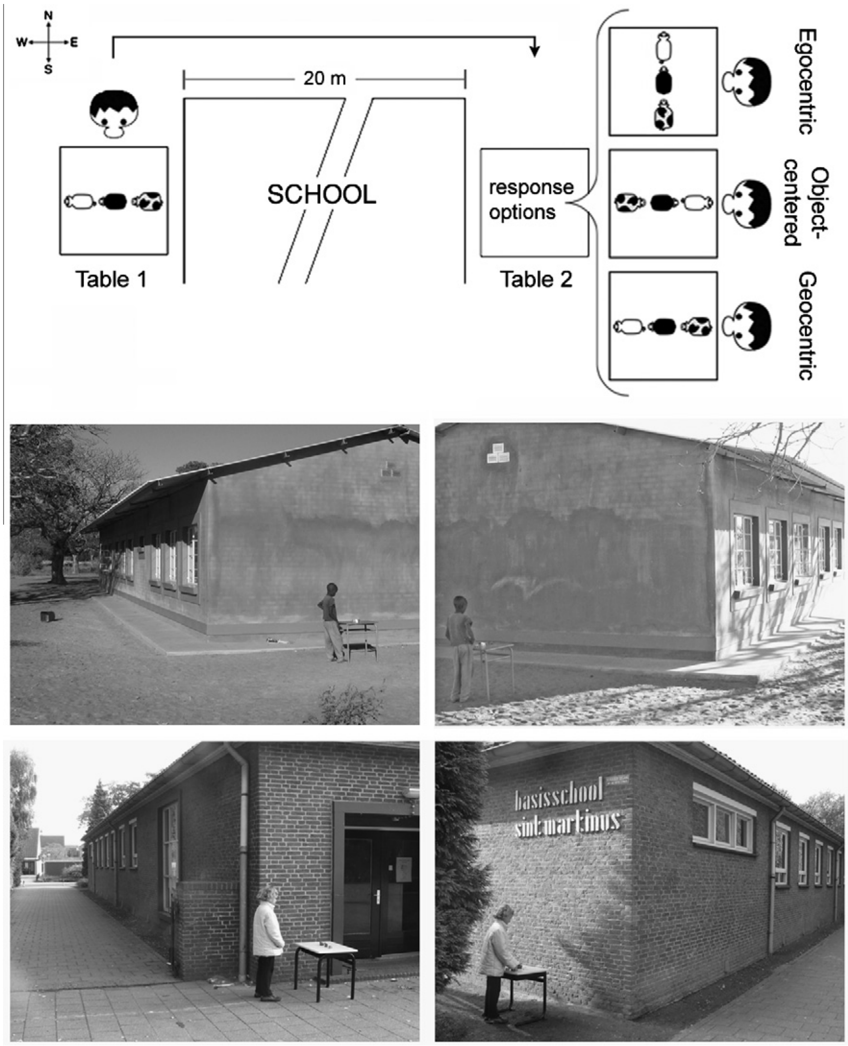

Fig. 2. Schematic experimental setup for both in Millingen (The Netherlands) and Farm 6 (Namibia). Subjects are presented with a spatial array on Table 1, then rotated 90° and asked to reproduce it on Table 2. In this setup, three frames of reference are distinguishable. Photographs show the two testing situations.

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heading right again, but if I memorize them as heading North, after a 180° rotation I'll arrange them heading left, which will be the North.

In a 180° rotation design it is difficult to conclude that a response is object-centered as opposed to geocentric (see for example Levinson et al., 2002; Li & Gleitman, 2002).

It is possible to design rotation experiments that could potentially distinguish between all three cognitive FoRs proposed above – this requires a 90° instead of a 180° rotation, together with a displacement around a salient object, as explained in Fig. 2. Under a 90° rotation, the heading and order of three toy animals on a table can be memorized relying on anyone of all three FoRs. If the animals on Table 1 are memorized as heading *right* (from the participants' point of view) in egocentric coordinates, subjects will reconstruct the array on Table 2 maintaining egocentric spatial relations: the reconstructed animals are heading right again. If participants use an *object-centered* FoR, so that the animals on Table 1 are heading away from the school, the animals will again be heading away from the school when reconstructed on Table 2.[1] If the subjects memorize the animals in terms of geocentric coordinates (heading West), the animals will maintain alignment with a compass direction regardless of rotation and displacement (Fig. 2).

This was the design employed in the Experiments 1–3 below. In such a set up, participants are free to memorize the same toys as either being right, West or away from the school of another toy. The type of coding used by the observer is, after rotation, transparent to the investigators.

1.2. Preference vs. competence

In the literature, there has been some confusion about the target of cross-cultural research in spatial cognition (Levinson et al., 2002): Has the aim been to show that populations differ in their normal response patterns or preferred strategies, or has it been to show that they differ in their underlying capacities, their abilities to use different strategies? The goal of most of the research has been directed at preferences – the argument has been that language may play a role in preferred choice of frame of reference (Levinson et al., 2002; Li & Gleitman, 2002; Mishra & Dasen, 2005, 2010; Neumann & Widlok, 1996; Pederson et al., 1998; Wassmann & Dasen, 1998). Nevertheless, other authors have argued that the competence issue was the major target (Li & Gleitman, 2002; Li et al., 2005). They have therefore argued against experimental designs where the spontaneous inclinations are explored through tasks in which there are more than one solution, and in favor of tasks where there is only one correct solution or participants are trained in a single strategy.

While these are clearly different experimental targets, they are not necessarily unrelated. In particular, if a certain strategy is culturally required (for example through language use), and thus heavily practiced leading to a preferred or default cognitive strategy, there is reason to expect performance using that strategy to be better (Haun et al., 2006). In experiment 4 below we instructed speakers

[1] The success of this design relies partly on the saliency of the object around which the participant is moved. If the saliency is high, any participant using an object-centered FoR will likely rely on this very object to memorize the array. Object-centered FoRs are however highly flexible and might rely on another object in or even out of sight.

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-3ps	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	take
/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		

Fig. 3. 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 to 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.

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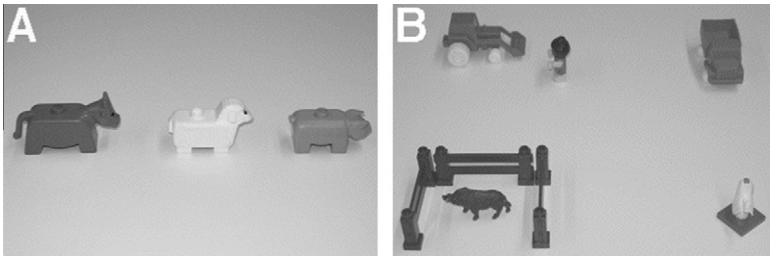

Fig. 4. Simple (A) and complex (B) array of toys used as stimuli in both communities.

of a predominantly absolute language, to solve an array reconstruction task following instructions and training in *both* egocentric and geocentric spatial strategies. Any difference in performance across spatial strategies would indicate not only a preference but also a relative increment in competence.

1.3. Instructions

In earlier studies (and Experiments 1 and 2), instructions were deliberately kept general (they were of the kind "rebuild the array"), so that subjects would use whatever preferred strategy comes naturally to them. But given an 'open' task, subjects might do whatever they find culturally appropriate, which might drive the observed cross-cultural variation instead of the proposed cognitive preferences (Newcombe & Huttenlocher, 2000). Also, 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 the usage patterns: Dutch predominantly using relative left/right descriptions, and ≠Akhoe Hai||om predominantly using absolute North/South descriptions, as exemplified in Fig. 3. In Experiment 3 we instructed children of both communities using their first language to employ the FoR they do not habitually use (absolute for Dutch, relative for ≠Akhoe Hai||om). If cross-cultural differences are merely varying interpretations of open instructions, and all cognitive options are equally available, an overt instruction to use a particular strategy should quite easily induce a different response pattern.

1.4. 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 the underlying set of options and cognitive biases is invariant (Li & Gleitman, 2002; Li et al., 2005). For example, many cognitive scientists have argued, following Kant (Kant, 1768), that spatial cognition is fundamentally egocentric (Halligan, Fink, Marshall, & Vallar, 2003; Miller & Johnson-Laird, 1976). But if cultural compliance requires a geocentric spatial strategy, the individual might achieve this by momentarily overriding a 'natural' or innate tendency, using additional aids 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, either switching spatial coding completely, or introducing systematic errors in their culturally-preferred strategy. 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. Thus doubling the number of items in an array does not simply double the necessary linguistic coding units (say, clauses), but causes a combinatorial explosion. Imagine sub-vocally rehearsing the constellations in Fig. 4. A simple constellation such as Fig. 4A can quite concisely be described linguistically: "Cow, sheep, pig walking right". A linguistic description of a more complex situation such as Fig. 4B is dramatically more complicated: "The pig facing left in its sty with its open side down in the bottom left corner, the chicken facing up in the bottom right corner, the lorry facing down in the top right corner, the tractor facing right in the top left corner, the boy just right of the tractor facing left". The more complex the linguistic encoding becomes, the less suitable a sub-vocal linguistic strategy becomes for memory encoding. On the theory that cultural variation is an artificial and superficial layer over natural inclinations, increasing task-complexity thus predicts collapse of a cultural strategy that runs counter to a natural strategy.

1.5. Schooling and context

Comparing cognition across cultures, brings with it the difficulty of controlling for variation in formal education (Mishra & Dasen, 2005). An extensive review of empirical research on cross-cultural cognitive testing finds that literacy and school performance have considerable effects on both "patterns of thought" and "language socialization practices for the inculcation of cultural world-view" (Lucy, 1996, p. 57). A good solution is to focus on elementary school children – in their first years of schooling children have not yet diverged to the extent that adults of different groups may have. In the experiments below we therefore

Table 1
Distributions of participants' dominant response strategy in Dutch and Hai||om populations 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		2		3	
Array	Simple		Complex		Complex	
Instructions	Free		Free		Instructed	
Language	Dutch	Hai||om	Dutch	Hai||om	Dutch	Hai||om
Egocentric	12	0	12	0	5	2
Object-centered	0	1	0	0	1	4
Geocentric	0	10	0	12	3	6
Other	0	1	0	0	3	0

compare two populations of elementary school children who are both exposed to standard schooling in their first language, testing situations, writing-systems and also to the same second language, namely English. Both populations received video instructions for the tasks in their first languages. Furthermore, prior research has established effects of testing outdoors vs. indoors in the absence of strong landmarks (Li & Gleitman, 2002). To avoid confounds of testing context in all experiments involving direct comparisons across populations, both populations were tested outdoors next to their school buildings, which were of similar size and both oriented along an East–West axis (see photographs in Fig. 2). When not comparing across groups (experiment 4) we included testing context as a factor in our design. Constancy across populations and control within a population are the most promising ways to exclude alternative explanations based on context.

2. Experiments

The following experiments were run in two culturally distinct populations, Dutch and ≠Akhoe Hai||om (Widlok, 1999). 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 (Levinson, 2006).

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).[2]

Experiment 1 uses a *simple* spatial array and *unspecified* instructions similar to previous studies (Neumann & Widlok, 1996; Pederson et al., 1998; Wassmann & Dasen, 1998). 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 Experiments 3 and 4 we test whether participants are easily able to adopt any strategy to remember a *complex* spatial array when given *clearly specified* instructions (Table 1).

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

2.1. Experiment 1

Experiment 1 was designed to replicate previous studies, using unspecified instructions and simple spatial arrays, with one difference: It uses a 90 instead of a 180° rotation (see 'Frame of Reference distinctions' above).

2.1.1. Method

2.1.1.1. Participants. Our sample consisted of 12 children from each of the Dutch and the Hai||om communities. The Dutch children (six males, six 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 (eight males, four females; *mean-age* = 8;7 years, *range* = 7–11 years, *SD* = 1;4 years) were recruited from |Khomxa Khoeda Primary School. All participants received token rewards for participation and teachers and/or parents gave their informed consent.[3]

2.1.1.2. 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, which is a salient, familiar local landmark (Fig. 2). 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. *Egocentric:* The toys were placed maintaining their spatial relations relative to the participants' viewpoint.
2. *Object-centered:* The toys were placed maintaining their spatial relations to the local landmark (school building).
3. *Geocentric:* 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.

2.1.1.3. Procedure. Participants were given a standardized instruction recorded on video. Dutch instructions were recorded using a native speaker of Dutch. Hai||om

[3] The 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.

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instructions were recorded by the participants' teacher, a native speaker of Khoekhoe. Khoekhoe and Hai||om are highly related variants of the Khoekhoe language cluster. We further made sure the instructions were clear by acquiring back-translations into English from an independent adult Hai||om consultant. The instructions 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 "rebuild it later". A row of three out of four toy animals (cow/pig/horse/sheep) was placed on Table 1, all facing either right or left of the participant (Fig. 4A). The direction and identity of 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, after a short delay, 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.

2.1.2. Results

The array-internal order of animals was used as an indicator of general performance. Participants rarely got the array-internal order wrong (% correct: *Median* = 100; *min* = 60; *max* = 100). Participants were categorized based on their dominant response (at least 4 of 5 trials). Any participant who did not respond using one particular strategy at least four times was coded as 'other'. Eleven Hai||om participants gave at least 4 of 5 geocentric responses while only one gave dominantly object-centered responses and none responded egocentrically even once. One Hai||om participant responded geocentrically three times and object-centered twice. This latter participant's preference was coded as 'other'. In contrast all Dutch participants responded four or more times egocentrically. These distributions of preference were significantly different across populations (Fisher-exact, $p < .05$). Table 1 presents the number of participants who dominantly used each of the FoRs in each of Experiments 1–3.

2.1.3. 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 (Widlok, 1997). Hence, using a simple spatial array and unspecified instructions we find that our data replicates previous reports claiming cross-cultural diversity of cognitive preference as well as the close alignment of language and non-linguistic cognitive preferences. Additionally our data show that speakers of a predominantly absolute language prefer not only any non-egocentric over an egocentric spatial strategy, but also a geocentric over an object-centered one. The correspondence between linguistic and cognitive preferences appears to be one to one.

2.2. 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.

2.2.1. Method

2.2.1.1. Participants and Setup. Participants and setup were identical in Experiments 1–3, which were conducted one right after the other.

2.2.1.2. Procedure. Participants were shown one of three different complex arrays including six toys (see example Fig. 4B) 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 condition). Responses were recorded on paper and by photograph.

Across a 90° rotation, egocentric, object-centered and geocentric frames of reference produce three different correct responses (for simple examples see Fig. 2). Children's responses were compared to the three correct solutions in the three different FoRs. Similarities between the correct solutions and the constructed arrays, in either position or orientation, were scored as points. Children could score maximally 6 orientation- and 5 position points (the pig and its sty could be placed in different orientations independently of each other, but their position within the array was codependent). We scored performance out of 11 and then converted the scores to percent correct. Whichever FoR was the closest fit (highest score) to their response was counted as their choice of strategy. This score was also used as a measure of performance and later compared to Experiment 3. Any response with 33% correct or less in any FoR was scored 'Other'.

2.2.2. Results

Reconstructing the complex array, performance was worse than in Experiment 1(% correct: *Median* = 81.82, *max* = 100.0, *min* = 36.36). The populations once again differed significantly in the distribution of strategy choices (Fisher-exact, $p < .0001$). Dutch participants exclusively used an egocentric FoR to reconstruct the animals (100% of Dutch subjects), while the Hai||om population exclusively produced geocentric responses (100% of Hai||om subjects) in the FREE-condition (Table 1).

2.2.3. Discussion

In Experiment 2 we used a more complex spatial array to increase task demand and reduce possible effects of subvocal rehearsal. Despite the lower overall performance in comparison to Experiment 1, cognitive preferences were unchanged. 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, which make sub-vocal rehearsal impractical.

2.3. Experiment 3

In this experiment we instructed children of both communities 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 unambiguous instruction to solve the task in the non-habitual FoR should easily reverse response patterns.

2.3.1. Method

2.3.1.1. Participants and Setup. Participants and setup were identical in Experiments 1–3, which were conducted one right after the other.

2.4. Procedure

Participants saw a video instruction in their first language, which instructed them in how to use the FoR that is non-habitual in their speech-community. 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. We made sure the instructions were clear by getting feedback from independent bilingual consultants of both communities (class-teachers). After viewing the instructions participants underwent a brief training procedure in which two toys were placed on Table 1. Before removing the toys, the experimenter asked the participants to indicate which toy was on the western side (Dutch subjects) or the right side (Hai||om subjects). If they failed, the experimenter named all four directions for them. Then the experimenter removed the toys 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. Training trials were repeated until the participants performed two correct trials in a row. No participant required more than a total of four training trials. When participants had 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 again 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 condition). Responses were recorded on paper and by photograph.

Children's strategy choices were assessed in the same way as in Experiment 2. To measure their ability to follow the instructions, we compared children's responses to the correct responses, i.e. geocentric for Dutch and egocentric for Hai||om children. Similarities between the correct solutions and the constructed arrays for each individual object, in either position or orientation, were scored as points. Children could score maximally 6 orientation- and 5 position points (the pig was always in the sty). We scored performance out of 11 and then converted the scores to percent correct.

2.4.1. Results

To see if instructions had an effect, we compared distribution of choices between Experiment 2 in which participants could freely choose strategy (FREE condition) and the instructed Experiment 3 (INSTRUCTED condition) 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 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 a geocentric FoR, outperformed Dutch children following geocentric instructions (Mann–Whitney-U-test: $U = 5.00$; $p < .0005$). Similarly, Dutch children, freely choosing to respond in an egocentric FoR, outperformed Hai||om children following egocentric instructions (Mann–Whitney – *U*-test: $U = 2.00$; $p < .0005$). In all tests on point-scores, *p*-values

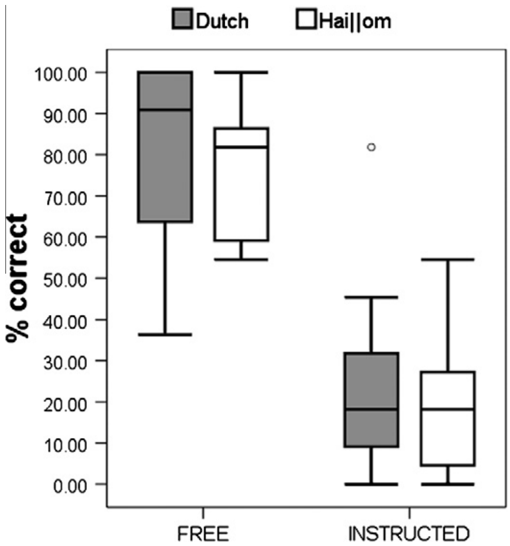

Fig. 5. Boxplot of % correct scores (Experiment 3) in Dutch and Hai||om in Complex-Array trials without (free) and with instructions (instructed). The height of the box represents the interquartile range of the sample. The black lines are the sample medians. Whiskers extend to the minimum and maximum of the samples. Descriptives statistics error-scores: Dutch: FREE: *Median* = 90.91, *min* = 36.36, *max* = 100.00; INSTRUCTED: *Median* = 18.18, *min* = 0.00, *max* = 81.82 – Hai||om: FREE: *Median* = 81.82, *min* = 54.54, *max* = 100.00; INSTRUCTED: *Median* = 18.18, *min* = 0.00, *max* = 54.55.

were corrected for multiple comparisons (Bonferoni). Descriptive statistics are given in Fig. 5.

2.4.2. Discussion

Despite the instructions, only around half of the subjects were able to noticeably diverge from their habitual strategy, and only one fifth of them successfully changed to the newly instructed strategy. Interestingly, some children in both populations switched to an object-centered FoR (Table 1). It is impossible to tell if this is due to a conscious switch to this alternative or a rotational mistake during the attempt to follow the instructions.

In summary, 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 memory strategy which they do not habitually use, and which is only infrequently used in their language. This was true even though the instructed strategy was preferred by the other group, and therefore not harder per se. However, the increase in error rates after instruction might alternatively be due to the difficulty to switch between *any* two strategies (Cepeda, Kramer, & Gonzales de Sather, 2001; Luchins, 1942). In Experiment 4 we attempt to isolate the structure of Hai||om competence by controlling for order effects and switching cost.

2.5. Experiment 4

In Experiment 4 we instructed Hai||om participants to switch both to and away from their preferred cognitive strategy, in order to isolate the contribution of cross-culturally variant cognitive preferences and switching cost to the decrease in performance reported in Experiment 3. Experiment 4 was conducted on a new sample of children in November 2008, 2 years after Experiments 1–3.

2.5.1. Method

2.5.1.1. Participants. Our sample consisted of 16 children from the Hai||om community. Children (12 males, 4 females; *mean-age* = 9;2 years, *range* = 7–11 years, *SD* = 1;6 years) were recruited from |Khomxa Khoeda Primary School. All participants received token rewards for participation and teachers gave their informed consent.

2.5.1.2. Setup. Similarly to Experiments 1–3 the task involved memorizing a spatial array, and then reconstructing it at a different location. Previous studies had demonstrated stronger egocentric coding indoors in the absence of distal landmarks (Li & Gleitman, 2002). To control for possible effects of testing context (indoors vs. outdoors), half of participants were tested outdoors with two tables placed on two sides of their school building. The other half was tested indoors in a classroom with very limited views of outside landmarks. A spatial array of four toys was placed on Table 1. Participants were always facing South during memorization and were then guided to Table 2 for reconstruction. Here, they were positioned facing West, and thereby rotated 90° relative to their orientation at Table 1.

2.5.1.3. Procedure. Participants saw a videotaped instruction in Khoekhoe. Half of the participants were instructed to place, say, the western objects back on the western side of the array when they reconstruct it (geocentric), while the other half was told to place, say, the rightmost objects back on the right-hand side of the array when they reconstruct it (egocentric). Their teacher, a native speaker of Khoekhoe, recorded both instructions. We made sure the instructions were clear by acquiring back-translations from an independent bilingual consultant. After viewing the instructions, participants underwent a brief training procedure in which two toys were placed on Table 1 following each other in one of four orthogonal directions. Before removing the toys, the experimenter asked the participants to indicate which direction the toys were facing, i.e. North–South–East–West (geocentric condition) or Right–Left–towards ego–away from ego (egocentric condition). Then the experimenter removed the toys and subjects were guided to Table 2 including a 90° rotation. Now they were asked to reconstruct the mini-array following the instructions they had just received. In case of an incorrect solution the experimenter named the correct orientation (according to condition) in the Hai||om language and placed the animals as instructed. Training trials were repeated until the participants performed two correct trials in a row, one along each orthogonal axis. When they mastered this test, they were presented with either simple or difficult trials first, in counterbalanced order. Simple trials consisted of remembering an array of four animals following each other in a straight line, and reconstructing the line using the correct four out of five available animals. Difficult trials consisted of remembering an array of four animals in a square formation facing different directions and reconstructing the array using the correct four out of five available animals. All participants received two blocks of two simple and two difficult trials each. After these initial four trials, participants received new video instructions telling them to apply the alternative FoR, i.e. children who had previously received the egocentric instruction would now be instructed in the geocentric one and vice versa. This second set of instructions was again followed by a brief training and four more test trials (two simple, two difficult). Responses were recorded on photograph.

Children could score "points" for discarding the correct animal (one point), placing the animals in correct order (one point), placing an animal in the correct position (up to four points), placing an animal in the correct orientation (up to four points) and filling a position with any animal in the correct orientation (up to four points), adding up to a total of maximally 14 points. After counting up the points out of 14 we converted the score to percent correct.

2.5.2. Results

The amount of training required by participants to pass criterion was significantly different between the two kinds of instructions, geocentric vs. egocentric (Wilcoxon-test: $Z(N = 16) = -2.20$; $p < .05$). Participants required less training to pass criterion after the geocentric construction in comparison to the egocentric instruction. Overall performance did not vary across the testing context, indoors vs. outdoors (Mann–Whitney-*U*-test: $U = 1720.5$; $p = .19$). On

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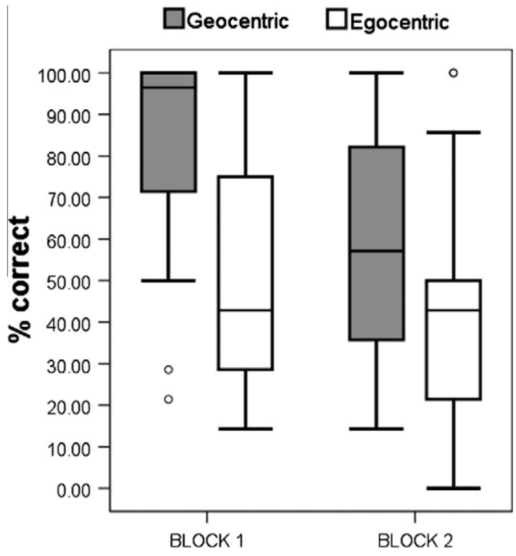

Fig. 6. Boxplot of % correct scores (Experiment 4) in Hai||om in trial-block 1 and 2 following geocentric or egocentric instructions. The height of the box represents the interquartile range of the sample. The black lines are the sample medians. Whiskers extend to the minimum and maximum of the samples. Descriptives statistics error-scores: BLOCK 1: Geocentric: *Median* = 96.43, *min* = 21.43, *max* = 100.00; Egocentric: *Median* = 42.86, *min* = 14.29, *max* = 100.00 – BLOCK 2: Geocentric: *Median* = 57.14, *min* = 14.29, *max* = 100.00; Egocentric: *Median* = 42.86, *min* = 0.00, *max* = 100.00.

the simple trials, participants did perform significantly better than in the more complex trials (Wilcoxon-test: $Z(N = 16) = -2.44$; $p < .05$). Participants showed no significant switch cost, measured by a difference in performance between trial-block 1 and 2 (Wilcoxon-test: $Z(N = 16) = -1.58$; $p = .12$). However participants performed better following the geocentric than the egocentric instructions (Wilcoxon-test: $Z(N = 16) = -2.30$; $p < .05$). Descriptive statistics are given in Fig. 6.

2.5.3. Discussion

As predicted based on Experiment 3, the Hai||om children show better performance for geocentric coding than for egocentric coding in a non-ambiguous, instructed task. Their habitual absolute language preference and interpretation of spatial arrays (Experiment 1–2) coincides with a greater expertise in geocentric coding (Experiment 3–4). Hai||om children in Experiment 4, just as in Experiment 3, struggled to reproduce the array using a strategy which they do not habitually use (egocentric), and which is only infrequently used in their language (Widlok, 1997), even after controlling for switching cost.

3. 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/non-egocentric) to a three-way distinction (egocentric/object-centered/geocentric) and thereby matched behavioral response-options to the threefold discrimination of FoRs in natural language. Our data show a correlation between the dominant linguistic strategy in the language and the preferred cognitive strategy used to process spatial relations. This correlation is fully robust by age 8. We would predict that the same correlation would hold for a cultural group that exhibited preferred linguistic use of the third FoR, the intrinsic frame, and we may hope that these studies will be replicated in such a culture, confirming the tight co-variation between spatial language and cognition we report here.

The cross-linguistic differences were stable across an increase of complexity in the spatial array. This manipulation was 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 single shared FoR across the two communities. Although further research would be required to rule out whether a set of even harder tasks would eventually produce a shared response tendency in both cultures, there is no indication in that direction.

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. We take this data to be consistent with different, stable behavioral preferences in the two cultures.

Furthermore we showed that Hai||om children do not only prefer geocentric spatial strategies over egocentric ones, but have an increased competence to apply a geocentric as compared to an egocentric strategy to the same spatial task. By requiring them to switch both to and away from their preferred strategy we controlled for order effects and switch costs. The remaining difference in performance across spatial strategies indicates not only a preference but also an increased competence to solve one kind of problem over another.

The human brain supports, egocentric, object-centered and geocentric spatial cognition (Burgess, Jeffery, & O' Keefe, 1999). Therefore cross-cultural variability of cognition in the spatial domain is unlikely to be a matter of absolute capacity, but of preference and relative competence. The question at stake is not what people can or cannot think, given their cultural background. Rather, the question is what kind of memory strategy they will use by default and the ease or difficulty with which other strategies can be adopted and used.

Our results suggest that, in the domain of memory for small-scale spatial arrays, language preferences and preferences in non-linguistic cognitive strategies align. These culture-specific preferences in small-scale spatial memory are accompanied by culture-specific increased competences to apply that preferred strategy. The results show that at least in some domains cultural diversity goes hand in hand with cognitive diversity. Cross-cultural diversity should be understood in the general context of the renewed interest in the variability of human performance. For the remarkable fact about cultural regimentation is that on the one hand it generates variant performance from a biologically common cognitive foundation (Haun et al., 2006), and on the other hand within a culture it engenders the common output essential to communication and cooperation, despite substantial individual differences (Evans & Levinson, 2009). This combination of between group variability and within group consistency lies at the heart of the human capacity for culture, as the special mode of adaptation that is the hallmark of the species.

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