Alternative spin on phylogenetically inherited spatial reference frames

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Abstract

People make use of different frames of reference (north-south; left-right) to talk about space. To explore the cognitive capacity that children bring to learning spatial language, Haun et al. (2006) examined children's ability to notice and abstract invariant frames of references across instances. They found that 4-year-olds and non-human great apes often noticed environment-defined allocentric relations and not body-defined egocentric ones, leading them to conclude that preschoolers are ready to learn environment-defined terms (e.g. "uphill"), but not body-defined ones (e.g., "left"). However, such a conclusion may be premature. In four new experiments we demonstrate that the previous findings could be an artifact of specific task constraints. With minor experiment modifications, similar-aged children readily noticed egocentric relations. Reviewing additional research, we provide an account of what makes acquiring frames of reference easy or difficult, and why full mastery of terms like "left" and "right" may take many years under normal circumstances.

Keywords: spatial frames of reference, allocentric, egocentric, left-right, linguistic relativity, word learning, spatial updating

Introduction

Languages vary in their stock of spatial frame of reference (henceforth, FoR) words. In some languages, like English, speakers prefer to use body-defined or egocentric terms ("left-right") when talking about locations and directions. Allocentric or environment-defined terms ("uphill-downhill", "north-south") are typically reserved for large-scale or map-space. In other languages, however, like ≠Akoe Hai||om (Khoisan, Namibia), speakers prefer environment-defined terms even when talking about small scale space (e.g., "Pass me the plate north of the cup."). While such languages may have body-defined terms, they are typically underutilized as a system for spatial reference and may only be used to label body parts (e.g., see Brown & Levinson, 1992, for Tseltal, Widlok, 2007, for Hai||om). These striking cross-linguistic variations have led researchers to raise the following two questions: First, to what extent are children ready to learn the range of spatial words that exist in the worlds' languages (Majid et al. 2004; Mandler, 1996; Bowerman & Choi, 2001, 2003). Is there a cognitive bias to encode spatial information using a particular frame of reference, making some linguistic systems easier for children to acquire (Haun, Rapold, Call, Janzen, & Levinson, 2006; Shusterman & Li, 2016)? Second, to what extent does learning spatial words drive speakers to analyze new relations and to restructure old ones (Pederson et al. 1998; Majid et al. 2004; Levinson, 2003)?

Research in the last two decades has mainly focused on addressing the second question although the conclusions are far from settled (e.g., see Li & Gleitman, 2002; Li, Abarbanell, Gleitman, & Papafragou, 2011, Li & Abarbanell, 2018 vs. Pederson et al., 1998; Majid et al. 2004; Levinson, Kita, Haun, & Rasch, 2002; Haun, Rapold, Janzen, & Levinson, 2011). In the current paper, we focus on the lesser studied first question, which addresses the cognitive capacities children bring to learning spatial FoR terms (Haun, Rapold, Call, Janzen, & Levinson, 2006; Shusterman & Li, 2016). We reconsider an influential study by Haun and colleagues (2006) that has frequently been cited in prominent review papers in cognitive and developmental psychology (e.g., Newcombe, Uttal, & Sauter, 2013; Henrich, Heine, & Norenzayan, 2010; Gentner, 2007). We reconcile, for the first time, the findings and claims made by this study with research from the spatial cognition literature on spatial updating and how context affects people's preference for encoding spatial information using different FoRs.

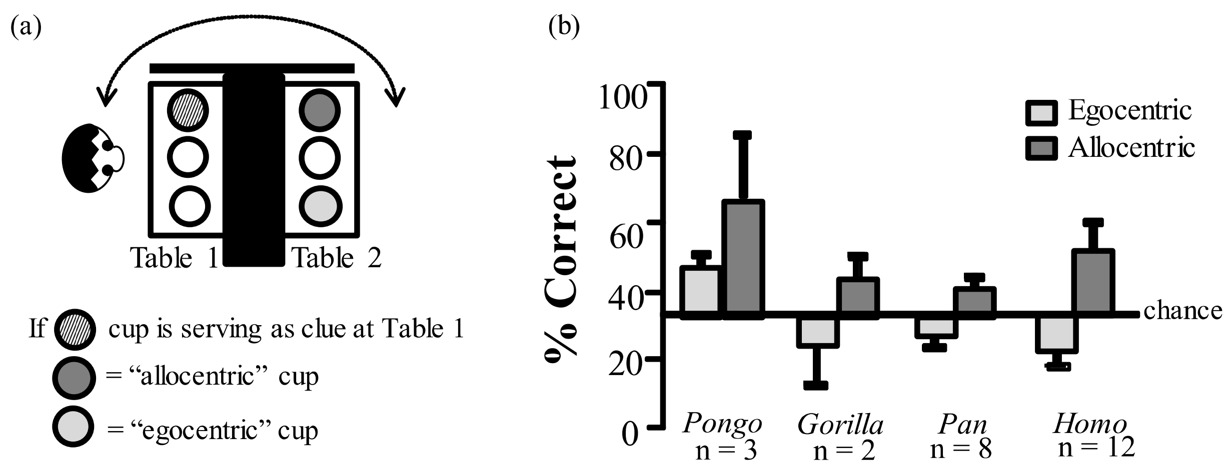

Figure 1. Set-up (a) and results (b) from Haun et al.'s Experiment 2 (2006). On each trial, primates were shown a hiding location at one table (e.g., left/northern-most cup) which served as a clue for retrieving a hidden treat from an identical array at the other table. Clues within a block of trials always followed egocentric relations or always followed allocentric relations. Participants were better at the allocentric than the egocentric condition.

Haun and colleagues asked whether there is a phylogenetically inherited preference for using a particular FoR that serves as the cognitive basis for acquiring spatial language. To do so, they compared German-speaking 4-year-olds (mean age: 4;10), who were expected to have little or no such spatial language, with three species of great apes. In their elegant task, the experimenter first hid an object under one of three identical cups at a first table while the participants watched. Participants then walked around a barrier to a second table to face 180^{o} from their initial orientation. They there had to search for another hidden object under an identical array of cups (Figure 1a). The hiding location at the first table served as a clue for finding the hidden object at the second. Across a block of trials, this clue either always obeyed the egocentric rule (e.g. a hidden object in the leftmost cup of the child at Table 1 means a hidden object in the leftmost cup of the child at Table 2), or always obeyed the allocentric/geocentric[1] rule (a hidden object in the northern-most cup at Table 1 means a hidden object in the northern-most cup at Table 2). Importantly, participants were not explicitly told this rule, but had to abstract it over the block of trials. In a way, their paradigm parallels word learning in which children must make generalizations from cross-situational observations (e.g., Yu & Smith, 2007; Trueswell, Medina, Hafri, & Gleitman, 2013).

As Haun et al. pointed out, philosophers and psychologists such as Immanuel Kant and Jean Piaget long assumed that our body is the initial source of our intuitions about space, and therefore that the egocentric FoR is primary. Contra Kant and Piaget, however, Haun et al. found that participants from all tested genera were dismal at learning the egocentric rule but excelled at the allocentric rule (see Figure 1b). Haun et al. also tested 8-year-olds and adults who have acquired language-specific spatial language on a more complex five-cup array. They contrasted speakers of Dutch who prefer body-defined terms, with speakers of Hai||om who prefer environment-defined terms. The Hai||om could figure out the allocentric but not the egocentric rule. The Dutch, in contrast, although they could figure out both rules, were faster at figuring out the egocentric one. Thus, unlike young children and non-human primates, older children and adults were better at figuring out the rule that aligned with the dominant FoR in their language.

The pattern of results led the experimenters to conclude that there is “a common

[1] Haun et al. sometimes chose the locution “allocentric” over “geocentric” because their experimental design did not distinguish between whether participants were making use of more local landmarks (e.g., walls, dividers in the room) over more global scope or abstract FoRs (e.g., “north”; sun-rise direction). We follow their lead but see Shusterman and Li (2016) for a discussion of these terms.

phylogenetic inheritance" to prefer allocentric over egocentric representations (p. 17572). This preference can be overridden through enculturation, especially via language as in the Dutch speakers; however, this "might be expected to incur some costs", predicting "the relatively greater difficulty of acquiring a predominantly egocentric coding system" (p. 17572). As Haun et al. noted, this concurs with the language acquisition data: Children in cultures that favor geocentric language learn environment-defined terms as early as age four and certainly before seven (Brown & Levinson, 2000; Dasen & Mishra, 2010), while English-speaking children do not master the full use of "left" and "right" until age eleven (Elkind, 1961; Rigal, 1994).

Although these claims follow directly from Haun et al.'s experimental results, these results seem at odds with previous research on spatial cognition that has shown that both allocentric and egocentric representations are readily available and often work in concert (e.g., Burgess, 2006; Gallistel, 2002; Newcombe, 2017). Which of the two informational sources is more salient in solving a problem depends highly on the task and situational context (see Pick, Yonas, & Rieser, 1979; Bloch & Morange, 1997; Bremner & Bryant, 1985; Newcombe & Huttenlocher , 2000; Newcombe, 2017 for review). For example, even 9-month-old infants have been shown to use both egocentric and allocentric information to guide them in object searches, relying more heavily on egocentric information in unfamiliar environments such as in a laboratory or office, and on allocentric information in familiar environment such as their homes (Acredolo, 1979). However, as these studies did not use the same paradigm of finding commonalities across instances, it is possible that Haun et al.'s tasks reveal differences in the salience of each system for rule or language learning, despite their availability for spatial cognition more generally. In the present paper, we revisit Haun et al.'s experimental set-up to test whether an alternative explanation can reconcile their results with previous findings. We turn to a phenomenon known as “spatial updating” (Wang, 2017) which we will show, through reviewing prior studies, may be central for understanding and interpreting Haun et al.’s results.

Studies of spatial cognition have shown that while one is walking to a new location, whether with eyes open or after being blindfolded, the locomotion automatically triggers an updated representation of the location of nearby stationary objects relative to one’s new position (e.g., Simons & Wang, 1998; Wang & Simons, 1999; Hollins & Kelley, 1998; Rieser, Guth, & Hill, 1986; Rieser, Pick, Ashmead, & Garing 1995; Mou, McNamara, Rump, & Xiao, 2006). This phenomenon, known as spatial updating, proceeds involuntarily, even when doing so might negatively affect reasoning about viewer-independent internal relationships among objects and landmarks (e.g., Lourenco, Huttenlocher, & Vasilyeva, 2005). Effects of spatial updating are seen in classic perspective-taking studies, where participants are better at anticipating how a previously studied array of objects would look from a new vantage point if they walk to that new location than if they remain stationary (e.g., Huttenlocher & Presson, 1973; Rieser, 1989). They are also better at anticipating the new view of the array after locomotion in comparison to anticipating an array rotation that results in the identical retinal view (e.g., Simons & Wang, 1998). Researchers suggest that the ability for spatial updating, whether evolutionarily given or experience driven, make sense since “most real-world view changes are caused by observer movements and not by object rotations” (Simons & Wang, 1998, p. 315).

Relevant to the present Haun et al.’s experimental set-up is a series of spatial updating studies that varied whether an array and/or participants are rotated in order to dissociate different perspectives (Simons & Wang, 1998; Wang & Simons, 1999). In Simon and Wang’s studies, participants were first asked to study an array (initial egocentric view) which was subsequently covered. Conditions then varied whether the participant moved to another location around the table and/or whether the table was rotated (see Figure 2 for two such conditions). The array was then uncovered and participants were asked to identify which of the several objects the experimenter had surreptitiously moved. The results showed that participants performed better when only they moved but the array remained constant than when the array also moved (contrast Figure 2a vs. 2b; see also Burgess, Spiers, & Paleologou, 2004’s self vs. self-and-table conditions; Nardini, Burgess, Breckenridge, Atkinson, 2006’s child-move vs. both-move conditions). These finding makes sense in light of the fact that spatial updating is automatic: *the updated relationships of the object array to oneself after moving is weighted more heavily and competes with the view of the object array at the initial location (i.e., the pre-updated view)*.

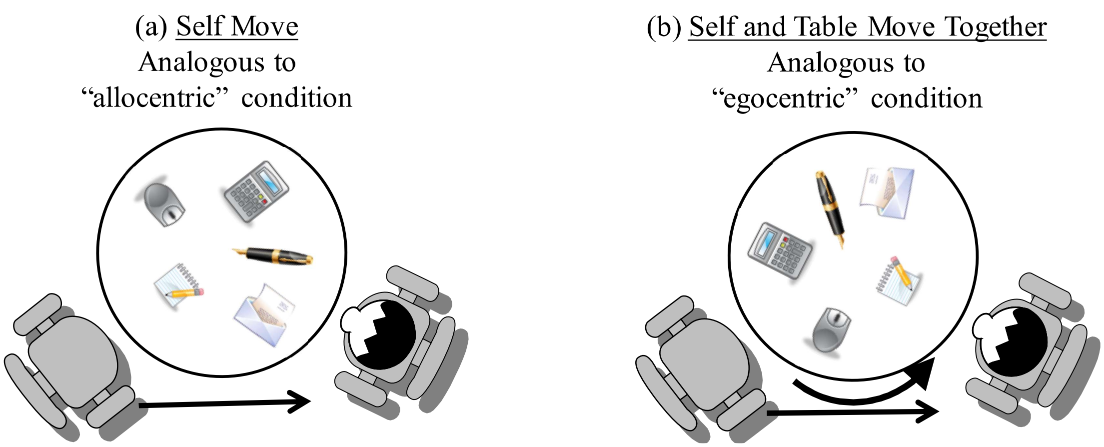

Figure 2. Set-up of spatial updating experiments. In (a), the participant moves to a new location while the array remains stationary. In (b), the array rotates with the participant, maintaining the same retinal image of the array as the initial egocentric view. Participants are then tested on their memory of object locations. The two depicted conditions mirror the “allocentric” and “egocentric” conditions in Haun et al. (2006) respectively.

Notice Haun et al.’s allocentric condition, in which participants walk around a divider to the second table while the location of the hidden object remains stationary with respect to the environment, is analogous to the condition in which the array remains stationary while the participant moves (Figure 2a). Their egocentric condition, in which the location of the hidden object essentially moves along with the participant, is analogous to the condition in which both the array and the participant move together (Figure 2b). Thus, Haun et al. might have coincidentally picked a set-up that favored learning the allocentric rule, while other set-ups, as we shall experimentally test, could favor learning the egocentric rule.

Importantly, the ease of spatial updating is mediated by various factors. People tend to only update multiple landmarks and objects over short distances, as errors in updating accumulate as the distance traveled increases. In several studies, spatial updating is found (among English-speakers, at least) to be more difficult the greater the distance one travels or the greater the degree one rotates away from the array of objects one is tracking (Rieser 1989; Farrell & Robertson, 1998; Mou, Zhang, & McNamara, 2009; Waller & Hodgson, 2006; Brockmole & Wang, 2005). Spatial updating, while automatic even when locomoting without vision, is also hampered by the removal of salient objects and landmarks in the environment, which might serve as means to recalibrate and correct accumulated errors when one can see the environment (Simons & Wang, 1998; Burgess et al. 2004; Zhang, Mou, & McNamara, 2011; Etienne, Maurer, & Seguinot, 1996; Foo, Warren, Duchon, & Tarr, 2005). On the whole, depending on the experimental set-up, the spatially updated representation of object arrangements (i.e., allocentric FoR) can compete more strongly or weakly with the representation of object arrangements matching one's initial view (i.e., egocentric FoR).

In sum, based on prior spatial updating studies, Haun et al. may have picked a table set-up that especially favored learning the allocentric rule. If so, changes in how much participants move relative to their original position and changes in the visibility of landmarks for recalibration may alter the ease of spatial updating and hence alter how much the initially studied (egocentric) view is in conflict with the ongoing computation of where objects are located from one's new position. In the present study, by changing the table set-up, we seek to shift which rule is more favorably learned. In doing so, we hope to show that children who have not yet robustly acquired left/right language can learn the egocentric rule. This finding would both explain and reconcile Haun et al.'s findings with prior studies.

Alternatively, Haun et al.'s finding should still stand if allocentric relations are more readily abstracted across instances as in rule or language learning, regardless of the contextual factors that affect their salience for spatial cognition. A recent study from our laboratory in which children guessed the meanings of novel spatial words, at first blush, supports this possibility (Shusterman & Li, 2016). In that study, children played a game in which they had to choose between two boxes for the one with a prize. The experimenters used novel words to indicate in which side box the prize was for each trial ("The toy is on the *ziv/kern* side"). Children faced one direction on some trials and turned 180° to face the opposite direction on other trials. After each trial, the children received feedback by opening the box, similar to the study by Haun et al.. Children who were exposed to the allocentric rule (i.e., the *ziv* box remained the eastward side box after turning 180°) found the prize more often than those exposed to the egocentric rule (i.e., the *ziv* box remained the box on the child's left after turning 180°). Only when given explicit information upfront that the novel term referenced the child's body ("Your body has two sides…. This whole side of your body is your *ziv* side."), or by having them play an "exercise" game ("Raise your *ziv* elbow"), did the children improve at finding the prize when exposed to the egocentric rule. However, a limitation in drawing conclusions from this study is that participants were introduced to the novel words and given feedback about their meanings while standing and turning in one location. Given that spatial updating is more difficult with greater displacement, had the children been exposed to the words across different rooms, egocentric meanings might have been easier to learn.

With Haun et al.'s design as a starting point, in the present experiments we therefore tested whether the allocentric rule is always easier to learn by systematically varying the table set-up. In Experiment 1, we first tested for the replicability of Haun et al.'s results with English-speaking children, using two adjacent tables with a divider in between. In Experiment 2, we changed the placement of the two tables to manipulate the distance traveled and the visibility of stable features in the environment that strengthen allocentric representations. These two factors have previously been shown to affect the ease of spatial updating, and hence should affect whether the allocentric or the egocentric rule is easier to learn. In Experiments 3 and 4, we varied the axes (sagittal vs. transverse) along which the array of cups was placed with respect to participants' bodies. This variation has been suggested to also be pertinent to which FoR is favored (Brown & Levinson, 1993). Altogether, the findings from the present studies will help us evaluate whether our phylogenetic inheritance is primarily environment-centric, as Haun et al. argued, or whether which FoR is favored depends on the precise details of the task. The findings also have the potential to enrich our understanding of how children acquire FoR words and may have implications for how best to teach their meanings.

Experiment 1

Experiment 1 is a replication of Haun et al.'s search task. We tested a group of English-speaking children similar in age to Haun et al. (2006)'s German-speaking children (their mean age = 4;11 and our mean age = 4;9). In English, like German, speakers prefer to use egocentric, body-defined terms for spatial reference. Studies have shown that English-speaking children at this age are unlikely to know the full meanings of "left" and "right", although they may understand that the words apply to the transverse axis and have some knowledge that "left" and "right" are opposite directional terms (Dessalegn & Landau, 2008; Shusterman & Li, 2016). We therefore expected the English-speaking children, like Haun et al.'s German-speaking 4-year-olds, would be better at guessing the allocentric rule than the egocentric rule. We also included a slightly older group (mean age = 6;5) of English-speaking children. Haun et al. (2006) established that 8-year-olds were better at guessing the rule that aligned with their language (see also Haun et al. 2011; Li & Abarbanell, 2018). With the 6-year-olds, we explore whether an influence of (left-right) language is present even before 8-years-old. Studies show that six-year-olds are more likely to be able to correctly identify the "left" and "right" sides of their own body when asked (Rigal, 1994), which may thereby improve their ability to guess the egocentric rule.

Methods

Participants. Twenty native English-speaking children participated. The children were divided into a younger group (N = 10, 6 female, 4 male; mean age: 4;9; range: 4;0-5;10) and an older group (N = 10, 5 female, 5 male; mean age: 6;5; range: 6;1-6;8).[2] A signed consent was obtained from the children's legal guardians. The children also provided verbal assent; they were informed in advance that they would be compensated with stickers, one for every three coins they find in a coin hiding game. All participants were visitors at a large metropolitan science museum and were tested in the corner of an exhibition hall. When facing the corner, the left wall consisted of a wall of windows overlooking a river and the right wall was a solid wall with some decorations. The tables were placed parallel to the wall of windows. In the visible vicinity was a station for crafts and activities and some terrariums housing critters.

Materials and Procedures. Two round tables (diameter: 40cm, height: 60cm) were placed next to each other with a gap of approximately 5cm between them. A solid opaque screen

[2] We chose to test 10 children per experimental condition based on the sample sizes in Haun et al. (2006)'s study and a prior study on children's acquisition of spatial words (Shusterman & Li, 2016). Power analysis on the basis of these prior studies also revealed that n = 10 is a sufficient sample size. The effect size from Haun et al.'s study with German children is 1.72. If we assume the effect size to be 1.72 and set α probability error at .05, a sample size of 10 has power of .99 (Faul, Erdfelder, Lang, & Buchner, 2007).

separated the two tables visually. On each table, three identical opaque cups, which served as potential coin hiding locations, were placed in a straight line, equidistance from each other. Across trials, children were shown where a coin was hidden under one of the cups at one table, and then had to find where a coin was hidden at the other table. Figure 3a shows the alignment of the tables and cups in addition to where the children stood while facing the tables. Children participated in two consecutive blocks, one "egocentric" and one "allocentric." In the egocentric block, the target cups maintained the same position relative to the viewpoint of the participant. If the hiding cup was the one to the child's left-hand side at the first table, the correct finding cup was again the one to the child's left-hand-side. For the allocentric block, the target cups maintained the same position relative to the surrounding environment. For example, if the hiding cup was the northern-most cup, the finding cup was again the northern-most one at other table.

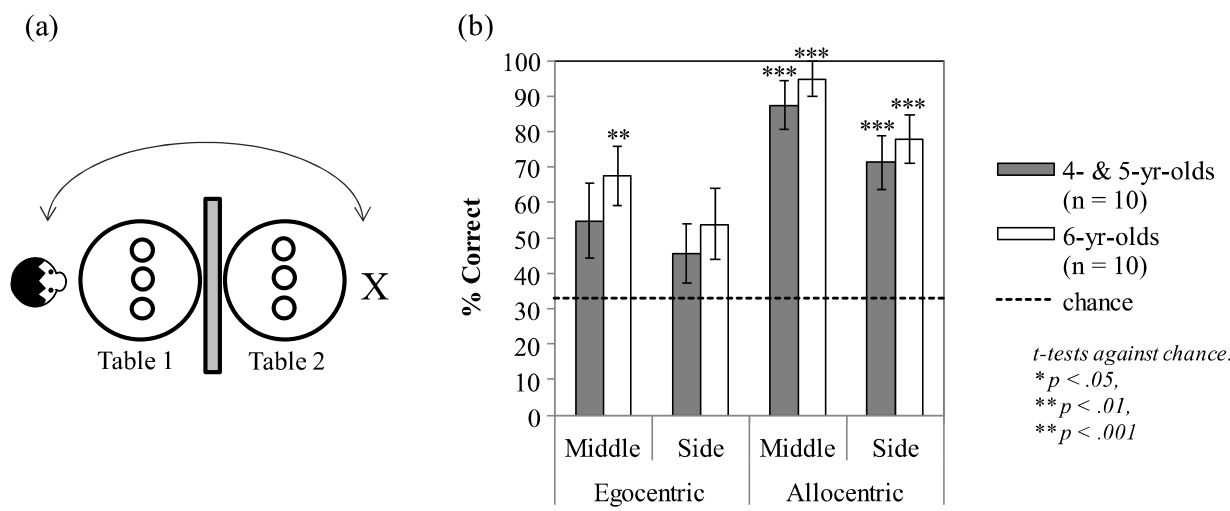

Figure 3. Set-up (a) and results (b) of Experiment 1. For (a), the large circles represent the tables, the small circles represent the cups, and the gray line is an occluder. Percentage correct in identifying the target cup is plotted in (b), showing that children were better at the allocentric condition.

Each block consisted of twelve test trials. The coin was hidden in the left/north cup for four trials, the right/south cup for four trials, and the middle cup for four trials. With the exception of the middle trials, the order of the side trials was random. The coin was hidden in the middle cup in trials 2, 5, 8 and 11. Haun et al. expected children to find middle trials easy as both rules (egocentric or allocentric) led to the same solution. Middle trials distributed evenly across the blocks thus provided a means to keep children attentive and non-frustrated throughout.

The order of the two blocks was counterbalanced across children. At the beginning of the first block, the participant was positioned in front of table 1 facing the screen. The experimenter said, “There are three cups on this side. I’m going to hide the coin on this side to give you a clue about where the coin is on the other side. Where I hide the coin on this side will give you a hint about where the coin is on the other side.” They watched the experimenter place a coin under one of the three cups. In the meantime, a second experimenter at table 2 hid a coin in the corresponding cup, as determined by block. The participants were then directed to table 2 (see Figure 3a) and told, “Can you point to the cup with the coin? Remember, where I put the coin there will help you find the coin here.” After their response, the experimenter turned over their cup of choice and, in the case of an incorrect choice (choosing any cup without a hidden target), turned over the correct cup in order to provide feedback that could allow participants to adjust their behavior. The second experimenter recorded the cup that the participant picked. Trial 2 started with a new hiding at table 2, after which participants returned to table 1 for finding. The procedure of hiding and finding was iterated for all twelve trials. After each trial, the children received feedback as to whether they were correct, and if not, the experimenter revealed the correct location of the coin. After the first two trials, however, the experimenter no longer reminded the children that the hiding location at one table served as a cue for the location at the second table. At the end of the twelve trials, and before beginning the second block, children were told, “We’re going to play the game again, this time a little differently, but what I show you on this side will still help you on the other side.” This instruction was intended to cue children that the prior winning strategy no longer worked, and a new one had to be learned.[3] The study then proceeded as before for another twelve trials.

Table 1. Comparing Allocentric vs Egocentric Performance by Number of Individuals. Cells show the number of participants categorized by whether they scored higher on the allocentric block than the egocentric block, the same, or the egocentric block higher than the allocentric block.

Experiment Number	Table Distance	Cup Alignment	Age	N	Allo> Ego	Allo = Ego	Ego > Allo
Exp 1	Together	LR	4-5- yr-olds	10	9	1	0
			6 yr-olds	10	7	2	1
			Both groups	20	16	3	1
Exp 2	Apart	LR	4-5- yr-olds	20	7	2	11
Exp 3	Apart	Near-Far	4-5- yr-olds	20	2	0	18
Exp 4	Apart	LR	4-5- yr-olds	16	6	0	10
		FB	4-5- yr-olds	16	5	4	7

Results and Discussions

Percentage correct (i.e., choosing the correct cup) was entered into an ANOVA with Cup Position (middle vs. sides) and Block (egocentric vs. allocentric) as within-subjects factors, and Block Order (ego-to-allo vs. allo-to-ego) and Age Group (young vs. old) as between-subjects factors (see Figure 3b for the percentages). As expected, there was an effect of Cup Position, $F(1, 16) = 7.09$, $p = .01$, $\eta_p^2 = .31$, indicating that children were better at the middle cup trials than the side cups trials (76.3% vs. 62.2%). There was also an effect of block, $F(1, 16) = 34.67$, $p < .001$, $\eta_p^2 = .68$, such that children were better at the allocentric block than the egocentric block (82.9%

[3] Unlike Haun et al. (2006), we explicitly told children that where the experimenter hid the coin at one table served as a clue to where the coin was hidden at the second table. We also marked the change in block where they did not. This is because Haun et al. (2006) reported excluding a high number of participants who either failed to correctly select the middle cup more than 50% of the time or selected it more than 50% when side cups were involved. Indeed, in pilot testing the procedure, we found that children performed poorly even on the middle trials when not told that the hiding location at one table was a clue for the other. Furthermore, we also piloted the same procedure on older children (7- to11-year-olds), some of whom told us after debriefing that they were not aware that they were supposed to be looking for a relationship between the two tables. Thus, we chose to make our task goal more explicit rather than building in some criteria for throwing away participants.

vs. 55.5%). No other main effects or interactions were significant (p's > .09).[4]

The lack of Age Group by Block interaction (p = .72, n.s.) indicates that the older children were not more likely than the younger children to be better at the egocentric block than the allocentric block. See Table 1 for the number of children in each age group classified on the basis of their allocentric percentage correct relative to their egocentric percentage correct. The two groups pattern alike, with the majority being better at the allocentric block. The null difference between the groups is further verified by a Mann-Whitney comparing the difference scores of the two blocks by age group (Mann-Whitney $U = 50$, $n1 = n2 = 10$, p = 1, n.s.). Experiment 1 thus replicates Haun et al. and extends these findings to 6-year-old children. Despite 6-year-olds being more likely than 4-year-olds to have mapped "left" and "right" successfully onto their own bodies, learning spatial language has not yet influenced their performance.

Our replication of better allocentric performance is consistent with the possibility that there is a phylogenetically inherited cognitive preference for noticing invariant allocentric relationships across trials, as put forth by Haun and colleagues. Another possibility, as we discussed in the introduction, is that the arrangement of the tables might have favored the allocentric condition by triggering spatial updating. In the next experiment, we therefore tested similar-aged children in the same environment, but changed the set-up of the tables to hinder spatial updating.

[4] While it is standard to run and report by-subjects ANOVAs, we also verified the findings with equivalent by-items ANOVAs for all experiments (Clark, 1973). The findings are the same with two exceptions. With by-items, we find an interaction between Block Order (ego-to-allo, allo-to-ego) and Block (ego vs. allo) for all experiments. Participants who got a block first generally did better than those who got the same block second. We can think of this as a perseveration effect, where switching FoR is difficult. Specifically, those who were successful in the first block often had greater difficulty on the second block (see Li & Abarbanell, 2018 for same finding). Second, we also found an age effect in Experiment 1, $F(1, 20) = 7.09$, $p = .02$, where older children scored higher than younger children (see Figure 1b). This is because, in averaging across subjects by trial, the by-items analysis has reduced individual variability; the fact that some younger children figured out the rule quickly and some older children figured it out slowly has less impact.

Experiment 2

We pulled the two tables apart to increase the distance traveled from the first to the second table, which should hinder the ease of spatial updating, and thereby hinder the learning of the allocentric rule. Furthermore, the children walked between the two tables rather than around. This would likely decrease the number of shared landmark features that they can see at the two positions (compare Figure 4a and 4b), removing useful visual cues that support the calibration of updating. This may make them rely more heavily on their own bodies as a point of reference. If the children continue to perform better in the allocentric block, this would support the hypothesis of a phylogenetically inherited cognitive preference for allocentric spatial relations. On the other hand, if spatial updating is at play, we might expect children in Experiment 2 to now perform worse on the allocentric block and better on the egocentric block than children in Experiment 1.

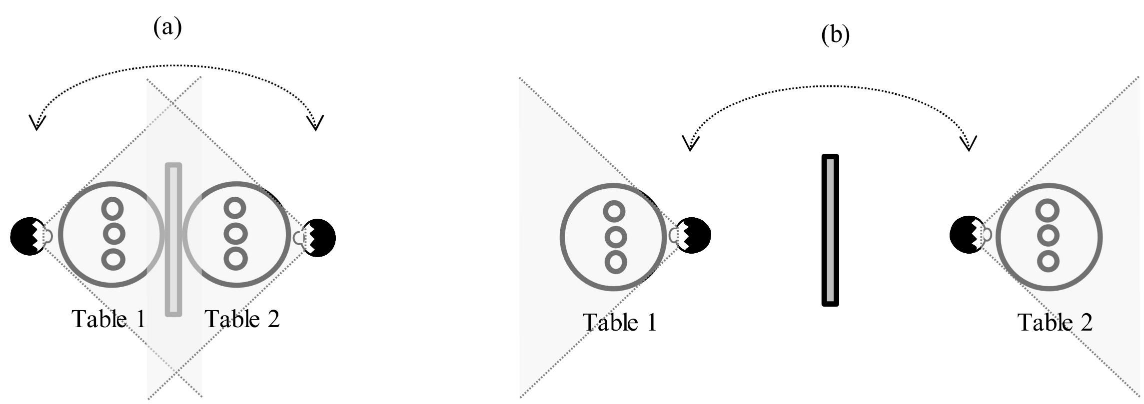

Figure 4. Comparing participants' sightlines across Experiments 1 (a) and 2 (b). Grayed regions show the surrounding environment that are easily visible to the participants at the two table positions. There is greater overlapping view for arrangement (a) than (b).

Methods

Having established the lack of age effect interacting with egocentric vs. allocentric performance in Experiment 1, we did not manipulate age in Experiment 2. We focused on recruiting the younger group (children under six years old), who are less likely to have correctly mapped left-right, to see if they would switch to better performance on the egocentric block over the allocentric block. Twenty new native English-speaking children, recruited to match the same number as Experiment 1, participated (mean age: 5;2, range: 4;2-5;8; 11 female, 9 male). The recruitment, test location, materials, and procedures were the same as Experiment 1, except the tables were now 1m apart instead of 5cm. Instead of walking around the tables, which ensured that the children had overlapping views of the environment across the two tables, participants walked between the two tables, ensuring that the views were non-overlapping (see Figure 4).

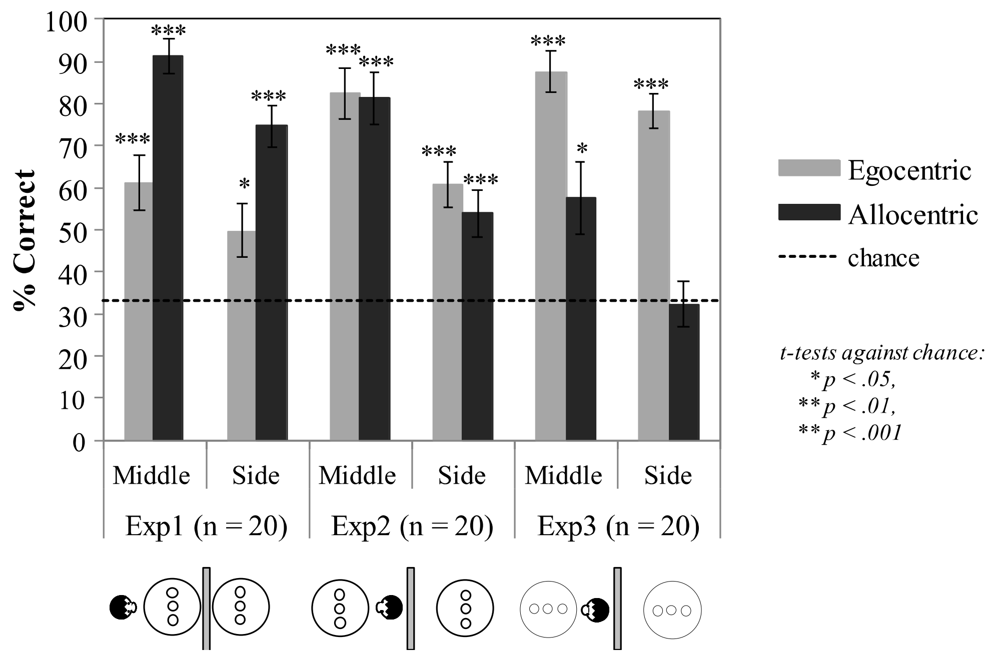

Figure 5. Results for Experiments 1-3. Children's relative performance on the egocentric vs. allocentric conditions varied by experiments (table set-up).

Results and Discussions

The performance as measured by percent correct for this group of children (N=20) was compared to all the children in Experiment 1 (N=20) in a 2 Table Distance (Exp. 1: Tables together vs. Exp. 2: Tables apart) x 2 Cup Position (middle vs. sides) x 2 Block (egocentric vs. allocentric) x 2 Block Order (ego-to-allo vs. allo-to-ego) ANOVA (see Figure 5). As expected, an effect of Cup Position confirmed that the middle cup trials were easier than side cups (middle:

79.1% vs. sides: 59.8% correct, $F(1, 36) = 21.56$, $p < .001$, $\eta_p^2 = .39$). There was also an effect of Block, with allocentric trials being easier than egocentric trials (allo: 75.3% vs. ego: 63.6% correct; $F(1, 36) = 8.36$, $p < .01$, $\eta_p^2 = .19$). Lastly, there was an Table Distance by Block interaction ($F(1, 36) = 15.05$, $p < .001$, $\eta_p^2 = .30$). No other effects were significant (other p's > .17). The Table Distance by Block interaction was due to the fact that the allocentric only differed from the egocentric block in Experiment 1 (tables together) and not Experiment 2 (tables apart). The null effect of Block in Experiment 2 (tables apart) was verified by a 2 Cup Position x 2 Block x 2 Block Order ANOVA for just the Experiment 2 children, which found only an effect of Cup Position (middle: 81.9% vs. sides: 57.4%; $F(1, 18)=20.85$, $p < .001$, $\eta_p^2 = .54$). All other effects were not significant (other p's > .21). Supplementing these findings, Table 1 shows a decrease from Experiment 1 to Experiment 2 in the number of children who scored higher on the allocentric block than the egocentric block. More children in Experiment 2 than in Experiment 1 scored higher on the egocentric block than the allocentric block. Mann-Whitney test on the difference scores between the allocentric and egocentric block verified the tendencies differed across the two table distances/arrangements (Mann-Whitney $U = 72$, $n1 = n2 = 20$, $p = .001$).

In sum, performance on the allocentric trials was not superior to the egocentric trials in Experiment 2, providing evidence that the allocentric FoR is not always privileged on such rule-finding tasks. Our results suggest that how participants navigate from the first to the second table affects which rule is easier to learn. It is possible that had we pulled the tables even further apart, the children would have performed better on the egocentric block relative to the allocentric block. While we did not test this possibility, Rosati (2015), adopting Haun et al.'s simplified third experiment where participants were reinforced several times to pick a particular cup before turning to make their choice, provided supportive evidence. Bonobos predominantly searched in the egocentric location when the second table was located across a hall in another room, but predominantly searched in the allocentric location after turning 180º in the same room.

Next, we turn to another contextual manipulation. In addition to spatial updating, the tendency to encode information allocentrically versus egocentrically may also depend on which body axis the array is aligned with.

Experiment 3

In Experiments 3 and 4, we explore how inherent differences in the salience of body-based asymmetries might favor the egocentric FoR over the allocentric FoR. Specifically, we explore which FoR rule is easier to learn when the cups are aligned along the child's sagittal (front-back) versus transverse (left-right) axis. In most studies that tested whether crosslinguistic variations in spatial language result in differences in how speakers habitually reason about space, very little attention has been paid to the axis with which stimuli are aligned (e.g. Pederson et al. 1998; Li & Gleitman, 2002). One of the first studies, Brown and Levinson (1993) is an exception. They compared Dutch speakers who favor an egocentric FoR in their language with Tseltal (Mayan, Mexico) speakers who favor a geocentric FoR. Using the same table set-up as our Experiment 2, their participants were told to memorize a spatial array (e.g., two dots on a card; a row of objects) at the first table and then prompted to choose or recreate the array after turning 180º and walking to a second table. Dutch speakers overwhelmingly chose or recreated the egocentric array while Tseltal speakers more often preferred the allocentric array. A less-discussed result, however, is that the Tseltal-speakers showed a greater preference for the egocentric response when the array was aligned with their sagittal (front-back) as opposed to their transverse (left-right) axis.

Why might the preference be different for the two body axes? Brown and Levinson

(1993) suggested that "the strong egocentric axis is the 'away' (front/back) one, while the 'weak' egocentric axis is the 'across' (left/right) one" (p. 47), referencing the intuition that "many relative-coders confus[e] left and right to some extent" (Levinson, 2003, p. 207). While studies corroborate the intuition (Corballis & Beale, 1976), the locus of confusion is not entirely understood (e.g., Sholl & Egeth, 1981; Gregory & McCloskey, 2010). Some appeal to the bilateral symmetry of our brain, which may cause difficulties with perceptual discrimination or encoding due to the transfer of left-right reversed visual information across the hemispheres (Corballis & Beale, 1976). Others propose the difficulty is linguistic and show that the when tasks do not require the use of "left" and "right" verbal labels, discrimination of left-right is no longer disadvantaged relative to relations along another axis, such as up-down (Sholl & Egeth, 1981; Maki, 1979; Maki, Grandy, & Hauge, 1979). It remains to be seen whether the axial effect found by Brown & Levinson (1993) can be replicated on Haun et al.'s rule-finding task.

Another possible explanation for the axial effect found by Brown and Levinson that they did not discuss has to do with the fact that the stimuli were all placed in front of the participants. When aligned with the sagittal (front/back) axis, all objects in the array could therefore be encoded as being further away or closer to oneself. This is unlike the transverse (left/right) axis, where the stimuli on the left and right sides were equidistant from the ego or self. The near-far egocentric relation is said to be salient since the near (peripersonal) and far (extrapersonal) distinction has associated neural correlates in both humans and non-human primates, and the distinction appears in the majority of the world's languages (e.g., "this" vs. "that" in English; see Diessel, 1999, 2005; Kemmerer, 1999; Coventry et al. 2008). It is therefore possible that the near-far relationship of cups to the self would help highlight the invariant egocentric relations of the hidden coins across the two tables.

In line with our goal in the present study to characterize the circumstances that favor one frame of reference over another, we therefore ask whether the egocentric rule is now easier than the allocentric rule when the cups are aligned with the children's sagittal (front-back) rather than transverse (left-right) axis. We first examine the salience of the sagittal axis with the cups all in front of the child in Experiment 3, providing a point of comparison with Brown and Levinson's (1993) landmark study (see Figure 5's Experiment 3). In Experiment 4, we turn specifically to "front" and "back", by placing the cups equidistance in front and back of the child.

Methods

Twenty new native English-speaking children (mean age: 4;10, range: 4;0-6;0; 10 female, 10 male) were recruited and tested in the same manner as Experiment 2 with one exception. Instead of the cups being arranged left-to-right in front of the participants, they were arranged in front and aligned with the sagittal axis of the participants (see Figure 5, Experiment 3).

Results and Discussions

Children in Experiment 2 and 3 differed only in the axis by which the cups were aligned and were therefore compared (see Figure 5). The percent correct was entered into a 2 Axis (Exp. 2: transverse vs. Exp. 3: sagittal) x 2 Cup Position (middle vs. sides) x 2 Block (egocentric vs. allocentric) x 2 Block Order (ego-to-allo vs. allo-to-ego) ANOVA. The analysis revealed an effect of Cup Position, Block, and Block x Axis. All other effects were not significant (p's > .10). Again, as expected, performance was better on the middle cups than the side trials (77.2% vs. 56.4%, $F(1, 36) = 27.73$, $p < .001$, $\eta_p^2 = .44$). However, for Block, children as a group now performed better on the egocentric block than the allocentric block (77.3% vs. 56.3%, $F(1, 36) = 22.30$, $p < .01$, $\eta_p^2 = .29$). Finally, the Block x Axis interaction (see Figure 5, $F(1, 36) = 14.07$, $p = .001$, $\eta_p^2 = .29$), showed that this was due to the fact that performance on the egocentric block was better than the allocentric block for the sagittal axis (81.3% vs. 40.6%; $t(19) = 14.07$, $p = .001$) and not the transverse axis (67.9% vs. 63.0%; $t(19) = 0.80$, $p = .44$, n.s.). See also Table 1, which shows an increase from Experiment 2 (transverse) to Experiment 3 (sagittal) in the number of children who scored higher on the egocentric block than on the allocentric block (Mann-Whitney $U = 66.5$, $n1 = n2 = 20$, $p = .001$).

The present results, like Experiment 2, again disconfirm the claim that allocentric/geocentric relations are necessarily more basic. Instead, which frame of reference is more salient depends on the task details. In the next experiment, we extend this work to look more specifically at front/back relations.

Experiment 4

In Experiment 4 the children were assigned to one of two conditions: A transverse condition (Figure 6a) that served as a direct replication of Experiment 2, and a sagittal condition (Figure 6b) that allowed us to explore the nature of the axial effect reported in Brown and Levinson (1993) and confirmed in our Experiment 3. In the new sagittal condition, the cups were now aligned along and parallel to the sagittal axis such that one was in front of and one in back of the child. Both were equidistance from the child. This removed near-far as consideration in order to see if performance on the egocentric block along the sagittal axis would remain markedly better than the allocentric block.

Methods

Altogether, thirty-two new children, sixteen in each condition[5], were recruited (mean age:

[5] Using difference in percentage correct between egocentric and allocentric block as a dependent measure, the univariate ANOVA comparing Experiments 2 and 3 yielded an effect size of 6.38. Using that then as an estimate of effect size for the present experiment with $\alpha = .05$ and power $(1-\beta) = .8$, a minimal sample size of 22 children (or 11 per condition) is needed (Faul, Erfelder, Lang, & Buchner, 2007). With the removal of near-far relation from consideration, it is possible that the magnitude of a difference, should there be one, could be smaller. We therefore

4;8, range: 3;11-5;4; 12 female, 20 male) from a laboratory database and tested in a quiet laboratory hallway alcove. The two tables were arranged as Experiment 2, with a cardboard divider in the middle. The children were instructed prior to the test trials on how and where to stand with footprint markers on the floor, which helped maintained their facing orientation especially in the sagittal condition such that the front cup was in full view and the back cup was visible from the corner of their eye. The location of the tables was chosen to mimic the museum setting of close proximity to walls at one table and openness at the other table. Note that while the location changed, locomotion that triggers spatial updating remains at work, and thus the results should not differ greatly, if at all. Testing in the laboratory allowed us to tack on a language comprehension task to test children's knowledge of left-right language, which was not possible with the museum's regulations to keep testing sessions short. The details of the language task and results are available as supplemental materials. The results verified that children at this age typically have not yet acquired these terms, and that performance on the main task did not correlate with knowledge of "left" and "right" terms.

Results and Discussions

The percentages correct (see Figure 6c) were entered into a 2 Axis (sagittal vs. transverse) x 2 Cup Position (middle vs. sides) x 2 Block (egocentric vs. allocentric) x 2 Block Order (ego-to-allo vs. allo-to-ego) ANOVA. The analysis revealed only one main effect of Position: the percentage correct for the middle cup position was higher than that for the sides (78.9% vs. 52.7%; $F(1, 28) = 45.39$, $p < .001$, $\eta_p^2 = .62$). All other effects were non-significant (p's > .18). Replicating Experiment 2, performance on the egocentric block was not worse than on the allocentric block (Ego: 68.1% vs. Allo: 63.5%); When participants made a different 180°

increased the number of children to 32, or 16 per condition, to increase the power of detecting a difference between front-back vs. left-right axis.

turn than that in Haun et al. and our Experiment 1, the allocentric advantage disappeared. Unlike Experiment 3, however, we did not find an Axis by Block effect. That is, performance on the egocentric block was not significantly better than on the allocentric block when the cups were aligned along the FB-sagittal axis. In fact, there was no difference in performance between the FB-sagittal and LR-transverse axes (see also Table 1, Mann-Whitney $U = 127.4$, $n1 = n2 = 16$, p = .99, n.s.), suggesting that despite left-right bilateral body symmetry children can draw upon somesthetic asymmetry or handedness to learn to discriminate left vs. right just as well as front vs. back (see also Greenspan, 1975; Jeffrey, 1958; Vingerhoets & Sarrechia, 2009; Shusterman & Li, 2016). Finally, comparing these results with Experiment 3 suggests that deictic near-far relationships are more salient than egocentric front/back.

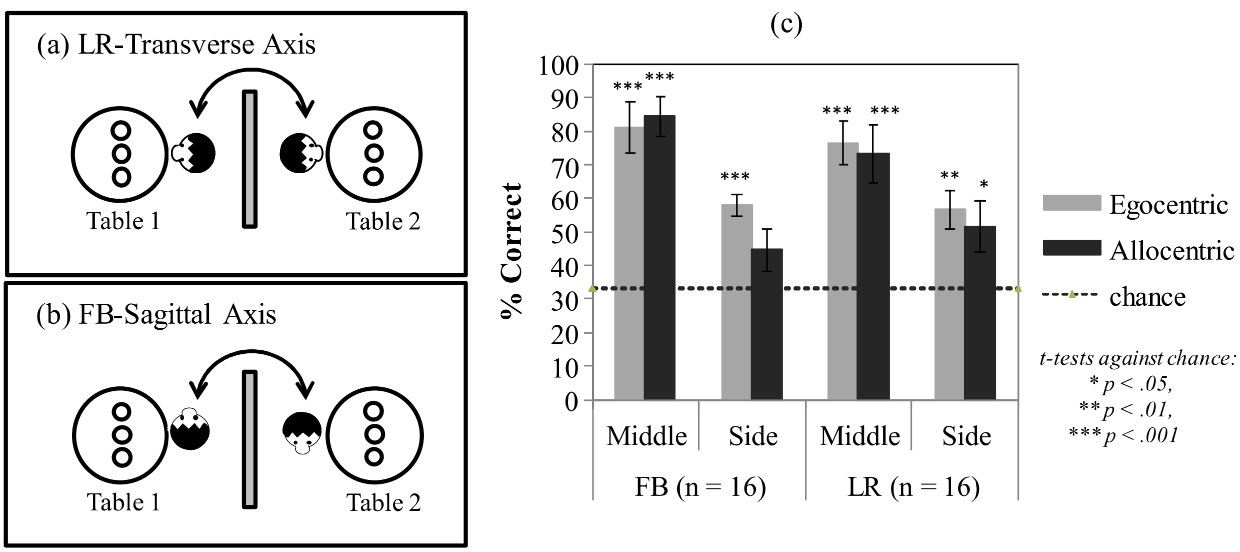

Figure 6. Set-up (a-b) and results (c) for Experiment 4. In the sagittal condition (b), the cups are aligned with the child's sagittal axis such that one cup is in front of the child and one cup is behind. Front and back cups are equidistant from the child, thereby removing near-far as a consideration. Egocentric vs. Allocentric performance did not differ across the two axes (FB-Sagittal, LR-Transverse).

General Discussions

Summary of Findings

In the present study, we sought to reexamine Haun et al.'s claim of a phylogenetically inherited preference for using an allocentric/geocentric FoR among the Hominidae genera, and that a preference for the egocentric FoR may only develop through enculturation with left-right language. Although these claims follow from the experimental findings and are endorsed by many (Henrich, Heine, & Norenzayan, 2010; Newcombe, Uttal, & Sauter, 2013; Gentner, 2007), we argued that they warrant reexamination in light of researchers who convincingly argue that egocentric and allocentric representations are both necessary and work in concert (see Gallistel, 2002; Newcombe, 2017; Burgess, 2006). Furthermore, the experimental/table set-up used by Haun et al. shared similarities with conditions that have previously induced favorability for the allocentric FoR in studies on spatial updating (Burgess, Spiers, & Paleologou, 2004; Nardini, Burgess, Breckenridge, Atkinson, 2006), leaving open the possibility that other set-ups might reverse this favorability. We therefore tested whether modifications of the testing conditions could readily shift the salience of the egocentric vs. allocentric FoR. It was not, however, a given that any modifications would readily affect performance. In particular, Haun et al. (2006; Gentner, 2007) suggested that the current paradigm of asking participants to abstract a rule involves relational learning that prior studies may not have necessarily tapped. Furthermore, a recent novel spatial word learning study at first blush seemed to show children favor "north"/"south"-like meanings over "left"/"right" (Shusterman & Li, 2016).

In Experiment 1, we first replicated Haun et al.'s study with a similar arrangement of tables and turn, and found that, like their study, children performed better on the allocentric rule than the egocentric rule. This held true not only for 4-year-olds, but also for slightly older children who have had some exposure to "left" and "right" language. Experiments 2 and 4 showed that children performed equally well on both rules when the tables were further apart and the children made a different 180º turn so that they did not face the original table. It is possible that had the tables been even further apart, the children would have shifted to being better on the egocentric rule than the allocentric one as suggested by Rosati (2015)'s finding with bonobos, a genus of primates Haun et al. also tested. These results supported the argument that Haun et al.'s original table arrangement might have primed the allocentric perspective via spatial updating.

Experiments 3 and 4 compared children's ability to learn the egocentric and allocentric rules when the cups were aligned with the children's sagittal rather than transverse axis. In Experiment 3, with both of the cups in front of the children in a near/far relationship, the children were now more successful on the egocentric rule. In Experiment 4, with the cups aligned more directly with the children's front and back, they performed equally well in the egocentric and allocentric conditions. Together, these experiments indicate that the egocentric rule is not always more difficult, and so the claim that there is an inherited preference for environment-based FoR over egocentric FoR was perhaps made too hastily. While these studies were about finding a common rule or relation across trials, the factors that affect rule-finding align with what prior spatial studies suggest affects the weighting of different reference frames (e.g., Burgess, Spiers, & Paleologou, 2004; Brown & Levinson, 1993).

Language Enculturation and Gricean Considerations

Haun et al.'s results testing 8-year-old children and adults showed that Dutch speakers were faster at figuring out the egocentric rule than the allocentric rule, while the Hai||om speakers could only figure out the allocentric rule. These finding led Haun et al. to conclude that learning "left" and "right" language led speakers to override a phylogenetically inherited preference for allocentric representations in favor of egocentric ones, suggesting that habitual spatial language comes to shape speakers' nonlinguistic encoding of spatial relationships. Given this line of reasoning, one might wonder whether our English-speaking children were only able to guess the egocentric rule because they were in the process of learning “left” and “right” language. After all, despite being at chance on distinguishing “left” and “right” linguistically, 5-year-old English-speakers do possess partial understanding of those terms (Dessalegn & Landau, 2008). Thus, had we tested children learning a geocentric language, they might have failed on the egocentric rule. To ascertain with greater confidence that there was no language influence, future studies could test 4- or 5-year-old geocentric language learners on the present table set-ups.

There is, however, already some evidence that geocentric language learners might not have difficulties with egocentric left-right relations, and that they would show the same effects of spatial updating. First, several tasks that pit an egocentric condition against an allocentric condition found that that adult speakers of a geocentric language had no difficulties representing egocentric (left-right) relations and were often better at the egocentric than the allocentric condition (Li, Abarbanell, Gleitman, & Papafragou, 2011). Many of these studies involve a 180° turn, like Experiment 2, between two tables that are at two ends of a testing room to minimize the shared view across them. For example, in a coin search task reminiscent of the present experiments, Tseltal speakers watched as the experimenter hid a coin underneath one of three cups arranged in a symmetrical V-shape on top of a cardboard circle. The experimenter then carried the cardboard to the second table at the other side of the room, where it was placed to maintain either the egocentric (V) or allocentric (inverted V) orientation of the cups in relation to the participants. After placement, the participants walked to the second table to search for the hidden coin. The Tseltal speakers performed better using the egocentric perspective. Further, a more recent study (Li & Abarbanell, 2018) testing eight-year-old Tseltal-speaking children on a task involving recreating arrays of toy animals, provides supporting evidence that varying the distance or the type of turn (i.e., 90° vs. 180°) between the two tables affects which FoR, egocentric or allocentric, is easier to use.

Li and colleagues' studies with Tseltal-speakers therefore suggest flexibility in spatial reasoning that is independent of habitual language use. This may seem at odds with Haun et al.'s finding that Hai||om speaking adults could not figure out the egocentric rule. However, there is a fundamental difference between the two sets of tasks. While Haun et al.'s task is about guessing a rule that the experimenter has in mind, Li et al.'s tasks were not. For example, in Li et al.'s V configuration coin search task, participants could solve the task by noting the configuration of cups at the second table without having to guess how the experimenter wanted them to interpret the configuration (see Li et al. 2011 and Li, Dunham, & Carey, 2009 for a similar discussion on open-ended vs. non-open-ended tasks). As many have noted, people quickly and often effortlessly draw upon common-ground and shared conventional knowledge when interpreting the intent of a speaker (Grice, 1989; Horn, 1972, 1989; Clark, 1992; Sperber &Wilson, 1995). Being a member of a linguistic community leads one to become attuned to these conventions. This attunement shapes the hypotheses one entertains in communicative situations, such as figuring out the rule the experimenter has in mind. As a result, older participants, who have had prolonged exposure to their native language, are more likely to consider the language-congruent rule over language-incongruent ones. This explains why Dutch and Hai||om adults were better at guessing the rule consistent with their own language. However, beyond communicative situations, the extent of language's influence on cognition might be limited.

Learning Linguistic FoRs

As Haun et al. intended to examine the cognitive biases that support language acquisition, we next turn to speculations on what the current findings reveal about the acquisition of frame of reference terms such as "uphill"/"north" or "front"/"left"? How do our current findings corroborate or extend prior knowledge about the acquisition of these terms? Are the distinctions that they encode available early on, or are certain distinctions, specifically left/right, constructed through language enculturation? Following Haun et al. and other cognitive psychologists, we have framed our discussion thus far around the egocentric-allocentric distinction that distinguishes one's own perspective from all other perspectives. A more appropriate way for characterizing linguistic FoR, however, is to divide them on the basis of the physical world between FoRs that are anchored to and invariant of the earth (i.e. geocentric or environment-centric FoRs) and FoRs that are derived from entities that move around on earth (i.e.., object-centered FoRs). See Shusterman & Li, 2016 and Figure 7 for the different typologies.

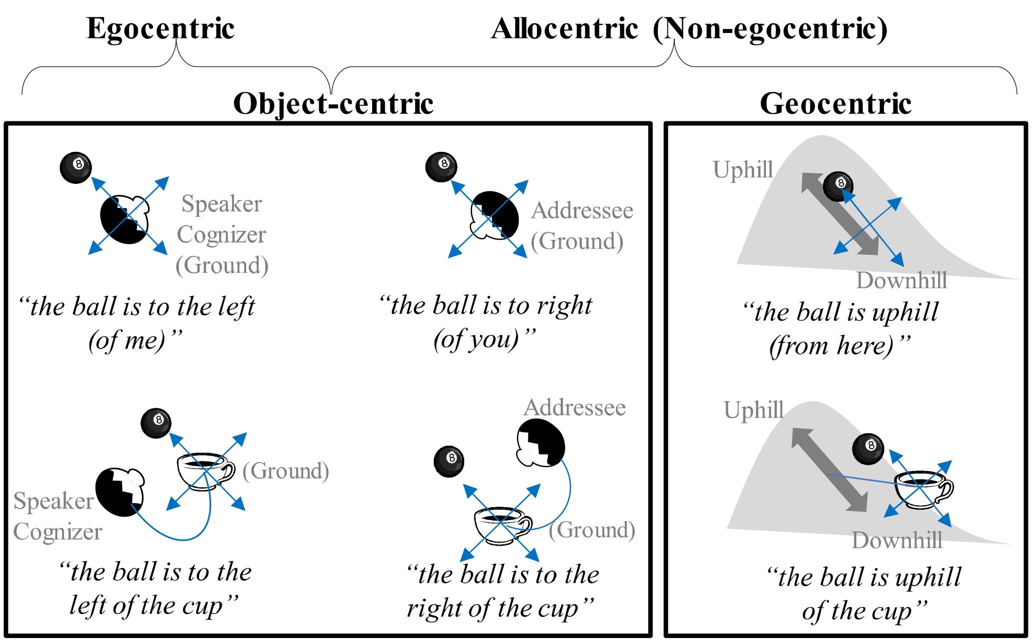

Figure 7. Classifications of FoRs. Egocentric vs. allocentric divides FoRs on the basis of coordinates involving oneself or not. In above examples, the ball (figure object) can be described using egocentric coordinates (my left) or not (your right; uphill-ward). Object-centric vs. geocentric divides FoRs with respect to whether the coordinates are derived from moving entities (e.g., people, a chair) or earth-anchored entities (e.g., a house, a hill). A third popular division not discussed in the present text is Levinson (1996)'s intrinsic vs. relative FoR, contrasting whether the ground object is also the contributor of the coordinates or not (contrast top and bottom rows of pictures above; see Shusterman & Li, 2016).

With respect to learning environment-based terms, our Experiment 1 replicated Haun et al. (2006) by showing children could easily learn the allocentric rule. However, one cannot ascertain on the basis of this evidence whether children solved the allocentric rule by noticing the invariant relation of the cups at both tables to local objects, such as the walls of the room or the sides of the tables, or to large anchored landmarks, such as the north/south axis of their terrain. However, another study from our laboratory (Shusterman and Li, 2016) did show that English-speaking 4-year-olds, who were given evidence and learned that novel spatial words had non-egocentric (i.e., allocentric/geocentric) meanings, pointed in the appropriate cardinal directions when tested immediately outside the room ("Which way is *ziv*?") and then down the hallway from where the words were first introduced. Thus, it does appear that our cognitive foundation supports learning geocentric reference words.

What about learning object-centric terms, particularly those that are based on the axes of the body? Experiments 2-4 demonstrated that children can easily abstract egocentric relations across two tables when competing allocentric/geocentric meanings are reduced. This suggests that learning "left" and "right" may have a better outcome when the words are reintroduced across a longer distance, where it is difficult to track geocentric relations.

Studies, however, show children experience greater difficulty learning the words "left" and "right" than "front" and "back" (Kuczaj & Maratsos, 1975; Rigal, 1994) when our children were equally good at the left-right versus front-back rules (Experiment 4). Why might the axial difference be present for word learning, but not found in the present study? One possibility is that the hypothesis space children consider for rule learning differs from that of word learning. Children may be accustomed to the idea that contrasting words should label facets that appear different. Since left-right sides are identical-looking, this might not strike children as a plausible distinction marked by language. They may have fewer preconceived assumptions for the rule learning game. A second possibility is that even if children know “left” and “right” label opposite directions or sides of their body, remembering which label applies to which side is harder to do than for “front” and “back” where there is a greater contrast in directional valency. A third possibility requires distinguishing between egocentric and non-egocentric object-centric relations and, further, considering non-egocentric object-centric relations across the two axes. Our Experiment 4 supports the possibility that egocentric left-right relations can be just as salient as egocentric front-back relations. In the present paradigm, children had to move, point, and select cups, potentially tapping into somesthetic asymmetry. Several studies have shown that highlighting that asymmetry and body sense can help children learn how to apply “left” and “right” terms to their own bodies (Greenspan, 1975; Jeffrey, 1958), but not to other’s bodies (Shusterman & Li, 2016). With respect to non-egocentric relations, children cannot easily identify others’ left-right as they can for front-back by looking for visible physical differences, nor can they rely on the somesthetic asymmetry that is available to distinguish their own “left” and “right”. Thus, children would not have the means to verify or even understand some of the instances they hear of “left” and “right” (i.e., non-egocentric uses), while they would have an easier time checking their hypotheses for “front” and “back”.

Conclusions

We began with Haun et al.’s findings, but then probed further to see whether their claim regarding phylogenetic inheritance of allocentric over egocentric spatial representation was warranted. Our four experiments, along with considerations of other reported studies, paint a different and more coherent picture of children’s initial endowments. Contrary to Haun et al, linguistic enculturation is not responsible for making egocentric representations more prominent in thought; egocentric representations are just as readily available as allocentric representations from the outset. We share Haun et al.'s intuition that learning a geocentric reference system in one's language is easy, but we disagree with their suggestion that the reason why learning an egocentric reference system in one's language such as the left-right system in English is difficult is because egocentric representations are less prominent cognitively. Rather, our findings here, together with a large body of literature on spatial cognition across species, shows that egocentric relations are just as accessible as geocentric ones. The somewhat later acquisition of "left" and "right" terms may instead be attributable to their symmetry and the difficulty of representing non-egocentric left-right relations (Rigal, 1994; Lasky, Romano, & Wenters, 1980; Abarbanell & Li, 2015). We suggest that, if anything, non-egocentric left-right is where learning spatial language might highlight a less salient relationship that then gets deployed for problem-solving and spatial reasoning.

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Appendix A: Supplementary Material

The following are supplementary material and data to this article:

Language Assessment Procedure and Results: [PUT LINK HERE]

Data: https://data.mendeley.com/datasets/57mw3vyn4g/draft?a=abec8ea1-d51b-4b43- adcc-1db827b70969

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