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 often noticed environment-defined relations (e.g., "north") and not egocentric body-defined ones (e.g., "left"), leading them to conclude that preschoolers are ready to learn environment-defined terms, but not body-defined ones. However, such a conclusion may be premature. Four new experiments demonstrated that the previous findings could be an artifact of specific experimental manipulations. With minor experiment modifications, 4-year-olds now readily noticed egocentric body-defined 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 multiple years under normal circumstances.

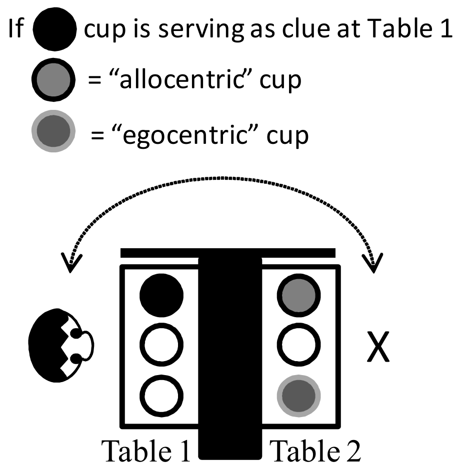
Keywords: spatial frames of reference, allocentric, egocentric, left-right, linguistic relativity, word learning

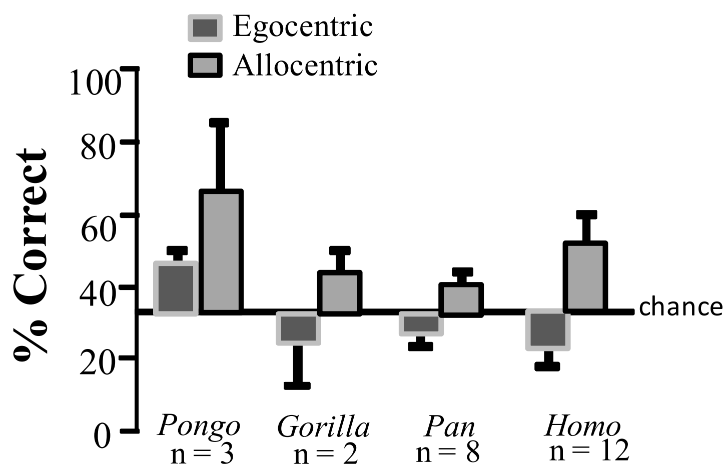
Introduction

Languages vary in their stock of spatial frames of reference (henceforth, FoR) words. Some languages, like English, prefer body-defined terms ("left-right"). Other languages, like Hai||om, prefer environment-defined terms ("north-south") even for small scale space, such as for describing things on a tabletop (e.g., "Pass me the plate north of the cup."). Cross-linguistic variations in how speakers talk about directions and locations have led to researchers to ask 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; Haun et al. 2006)? Second, to what extent does learning spatial words drive speakers to analyze new relations and/or to restructure old ones (Bowerman & Choi, 2001, 2003; Pederson et al. 1998; Majid et al. 2004; Levinson, 2003)? Research in the last two decades has mainly focused on addressing the second question (Pederson et al., 1998; Majid et al. 2004), although the conclusions are far from settled (e.g., see Li & Gleitman, 2002; Li, Abarbanell, Gleitman, & Papafragou, 2011 vs. Levinson, Kita, Haun, & Rasch, 2002, Haun, Rapold, Janzen, & Levinson, 2011). In the current paper, we focus on the first question, which addresses the cognitive capacities children bring to learning spatial FoR terms.

Specifically, we question the claims made by an influential study (Haun, Rapold, Call, Janzen, & Levinson, 2006) that has been cited in several prominent review papers in cognitive and developmental psychology (e.g., Newcombe, Uttal, & Sauter, 2012; Henrich, Heine, & Norenzayan, 2010; Gentner, 2007). Haun and colleagues conducted a simple and elegant study to address whether there are phylogenetically inherited frames of reference that serve as the cognitive basis for acquiring spatial language. Their study tested populations without spatial language, which included non-human primates and German-speaking 4-year-olds (mean age:

4;10). Haun et al. chose German-speaking 4-year-olds as not knowing spatial language because studies since Piaget (1928) have established that children in Western industrialized societies only begin to acquire spatial words such as “left” and “right” at age five and that it is not until years later that they achieve complete competency (e.g., Elkind, 1961; Rigal, 1994).





(a) (b)

Figure 1. Set-up and results from Haun et al.’s Experiment 2 (2006). Four genera of primates were shown on each trial a hiding location at the first table as a clue for retrieving a hidden treat at the second table (when they move to face the table at spot X). Clues within a block of trials always followed egocentric relations or always followed allocentric relations. The above example (a) depicts which cup maintains the egocentric relation and which the allocentric one at Table 2 when the left-/northern-most cup at Table 1 served as the clue. Overall, participants were better at the allocentric than the egocentric condition (b).

In Haun et al’s study, participants were shown an object hidden under one of three identical cups and then led to a second table with a second set of three identical cups, where they had to search for another hidden object (Figure 1a). Critically, where the experimenter hid the object at the first table served as a clue or a hint for finding the hidden object at the second table. Across a block of trials, the experimenter’s 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 the clue 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). Over trials, through feedback of looking for the hidden object at the second table, the participants had to figure out the rule the experimenter had in mind. This paradigm parallels word-learning where children have to abstract a consistent pattern across instances.

Haun et al. posited several possible outcomes. The participants might find both egocentric and allocentric rules easy to learn. This finding would suggest that both FoRs are conceptually available at the start to support word learning and abstract reasoning. Alternatively, both FoRs might be equally difficult, suggesting that learning may require scaffolding and enculturation. Lastly, it is possible for one of the FoRs to be easier and more dominant than another. As Haun et al. pointed out, many philosophers and psychologists such as Immanuel Kant and Jean Piaget have favored the egocentric FoR as being more basic and assumed that our body is the initial source of our intuitions about space. Contra Kant and Piaget, however, Haun et al. found that across all tested genera, participants were dismal at learning the egocentric rule but excelled at the allocentric rule (see Figure 1b for the results by genera and FoR).

Haun et al. also tested children and adults who have acquired language-specific spatial language (8-year-olds and adults). For the older population, Haun et al. increased the difficulty of the search by increasing the number of cups from three cups in a line to five cups aligned in an X configuration. They contrasted speakers of Dutch, a language that prefer body-defined terms, with speakers of Hai||om, a language that prefers environment-defined terms. The findings showed that although Dutch participants could figure out both egocentric and allocentric rules, they were faster at figuring out the egocentric rule. Hai||om speakers performed worse overall,

[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 importantly, they could figure out the allocentric rule, but not the egocentric rule. Thus, unlike young children (and non-linguistic, non-human primates), older children and adults were better at figuring out the rule that aligned with their language.

The pattern of results led the experimenters to the following concluding remarks: “All genera prefer environment- to self-centered processing… suggest[ing] a common phylogenetic inheritance of a preference” (p. 17572). This preference, however, can be overridden as in the case of Dutch speakers. “Nevertheless, overriding the bias might be expected to incur some costs; the theory makes predictions about the relatively greater difficulty of acquiring a predominantly egocentric coding system” (p. 17572). Haun et al. bolster the last remark by citing the fact that children in cultures that favor geocentric language learn environment-defined terms as early as four years old and certainly before seven (Brown & Levinson, 2000; Dasen & Mishra, 2010), while English-speaking children do not master “left” and “right” until eleven (Elkind, 1961; Rigal, 1994).

In the present paper, we revisit the experimental design and question the claim of an inherited preference for environment-based representations over self-centered representations. Although the claim follows directly from their experimental results, the results are at odds with previous research that has shown that both types of representations are readily available and often work in concert (see Burgess, 1996 for review). Furthermore, in studies where egocentric and allocentric frames were pitted against each other, which of the two representations was preferred depended highly on the task and situational context (Acredolo, 1979; Acredolo & Evans, 1980; Bremner & Bryant, 1977; Bremner, 1978a, 1978b; Pick, Yonas, & Rieser, 1979; Rieser, 1979). For example, Acredolo (1980) showed that 9-month olds relied more heavily on the egocentric frame of reference in object search tasks when tested in unfamiliar environments (e.g., a small laboratory room or an office), and made use of environmental landmarks in familiar environments such as their house. In another study that showed heavy reliance on egocentric representations, four-year-old English-speaking children who were asked to retrieve a hidden object from one of two locations on opposite walls of an empty room often mistakenly used their own egocentric FoR after turning 180 degrees, and had to be reminded that they turned to correctly retrieve the hidden object (Acredolo, 1977). Thus, a claim about a cognitive predisposition for allocentric or environment-based FoR over egocentric FoR is inconsistent and at odds with several studies since Piaget (1928) that show that infants and children under some circumstances heavily weigh egocentric information (see Bloch & Morange, 1977 for review).

We suspect, like Haun et al., that "the model for human cognition… has a rich, inherited primate basis" (p. 17571), and that there are cognitive neural substrates that support both egocentric and allocentric FoR. However, unlike Haun et al., we do not hold that allocentric/geocentric representations are always the preferred FoRs before any exposure to language and culture. Instead, whether egocentric or allocentric representation is weighed more heavily will depend in part on the testing situation (Burgess, 1996; Bloch & Morange, 1977).

Why then did Haun et al.'s experiments show that the allocentric FoR is favored over the egocentric FoR? Here, we turn to a phenomenon known as "spatial updating." Studies from spatial cognition literature have shown that while one is walking to a new location, the locomotion automatically triggers an update of where stationary objects are located relative to one's new position, giving rise to an "allocentric" representation (e.g., Simons & Wang, 1998; Wang & Simons, 1999; Mou et al. 2004; Bremner, 1978; Rieser & Heiman, 1982). The ease of spatial updating is mediated by various factors. Spatial updating is more difficult the greater the distance one has to travel or the greater the degree one has to rotate away from the array of objects one is tracking (Rieser & Heiman 1982; Waller & Hodgson, 2006; Brockmole & Wang, 2005). Spatial updating is also hampered by the removal of salient features/landmarks in the environment (Simons & Wang, 1998; Burgess et al. 2004; Foo, Warren, Duchon, & Tarr, 2005). These studies show that, depending on the experimental setup, the updated representation of object arrangements (i.e., allocentric FoR) can be either stronger or weaker than the representation of object arrangements matching one's initial view (i.e., egocentric FoR).

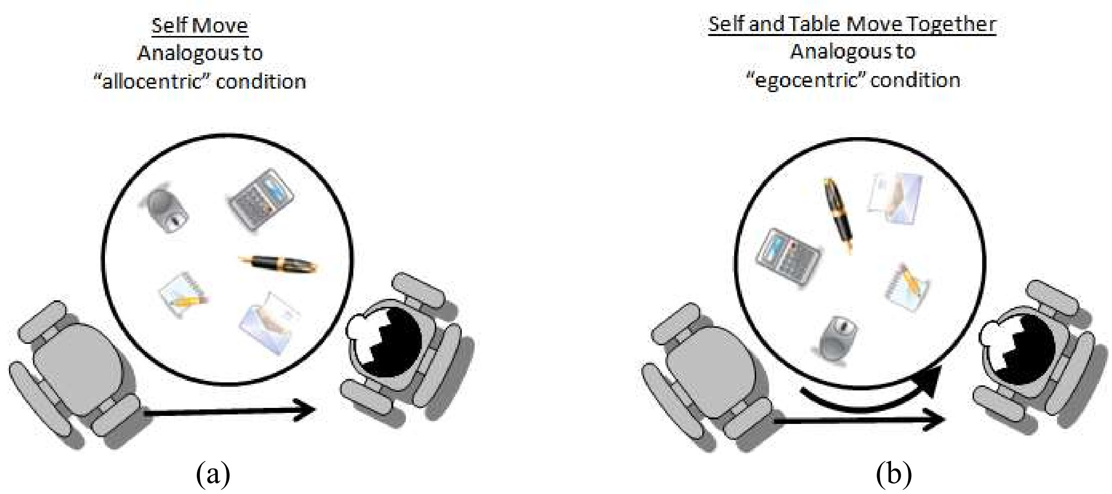


Figure 2. Two conditions of typical spatial updating experiments, where participants have to memorize an array of objects and then later recall the objects after the table or they themselves have moved. The two depicted conditions mirror the "allocentric" and "egocentric" conditions of Haun et al. (2006) study, respectively.

Haun et al.'s setup is similar to studies with setups that found more robust allocentric representation than egocentric representation (e.g., Burgess, Spiers, & Paleologou, 2004; Nardini, Burgess, Breckenridge, Atkinson, 2006). These studies involved detecting a change in an array of objects on a table (e.g., one object may be surreptitiously moved), or recalling where an item was hidden amongst several containers. Participants were first asked to study an array (initial egocentric view), after which the array was covered. Conditions then varied whether the participant moved to another position around the table and/or whether the table was rotated.

Then the array was uncovered and participants had to identify which of the several objects had moved, or recall which object contained a hidden item. The condition in which the table remained stationary while the participant moved (Figure 2a) is analogous to Haun et al.'s allocentric condition. The condition in which both the table and the participant moved and rotated together (Figure 2b) is analogous to Haun et al.'s egocentric condition. Studies found that participants performed better on the former condition than the latter. That is, participants were better at detecting which object amongst several was subsequently moved or which container amongst several served as a hiding location when the table remained stationary while the participant moved (Burgess, Spiers, & Paleologou, 2004: see their self (allocentric) vs. self-and-table (egocentric) conditions; Nardini, Burgess, Breckenridge, Atkinson, 2006: see their child-move (allocentric) vs. both-move conditions (egocentric)).

Our intuition, based on prior studies, is that Haun et al. may have picked a table setup that especially favored learning the allocentric rule. If so, changes in how much participants move relative to their original position and changes in which direction they are facing 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. If true, we may thus be able to shift children's preference with another table setup, and show that children can learn the egocentric rule.

However, it is possible that our intuitions are incorrect. Although prior studies suggest that children draw upon multiple FoRs when reasoning about space, these implicit uses of different FoRs may not be available for the purposes of learning and abstracting rules across instances. In which case, Haun et al.'s finding should still stand. The present experiments therefore tested their claim that the inherited mode of cognitive preference is allocentric by slightly varying Haun et al's design. In Experiment 1, we first tested for the replicability of Haun et al's results, using two adjacent tables and 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 been previously shown to affect whether egocentric or allocentric representations are weighed more heavily. The findings from the present studies will be relevant for claims one can make regarding our phylogenetic inheritance. Although Haun et al.'s data showing that all primate genera were better with the allocentric rule than the egocentric rule does convincingly "upset the Kantian assumption of the priority of egocentric spatial reasoning," (Haun et al. 2006, p. 17572), it remains to be seen whether allocentric FoR is easier across a variety of similar tasks, or whether which FoR is easier depends on the precise details of the task. The findings also have the potential to enrich our understanding of how children acquire words such as "left" and "north," and may have implications for how we should teach children the meanings of such words.

Experiment 1

Experiment 1 is a replication of Haun et al., where children played a coin finding game by using a clue given by the experimenter at one table to locate the coin at another table. We tested children of similar age to Haun et al. (2006)'s (their mean age = 4;11 and our mean age = 4;9), but also included a slightly older group (mean age = 6;5). Haun et al. (2006) established that 8-year-olds were influenced by the way their language community talks about space when guessing the rule the experimenter had in mind (see also Haun et al. 2011; Abarbanell, Montana, & Li, 2011). With the 6-year-olds, we explore whether the influence of language is present even before 8-years-old.

Methods

Participants. Twenty native English-speaking children participated. All participants were visitors at a large metropolitan science museum and were tested in the corner of an exhibition hall. A signed consent was obtained from the children's legal guardian. 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.

The children were divided into a younger group (mean age: 4;9; range: 4;0-5;10; 6 female, 4 male) and an older group (mean age: 6;5; range: 6;1-6;8; 5 female, 5 male). The younger group of children is unlikely to know the meanings of "left" and "right", although they may have some knowledge that "left" and "right" are opposite directional terms (Dessalegn & Landau, 2008). The group is also unlikely to be attuned to their linguistic community's linguistic FoR preferences (Haun et al., 2006), and thus it is unlikely that linguistic preferences would influence the guesses of the rule. On the other hand, the older group is more likely to be able to identify the "left" and "right" sides of their own body when asked (Rigal, 1994), which may improve their ability to guess the egocentric rule.

Materials and Procedures. Two round tables (diameter: 40cm in diameter, height: 60cm) were placed next to each other with a gap of approximately 5cm between them. A solid opaque screen 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 three 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 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 larger, surrounding environment. If the hiding cup was the northern-most cup, the finding cup was again the northern-most one at other table.

Each block consisted of twelve 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 target was hidden in the middle cup in trials 2, 5, 8 and 11. In these middle trials, both rules (egocentric or allocentric) led to the same solution. Haun et al. found children had relatively little difficulty with these trials. Thus, distributed evenly across the block, these trials provided a means to gauge whether children were attentive.

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 target under one of the three cups. In the meantime, a second experimenter hid a coin in the corresponding cup at table 2 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 to allow participants to adjust their behavior in order to maximize the hit rate. 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 twelve trials, but without further reminder after the first two trials that where the coin was hidden at the first table served as a clue for where the coin was to be found at the second table. At the end of the twelve trials, and the beginning of 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.[2] The study then proceeded as before for another twelve trials.

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. Analysis revealed an effect of Cup Position, $F(1, 16) = 8.13$, $p = .01$, $\eta_p^2 = .34$, and an effect of Block, $F(1, 16) = 35.87$, $p < .001$, $\eta_p^2 = .69$. No other main effects or interactions were significant (p's > .09). Figure 3b, which plots the average percentage correct for the two age groups broken down by block and cup position, reflects the analysis. The younger children did

[2] 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.

not differ from the older children. Both groups were better at the middle cup trials than the side cups (76.3% vs. 61.2%), and better at the allocentric block than the egocentric block (82.8% vs. 54.7%). The results thus replicate Haun et al. (2006).

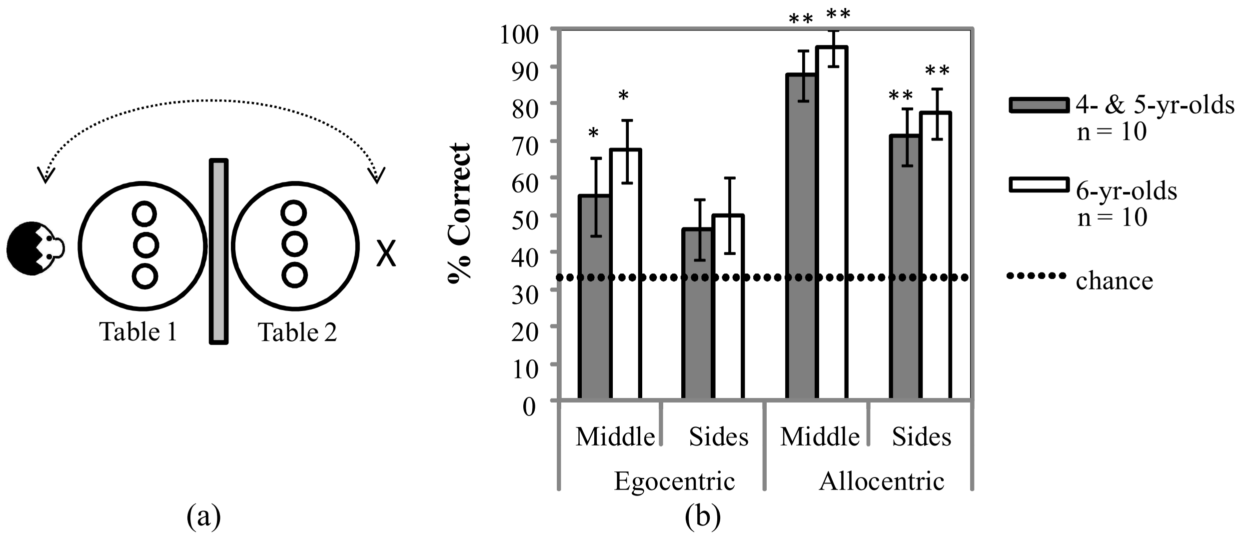


Figure 3. Set-up (a) and results (b) of Experiment 1. For the set-up (a), X marks where the child stands at Table 2 while facing the table and screen. The large circles represent the two circular tables and the small circles represent the cups. The gray line in between the tables is an occluder. Percentage correct in identifying the target cup is plotted in (b). The asterisks indicate t-tests against chance of 33.3% (1 in 3 cups). * p's < .05; ** p's < .01.

Experiment 2

Having replicated Haun et al.'s study, we changed the set-up of the two tables in Experiment 2 to ask whether table arrangements could shift the allocentric vs. egocentric performance. The two tables were pulled apart to increase the distance traveled from the first to the second table, which should affect spatial updating. Furthermore, children walked between the two tables rather than around. This would likely decrease the number of shared landmark features that the children can see at the two positions (compare Figure 4a and 4b). When participants can no longer see the part of the room where they initially viewed the array, this may make them rely more heavily on their own bodies as a point of reference.

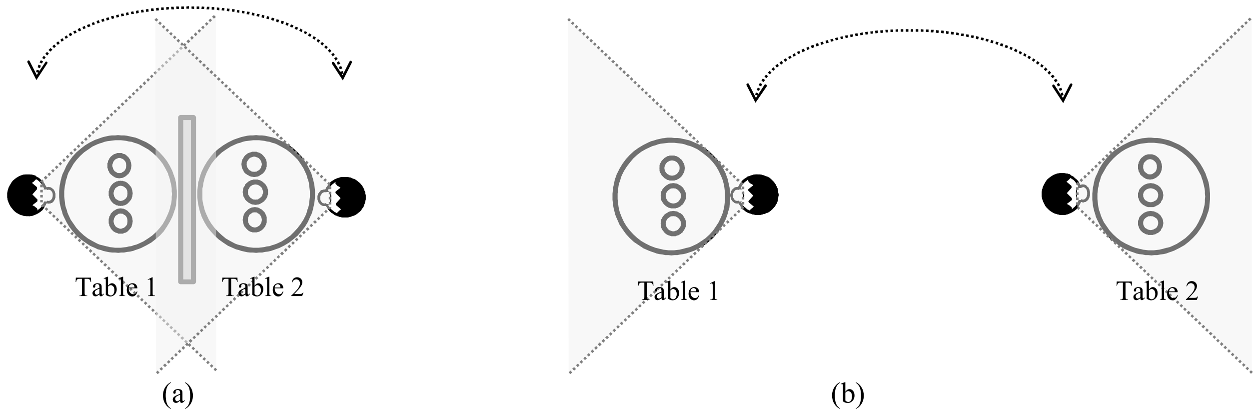


Figure 4. Comparing participant's sightlines across two experimental conditions with (a) for Experiment 1 and (b) for Experiment 2. Grayed zones cover regions of the surrounding environment that are easily visible to the participants at the two table positions. There is overlap in regions for (a), but not (b).

Methods

Ten new native English-speaking children within the same age range as children in Experiment 1 (mean age: 5;6, range: 5;2-5;8; 4 female, 6 male), recruited in the same manner as Experiment 1, participated in the experiment. The test location, materials, and procedure were the same as Experiment 1, except the tables were now 1m apart instead of 5cm. Instead of walking around the tables, participants walked between the two tables.

Results and Discussions

The performance as measured by percent correct for this group of children was compared to all the children in Experiment 1 in a 2 Experiment (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). An effect of Cup Position, with middle cup being easier than side cups, was found (middle: 81.2% vs. sides: 60.4% correct, $F(1, 26) = 20.93$, $p < .001$, $\eta_p^2 = .45$), as well as an effect of Block, with allocentric trials being easier than egocentric trials (allo: 78.6% vs. ego: 63.1% correct; $F(1, 26) = 13.73$, $p = .001$, $\eta_p^2 = .35$). Lastly, there was an Experiment by Block interaction ($F(1, 26) = 9.02$, $p < .01$, $\eta_p^2 = .26$). No other effects were significant (other p's > .11). The Experiment by Block interaction is due to the fact that egocentric block only differed from the allocentric block in Experiment 1 and not Experiment 2. The null effect of Block in Experiment 2 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: 86.2% vs. sides: 59.6%; $F(1, 8)=11.08$, $p = .01$, $\eta_p^2 = .58$). All other effects were not significant (other p's > .16). In sum, performance on the allocentric trials is not superior to egocentric FoR in Experiment 2, providing evidence that allocentric FoR is not always privileged.

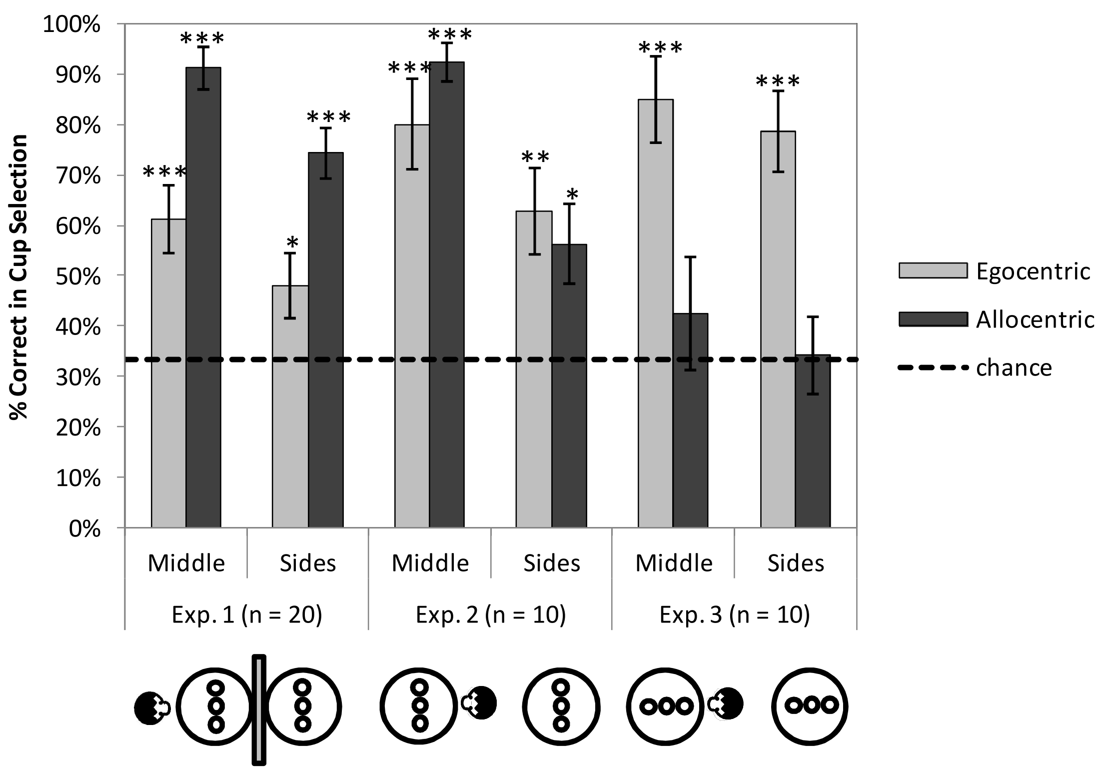


Figure 5. Results for Experiments 1-3. Asterisk mark significant of t-tests against chance. * p < .05, ** p < .01, ** p < .001

Experiment 3

In Experiment 3, we explore another context that might favor egocentric FoR over allocentric FoR. We pit egocentric FoR against allocentric FoR when the cups are aligned along the child's sagittal (front-back) rather than 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 in which stimuli are aligned (e.g. Pederson et al. 1998; Li & Gleitman, 2002, but see Brown & Levinson, 1993, for an exception). There is reason to believe, however, that egocentric perspective relations along the front-back axis are more salient than left-right relations (Corballis, 1976). As humans, we face and walk forwards rather than sideways, so we may have developed a stronger tendency to process what is directly ahead more than what is to our sides. Our front and back sides are also physically different from each other, while our left and right sides are symmetrical. What is appropriately labeled "left" or "right" is therefore defined with respect to what is "front" and "back"; that is to say, the left-right axis is secondary to the front-back axis. It is reasonable to suppose that in communicative situations, such as word learning and guessing the communicative intent of others, one might figure out the primary relationship before the secondary one. Indeed, children learning languages with "left" and "right" acquire "front" and "back" earlier than they acquire "left" and "right" (e.g., Kuczjac & Maratsos, 1975). It is also the case that while many languages lack terms for "left" and "right", "front" and "back" terms always exist (Svorou, 1994). Given the privilege of front-back over left-right, a valid question is whether the allocentric rule is still easier than the egocentric rule when cups are aligned along the sagittal (front-back) rather than the transverse (left-right) axis. It is possible that that along the sagittal axis, the egocentric rule becomes easier.

Furthermore, the cups are aligned to allow near and far encoding of cup-and-coin relations (near cup vs. far cup) from the egocentric perspective of the child at both tables. The near-far relation is also said to be salient, just as front-back relation is salient, since the near (peripersonal) and far (extrapersonal) distinction has associated neural correlates in both humans and non-human primates and surfaces in majority of the world's languages (e.g., "this" vs. "that" in English; see Diessel, 1999; Kemmerer, 1999; Coventry et al. 2008). As such, egocentric relations might be elevated relative to allocentric relations when children are guessing the invariant relationship of the hidden coin across the two tables.

Methods

Ten new native English-speaking children (mean age: 5;0, range: 4;4-5;11; 5 female, 5 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 along the sagittal axis of the participants (see Figure 5, Experiment 3).

Results and Discussions

Children in Experiment 2 and 3 differed in the axis by which the cups were aligned. Performance for these two groups was compared in an ANOVA. See Figure 5 for the results and comparison across experiments. 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, performance was better on the middle cups than the side trials (75.0% vs. 58.0%, $F(1, 16) = 9.93$, $p < .01$, $\eta_p^2 = .38$). However, for Block, children as a group now performed better on the egocentric block than the allocentric block (76.6% vs. 56.4%, $F(1, 16) = 11.19$, $p < .01$, $\eta_p^2 = .41$). Finally, the Block x Axis (see Figure 5, $F(1, 16) = 14.68$, $p = .001$, $\eta_p^2 = .48$) is due to the fact that egocentric block was better than the allocentric block for the sagittal axis (82.5% vs.

36.9%; t(9) = 4.52, p = .001) and not the transverse axis (68.3% vs. 68.3%; t(9) = 0, n.s.). The present results, like Experiment 2, again disconfirm the claim that allocentric/geocentric relations is necessarily more basic. Instead, which frame of reference is more salient depends on the task and situation.

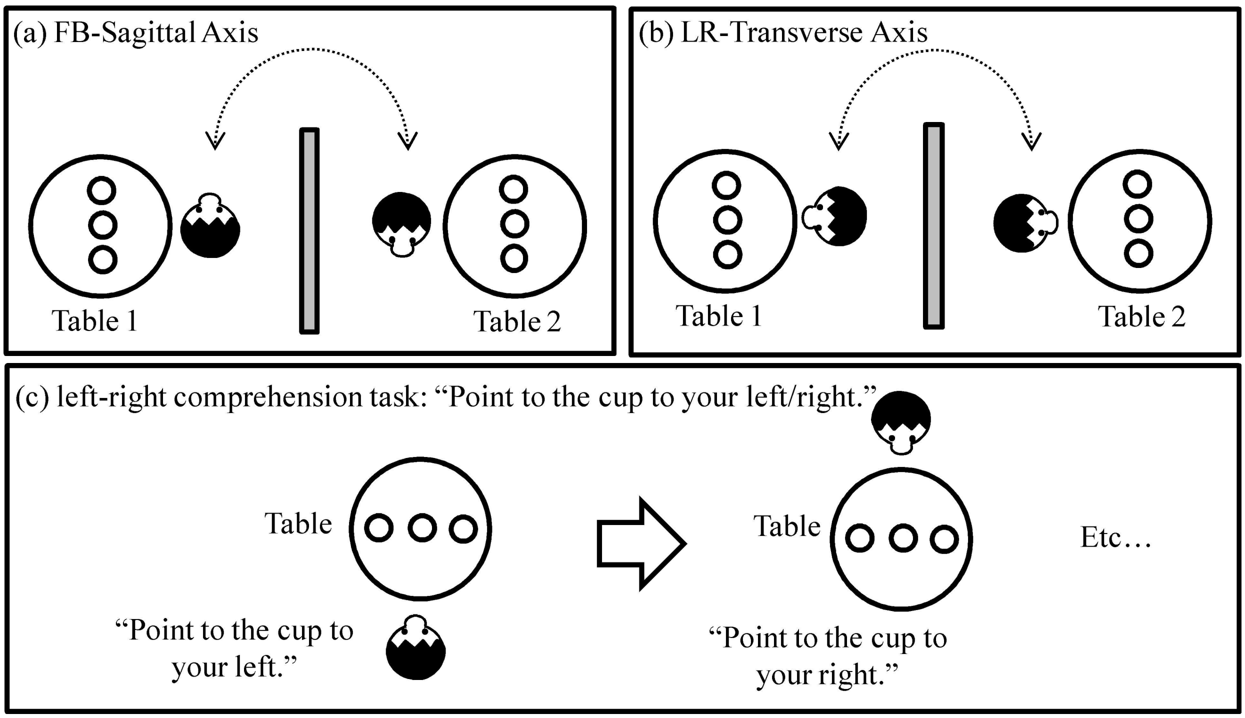


Figure 6. Set-up for Experiment 4. Display (a) depicts children’s facing directions for the FB-sagittal group, and display (b) depicts children’s facing directions for LR-Transverse axis. Finally, (c) shows the set-up for the left-right comprehension task, where children were asked to point to a cup either to their left or right and then moved to the opposite side of the same table for each subsequent trial and were asked to point again to a cup.

Experiment 4

Experiment 4 served as an extension of Experiment 3 and a replication of Experiment 2. The cups in Experiment 3 were aligned along the child’s sagittal axis. All were in front of the child, allowing for the use of an egocentric near-far strategy to reason about the cups. Either the sagittal alignment or the near-far relation could have contributed to better performance on the egocentric than the allocentric block. In Experiment 4, near-far was removed as a possible consideration. Cups were aligned parallel to the child's sagittal axis such that one was in the front of and one was in the back of the child, and the child made 180° turns to the second table that dissociated egocentric relations with environment-based relations (see Figure 6a). As with Experiments 2 and 3, the tables were apart and the turn minimized shared views, which were further minimized by an occluder placed between the two tables (Figure 4b). We asked whether performance on the egocentric block would still remain better than the allocentric block with the removal of the egocentric near-far relation as a possible hypothesis. Minimally, to replicate Experiment 2, performance on the egocentric block should be at least as good as on the allocentric block because children were asked to make the same turn as Experiment 2.

The sagittal condition was compared to the transverse condition, a direct replication of Experiment 2 in which another set of children faced the tables so that the cups were aligned along the axis parallel to the transverse axis of the child (Figure 6b). Under the transverse condition, following Experiment 2's results, we expected children to be equally good at the egocentric and allocentric blocks. Altogether, thirty-two new children, sixteen in each condition, were recruited (mean age: 4;8, range: 3;11-5;4; 12 female, 20 male) from a laboratory database and tested in a quiet hallway. The distance of the two tables was 2 meters apart. All other procedures were identical to those in the previous experiments.

Additionally, at the end of the experiment, children were tested on their comprehension of left-right language to verify previous reports that children at this age typically do not know the language to talk about objects to the left and right of them. For each trial, children were asked to face the same round table with three cups, and to point to one of the cups (e.g., "Point to the cup to your left."). Children were queried eight times, four with "left" and four with "right", in one of two pre-determined orders (RRLLRLLR, LLRRLRRL). After each query, children had to move around the table to the opposite side before the next query (see Figure 6c). The alternation of facing directions tested whether children used a FoR anchored to their own body or a FoR anchored to the environment when identifying the “left” and “right” cups. We did not test children on “front” and “back” as these are the terms that previous literature suggests that children already know by age four (Kuczaj & Maratsos, 1975).

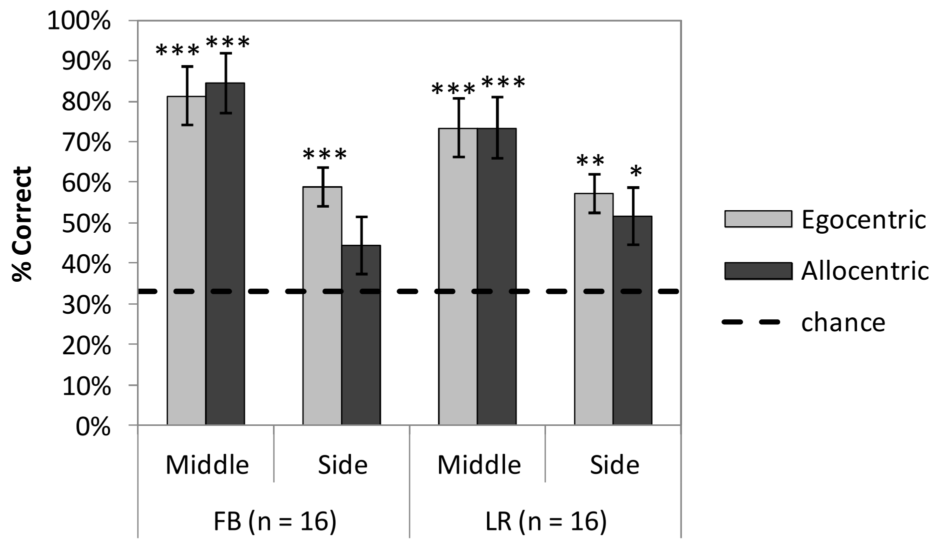


Figure 7. Results of Experiment 4. Asterisks mark significance of t-tests against chance. *** p’s < .001, ** p’s < .01, * p’s < .05.

Results and Discussions

The percentages correct (see Figure 7) 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, where percentage correct for the middle position was higher than that for the sides (78% vs. 53%; $F(1, 28) = 40.62$, $p < .001$, $\eta_p^2 = .59$). All other effects were non-significant. This means performance on the egocentric block was not worse than that of the allocentric block (Ego: 68% vs. Allo: 64%), replicating Experiment 2; when participants made a different 180° turn than that of Haun et al. and Experiment 1's participants, the allocentric advantage disappeared. However, as evidenced by non-significant Axis by Block effect, we did not find that the egocentric block was now significantly better than the allocentric block along the FB-sagittal axis. This suggests the near-far relationship was the driving force in Experiment 3 that made the egocentric relation more salient than the allocentric one.

We next examined children's performance on the left-right comprehension task. As a group, children performed no different than chance (55% correct, stdev = 22%, $t(31)=1.15$, $p = .26$, n.s.), verifying that children at this age typically do not know the language to label objects to their left and right sides. None of the correlations between language comprehension and how well the children did at locating the hidden coins were significant ($|r|$'s < .18, p's > .31, n.s.). Importantly, for the LR transverse group, left-right comprehension was not correlated with performance for the egocentric block ($r = .18$, $p = .31$, n.s.) or the allocentric block ($r = -.002$, $p = .99$). Thus, acquiring left-right language by the current group of children cannot be used as a ready explanation for why they showed equal performance on the egocentric and allocentric condition whereas Haun et al. and children in Experiment 1 showed better performance on the allocentric than egocentric condition.

General Discussions

Summary of Findings

The present study sought to reexamine the robustness of Haun et al.'s claim that the phylogenetically inherited preference for coding spatial FoR of the hominidae genera is allocentric/geocentric, and that a preference for egocentric FoR is only augmented through enculturation with left-right language. Although their claim is based on experimental and replicable findings, the claim warrants reexamination for several reasons. First, it seems unusual that the (egocentric) perspective by which we take in information and program our bodily movements in space would not be a salient FoR that we rely upon for spatial reasoning (Gallistel, 2002). Most researchers assume that egocentric and allocentric representations are both necessary and work in concert (Burgess, 2006). Second, studies that pit egocentric with allocentric representations have sometimes found a preference for egocentric FoR (e.g., Acredolo, 1987). Lastly, the experimental setup shared similarities with specific conditions in prior studies that induced favorability for allocentric FoR, leaving open the possibility that other experimental setups might ameliorate the favorability (Burgess, Spiers, & Paleologou, 2004; Nardini, Burgess, Breckenridge, Atkinson, 2006). We therefore questioned whether minor modifications of the testing conditions could readily shift which of two pitted FoRs (egocentric or allocentric) is more salient.

Experiment 1 replicated Haun et al.'s study with a similar arrangement of tables and turn, and we 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 for older children who have had some exposure to "left" and "right" language. Experiments 2 and 4 showed that children performed equally on both rules when the tables were further apart and the children made a different 180-degree turn so that they did not face the original table that might prime the allocentric perspective. Experiment 3 compared children's ability to learn the egocentric and allocentric rules when the cups were aligned directly in front of the child along the sagittal axis rather than the transverse axis, and in this setup, the children were now more successful on the egocentric rule. Experiment 4 probed further and its results suggested that it was the near-far relationship in Experiment 3 that contributed to egocentric relation trumping the allocentric relation. Together, these experiments indicate that the egocentric rule is not always more difficult, and so the claim that there exists an inherited preference for environment-based FoR over egocentric FoR was perhaps made too hastily.

A recent study on Bonobos, motivated by the small sample size of Haun et al.'s study (see Figure 1b), also casts doubt that the inherited preference among primates is allocentric (Rosati, 2015). Rosati tested Bonobos in two experiments. In one, she employed a classic place-response paradigm testing whether animals were "place" (allocentric) or "response" (egocentric) learners (Tolman, Ritchie, Kalish, 1946). Bonobos were reinforced for always finding a treat hidden at one of two locations (e.g., always north/left and not south/right). Then at test, the bonobos were turned to face the opposite direction to see whether they would search the allocentric (north/right) or egocentric (south/left) location. In another experiment, Rosati used Haun et al.'s paradigm, except the two tables with the baited cups were in different rooms. Bonobos, when tested in the place-response paradigm, exhibited an allocentric preference, but when tested in the Haun et al. paradigm, exhibited an egocentric preference. Perhaps the distance traveled to get from one table to the next and the lack of shared landmarks across the two rooms led Bonobos to an egocentric preference. Importantly, these two experiments again show that testing contexts can affect which FoR was preferred. Furthermore, the findings suggest that both kinds of FoR, allocentric and egocentric, are phylogenetically ancestral to primates.

Language Enculturation and Gricean Considerations

Haun et al. found that learning spatial language had an impact on the speakers' ability to guess the invariant rule across two tables. Dutch speakers were faster at figuring out the egocentric rule than the allocentric rule. On the other hand, Hai||om speakers could only figure out the allocentric rule; they were at chance when guessing amongst the three cups for the egocentric block. This finding led Haun et al. to conclude that learning a "left" and "right" language led speakers to override inherited allocentric representation in favor of an egocentric one, and to suggest that habitual spatial language comes to shape speakers' nonlinguistic encoding of spatial relationships. Given this line of reasoning, one might ask whether it is possible that our English-speaking children were affected by the language that they were learning, and hence were therefore better able to guess the egocentric rule than if they were growing up learning a geocentric language such as Hai||om. Although possible, Experiment 4 found that children were at chance at distinguishing "left" vs. "right" linguistically, and performance on the language comprehension task did not predict how well children were able to guess the egocentric rule, nor did it predict how poorly they were able to guess the allocentric rule. Thus, we doubt that language acquisition could explain why children in our study were able to figure out the egocentric rule. A more parsimonious account, given that nonlinguistic creatures also sometimes exhibit a preference for egocentric FoR (e.g., Rosati, 2015; Restle, 1957), is that cultural overriding was not involved. Nonetheless, to ascertain with greater confidence whether there was no cultural or language influence, future studies could test geocentric language learners using the current experimental setup to see if they too show the same pattern across the four experiments as English-speaking children.

There is, however, already some evidence to suggest that geocentric language learners might behave similarly to egocentric language learners (Li, Abarbanell, Gleitman, & Papafragou, 2011; Abarbanell, Montana, & Li, 2011; Li & Abarbanell, under review). Li et al. (2011) tested adult speakers of Tseltal, a Mayan language that uses terms like "sunrise/sunset" and "uphill/downhill" to describe tabletop scale object arrays (Brown & Levinson, 1993). In Li et al.'s Experiment 4, they tested Tseltal speakers on a coin searching task involving two tables, similar to the present study. Three inverted cups were arranged symmetrically in a V-shape on top of a circular cardboard at table 1. The participants watched as the experimenter hid the coin underneath one of the cups at the first table. Then the experimenter carried the circular cardboard with the cups to the second table. The participant then walked to the second table to search for the hidden coin. Crucially, the arrangement of the cups either maintained the egocentric (V) or allocentric (inverted V) relation between the two tables. The Tseltal speakers were not at ceiling, and they were better at finding the coin when the arrangement maintained egocentric relations than allocentric relations. The two tables in Li et al. (2011)'s experiment, like the present Experiments 2-4, involved two tables pulled apart and a turn that minimized the shared view across the two tables. The finding is therefore consistent with the present study. A more recent study, testing eight-year-old Tseltal-speaking children on a task involving the recreation of arrays of animals, provided further converging evidence that which FoR, egocentric or allocentric, is easier is affected by the distance traveled and the type of turn one has to make between the two tables (Li & Abarbanell, under review).

Li, Abarbanell, and colleagues' studies on 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 one fundamental difference between Haun et al.'s tasks and Li et al.'s tasks. While Haun et al.'s task is about guessing a rule that the experimenter has in mind, Li et al.'s task is not. For example, in Li et al.'s V configuration coin search task discussed above, 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 had 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.

Many, including Haun et al. take the finding of Dutch and Hai||om adults as evidence that habitual language use can profoundly restructure spatial predispositions and strategies. Another possibility, not considered by Haun et al., is that, beyond communicative situations, the extent of language's influence on cognition might be limited. Li and colleagues' studies support this possibility as they repeatedly found that when solving spatial tasks that do not involve figuring out the intent of others, speakers of different languages often do not differ in how they reason about space (Li et al. 2011; Abarbanell et al. 2011; cf. Abarbanell & Li, 2015; Pyers et al., 2010). Tseltal and English speakers share the same pattern of performance and errors, with better allocentric response in specific setups and worse in other setups, suggesting that both groups recruit the same cognitive processes – e.g., as they move, they are spatially updating the relationship of objects to themselves.

Learning Linguistic FoRs

The present study, which tests children who lack left-right language, was not intended to address the issues of linguistic relativity, but to examine cognitive precursors that could support language acquisition. We therefore turn to speculations on what these studies tell us regarding language acquisition. What might these studies tell us about acquisition of spatial terms such as "uphill"/"north" or "front"/"left"? Furthermore, how do we make sense of the prolonged acquisition of left-right language cited by Haun et al. (2006) as supporting their argument that an allocentric perspective is cognitively prior?

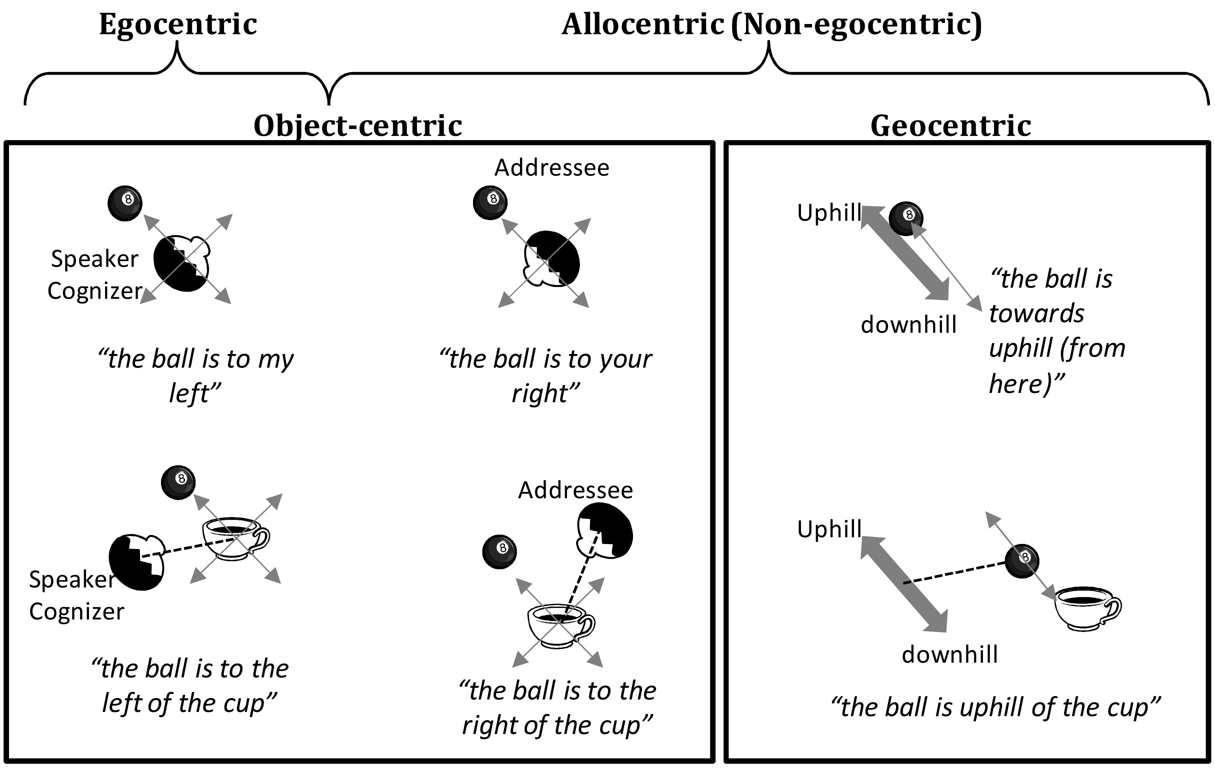


Figure 8. Different classifications of FoRs. Egocentric vs. allocentric divides FoRs on the basis of coordinates that involve oneself vs. those that do not. For instance, in the examples above, the ball can be described from the egocentric perspective (my left) or the non-egocentric perspective (your right; uphill-ward). Object-centric vs. geocentric divides FoRs with respect to whether the coordinates are derived from moving entities or earth-anchored entities (e.g., between people and landscape-derived terms as pictured). Another frequent division of FoRs in the literature that is not discussed in the text is Levinson (1996)'s relative vs. intrinsic, vs. absolute FoRs (see Shusterman & Li, in press, for how the examples above are divided into the three FoRs).

Before discussing spatial language acquisition, we briefly define the relevant spatial FoR terminologies (see Figure 8). Cognitive psychologists often single out the *egocentric* FoR, the perspective by which we take in information about the environment and program our motor movements as a privileged type of FoR, and call all other frames *allocentric*. An alternative and natural way to partition frames of reference, based on the physical world, is 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 (e.g., *object-centered* FoRs). Figure 8 illustrates the different divisions and provides linguistic examples for these FoRs.

As can be seen from Figure 8, allocentric FoRs encompass not just geocentric FoRs, but non-egocentric object-centric FoRs (e.g., a car's front/back axes, a doll's left/right axes). One cannot ascertain whether children solved the allocentric rule in our task here or that of Haun et al. (2006) by noticing the invariant relation of the cups at both tables to local stationary objects, such as the walls of the room or the sides of the tables or to large anchored landmarks, such as north/south axis of their terrain. However, like Haun et al., we agree that the finding that children can readily discover this rule suggests that our cognitive foundation readily supports learning geocentric reference words. Corroborating evidence comes from a recent study that introduced novel spatial words to 4-year-old English-speaking children. Children were introduced to directions with novel words ("this way is ziv") before and after turning 180 degrees in place. The study found that children could map novel words to geocentric meanings. When turned to face a different direction or led outside and down the hall from where the novel word was introduced, children correctly pointed to the appropriate cardinal direction when asked ("which way is ziv?"; Shusterman & Li, under revision). Thus, Haun et al. appears to be correct that our cognitive structure supports learning geocentric terms. Observations of children in language communities that primarily use a geocentric reference system show that indeed this is the case; by four years of age, children show appropriate relational use of the relevant environment-based terms (e.g., de Leon, 1994, 1995; Brown & Levinson, 2000).

What about learning object-centric terms, particularly those that are based on the axes of the body, as in a left/right/front/back system? In the present study, children could easily abstract front-back and left-right relations across the two tables. Does this experimental finding then suggest that learning such body-based frames of reference poses no difficulty? The answer is that it depends on which body-based contrast one is learning. Words that denote a salient asymmetry such as “front” and “back” are readily acquired (Kuczaj & Maratsos, 1975), while figuring out “left” and “right” takes a prolonged period of time (Rigal, 1997). The crucial insight to why this is so requires recognizing that not all “left” and “right” relations are the same. The computation required for distinguishing between front and back is easier than for left and right. While front and back sides have distinct attributes, left and right sides are symmetrical and require the prior distinction of a front-back axis especially when computing other’s left-right sides. Proprioception, or body sense, provides a means for distinguishing between one’s own “left” and “right” sides, but is unavailable for distinguishing another’s “left” and “right”. Determining the left or right side of another person is therefore especially challenging. One has to assess what is to the left and right in relation to the front and back axis of that other person, and this may often require mental rotation to align one’s own axis with that of the other person when he or she does not face the same direction. Indeed, language comprehension tasks show that understanding egocentric uses of “left” and “right” happens a year or two before learning non-egocentric “left” and “right” uses (i.e., “the ball is to my left” vs. “the ball is to the doll’s left”) (Piaget, 1928; Rigal, 1994; 1996).

There is evidence that young children are incapable of computing non-egocentric left-right relations. In Shusterman and Li (in press, under revision)’s novel word learning study, when 4-year-old children were told, “Your body has a ziv side and a kern side, and this is your ziv arm," the children quickly learned the left-right meanings of these words and understood them in new uses ("Point to the ziv toy."; "Which cup is ziv of the ball?") from their own perspectives. In contrast, same age children could not learn the novel words when introduced in the same way on others' bodies. Furthermore, 4-year-olds were at chance when asked to find a coin placed in either the left or right pocket of a doll. They watched as the coin was placed in either the left or right pocket of a doll, closed their eyes as the experimenter rotated the doll, and then upon opening their eyes had to retrieve the coin. Though Shusterman and Li did not test older children, several similar studies suggest that most children do not pass such a task until 9 or 10 years of age (Lasky, Romano, & Wenters, 1980). Reasoning about other's left and right might therefore be a case in which language acquisition makes salient a distinction that one would not otherwise normally compute. Recent cross-linguistic studies comparing Tseltal and Spanish speaking 10-year-olds corroborated that learning to speak a language that habitually uses "left" and "right" makes such non-egocentric relations more salient and deployable in cognitive tasks (Abarbanell & Li, 2009; 2015).

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 therefore only share Haun et al.'s intuition that learning a geocentric reference system in one's language is easy, but 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, with the somewhat later acquisition of "left" and "right" terms attributable to the symmetry and difficulty in representing non-egocentric left-right relations (Rigal, 1994; Lasky, Romano, & Wenters, 1980). We suggest that if anything, non-egocentric left-right is where learning spatial language might come to highlight a new relationship that then gets deployed for problem-solving and spatial reasoning.

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