Revisiting the Plasticity of Human Spatial Cognition

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Abstract. In a recent study by Haun et al. (2011), Dutch-speaking children who prefer an egocentric (left/right) reference frame when describing spatial relationships, and Hai||om-speaking children who use a geocentric (north/south) frame were found to vary in their capacity to memorize small-scale arrays using their language-incongruent system. In two experiments, we reconcile these results with previous findings by Li et al. (2011) which showed that English (egocentric) and Tseltal Mayan (geocentric) speakers can flexibly use both systems. In Experiment 1, attempting to replicate Haun et al., we found that English- but not Tseltal-speaking children could use their language-incongruent system. In Experiment 2, we demonstrate that Tseltal children can use an egocentric system when instructed nonverbally without left/right language. We argue that Haun et al.'s results are due to the Hai||om children's lack of understanding of left/right instructions and that task constraints determine which system is easier to use.

Keywords: linguistic relativity, frames of reference, Tseltal Mayan.

1 Introduction

Recent years have seen a resurgence of work on the linguistic relativity hypothesis, the idea that the language we speak can have a profound effect on the nonlinguistic concepts we form (see Bowerman & Levinson, 2001; Gentner & Goldin-Meadow, 2003; Gumperz & Levinson, 1996, see also Whorf (1956) for the original formulation of the hypothesis and Gleitman & Papafragou (2005) for a review of the recent literature). One of the more controversial areas of current investigation concerns the perspectives, or frames of reference, speakers use to talk about locations and directions. In English, speakers tend to adopt the perspective of a (typically egocentric) viewer (e.g., "The cup to the right of the pitcher"), while speakers of other languages use fixed aspects of the (geocentric) environment. For example, in Tseltal Mayan (Chiapas, Mexico), speakers use the uphill/downhill slope of their terrain and other salient landmarks ("The cup to the downhill of the pitcher"), while body part terms like 'left' and 'right' are not typically projected to regions outside the body (Brown, 2006; Brown & Levinson, 1993a; 1992, cf. Abarbanell, 2007).

While a third, object-based system arguably cuts across both ("The cup at the mouth of the pitcher") (see Terrill & Burenhult, 2008), most of the literature has focused on how the habitual use of an egocentric versus a geocentric perspective can

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affect how spatial representations are interpreted, stored and retrieved across modalities, resulting in greater facility using language-congruent cognitive strategies and a dispreference for language-incongruent ones. This dispreference, in turn, has been argued to yield practice effects, making it difficult for speakers to use the reference frame that is less frequently used in their language on non-linguistic spatial tasks, such as memorizing a small-scale spatial array (Brown & Levinson, 1993b; Levinson, 1996, 2003; Majid, Bowerman, Kita, Haun & Levinson, 2004; Pederson, Danziger, Wilkins, Levinson, Kita & Senft, 1998). For example, in the animals-in-a-row task, participants are shown a row of toy animals facing in a given direction (e.g., left/north). They are then asked to recreate the "same" array after turning 90° or 180° to face a second table. Studies with over 20 language groups revealed a robust and striking correlation: speakers of languages like English that habitually use an egocentric reference frame rotated the animals along with their body, while speakers of languages like Tseltal held them constant with the environment (see Figure 1).

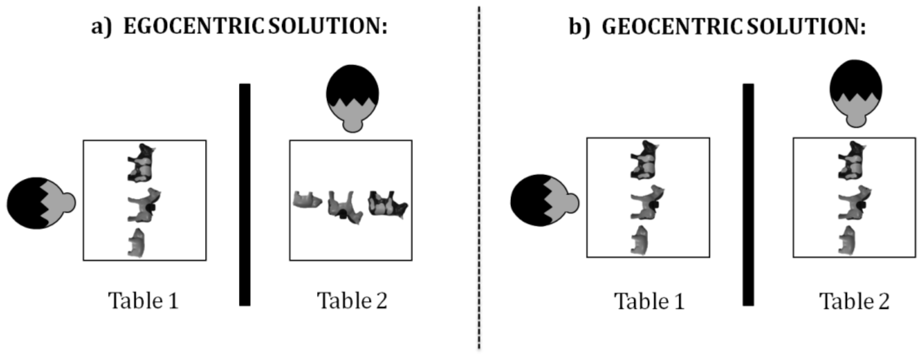

Fig. 1. Animals-in-a-row task, showing (a) egocentric and (b) geocentric solutions

Not all researchers, however, accept these results as necessarily demonstrating language use shaping the availability of frames of reference in everyday spatial reasoning as argued by proponents of linguistic relativity, taking issue in particular with open-ended tasks for which there are at least two correct solutions (Li & Gleitman, 2002; Li, Abarbanell, Gleitman & Papafragou, 2011; Newcombe & Huttenlocher, 2000; Pinker, 2007). In such cases, speakers must make pragmatic inferences about the desired or expected response. That is, how one's linguistic community customarily speaks about or responds to inquiries about locations and directions may affect how speakers interpret what appropriately counts as the "same" array (Li & Gleitman, 2002).

To adjudicate between "linguistic relativity" and "pragmatic inference" hypotheses, Li et al. (2011) and Abarbanell (2010), tested English and Tseltal-speaking adults and children on non-open-ended tasks that required participants to respond in a certain way, either using egocentric or geocentric coordinates. When the expectations were made clear, under matched conditions, they found that the two language groups performed similarly: Contrary to the predictions of Levinson (2003) and colleagues, both English (egocentric) and Tseltal (geocentric) speakers showed a pattern of equivalent or enhanced performance on egocentric as compared with geocentric tasks.

1.1 Contradictions in the Literature: Haun et al.

A recent study by Haun, Rapold, Janzen, and Levinson (2011), however, found seemingly contradictory results. They compared Dutch speakers in the Netherlands who primarily use an egocentric reference frame, with speakers of ≠Akhoe Hai||om, a Khoisan language spoken in Northern Namibia that primarily uses a geocentric reference frame, on both open- and non-open-ended versions of the animals-in-a-row task. Seven to eleven-year-old children were tested to control for educational differences in adult community members across language groups. The children were shown an array of animals at one table and then walked to a second table where they faced 90° from their original orientation and were asked to recreate the same array. The two tables were separated by a school building which ostensibly could have been used to orient the animals (e.g. "The animals are facing the building"), to probe the children's tendency to use a salient local landmark versus a larger-scale directional system. The children were tested on a block of simple trials, using three animals in a row, followed by a block of more difficult trials involving a six-object array, to test the possibility that arrangements which are harder to encode linguistically will cause participants to fall back on a more 'innate', or language-independent strategy. Using videotaped instructions, the children were simply told to "rebuild the array".

In line with previous findings from open-ended tasks, both groups of children aligned the animals in accordance with their language-congruent reference frame: the Dutch-speaking children were exclusively egocentric while the Hai||om were overwhelmingly geocentric. Next, the children received a third block of hard trials in which they were instructed to rebuild the array using the opposite system to the one they had just used (e.g., children who had aligned the animals egocentrically on the open-ended blocks were instructed to align them geocentrically and vice-versa) In contrast to the flexibility of the English and Tseltal-speakers tested by Abarbanell and colleagues, the Dutch and Hai||om showed little capacity for switching to their language-incongruent system.

Children, however, and sometimes even adults, exhibit difficulty in switching to a different way of solving a problem after being accustomed to one way of solving it (Cepeda, Kramer & Gonzales de Sather, 2001; Luchins, 1942; Yerys & Munakata, 2006). In a follow-up study, to control for the possibility of such a perseveration effect, a new group of Hai||om-speaking children were given two blocks of instructed trials, one with instructions to recreate the array egocentrically (e.g., "place the rightmost objects back on the right-hand side of the array") and the other geocentrically (e.g., "place the western objects back on the western side of the array"), again using videotaped instructions, with the order of the two blocks counterbalanced across participants. Once again, the Hai||om-speaking children performed significantly better in the geocentric than the egocentric condition, struggling to use their non-dominant egocentric system regardless of block order.

These findings seemingly contradict those of Li et al. (2011) and Abarbanell (2010) in two ways. First, Li and colleagues found that when tasks were non-open-ended, Tseltal and English speakers often performed similarly. Second, across several tasks, they found that recalling the arrangements of spatial arrays from an egocentric perspective, the perspective in which one takes in information about the world, can sometimes be easier than from a geocentric perspective. Thus, Tseltal speakers who do not predominantly use left/right language just like Hai||om speakers, often performed better on tasks requiring the egocentric solution than tasks requiring the geocentric solution. There are, however, several different ways to reconcile these seemingly discrepant results, including the fact that these were different comparison populations and there were many procedural differences. Li and colleagues tested different spatial tasks (card choice and route tracing), and participants took a 180° rather than a 90° turn. Finally, the way in which Li et al. indicated which response they expected from participants did not involve spatial language, while Haun et al.'s instructions did. The possibility of task-specific and population-specific effects makes it crucial to try to replicate seemingly divergent results across different comparison groups that share the same frame of reference preference in order to disentangle the possible contribution of language from that of other cultural, environmental, and task effects.

1.2 Replication and Left/Right Comprehension Difficulty in Children

We will return to these points in the General Discussions. For now, we turn to a possible alternative explanation for Haun et al.'s results. One valid concern is whether or not Hai||om children actually understood the egocentric verbal instructions. Given that even English-speaking children have a difficult time acquiring the full extent of "left" and "right" use in a culture that more frequently uses these terms (Piaget, 1928; Rigal, 1994, 1996), there is cause to be wary of the assumption that Hai||om-speaking children would understand the verbal instructions with "left" and "right". While the Hai||om use front/back terms projectively to describe spatial relationships as well as metaphorically to describe relationships in other domains (e.g., younger people 'follow behind' their elders), they reportedly do not do the same with left/right. Rather, left/right language remains relatively dispreferred and undeveloped, e.g., in discussions about routes or object manipulations, especially as compared to languages like English or Dutch (Widlok, 2007: 272). Without this type of left/right language readily available in the input, it is possible that the Hai||om-speaking children, whose left/right comprehension was not assessed by the experimenters, had not acquired the full meaning of "left" and "right" and did not understand the instructions for the egocentric block. They therefore naturally performed better on the geocentric block for which they understood the instructions.

Given that alternative interpretations exist for Haun et al.'s results, it is presently unclear whether their results truly contradict Li et al.'s. In order to try to reconcile the Haun et al. (2011) and Li et al (2011) results, we turned to Tseltal and English speakers, asking whether Haun and colleagues' results are replicable with this comparison population, and, if so, whether they could be attributable to a difficulty with left/right language. In Experiment 1, we first replicated Haun et al.'s study and verified whether the Tseltal-speaking children indeed understand left/right language. In Experiment 2, we again tested children in non-open-ended versions of the task, but with instructions that do not make use of left/right language, following the methodology from Li et al.

2 Experiment 1: Haun et al. Replication

2.1 Methods

Participants. Thirty-nine English-speaking children between the ages of seven to ten were recruited from the Cambridge MA area through town email lists, afterschool programs, and at the Boston Museum of Science. The children were randomly assigned to one of three conditions: an open-ended condition (N=14, mean age 7.93 years; SD = .83), an Ego-to-Geo condition (N=13, mean age 8.31; SD = 1.03), and a Geo-to-Ego condition (N=12, mean age 7.92; SD = .67). The children received a small prize for their participation.

Forty-six Tseltal-speaking children were recruited from the community of Tenejapa, Chiapas, Mexico, through a research assistant who was from the community, and were also randomly assigned to the three conditions: open-ended (N=14, mean age 9.21; SD = .89), Ego-to-Geo (N=16, mean age 8.06, SD = .68), and Geo-to-Ego (N=16, mean age 8.94, SD = 1.00). Testing was conducted in a local house in Tenejapa and participants were compensated with 20 pesos (~2 USD). All instructions were administered in Tseltal by the research assistant, a native-Tseltal speaker who was bilingual in Spanish.

Setup. Haun et al. varied whether participants were run outdoors or indoors and found no difference in the results; we therefore did not manipulate this factor. All of our participants were tested indoors. Two square tables were placed approximately 1.5 meters apart, with a barrier in between so that when seated at one table, participants could not see the other table.

The arrays were created from a set of eight toy farm figurines (a cow, horse, pig, sheep, bale of hay, boy, girl, and cart). Following Haun et al., we included easy and hard trials. The easy trials were lines of three animals, all facing the same direction. The hard trials used six figurines in two rows of three, with the figurines varying in their facing orientation (either right or left). The easy trials could be easily described linguistically (e.g., “cow, sheep, pig walking right”) while hard trials would require longer descriptions (“The pig is facing left towards the cow that is facing right…”). Therefore, any language-specific strategies driven by sub-vocalizing, would be expected to yield to a universal default strategy on the more difficult trials (Haun et al., 2011). For both trial types, participants had to choose the correct figurines from the collection of eight. The test arrays were predetermined by a computer program that randomly selected the figurines and their facing orientations.

Procedures. Participants were randomly assigned to one of the three conditions. In all conditions, the children were seated at Table 1, where they were given as much time as they wanted to memorize the array. They then moved to Table 2 where they sat at a 90° rotation from their original orientation.

In the *open-ended condition* participants were simply instructed to “place the animals in the same way” at the second table. The children received three easy followed by three hard trials. The two *non-open-ended* conditions, *Ego-to-Geo* and *Geo-to-Ego*, were counterbalanced conditions in which participants were instructed to provide a specific solution. In the *Ego-to-Geo* condition, participants were instructed to replicate the arrays using an egocentric solution for the first block of trials, followed by geocentric instructions for the second block, and vice-versa for the *Geo-to-Ego* condition. Each block consisted of three easy followed by three hard trials.

In all conditions, the participants were introduced to the task of recreating an array with three practice trials, using just the first table. For each practice trial the experimenter made an array of three animals aligned in a row to either all face left or right, and then asked the child to make the same array on the same table. For the first practice trial, the original array remained in view of the child. For the second and third practice trials, the experimenter covered up the array after the children indicated that they were ready. They were then asked to make the same array from memory. These memory trials served as a quick check for whether participants in all conditions were comparable in their ability to recreate arrays from memory.

In the non-open-ended conditions, the children received two additional training trials in which they walked to the second table before recreating the array. On these trials, the children received instructions that familiarized them to the expected solution, either egocentric or geocentric according to block. To induce the use of an egocentric reference frame, the children were shown which animal was to their left and right (e.g., "The horse is on this side towards your left. It is to the left"/"*Ja' te cawayo ay ta izquierda a'w-u'un. Ay ta izquierda*"). We used the Spanish terms to express the ideas of "left" (*izquierda*) and "right" (*derecha*) to Tseltal speakers, although all other instructions were given in Tseltal. All of the Tseltal-speaking children in the sample were currently attending school where teachers report explicitly teaching and using a left/right system in Spanish. In contrast, left/right terms in Tseltal are rarely explicitly taught in the home according to parental reports, and teachers do not expect the children to necessarily know the words (Abarbanell, 2010).

For the geocentric trials, the children were introduced to geocentric terms at the first table. The English-speaking children were shown which animal was to the north/closer to the northern wall, and which animal was to the south/closer to the southern wall. North/south was used with the English-speakers as the children were likely to be more familiar with these than with east/west terms. Children typically learn these terms when learning about maps in school which are oriented north, and "north" and "south" refer to salient locations on the globe while "east" and "west" do not. Further, north/south terms are predicted to be more frequent in discourse directed to children than east/west (e.g., "Santa lives at the North Pole"). The Tseltal-speaking children were shown which animal was towards where the sun rises (*ta slok'ib k'aal*)/towards the sunrise wall (*ta slok'ib k'aal pajk'*), and which animal was towards where the sun sets (*ta smalib k'aal*)/towards the sunset wall (*ta smalib k'aal pajk'*). For the Tseltal children, although uphill/downhill has been identified as the most salient directional axis for Tseltal speakers (Brown, 2006; Brown & Levinson, 1993a), more recent data suggests that the dominant axis as well as the exact quadrants specified by different directional terms, varies for different regions within the municipality of Tenejapa. For example, Abarbanell (2010) found that Tseltal-speaking adults from the same region as the children tested here frequently used sunrise/sunset terms on language elicitation tasks in contrast to the near-absence of any uphill/downhill language, an absence that was also noted by Polian (2010). We therefore opted to use the sunrise/sunset terms.

At the second table, children in both language groups were asked to raise their left and right hands in the egocentric block, and to point in the appropriate directions in the geocentric block, and then to tell the experimenter which animal was located at each hand/in each direction. They were then instructed to line up the animals. If the children aligned the animals using a different reference frame from what was expected, the experimenter guided the participant in aligning the animals correctly, reminding the children where the animals went in relation to their left/right or to the environment. No such explicit feedback was given on the three easy or three hard test trials that followed this initial training period.

At the end of the experiment, the Tseltal-speaking children were tested on their left/right comprehension. A doll (the boy or girl figurine from the farm animal set) was placed in the center of the table with a different animal figurine at each left/right side, and the children were asked to identify which animal was to the doll's left and right. The Tseltal third-person possessive prefix (*-s*) was affixed to the Spanish left/right terms so that it was grammatically unambiguous that the doll's and not the child's left/right was intended (*"Binti chambalam ay ta s-derecha/s-izquierda te muñeca?"/*"Which animal is to the doll's left/right"). The children received four such trials, two for each side, blocked by side and counterbalanced across children. For each side, there was one trial with all of the figurines facing away from the participant followed by one trial with all figurines facing toward.

Scoring. For each trial, the children received one point for each figurine placed in the correct position and one point for each figurine placed in the correct orientation, for a total of six possible points for the easy trials and twelve points for the hard trials. The orientation score was calculated in two ways, with the max of these two ways taken as each child's final score. In the first way, each figurine was scored for correct orientation regardless of the position in which it appeared. Second, the orientation of the figurine in each position was scored regardless of whether the figurine was the correct one. These two ways took into consideration the possibility that the children might have incorrectly swapped figurine positions but correctly remembered the figurines' orientation or the possibility that the children misremembered the figurine (e.g., boy instead of girl), but remembered the orientation of the figurine at that position. The percentage correct for each trial was then computed by dividing the number of points out of the total possible number of points.

2.2 Results

Open-ended condition. Participants in the open-ended condition were classified as either egocentric, geocentric, object-centric, or untypable based on their general response strategy (at least two out of three trials each for the easy and hard trials aligned with the same reference frame). The percent correct was then calculated for each child, according to their preferred reference frame. The distribution confirmed that the children's preferences aligned with the dominant frame of reference in their language (see Table 1). We note that none of the children opted to use the divider between the tables as a reference point. Using the divider meant recreating an array in which the line of figurines which was closest to the divider at the first table remained closest to the divider at the second table.

Table 1. Distribution of dominant response strategies in English (N=14) and Tseltal (N=14) speakers for the open-ended condition. The mean percentage correct and standard deviation are given for consistent (egocentric and geocentric) response strategies only.

	Egocentric Response	Geocentric Response	Object-centric Response	Untypable Response
English	N=12 Easy: 86.11 (14.51) Hard: 71.69 (10.69)	N=2 Easy: 75.00 (8.49) Hard: 70.83 (16.90)	N=0	N=0
Tseltal	N=1 Easy: 61.11 Hard: 55.56	N=11 Easy: 76.77 (18.56) Hard: 56.82 (14.13)	N=0	N=2

Non-open-ended conditions. For the two non-open-ended conditions, a 2 (difficulty: easy, hard) x 2 (trial type: egocentric, geocentric) x 2 (block order: Ego-to-Geo, Geo-to-Ego) x 2 (language: English, Tseltal) ANOVA yielded main effects of difficulty ($F(1,53) = 114.80$, $p < .001$, $\eta_p^2 = .68$), trial type ($F(1,53) = 56.91$, $p < .001$, $\eta_p^2 = .52$), and language ($F(1,53) = 22.83$, $p < .001$, $\eta_p^2 = .30$). The effect of block order was not significant ($p = .86$, n.s.). Collapsing across block order, Figure 2 depicts these main effects. Overall, participants did better on the easy (74.37% correct) than the hard trials (44.99% correct), better on the geocentric (74.07% correct) than the egocentric trials (45.29% correct), and the English-speakers (70.14% correct) did better than the Tseltal (51.51%).

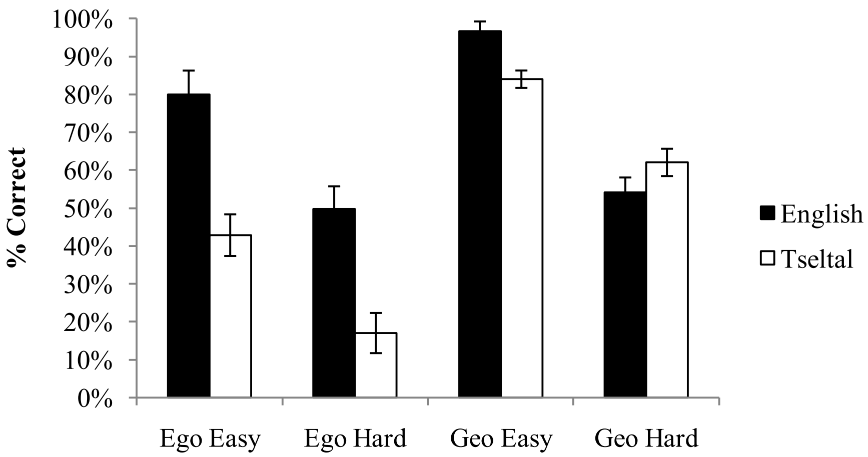

Fig. 2. Percentage correct by trial type and difficulty, collapsing across blocked conditions (Ego-to-Geo, Geo-to-Ego), comparing the English (N=25) and Tseltal speakers (N=32)

The ANOVA yielded three significant interactions, two of which involved language. First, the effect of language varied by difficulty ($F(1,53) = 5.01$, $p = .03$, $\eta_p^2 = .09$), with the two groups diverging more on the easy (English: 88.33%, Tseltal: 63.45%; $F(1,56) = 31.56$, $p < .001$, $\eta_p^2 = .37$) than the hard trials (English: 51.94%, Tseltal: 39.56%; $F(1,56) = 5.96$, $p = .02$, $\eta_p^2 = .10$). Second, language by trial type was significant ($F(1,53) = 20.26$, $p < .001$, $\eta_p^2 = .28$). However, this interaction was not due to the English-speaking children performing better on the egocentric than the geocentric trials and vice versa for the Tseltal-speaking children. In fact, both language groups performed better on the geocentric than the egocentric trials (English: 75.39% vs. 64.89%, $F(1,24) = 4.46$, $p = .05$ $\eta_p^2 = .16$; Tseltal: 73.05% vs. 29.97%, $F(1,31) = 71.05$, $p < .001$, $\eta_p^2 = .70$). An analysis of the simple effects showed that the language by trial type interaction was driven primarily by the comparatively lower performance of Tseltal-speaking children on the egocentric trials (English: 64.89%, Tseltal: 29.97%; $F(1,56) = 27.22$, $p < .001$, $\eta_p^2 = .33$) but not the geocentric trials (English: 75.39%, Tseltal: 73.05%; $F(1,56) = .48$, $p = .49$, $\eta_p^2 = .01$).

Lastly, there was a three-way interaction between trial type, block order, and difficulty ($F(1,53) = 16.20$, $p < .001$, $\eta_p^2 = .23$). As Figure 3 indicates, the order in which the trials were given (Ego-to-Geo, Geo-to-Ego) affected the hard, but not the easy trials. For the hard egocentric trials, the group tested on the egocentric block first performed better than the group tested on the geocentric block first (Ego-to-Geo: 42.05% correct vs. Geo-to-Ego: 20.39% correct). For the hard geocentric trials, the group tested on the geocentric block first now performed better than the group tested on the egocentric block first (Geo-to-Ego 65.48% vs. Ego-to-Geo: 51.92%). This finding suggests that the children had a difficult time switching from the response pattern of their first block to the requested reference frame of their second block.

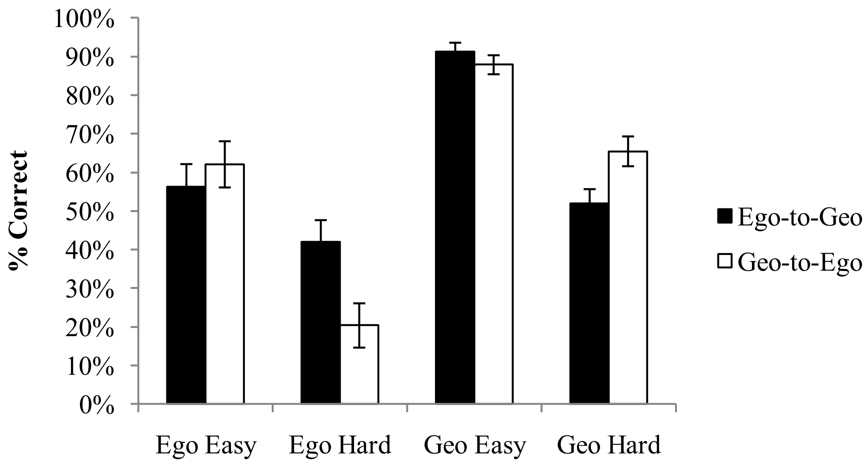

Fig. 3. Percentage correct by trial type and difficulty, collapsing across language group (English, Tseltal), comparing Ego-to-Geo (N=29) and Geo-to-Ego (N=28)

Results from the left/right comprehension tests for the Tseltal-speaking children were broken down according to whether the children participated in the open-ended condition or the instructed conditions. The children in the instructed conditions received explicit input regarding how to label their left and right hands and the animals next to their hands during the previous task while the children in the open-ended condition did not. Therefore, if children were unfamiliar with the words, left-right input could potentially benefit the children in the instructed condition and not the open-ended condition. The comprehension scores were scored in two ways with the consideration that for half of the trials, the doll faced the same direction as the child and for half of the trials the doll faced the opposite direction as the child. Although the third person possessive prefix in the test phase specified for animals to the doll's left or right, computing another person's left and right is relatively more difficult than computing one's own left and right. Several studies with English-speaking children reveal that at the earliest stages of learning "left" and "right" children do not consider the left and right sides of others and apply their own left and right to interpret left-right commands (e.g., "choose the animal on the doll's left side"; see Li, Shusterman, & McNaughton, under review). It is possible that Tseltal-speaking children would also ignore the doll's facing direction. The percentages correct were therefore scored once in consideration of the doll's facing direction and once ignoring the doll's facing direction. In this latter case, the percentages correct were determined by the perspective of the child and not of the doll. See Table 2 for the results.

As the results indicate, children's performance hovered around chance. Only the Geo-to-Ego condition seemed to be above chance when the left-right comprehension score was coded from the perspective of the child, which could be due to the fact that they had just completed the Egocentric block prior to being tested on left-right comprehension and hence had some recollection as to how the experimenter applied the words to describe the animals.

Table 2. Percent correct on left/right language comprehension tasks scored two ways and broken down by condition. The p-values reflect t-test comparisons against chance (.50).

	Doll's Facing Direction Considered	**Doll's Facing Direction Ignored**
Open-ended (n = 14)	66.07% p = .07	51.79% p = .75
Ego-to-Geo (n=16)	59.38% p = .30	62.50% p = .10
Geo-to-Ego (n=13)	55.77% p = .27	75.00% p = .02*

2.3 Discussion

Our findings confirm that there is a strong correlation between habits of language use and response preference on open-ended tasks (Brown & Levinson, 1993b; Pederson et al., 1998; Haun et al., 2011). On the instructed conditions, however, the English-speaking children were able to successfully switch to their non-preferred system while the Tseltal-speaking children were not. Further, both groups of children performed better on the geocentric than the egocentric trials. These findings contrast with those of Li et al. (2011) and Abarbanell (2010) who found a similar flexibility across both language groups and an egocentric advantage on some tasks. The performance of the English-speaking children also contrasts with the inflexibility of the Dutch-speakers tested by Haun et al. (2011). What could account for these divergent results? Close comparison of the procedures across studies yields at least two explanations.

One important difference concerns the 90° turn we used here versus the 180° turn used by Li et al., together with the relatively close distance between tables we used here compared with the arrangement in Haun et al.. Studies in the spatial cognition literature, mainly testing speakers of languages that make use of left/right language, show that we mentally update the relationship between objects and how they look from our new perspective as we move, thereby maintaining a stable representation of the objects with respect to the environment (Simons & Wang, 1998). The representation of the objects with respect to the environment differs from and can compete with the representation of the objects as we initially viewed them. Some studies involving detecting changes in an array of objects show that under some circumstances our ability to detect changes is better when the display matches the geocentric than the egocentric view.

This ability to update, however, is mediated by both the distance travelled and the degrees of displacement: The greater distance and degrees the harder it is to update how objects look in the new position. Furthermore, with 180° rotation, participants can no longer see the part of the room where they initially viewed the array, making it easier for them to use their own bodies as a point of reference. In our study, although the children could no longer view the first table, they could still see the side of the room where they initially memorized the array, likely strengthening the geocentric representation. Contrariwise, although Haun et al. also used a 90° rotation, the children walked around an entire building, causing a drastic change in environment. We would therefore predict that the Haun et al. task would favor an egocentric response, similar to the tasks in Li et al.

Why, then, would the Hai||om-speaking children have difficulty with the egocentric condition of their task? Further, why would only the English-speaking children show flexibility regardless of rotation? One possibility, which we consider next, concerns the use of verbal versus nonverbal instructions. In Li et al., participants were shown the expected response, egocentric or geocentric, with the use of nonverbal prompts (e.g., by carrying a covered array to the second table so that it either rotated with their bodies or was held constant with the environment, and then uncovering the array to check their response). They were not required to decode spatial language that they rarely, if ever, use. Left/right systems, in particular, are notoriously difficult to acquire and ambiguous in use (Piaget, 1928; Rigal, 1994, 1996). Children who are only marginally versed in the use of such a system, like the Tseltal and Hai||om, would likely have a hard time understanding the egocentric instructions – even more so if they are administered via a video recording as in Haun et al. As the experimenters did not test the children's left/right language comprehension, we have no way of assessing their understanding of these terms.

Similarly, the Dutch-speaking children were told, e.g., to "place the western objects back on the western side of the array". While we could find no studies on the acquisition of these terms in egocentric reference languages, as already noted, there is reason to believe that east/west terms may be less salient and less frequent in discourse directed to children than north/south (e.g., "We're going on vacation on the North Sea"). Data from Tsotsil speakers in Zinacantan, Chiapas, Mexico, a Mayan language closely related to Tseltal that uses a similar uphill/downhill system, documents an asymmetry in children's acquisition of these terms based on the social salience of different directions and locations. The children begin using the term *olon* 'downhill' while pointing randomly, only later affixing it to the correct direction, and still later acquiring the full upland/downland contrast (de León, 1994). It is therefore plausible that Dutch-speaking children, who do not habitually use a cardinal direction system, would show a similar asymmetry in their understanding of these terms.

Further, as our data indicates, the children showed a perseveration effect on the hard trials: those who received the egocentric trials first did better on the hard egocentric trials than those who received the geocentric trials first, and vice-versa for the hard geocentric trials. Since Haun et al. did not test the Dutch-speaking children using counterbalanced instructed trials, it is possible that perseveration affected their performance on the geocentric trials, all of which were hard, in addition to any difficulty interpreting east/west geocentric instructions.

3 Experiment 2: Eliminating Left/Right Language

To eliminate any difficulty presented by the use of left/right language, we tested a new group of Tseltal-speaking children using non-verbal means to convey the required reference frame, following the procedures developed by Li et al. (2011). Rather than telling the children to use the "left" and "right" sides of their bodies, the animals were arranged at Table 1 on a square cardboard tray, which was then covered prior to having the children carry the tray to the second table. In the egocentric condition, the children carried the tray so that it rotated with their body as they turned 90° at the second table, while in the geocentric condition the children dropped the tray at the second table prior to rotation (see Figure 4).

In Experiment 2, children were always tested first on the egocentric trials before the geocentric trials since we were primarily interested in addressing whether Tseltal-speaking children would be able to produce the egocentric response using this non-verbal version of the task. We contrasted this group of children's performance with Tseltal-speaking children's performance in the ego-to-geo condition of Experiment 1. We did not test English-speaking children since they already did well on the egocentric trials in Experiment 1. We reasoned that if comprehending the left-right instructions was a problem for Tseltal children in Experiment 1, performance on the egocentric trials should be higher in Experiment 2 relative to Experiment 1 while performance on the geocentric trials should remain roughly the same across the two experiments. However, if Haun et al. are correct that children cannot flexibly produce the language-incongruent response, Tseltal-speaking children should perform similarly across Experiments 1 and 2, with equally poor performance on the egocentric trials and equally better performance on the geocentric trials.

3.1 Methods

Participants and Setup. Sixteen Tseltal-speaking children that had not been tested previously (mean age = 7.88 years; SD = .62) were recruited from the same population and were tested under the same conditions as in Experiment 1.

Procedure. The children were given three practice trials at the first table, identical to those in Experiment 1. They were next given two training trials using both tables to familiarize them with the expected solution to the task. For the Egocentric condition, with the help of a native Tseltal-speaking research assistant, the children were told that they would use the two sides of their body without the use of any left/right terms (using the term *jejch* for ‘side’). The research assistant then touched the child on each shoulder/arm in turn while naming the animal on the indicated side. The children were then asked to raise each hand and name the animal located at that hand, and to raise the hand towards which the animals were looking.

For the Geocentric condition, the children were asked to point toward sunrise (*slok’ib k’aal*) and sunset (*smalib k’aal*). They were then shown which animal was located towards each direction, indicating the wall of the room as well as the (sunrise/sunset) direction. The children were then asked to repeat which animal was located towards sunrise and sunset and to name the direction towards which the animals were looking.

When the children indicated that they were ready, they were instructed to carry the (uncovered) tray to the second table. In the Egocentric condition, the children held the box as they turned at the second table to face 90° from their original orientation. In the Geocentric condition, the children dropped the box at Table 2 prior turning so that the orientation of the box remained constant with the environment (see Figure 4). The box was then covered and the children were asked to recreate the array after first naming the animals that were located in the appropriate directions (at each hand, towards sunrise/sunset). The cover was then lifted so the children could see if their response was correct. They were prompted to correct any errors.

The test trials were identical to the training trials, except that the tray was covered prior to walking to the second table. The children were prompted to verbally identify the animals located at each hand/towards sunrise/sunset for the first test trial only. The children received three easy and three hard trials, following the same protocol as in Experiment 1. For each trial, after the children’s response at the second table was recorded, the cover was lifted from the tray and the children were prompted to visually check and then correct their answers. In this respect, the procedure deviated from Experiment 1, where the children could not visually check their answers and were not prompted to make corrections.

Following the main task, the children were tested on their comprehension of left/right terms using a doll facing away and towards them as in the previous experiment. In the same manner, they were also tested for their knowledge of sunrise/sunset terms, with the order (left/right, sunrise/sunset) blocked and counterbalanced across participants. Following both of these tests, the children were tested for their ability to identify left and right on their own bodies using simple commands (e.g., “raise your left arm”, “move your right leg”/*”toya te a-k’ab ta izquierda”, “tija te a’w-akan ta derecha”*). The children were given eight such trials, one for each arm/leg while facing towards and then away from the experimenter.

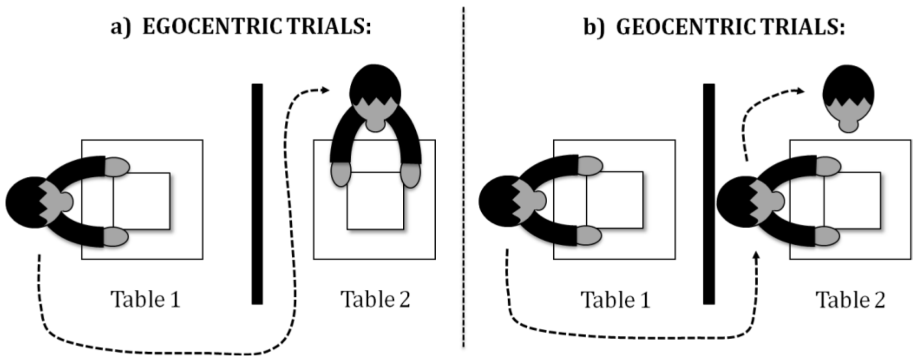

Fig. 4. Setup for Experiment 2 for the (a) Egocentric versus the (b) Geocentric trials

3.2 Results and Discussion

The percent correct on the test trials were compared with the performance of the Tseltal-speaking children in the Ego-to-Geo condition from Experiment 1 (see Figure 5 for the comparison). A 2 (difficulty: easy, hard) x 2 (trial type: egocentric, geocentric) x 2 (experiment: Exp.1 Ego-to-Geo, Exp. 2 Tray) ANOVA yielded main effects of difficulty ($F(1,30) = 31.56$, $p < .001$, $\eta_p^2 = .51$), trial type ($F(1,30) = 29.46$, $p < .001$, $\eta_p^2 = .50$), and experiment ($F(1,30) = 14.05$, $p = .001$, $\eta_p^2 = .32$). Overall, participants showed better performance on the easy (72.83% correct) than the hard trials (53.86% correct), on the geocentric (75.39% correct) than the egocentric trials (51.30% correct), and in Experiment 2 (73.44% correct) than Experiment 1 (53.26% correct).

The ANOVA yielded two significant interactions. The trial type by difficulty interaction ($F(1,30) = 6.88$, $p = .01$, $\eta_p^2 = .19$) revealed a bigger difference between the easy and hard trials for the geocentric trials (Easy: 88.37% vs. Hard: 62.41%; $F(1, 31) = 54.43$, $p < .001$, $\eta_p^2 = .64$) than the Egocentric trials (Easy: 57.29% vs. Hard: 45.31%; $F(1, 31) = 6.04$, $p = .02$, $\eta_p^2 = .16$). Crucially, the trial type by experiment interaction was significant ($F(1,30) = 12.06$, $p = .002$, $\eta_p^2 = .29$), confirming that the improvement from Experiment 1 to Experiment 2 held only for the egocentric trials (Exp 1: 33.51% vs. Exp 2: 69.10%, $F(1, 31) = 15.85$, $p < .001$, $\eta_p^2 = .35$) and not the geocentric trials (Exp 1: 73.00% vs. 77.78%, $F(1, 31) = 1.31$, $p = .26$, $\eta_p^2 = .04$).

As in the open-ended condition in Experiment 1, the language assessment revealed that these children had not fully acquired the left/right terms. They were at chance at identifying the animal to the left/right of the doll, both when facing away and towards their bodies. While they were above chance as a group at identifying their own left/right hands and legs, performance was not at-ceiling (75.0%). In contrast, their knowledge of sunrise/sunset was more robust (see Table 3).

In sum, when given clear instructions that did not involve the use of left/right terms, the Tseltal-speaking children showed improved performance on the egocentric trials, while still showing an overall advantage for solving the task geocentrically.

Table 3. Percent correct on left/right (LR) and sunrise/sunset (EW) language comprehension tasks for the tray condition (N=16), showing comparison against chance (.50)

Doll's Facing Direction Considered	Doll's Facing Direction Ignored	LR of Self (Body Parts)	EW
59.38% p = .16	56.25% p = .41	75.00% p = .006**	82.81% p < .001***

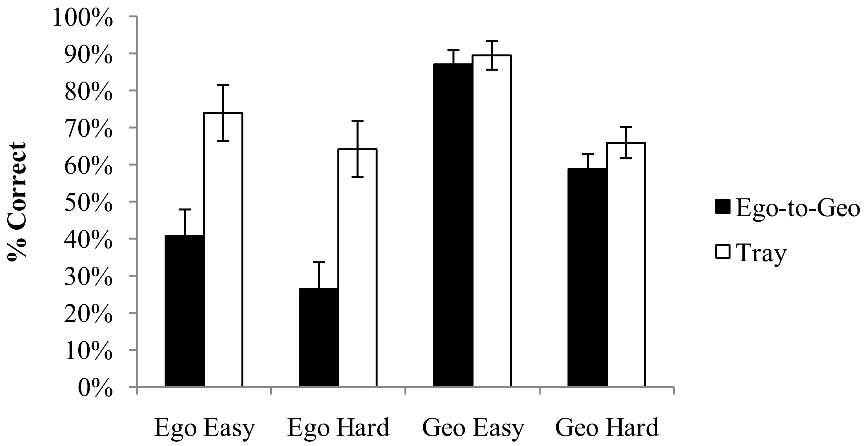

Fig. 5. Percentage correct by trial type and difficulty for the Tseltal-speakers only, comparing the Ego-to-Geo (Experiment 1, N=16) and Tray (Experiment 2, N=16) conditions

4 General Discussion

The goal of these studies was to reconcile contradictions in the literature concerning the cognitive flexibility of different language groups for memorizing small-scale spatial arrays using different coordinate systems (Haun et al., 2011; Li et al., 2011). The present results both confirm and diverge from previous findings, offering an important point of comparison. Our open-ended task replicated what appears to be a robust correlation between linguistic and nonlinguistic preferences on tasks that have more than one correct solution. Our ambiguous tasks, however, concurred with the findings of Li et al. by demonstrating cognitive flexibility across language groups. Although Tseltal-speaking children had difficulty on the egocentric trials when instructed using left/right terms, their performance improved significantly with more explicit nonverbal instructions. These results support an alternative explanation for the inflexibility of the Hai||om children whose left/right comprehension was not assessed by Haun et al.: language affects speakers' ability to comprehend verbal instructions.

Our results diverged from Li et al., however, in one important respect. The 90° rotation and proximity between tables appeared to trigger mental updating of a stable array, resulting in better performance on the geocentric vs. egocentric trials for both Tseltal and English-speakers, despite the fact that the latter preferred the egocentric response on the open-ended task. This contrasts with the egocentric advantage observed among both language groups by Li et al., despite Tseltal-speakers' preference for the geocentric solution on open-ended tasks (Brown & Levinson, 1993b). This dissociation between preference and performance supports the argument that pragmatic inferences are responsible for speakers' preferences on open-ended tasks: Language may influence how speakers interpret what constitutes "sameness", but this tells us little about how they reason about spatial relationships in their day-to-day lives (Li & Gleitman, 2002; Li et al., 2011). Moreover, these results suggest that task constraints rather than language determine which system is easier to use in any given context. Supporting this, we note that egocentric advantages have been observed among geocentric language speakers on tasks involving motion paths (Li et al., 2011; Mishra, Dasen & Niraula, 2003; Wassmann & Dasen, 1998; Senft, 2001). The relationship between language and thought in this domain does not appear to be one-to-one, as argued by Haun et al., rather, there is converging evidence of a dissociation between linguistic and nonlinguistic spatial representations.

The present results predict that Hai||om and Dutch speakers will show a similar flexibility if given explicit nonverbal instruction on the Haun et al. task, with the distance between tables perhaps yielding an egocentric advantage across language groups. It is possible, however, that task-specific constraints interacted with language to produce the observed pattern of results. While it was relatively easy for the English-speaking children to switch to a geocentric response on a task that encourages mental updating of an environmentally stable array, it may be inherently more difficult to do so through environmental shifts, unless one's language or culture requires a constant attunement to one's environment. It is therefore possible that the Dutch-speaking children would continue to have difficulty on the geocentric trials of the Haun et al. task, even if given clearer instructions. Likewise, the flexibility of the Tseltal-speaking children on the egocentric trials of our task, despite their preference for using a geocentric reference frame on open-ended tasks (Brown & Levinson, 1993b), predicts a similar flexibility for the Hai||om if given clear instructions – especially on a task that should encourage an egocentric response. However, it is possible that cultural and environmental factors specific to the Hai||om make a geocentric response both more salient and more entrenched for this particular language group.

The Hai||om are a semi-nomadic hunter-gatherer group whose survival depends on their attunement to subtle variations in soil type and vegetation. In addition to a linguistically strong east/west (sunrise/sunset) axis, speakers use a system of landscape terms on north/south, with the direction specified by each term shifting as one moves along the axis. These landscape-based terms are "ubiquitous" in Hai||om discourse, which is characterized by a "continuous flow of "topographical gossip"" (Widlok, 2008: 364-5, see also Widlok, 1996). Groups of people are named for the landscape they regularly inhabit (e.g., "people of the hard ground"), fusing landscape and people into what Widlok terms a "land-*cum*-people" terminology (2008: 366). It would not be surprising, then, if the Hai||om showed a stronger geocentric tendency than the Tseltal, whose agrarian lifestyle does not involve quite the same fusion between people and landscape, and where the visual saliency of the uphill/downhill slope may not demand the same level of mental updating as a contingent landscape system. It is possible, then, that the Tseltal-speakers would not show as strong a performance on geocentric trials as their Hai||om peers in the Haun et al. task, while the Hai||om may have difficulty suppressing a geocentric advantage on our task. If such culture-specific effects are found, it would argue that it is not the semantic system per se, but rather variation may arise across language groups that share the same semantic typology, depending on other cultural and environmental factors as well as the pragmatics with which each system is used. Such variations, however, are not likely to be absolute, but rather yield gradations in performance vis-à-vis the ease or difficulty with which inherent task constraints that favor the use of one system versus another can be overcome.

Haun et al. concluded that the habitual use of a particular frame of reference in one's language shapes speakers' competence as well as their preferences in the domain of memory for small-scale spatial arrays. We argue that these conclusions are at best premature. Converging evidence suggests that linguistic and nonlinguistic spatial representations are largely independent, with task constraints determining which system is most readily employed. Different language groups may vary in the ease with which they are able to overcome task-specific constraints; however, the extent to which further task manipulations uncover variability across language groups that share the same semantic typology, will confirm that language is but one factor among many that may shape the margins of what is otherwise a largely universal cognitive domain.

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