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Spatial Reasoning Skills in Tenejapan Mayans

Peggy Li (pegs@wjh.harvard.edu)

Department of Psychology, Harvard University
33 Kirkland St., Cambridge, MA 02138 USA

Linda Abarbanell (abarballi@gse.harvard.edu)

Department of Education, Harvard University
13 Appian Way, Cambridge, MA 02138 USA

Anna Papafragou (papafragou@psych.udel.edu)

Department of Psychology, University of Delaware
109 Wolf Hall, Newark, DE 19716 USA

Abstract

This paper examines possible influences of language on thought in the domain of spatial reasoning. Language communities differ in their stock of reference frames (coordinate systems to reference locations and directions). English typically uses egocentrically-defined axes ("left-right"). Other languages like Tzeltal lack such a system but use geocentrically-defined axes ("north-south"). We ask whether the lexical resources available in one's language determine the availability or salience of certain spatial concepts. Does a "left-right" lexical gap translate to a conceptual gap? In three experiments, we compared Tzeltal speakers' ability to solve spatial problems requiring an egocentric frame of reference to ones requiring a geocentric frame of reference. We found that Tzeltal speakers were above chance in solving the egocentric problems, demonstrating that a lexical gap does not necessarily lead to a conceptual gap. Furthermore, participants were statistically better on the egocentric version in two of the three experiments. These results speak against some current versions of linguistic relativity.

Introduction

Do speakers of different languages come to perceive and conceptualize the world differently (Whorf, 1956)? For the last half of this past century, the *linguistic relativity* hypothesis was viewed as untenable by many (e.g., Heider, 1972; Heider & Oliver, 1972). However, more recently, the hypothesis has returned to the forefront of many cognitive science debates (e.g., Bowerman & Levinson, 2001; Gentner & Goldin-Meadow, 2003) and many commentators now endorse stronger or weaker versions of it.

Fueling the debates is an extensive and influential set of cross-linguistic investigations demonstrating a striking correlation between the linguistic habits and spatial reasoning of members of different linguistic communities (Brown & Levinson, 1993; Pederson, Danziger, Wilkins, Levinson, Kita, & Senft, 1998; Levinson, 2003). These studies start with the observation that there is considerable cross-linguistic variation in linguistic communities' choices of spatial frames of reference. As English speakers, we typically make use of an egocentric, body-defined coordinate system to reference locations of objects ("The cup to the left of the bowl") or to give directions ("Turn

right"). However, some languages make little or no use of such a spatial frame of reference. One such language is Tzeltal, a language spoken by a group of Mayans residing in the Tenejapa area of Chiapas (Mexico).

Tzeltal lacks the linguistic conventions for encoding "to the left" or "to the right." Even though the language has the body part words "xin" (left) and "wa'el" (right), these words are extremely infrequent in speech and restricted in use. The words only exist to define body parts and never regions outside the body. Additionally most informants use "left" and "right" exclusively in nominal compounds with arm and leg terms and not for any other body parts (Brown & Levinson, 1992).¹

In place of egocentric coordinates, Tenejapans utilize a system of terms ("alan" and "ajk'ol") based on the overall inclination of the terrain ("downhill" and "uphill") which they inhabit. These geocentrically-defined terms are extended and used even when one is on flat terrain to reference the general directions of uphill and downhill which roughly correspond to the north-south axis. Moreover, they are used in descriptions of small scale arrays such as the arrangement of items on tabletops for which English speakers prefer "left" and "right."

The linguistic differences between Tzeltal and English in the domain of spatial relations have led researchers to consider the possibility that spatial concepts might correspondingly differ in the speakers of the two languages. For example, Levinson (1996) writes:

Tenejapans show an interesting tendency to confuse left-right inversions or mirror-images (i.e., reflections across the apparent vertical axis), even when visually presented simultaneously, which seems related to their absence of 'left' and 'right' terms, and the

¹ Strange as it may seem for Tenejapans to not extend the body location terms (*xin* and *wa'el*) to regions outside their body, Shusterman, Li and Abarbanell (in prep.) found that 4-year-old English-speaking children, after being taught novel words for the left and right sides of their bodies, do not automatically interpret commands using those terms as describing objects to their own left and right.

absence of related asymmetries in their material culture. (p.182)

And more recently he comments (Levinson, 2003):

...[O]ne simply cannot say in Tzeltal ‘The boy is to the left of the tree’, or ‘Take the first turning left’... We therefore believe that there is a systematic downgrading of left/right asymmetries in Tenejapan conception. (p. 149)

To explore this possibility systematically, previous cross-linguistic studies (e.g., Pederson et al., 1998; Majid et al., 2004) compared English- and Tzeltal-speakers’ spatial reasoning patterns. In these studies, speakers were shown a spatial array on a table (e.g., a red dot left/north of a blue dot). They then turned 180° to face a second table and were asked to identify or recreate the “same” array. Crucially, after turning, left and right coordinates rotate along with the participant, while north and south remain constant. However, where north and south is situated remains unchanged. By observing the speaker’s response, one could determine the speaker’s choice of frame of reference. These studies show that English speakers preferred the egocentric and Tzeltal speakers the geocentric response. From these results, Levinson and colleagues concluded that language shapes one’s underlying representation of spatial relations (in accordance with the linguistic relativity position). In other words, the lexical gap in Tzeltal (the absence of a left/right coordinate system in language) is taken to create a conceptual gap (the unavailability/low salience of left/right spatial concepts in thought).

Nevertheless, these data do not conclusively demonstrate the unavailability or the low salience of left/right concepts. First, these cross-linguistic studies test speakers’ preferences in encoding spatial arrays, rather than comparing their ability to solve spatial tasks which require different frames of reference. It could still be the case that Tzeltal speakers are quite capable of thinking about left and right, even though they do not use these distinctions if other options are available². Second, the scope and extent of the preferences displayed in these tasks is in question: is the selected preference representative of the habitual mode of spatial reasoning in everyday life? The attested preferences could alternatively be explained as effects of “language on language” (Li & Gleitman, 2002). Namely, the pragmatics of language use could implicitly influence how speakers come to interpret ambiguous commands such as “make it the same.” In other words, what appropriately counts as the “same” spatial array might be influenced by how one’s linguistic community customarily speaks about or responds

² An analogy can be drawn to the claim that Korean speakers are more likely than English speakers to categorize spatial relationships on the basis of tightness-of-fit because tight-fit is marked in Korean verbs. It would be strange, however, to claim that English speakers cannot distinguish tightness-of-fit (Hespos & Spelke, 2004).

to inquiries about locations and directions. Thus, these previous studies by themselves do not necessarily reveal anything about the unavailability or low salience of the left-right frames of reference in Tenejapan conception.

Notice that the *language on language* hypothesis assumes that the effect of language should diminish when speakers are tested on unambiguous spatial tasks that do not require the interpretation of the experimenter’s intent (i.e., tasks with a single correct solution). To rule out this hypothesis would therefore necessitate testing speakers on unambiguous tasks and seeing that linguistic influences on spatial reasoning persist.

We therefore conducted a series of three experiments which examined Tenejapans’ ability to solve spatial tasks. Our tasks were unambiguous (they had correct solutions). In each experiment there were two matched conditions that varied in whether the geocentric or the egocentric frame of reference is required to correctly solve the task. The egocentric condition alone would inform us of Tenejapans’ ability to reason about left-right. Comparing the matching conditions would permit the assessment of the relative difficulty in reasoning egocentrically and geocentrically. We reasoned that if Tenejapans experienced a systematic downgrading of left-right asymmetries and processed spatial information in the manner corresponding to their language as suggested by Levinson (2003), they should find the geocentric condition easier than the egocentric one (while English speakers should presumably find the reverse easier).³

Experiment 1

Method

Participants Twenty-six Tzeltal-speaking adults (mean age = 35, SD = 16.31) were recruited through Casa de Cultura in Tenejapa.⁴ The participants were tested individually in a quiet classroom. Each participant was paid 50 pesos for his/her time. Care was taken to recruit Tenejapans who knew little or no Spanish, a language that (like English) uses an egocentric (left-right) reference system.

³ A terminological note: Levinson (1996) elegantly described the types of reference frames in the world’s languages with a tripartite set of terms (relative, intrinsic, and absolute). For present purposes, we adopt the simpler terms “egocentric” vs. “geocentric”. “Egocentric” seemed appropriate since our nonlinguistic tasks tap participants’ reasoning in terms of their own left-right. Note therefore that “egocentric” is not exactly synonymous with either “relative” or “intrinsic”, nor does it subsume those terms. We cannot discuss these various terminologies here in any detail (but see Gallistel, 1999; Gleitman, Gallistel, Abarbanell, Papafragou, Li, in prep.).

⁴ Using the director-matcher task described in Li and Gleitman (2002), we also later verified that this population of Tzeltal speakers’ use of linguistic frames of reference was similar to what Brown and Levinson (1993) reported. Our 8 pairs of directors and matchers never used any “left” or “right” type terms in discussing spatial arrangements.

Stimuli Two sets of five identical (6 in. x 6 in.) cards (see Figure 1a) were made, each with two same-design dots. For one set, the two dots varied in size. For another set, the two dots varied in color.

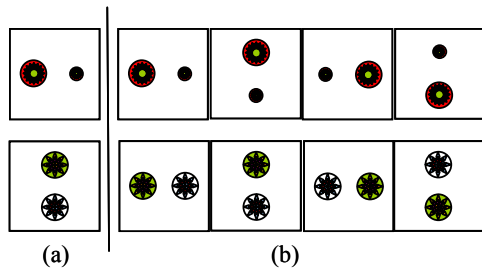


Figure 1. Stimuli set used in Experiment 1.

Procedure This task was adapted from Brown and Levinson (1993)’s “chips task.” The basic paradigm involved memorizing the orientation of two dots on a card (e.g., the green dot is left/south of the yellow dot) and then selecting the “same” card from four identical cards rotated 0, 90, 180, 270 degrees (see Figure 1b).

Prior to the test there was a familiarization phase to introduce what is meant by the “same.” The experimenter asked the participants to select the same card as the one in their hands from four other identical but distinctly oriented cards and provided feedback that orientation was crucial for sameness whenever necessary. The familiarization also included 4 memory trials for which the participants memorized the dot orientations. Then the experimenter covered the card and laid out the other four identical cards in their distinct orientations for the participant to choose. The familiarization phase involved only one table, with the participants always facing in a single direction.⁵

The test trials involved two identically oriented tables at two ends of the room. The participants stood between the two tables, close to and facing the first table, just as in Brown and Levinson (1993)’s studies. Initially, participants memorized the two dots on a card while facing the first table. Then the card was covered and carried by the participants to the second table, where participants had to identify the “same” card from four distinctly oriented identical cards. Participants were randomly assigned to either an egocentric or a geocentric condition. In the egocentric condition, they held the covered card as they rotated so that the covered card also rotated 180°. For the geocentric condition, the participants also held the covered card, but did not rotate the covered card even though they turned to walk to the second table. The correct solutions for the egocentric and geocentric condition were thus identical to how one expected English and Tseltal speakers’ to

respond respectively on the ambiguous version.⁶ After the participants selected the “same” card, the cover was lifted from the covered card to reveal the card underneath. There were 8 test trials, and orientation of the dots left-right/north-south or up-down/east-west was fully counterbalanced, as was the choice of set of cards used (variation in size/color of dots).

Results and Discussion

The memory trials served not only as familiarization, but also as a check to see if the participants in the Egocentric and Geocentric condition have comparable memory capacity. Indeed, the two groups were comparable on those trials (89.8% correct for Geocentric group vs. 85.9% correct for the Egocentric group, $t(24)=.57$, $p = .57$).

The percent correct for the test trials was submitted to a 2 (Condition: Egocentric, Geocentric) x 2 (Orientation: left-right/north-south, up-down/east-west) x 2 (Card Set: Size, Color) ANOVA, with Condition as a between-subject factor. The results yielded no main effects or interactions ($p > .15$). Most importantly, the non-significant effect of Condition ($F(1, 24)=1.38$, $p = .25$) indicated that the Geocentric group (74.0% correct) performed no better than the Egocentric group (84.6% correct). Both groups were well above chance.

The success on both conditions demonstrated that Tseltal speakers could keep track of the relationship between the card dots not only with respect to the environment, but with respect to oneself in memory. This finding begins to rule out the possibility that Tseltal speakers cannot reason using their left-right. The “chips” task, however, is arguably easy and might not be pushing the limits of Tseltal speakers’ abilities.⁷ We went on to test Tseltal speakers with other tasks (Experiments 2 and 3) to consolidate these findings.

⁶ For those familiar with Levinson’s set of terminology, some reviewers suggested that the intrinsic frame of reference is more readily available and easier than the relative frame. They wondered whether Tenejapans were solving the task using the intrinsic frame. As our tasks are based on Levinson et al’s studies, which unfortunately could be solved either way, it is true we could not tease the two apart. That said, Tseltal lacks both intrinsic and relative left-right. However, in other current studies we address this issue. Preliminary results, though, lead us to suspect that perspective choice (my left-right vs. someone else’s left-right) more strongly determines the availability and computational ease of spatial frames rather than the intrinsic-relative distinction.

⁷ One might, for example, argue that Tenejapans in the egocentric condition were really encoding the relations geocentrically (i.e., the green dot is south of the yellow dot) and then succeeding by learning to “flip” their responses (now the green dot is north of the yellow dot). The converse strategy is one that some English speakers have reported when tested on the geocentric condition. If flipping did occur with Tenejapans, we might expect them to make more errors for the egocentric than the geocentric condition as a result of the extra “flipping” step. However, we find no evidence for such difficulty when inspecting the percent correct for the test trials (Geo: 74% vs. Ego: 85%).

⁵ Consequently, familiarization trials did not necessarily train or reinforce left-right encoding; the participants could have encoded the relationship between the two dots using geocentric relations (e.g., the green dot is *south* of the yellow dot).

Experiment 2

We increased the difficulty level in Experiment 2 to see if the geocentric group would now out-perform the Egocentric group. Our task adapted Brown and Levinson (1993)'s maze task. In the original task, participants memorized a path traversed by a figurine on a tabletop surface. The participants then identified the "same" path from among several choices after turning 180° to face a second table. We increased the difficulty of the task by asking the participants to recreate the original path with a small ball at the second table. Also, unlike the original task, we turned the task into an unambiguous task with a single correct solution.

Method

Participants The same 26 Tselal speakers from Experiment 1 participated in this task. Participants were assigned to the same condition as in Experiment 1. For example, the egocentric condition participants in Experiment 1 were again assigned to the egocentric condition in Experiment 2.

Stimuli A 10 in. x 10 in. evenly-gridded square maze (Figure 2a) was constructed and laminated. A small ball was used during the experiment to demonstrate a path movement starting from the center of the maze that consisted of 1 leg, 2 legs, or 3 legs.

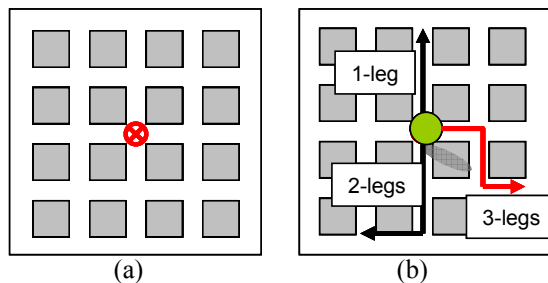


Figure 2. a. Picture of maze used in experiment.
b. Sample of paths traversed by the ball.

Procedure For each trial, participants memorized a path traversed by a ball on the maze (see Figure 2b). They were then asked to rotate 180°. In the egocentric condition, the maze was covered before the turn, held by the participants so that it also rotated 180° and then was uncovered on the second table. In the geocentric condition, the covered maze was carried to the second table by the participants who were careful not to rotate the maze despite their own rotation. Once the maze was uncovered, the participants were asked to recreate the path on the maze using the ball. Covering the maze discouraged visual tracing of the path on the maze while the maze was being transported. The cover also had a complex pattern of lines to distract and mask any visual imagery. Each participant was tested on 10 test trials (2 1-leg paths, 4 2-leg paths, and 4 3-leg paths in this order). The experimenter demonstrated the correct path in case of errors.

Results and Discussion

Figure 3 shows the average percent correct for the egocentric and geocentric group by the number of legs in the paths. A trial was counted as correct if the participant retraced the entire path correctly. As the figure indicates, Tselal speakers' performance on the Egocentric condition clearly surpassed the Geocentric condition as the number of legs in the paths increased. A 3 (Leg Number: 1, 2, 3) x 2 (Condition: Geocentric, Egocentric) ANOVA using percent correct as the dependent measure revealed a main effect of Condition ($F(1, 24)=24.7, p < .001$), reaffirming that the Egocentric Condition was easier than the Geocentric Condition. There was an effect of Leg Number ($F(1, 24)=64.7, p < .001$), with 1-leg being easier than 2-legs ($p < .001$) and 2-legs being easier than 3-legs ($p < .001$). Lastly, the Leg Number x Condition interaction was also significant ($F(1, 24)=14.7, p < .001$), suggesting that, as the number of legs increased, the difference between Geocentric and Egocentric conditions increased.

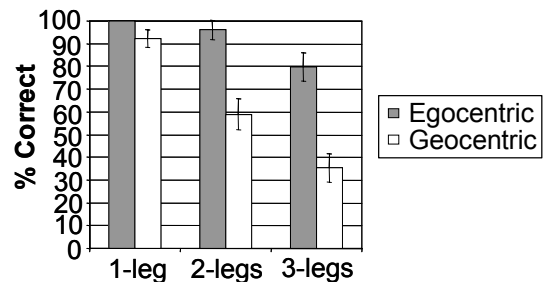


Figure 3. Comparing the Geocentric and Egocentric Conditions for the maze task (Experiment 2).

These results rule out the strong version of linguistic relativity by showing once again that Tselal speakers are capable of reasoning egocentrically. Even more stunningly, the results show that geocentric reasoning is harder than egocentric reasoning for a group of speakers whose language predominantly references directions and locations with geocentric terms. In fact, preliminary results from English-speaking college students show a similar asymmetry (even though, unsurprisingly, overall performance is much better regardless of condition). Our Tenejapan data thus rule out a version of linguistic relativity which suggests that the geocentric frame of reference is somehow more readily available than the egocentric frame in Tselal speakers. Combined with the preliminary results from English speakers, the Tenejapan data suggest that egocentric reasoning is universally easier and that habitual geocentric language use cannot override this egocentric advantage.

Experiment 3

In this last experiment, we used an entirely different methodology to compare egocentric reasoning with geocentric reasoning. Our task involved hiding objects to the left or right of the participants. The task was designed such that egocentric left-right encoding could be used to successfully locate the hidden objects in the egocentric

condition. Similarly, geocentric encoding could successfully retrieve the hidden object in the geocentric condition. Again, we asked how well Tenejapans would remember the locations of the hidden objects in both conditions and whether performance on one would be better than the other.

Method

Participants Twenty-four Tselal-speaking adults (mean age = 45.6) who had not participated in the previous experiments were recruited from the same Tenejapa population. The participants were tested individually in a quiet and furnished room with a large window with a view to the outside.

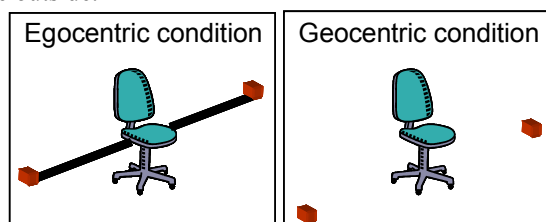


Figure 4. Swivel chair set up for Experiment 3.

Stimuli The stimuli consisted of a swivel chair with spokes to the left and right for attaching two identical boxes in the egocentric condition. In the geocentric condition, the spokes and boxes were removed and the boxes were placed on the floor (See Figure 4).

Procedure Each participant was tested on *both* the egocentric and geocentric condition, with 8 trials per condition. Order for the two conditions was blocked and counterbalanced. For the task, participants sat on the swivel chair with two boxes, one to each (left/right) side of the chair. In the egocentric condition, the boxes rotated with the chair and participant. In the geocentric condition, the boxes (on the floor) remained stationary while the subject was rotated. On each trial, the experimenter indicated in which box she was going to hide the coin. Then the participant was blindfolded and spun slowly. When the spinning stopped, the participant was positioned at 0, 90, 180, or 270 degrees from the initial position. With the blindfold then removed, the participant was asked to retrieve the coin on a single try. The final positioning of the chair was randomized with two trials per position for each condition.

Results and Discussion

The percentage correct (i.e., the retrieval of the coin on the first try) for the Egocentric Condition (92.3%) was surprisingly higher than the Geocentric Condition (80.0%; paired $t(23)=2.82, p=.01$). As ours was a within-subjects design, this means the same person typically found the Egocentric condition easier than the Geocentric condition.⁸

⁸ The better performance on the Egocentric condition is robust. We replicated the effect with another group of Tenejapans ($n=24$, Ego: 94.4% vs. Geo: 76.2%) in which we provided increased

There was no a priori reason to expect poorer performance on the Geocentric condition relative to the Egocentric condition. The Tenejapans could have easily encoded the correct box in the Geocentric condition (“The one to the south/The one next to the table”) and as a result performed correctly. In fact, given an anecdote from Brown and Levinson (1993b, p. 52) in which a Tenejapan blindfolded and spun around 20 times in a darkened house was able to point in the agreed direction while still dizzy and blindfolded, we expected at-ceiling performance from our non-blindfolded, non-dizzy participants.

Nonetheless, the unexpected finding accords with the findings from Experiment 2 showing that egocentric reasoning is easier than geocentric reasoning regardless of the language one speaks.

General Discussion

In this paper we have considered a linguistic difference in spatial terminology between Tselal and English (the encoding of left/right spatial coordinates) and its potential implications for the relations between language and thought. Several researchers have recently taken the position that such asymmetries in linguistic encoding give rise to asymmetries in spatial cognition:

Consider a language that has no terms for ‘in front’, ‘behind’, ‘left’, ‘right’, and so on ... preferring instead to designate all such relations, no matter how microscopic in scale, in terms of notions like ‘North’, ‘South’, ‘East’, ‘West’, etc. Now a speaker of such a language cannot remember arrays of objects in the same way as you and I, in terms of their relative location from a particular viewing angle... (Gumperz & Levinson, 1996, pp. 26–27).

The strongest interpretation of this position is equivalent to the view that one simply cannot entertain spatial concepts inexpressible in one’s language. Weaker interpretations of this position state that spatial linguistic distinctions may affect the availability of spatial distinctions in cognition by promoting the salience of those conceptual distinctions which are linguistically encoded. Although the strongest version seems extreme, ultimately the validity of both positions should be determined empirically (Carey, 2001; Gordon 2004).

The current set of studies provided us with a better understanding of how a population with a culture and a language so different than ours reason spatially. But our experimental results lead to entirely different theoretical conclusions from those in the previous literature (e.g., Pederson et al. 1998; Levinson, 2003; Majid et al. 2004). In particular, our studies show that the strong relativistic position is untenable, at least in the domain of the spatial notions under consideration: Tselal speakers are capable of reasoning in terms of left/right concepts despite the lack of

incentive to respond correctly on both types of trials by letting them keep the coins (actual currency) retrieved on the first try.

corresponding words for spatial coordinate systems in their language. Our results also cast doubt on some weaker relativistic views, since the availability of egocentric and geocentric frames of reference in the reasoning of Tzeltal speakers does not seem to correspond to the patterns of spatial linguistic encoding (where geocentric frames of reference are clearly dominant).

From a methodological point of view, our new data deflate the claim that correlations between linguistic communities' choices of spatial frames of reference and the preferred manner of response on open-ended tasks necessarily serve as evidence for language restructuring cognition. Our data thus also raise potential concerns about the use of open-ended tasks as tests of linguistic relativity.

Even though unexpected on previous theoretical and empirical relativistic claims in the literature, the conclusion that Tenejapan Mayans are not entirely different from us in their spatial reasoning may not be so surprising. After all, multiple frames of reference are necessary to represent where things are in everyday life (Gallistel 2002a, 2002b). In fact, under certain circumstances, locations of things are most aptly remembered using left-right coordinates. From this perspective, our egocentric condition in Experiment 3 is one of many cases where it is better to remember such relationships (*a dollar bill in the left pocket of the hanging jacket, a healed right knee* are further examples). In view of such examples it seems unlikely that linguistic habits usurp nonlinguistic needs to reason spatially. These observations, together with the experimental results reported above, can best be explained by assuming that the linguistic encoding of spatial frames of reference does not limit speakers' performance in nonlinguistic spatial tasks.

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