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# Spatial reasoning in Tenejapan Mayans

Peggy Li [a,*], Linda Abarbanell [d], Lila Gleitman [b], Anna Papafragou [c,*]

[a] Laboratory for Developmental Studies, Harvard University, 25 Francis Ave., Cambridge, MA 02138, United States
[b] Department of Psychology, University of Pennsylvania, United States
[c] Department of Psychology, University of Delaware, 109 Wolf Hall, Newark, DE 19716, United States
[d] Harvard Graduate School of Education, Harvard University, United States

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ABSTRACT

Language communities differ in their stock of reference frames (coordinate systems for specifying locations and directions). English typically uses egocentrically-defined axes (e.g., "left–right"), especially when describing small-scale relationships. Other languages such as Tseltal Mayan prefer to use geocentrically-defined axes (e.g., "north–south") and do not use any type of projective body-defined axes. It has been argued that the availability of specific frames of reference in language determines the availability or salience of the corresponding spatial concepts. In four experiments, we explored this hypothesis by testing Tseltal speakers' spatial reasoning skills. Whereas most prior tasks in this domain were open-ended (allowing several correct solutions), the present tasks required a unique solution that favored adopting a frame-of-reference that was either congruent or incongruent with what is habitually lexicalized in the participants' language. In these tasks, Tseltal speakers easily solved the language-incongruent problems, and performance was generally more robust for these than for the language-congruent problems that favored geocentrically-defined coordinates. We suggest that listeners' probabilistic inferences when instruction is open to more than one interpretation account for why there are greater cross-linguistic differences in the solutions to open-ended spatial problems than to less ambiguous ones.



## 1. Introduction

Do speakers of different languages come to perceive and conceptualize the world differently? During the last half of the past century, this linguistic relativity hypothesis was widely considered untenable (e.g., Heider & Oliver, 1972; Pinker, 1994) but recently has returned to the forefront of debates in cognitive science. Many commentators now endorse stronger or weaker versions of the position that language design features influence non-linguistic thought (see the essays in Gumperz and Levinson (1996), Bowerman and Levinson (2001), Gentner and Goldin-Meadow (2003), also Whorf (1956) for the original formulation of the hypothesis that habitual language use organizes and channels non-linguistic thought, and Gleitman and Papafragou (2005), for a review of the recent literature). Studies of lexical and grammatical effects on thought have been reported in a variety of domains including object individuation, number, theory of mind, and space (e.g., de Villiers & de Villiers, 2003; Feist & Gentner, 2007; Gordon, 2004; Lucy, 1992).

One of the best-known candidates for linguistic relativity is the domain of spatial location and orientation, which has been the focus of extensive and influential experimental investigations (Brown & Levinson, 1992, 1993a, 1993b; Levinson, 1996, 2003; Levinson, Kita, Haun, & Rasch, 2002; Li & Gleitman, 2002; Majid, Bowerman, Kita, Haun, & Levinson, 2004; Pederson et al., 1998). These studies start with the observation that there is considerable cross-linguistic variation in choices among spatial frames of

* Corresponding authors.
*E-mail addresses:* pegs@wjh.harvard.edu (P. Li), papafragou@psych.udel.edu (A. Papafragou).

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reference (henceforth, FoRs). For example, English speakers typically make use of an egocentric, body-defined coordinate system to refer to locations of objects (“The cup is to the left of the bowl”) or to give directions (“Turn right at the Pizza Hut”). However, many languages make little or no use of this body-centered FoR. One such language is Tseltal, an indigenous Mayan language spoken in the community of Tenejapa and other parts of the Highland region of Chiapas, Mexico. Although Tseltal has words for ‘left’ (*xin*) and ‘right’ (*wa’el*), they are so infrequent that some adult Tseltal speakers do not correctly interpret them when questioned. Moreover, the words are reportedly restricted in use: they define body-parts and are largely confined to nominal compounds with arm and leg terms (Brown, 2006; Brown & Levinson, 1992). More important, these words are apparently not used projectively to describe spatial regions beyond the body. Corroborating Brown and Levinson (1992), Abarbanell (2007) reported that only 69% of Tseltal speakers correctly identified the *xin* and *wa’el* sides of their body at rates above chance when given body-part commands (“Raise your left arm.”). And of these speakers who succeeded, only 64% understood unconventional commands extending the terms to reference objects at the left and right sides of the participant’s body (“Where is the left box?”).

In place of egocentric coordinates, Tenejapans utilize a system of terms (*alan* and *ajk’ol*) based on the overall inclination of the terrain they inhabit (“downhill” and “uphill”), which roughly coincides with the north–south axis.[1] Directions orthogonal to the uphill–downhill axis are referred to indistinguishably as *ta jejch* (‘crosshill’). Locations can, however, be further specified using other salient landmarks (e.g., ‘towards the red cliffs’) as well as the trajectory of the sun (sunrise-sunset). These terms are used even when one is on flat terrain to reference general directions which roughly correspond to the north–south and east–west axes. Although English speakers too use geocentric terms (“east of Fifth Avenue”, “Northern Italy”), they strongly disprefer these for small-scale arrays. For instance, Tenejapans might request a cup on a table by asking for the cup which is “uphill,” where English speakers would strongly prefer *left* and *right* (e.g., “Pass me the cup on your left”, rather than “Pass me the cup to your north.”)

Tenejapans have been reported to be unusually accurate in tracking geographical locations and directions even when traveling over long distances and after considerable time intervals. Brown and Levinson (1993b, p. 52) cite the case of a woman who was taken to a town she only rarely visited and, in a strange house at night, asked her husband whether the hot water tap was one *uphillward* (southern) (versus *downhillward* (northern)) on the sink. According to another report, a Tenejapan was blindfolded, spun around over 20 times in a darkened house and, “still blindfolded and dizzy”, pointed in the correct direction of *batz’il alan*, or “true downhill.”[2] These skills have been argued to arise as a matter of course throughout the Tseltal-speaking population of Tenejapa as a consequence of the everyday use of geocentric terminology (Brown & Levinson, 1993b).

Conversely, the rarity of *left–right* terms and the restrictions on their distribution have been claimed to result in “a systematic downgrading of left/right asymmetries in Tenejapan conception” (Levinson, 2003, p. 153). For instance, Levinson (1996, 2003) reports that Tenejapans have difficulty identifying mirror-image reflections of a picture across the vertical axis, even when the two versions of the pictures are visually presented simultaneously, and show a disregard for left–right asymmetries in their material culture (Brown & Levinson, 1992).

Brown, Levinson, and their collaborators have designed a variety of experimental manipulations to provide quantitative evidence on these topics. In a well-known series of studies, Tseltal-speaking Tenejapans were compared to speakers of Dutch (a language which, like English, emphasizes *left–right* terms) on a series of non-linguistic spatial tasks (Brown & Levinson, 1992, 1993a; Levinson, 1996, 2003). The tasks made use of the properties of different coordinate systems which dissociate under rotation. For example, participants were first shown a spatial array on a table (e.g., a card with a red dot to the left/north of a blue dot), then turned 180° to face a second table where they were asked to identify the “same” array from a range of alternatives. In another kind of manipulation, participants were asked to recreate the motion path of an agent moving along a maze after having themselves turned 180°. Crucially, after turning, there are at least two equally correct solutions, depending on the FoR adopted. One can either mentally rotate the array along with one’s body, preserving its left–right (egocentrically-defined) orientation, or translate the array with respect to the environment, maintaining its north–south (geocentrically-defined) orientation. In such tasks, Dutch speakers overwhelmingly produced egocentric responses, while Tseltal speakers primarily produced geocentric responses.

This apparently stable correlation between spatial language and spatial reasoning has led several investigators

[1] One can think of most frames of references as coordinate systems derived from entities that are either anchored to the earth (*geocentric*) or not anchored to the earth (*object-centered*). *Egocentric* FoRs are a special case of *object-centered* FoRs that refer to coordinates or directional axes derived from one’s own body position. Prior literature has often used the terms *relative, intrinsic,* and *absolute* to describe types of reference frames in the world’s languages (Levinson, 1996). *Absolute* frames of reference correspond to the special case of a *geocentric* frame where the scope of the directional axis extends beyond the range of the immediate array. *Relative* and *intrinsic* frames are *object-centered* FoRs, distinguished by the number of participants. Relative FoRs (as in “The green dot is to the left of the yellow dot (from my perspective)”) involve a three-place relation between a *figure* (the thing to be located – here, the green dot), a *ground* (the reference object – here, the yellow dot) and the viewpoint of a third entity (here, the left/right axis of the participant). Intrinsic FoRs (as in “The green dot is to my left”), by contrast, involve a two-place relation between just the *figure* (the green dot) and an inherently faceted *ground* (here, one of the participant’s body parts). For further discussion of the various terminologies in this domain, see Gallistel (1999), Newcombe and Huttenlocher (2000), and Watson, Pickering, and Branigan (2006).

[2] Levinson (2003) also reported formal studies showing that speakers of languages that use geocentric systems (Tseltal and Hai||om) were more accurate than speakers of languages that use egocentric systems (English and Dutch) at pointing to distant landmarks. However, the testing situations (type of environment, distance travelled, how participants arrived there, relative familiarity with surrounding, etc.) varied between the comparison groups (e.g., Dutch vs. Hai||om), making comparisons difficult.

to the conclusion that language shapes one's underlying preferences for representing spatial relations (Levinson et al., 2002; Majid et al., 2004; Pederson et al., 1998; cf. Gentner, 2007). Specifically, it is argued that people "appear to code their everyday non-linguistic spatial representations in line with their linguistic frames of reference" (Majid et al., 2004, p. 108; cf. Pederson et al., 1998). The necessity of encoding scenes in line with one's spatial language in order to communicate about them efficiently is said to be a major factor creating expertise for reasoning in terms of language-specific FoR's. In contrast, speakers whose language lacks the systematic encoding of a certain FoR are hypothesized to be limited in their use of it in processing spatial relations. In Levinson's words,

> "[s]emantic parameters are not universal, that is not shared by all languages. And if a language lacks such a semantic parameter, there is a good chance that the speakers of it fail to think in terms of those parameters too" (Levinson, 2003, p. 302).

These results have engendered considerable discussion and their interpretation has been debated. For example, Li and Gleitman (2002) showed that English speakers who typically use a left–right system show considerable flexibility in such tasks (as do animals, cf. Restle, 1957, and prelinguistic humans, Bloch & Morange, 1997; Acredolo, 1978) depending on details of the manipulation.

For the present research, we went to Tenejapa to further investigate spatial reasoning in this language group. Specifically, in these new experiments we reexamined Tseltal speakers' spatial reasoning skills in tasks where there is only a single correct answer. This is because participants' preference for language-congruent solutions in ambiguous (open-ended) tasks may represent a systematic interpretation of the experimenter's intent rather than (or in addition to) a bias in spatial reasoning. Notice that in solving *ambiguous* rotation tasks, when the participant is asked to reproduce the "same" spatial array or path as before, he or she needs to guess the experimenter's intent as to what counts as the "same." For example, in Brown and Levinson's (1993) "chips task" described above, participants were first shown a card (e.g., a card with a red dot to the left/north of a blue dot). Then after a 180-degree turn, participants had to find the "same" card among four other cards. "Same" could mean all four cards, because all four cards had a red dot to one side of a blue one. "Same" could also mean none of the cards, since none were exactly identical to the one at the first table. Yet participants ruled against both of these interpretations and decided that the experimenter must have intended one card as being the same, specifically the one that shared the same orientation as the first card. To infer what is intended to be construed as the same orientation, people may implicitly consult the way their language community customarily speaks about or responds to inquiries about locations and directions. If such a communicative bias exists, this would lead to systematic differences in the solution to spatial problems even if the listener understands that there are alternative interpretations of the experimental instructions: In Tseltal, where geocentric vocabulary is used even for small-scale arrays, spatial identity may be taken, as the default interpretation, to preserve geocentric coordinates. But in Dutch or English, where *left* and *right* are typically used for these small-scales, the "same" is (again, as the default) taken to preserve egocentric alignment. Under this explanation, the cross-linguistically varying choices correlate with ambiguity resolution as a consequence of communicative choice in the sense of Grice (1989): Try to discern what the speaker had in mind, and act accordingly.

How can it be determined whether the "linguistic relativity" results in the literature are a matter of communicative choice more than or rather than of spatial reasoning abilities and propensities that differ across linguistic communities? The straightforward way is to see how listeners behave when there is only a single correct solution for some spatial problem. If language restructures non-linguistic cognition along the lines suggested by Levinson (2003) and colleagues, the effect of language should persist under these unambiguous conditions. For example, if English speakers habitually encode spatial relations egocentrically, as dictated by their language, they might find it harder to recreate spatial arrays requiring a geocentric solution than an egocentric one. Similarly, Tseltal speakers should find it easier to solve tasks requiring or encouraging a geocentric perspective than those requiring or encouraging an egocentric perspective. But if the effects observed in prior experiments were due to a bias in interpreting task demands, the preference for language-congruent interpretations should diminish or disappear if task instructions are made clearer.

Our experiments tested Tseltal speakers in unambiguous versions of the classic rotation experiments. In each experiment there were two matched conditions that varied in whether the geocentric or the egocentric response was correct. Although there is a correct answer to the task, it is extremely important to notice that the participants were never explicitly instructed on the strategy they should use. If they preferred to or were more practiced at encoding geocentric relations, and if this preference impinged on the experimental task, they should incur greater computational cost when constructing an egocentric response over a geocentric one. Thus, a comparison of the two conditions allows us to assess Tenejapans' relative difficulty in reasoning egocentrically versus geocentrically when there is no "Gricean doubt" about the communicative intent of the experimenter. To assure that we were testing Tenejapan participants comparable to those previously studied in these regards, we included language elicitations as well as assessments of participants' comprehension of left–right terms in Tseltal (see particularly Experiments 2 and 4).

## 2. Experiments in spatial reasoning

### 2.1. Experiment 1: Rotating dots

This paradigm is adapted from Brown and Levinson's (1993a) "chips task." It first required the participant to memorize the relative placement of two dots on a card. For instance, from the perspective of the participant, the stimulus card might show a green dot situated to the left/south of a yellow dot. Next (as in Brown & Levinson, 1993a), the participants rotated 180° to walk to and then face a second table. Once at the second table, they were asked to select the "same" card as before from four identical cards rotated at 0°, 90°, 180°, and 270°. In the geocentric condition, participants had to select the card that maintained the same orientation with respect to an environmentally-defined axis. In the egocentric condition, participants had to select the card that maintained the same orientation with respect to the axes defined by their own body.[3]

If Tseltal speakers were more practiced at or preferred encoding geocentric relations, they might be inclined to encode the relations geocentrically at the first table. Then at the second table, asking them to pick out the matching card in terms of an egocentric perspective would result in greater computational cost, since the original geocentric representation would have to be converted to match the required egocentric perspective. In that case, participants should perform worse in the egocentric condition than the geocentric condition. Alternatively, egocentric representations might be highly available to Tseltal speakers. Then asking them to pick the matching card in terms of an egocentric perspective should pose no computational difficulties.

### 2.1.1. Methods

*2.1.1.1. Participants.* Twenty-six Tseltal-speaking adults, 16 women and 10 men (mean age = 34.96 years, SD = 16.31), were recruited through the Casa de Cultura in Tenejapa. Participants came from several *parajes*, or small communities located within 1–2 h walking distance from the municipal center, where the test site was located.

Participants' background, such as education, occupation, literacy, and knowledge of Spanish was assessed through an interview prior to the study. Most participants had little to no formal schooling or literacy skills (mean years schooling = 3.88, SD = 2.78). Most of the men worked in subsistence agriculture and the women were occupied with child rearing and domestic tasks. All these participants were paid 50 pesos for their time. In an effort to recruit participants with little exposure to Spanish, our sample ended up with more women, who on average have less schooling and are more monolingual, than men (Instituto Nacional de Estadística Geografía e Informática (INEGI), 2005).

Participants were tested in Experiment 1 and then Experiment 2. A language elicitation task was conducted for each participant only after he or she had gone through the procedures of both Experiments 1 and 2. This further testing was delayed so that the language tasks would not interact with performance in the experiments themselves. The language elicitation was to assure that, as in prior descriptions of language use among this population, the individuals we tested preferred geocentric language and did not use egocentrically-defined axes in describing the positions, relations, and movement of entities. Because the elicitation task was given following Experiment 2 and was tailored to that study, we describe it there.

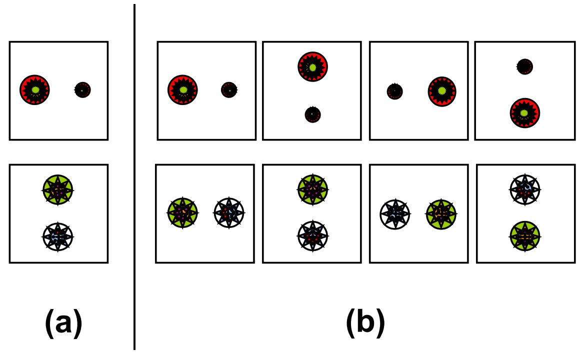


**Fig. 1.** Stimulus set used in Experiment 1. In the top row, dots vary in size, in the bottom they vary in color.

*2.1.1.2. Stimuli.* Two sets of 12 identical 15.24 cm × 15.24 cm cards, each with two same-design dots on it (see Fig. 1a),[4] were constructed. For one set, the two dots varied in size. For the other set, the two dots varied in color.

Two tables were placed at a distance of approximately 4.9 m apart, at the opposite ends of the room. For each trial, participants initially stood between the two tables, close to and facing one table. The left–right axis of the participant was aligned with the uphill–downhill axis.

*2.1.1.3. Procedure.* In this and all succeeding experiments, the participants were tested individually in a furnished room that had a large table and an altar on the southeast and southwest corners, respectively. The room had a door on the east side leading to a courtyard and a large window on the west side with a view to the outside overlooking a cornfield and a road heading towards the parajes where most participants were from.

As in Brown and Levinson's (1993a) chips task, a familiarization phase preceded the test trials. During familiarization, the experimenter first displayed four identical but distinctly oriented cards in a row. The participant was then asked to make another row with four more identical cards beneath the first row so that the new cards matched the first row in orientation. The experimenter demonstrated the solution once using the new cards and then asked the participants to do the same. Correction, although rarely necessary, was provided for misoriented cards. In the next two familiarization trials (*practice trials*), the participant was shown a stimulus card (see Fig. 1a for example) and had to find the "same" card among four identical cards that varied in orientations (see Fig. 1b for orientations). In this phase, the participant made the selection with the stimulus card in full view. The familiarization

[3] Note that the egocentric condition requires a three-place relation between a figure (e.g., the green dot), a ground (e.g., the yellow dot) and the origin of the coordinate axes (i.e., the body-defined axes of the participant), just as the geocentric condition involves a three-place relation between a figure, a ground, and a geocentrically-defined axis. The egocentric condition therefore involves relative frames of reference as defined by Levinson (1996).

[4] For interpretation of color in Figs. 1, 2, 4, 6, 8, 9, the reader is referred to the web version of this article.

then continued with four trials for which the participant memorized the dot orientations (*memory trials*). The stimulus card was placed inside a 15.24 cm. × 15.24 cm. square box and presented to the participant. Once the participant memorized the orientation of the card, the experimenter then closed the box and laid out the other four identical cards in their distinct orientations for the participant to select the "same" card. After selection, the box was opened to provide feedback. The practice and memory trials involved only one table, with the participants always facing in a single direction.

Subsequent *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. The tables were oriented such that the participant's left–right was aligned with the uphill–downhill (north–south) axis, the same table orientation that Brown and Levinson (1993a) found strong geocentric preference. Before the test trials, participants were given two rotation training trials to practice turning and to learn how to hold the box: Participants memorized the two dots on a card placed inside the square box while facing the first table. The box with the card inside was carried by the participant to the second table; there the box was closed and participants had to identify the "same" card from four distinctly oriented identical cards (*Banti ay maj sok?* or *Bi junuk ay maj sok?* – 'Where is it the same' or 'Which one is the same?'). Participants were randomly assigned to either the egocentric or the geocentric condition.[5] In the egocentric condition, they picked up the box containing the card as they turned so that the card also rotated 180°. In the geocentric condition, they rotated 180° themselves, and then picked up the box with the card and carried it to the second table; the box itself did not rotate (Fig. 2). These two different ways of carrying the box were meant as an indication of which type of response (egocentric or geocentric) was expected at the second table.

Participants then received 8 test trials in which the same rotation procedure was followed but the box containing the card was closed before the participant picked up the box and rotated. After selecting the "same" card at Table 2, the box was opened to reveal the card. In test trials, the orientation of the dots (left–right/north–south or up–down/east–west) was fully counterbalanced, as was the choice of card set used (variation in size/color of the dots). For these trials, participants in either condition could stare at the box because it was always in plain sight.

At the end of the session all participants were presented with a final set of four *leave-card trials*. They were instructed to leave the box with the card at the first table. They were also told that at the second table they were to select the same card as the one inside the box, just as they had done before. Leave-card trials were intended to completely exclude the possibility that participants could be using strategies such as staring at a particular location on the box to help remember a particular side.

[5] There were seven women and six men in the egocentric condition (Mean age = 37.9, SD = 17.3; Mean years schooling = 3.46, SD = 2.96) and nine women and four men in the geocentric condition (Mean age = 32.0, SD = 15.4; Mean years schooling = 4.31, SD = 2.63).

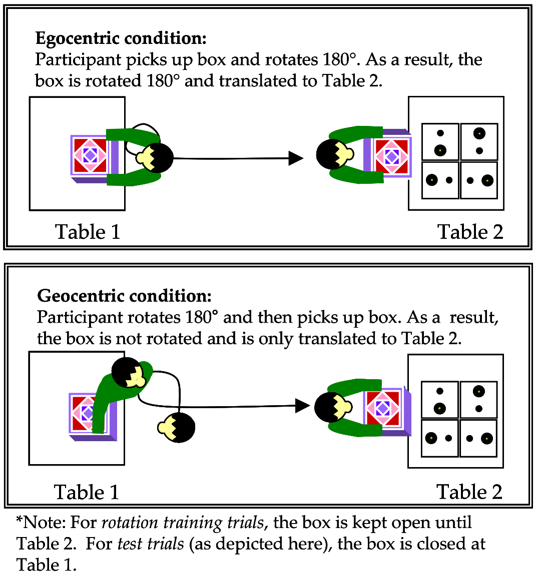



**Fig. 2.** Egocentric and geocentric conditions of the chips recognition task (Experiment 1). The top and bottom panels depict how the box is carried by the participant from Table 1 to Table 2.

For the leave-card trials, half of the participants from each of the two conditions (egocentric and geocentric) were assigned to the card set that varied in size, and half to the set that varied in color. All four orientations of the card were tested for each participant, with order randomized.

### 2.1.2. Results

Fig. 3 plots the results for the familiarization phase (practice, memory and rotation training trials) and the test phase (test and leave-card trials). Beginning with the familiarization trials, inspection reveals that performance did not differ between the geocentric and egocentric groups (practice trials: $M = 73\%$ for the geocentric group vs. 77% for the egocentric group, $t(24) = .27$, $p = .79$, $d = .11$; memory trials: $M = 88\%$ for the geocentric group vs. 83% for the egocentric group, $t(24) = .62$, $p = .55$, $d = .24$; rotation training trials: $M = 62\%$ for the geocentric vs. 77% for the egocentric group, $t(24) = 1.24$, $p = .22$, $d = .49$). These results are important because they confirm that the two groups of participants were comparable (e.g., in terms of memory capacity), and that they quickly understood the instructions for both the egocentric and the geocentric trials early on in the experimental session (i.e., neither condition required a lengthy explanation).

Turning to the test phase, the percent correct for the test trials was submitted to a 2 (Trial Type: Test, Leave-Card) × (Condition: Egocentric, Geocentric) × 2 (Orientation: Left–right/north–south, Up–down/east–west) ANOVA,[6] with Condition as a between-subjects factor. The

[6] In all the ANOVAs reported in this paper, the percentage correct is arcsine-root transformed to correct for non-normal distributions.

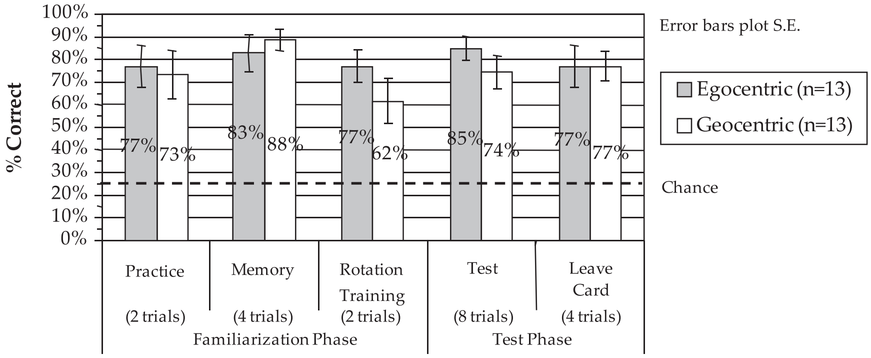



**Fig. 3.** Results for the chips recognition task (Experiment 1).

analysis found no significant effects ($p$'s > .20; $\eta_p{}^2$'s < .07). Two results are worth pointing out. First, the absence of a significant effect of Condition ($F(1, 24) = .25$, $p = .62$) indicated that the geocentric and egocentric groups were comparable in accuracy (76% vs. 81% correct respectively). Both groups' performance was significantly above chance (2-tailed $t$-test, $p < .05$). Second, the analysis returned no effect of Trial Type (test trials: 80% correct vs. leave-card trials: 77%; $F(1, 24) = .137$, $p = .71$). Therefore, the fact that participants did not physically carry the box had no impact on their ability to find the same card in the leave-card trials. Furthermore, even though the leave-card trials are more open-ended, the fact that participants had carried the box in prior manipulations was enough to bias them towards selecting the egocentrically oriented card in the egocentric condition and the geocentrically oriented card in the geocentric condition.

Next, we performed two trial-by-trial analyses of the participants' responses over the course of the experiment, one for the eight test trials and one for the four leave- card trials. It is possible that during the experiment, participants acquired skills that they did not have before, or enhanced their use of and success with each strategy. As proponents of linguistic relativity might argue, it could take several trials for participants to catch on and improve in the language-incongruent egocentric condition. If a practice effect accounts for the apparent ability of the Tenejapan participants to reason in line with egocentric, body-defined axes in this manipulation, their performance should have improved over the course of the experiment. But it did not. For the eight test trials, participants answered correctly was submitted to an 8 (Trial Number: $1, 2, \ldots 8) \times 2$ (Condition: Egocentric, Geocentric) logistic regression model. No significant effects were found (Trial Number: Wald $\chi^2(7) = 11.0$, $p = .14$; all other effects $p$'s > .42). The equivalent analysis for the leave-card trials also found no significant effects (Trial Number: $p = .68$; all other effects $p$'s > .17). The participants showed high success rates on the very first carry-box trial (Ego: 77% correct; Geo: 62%), and the performance on that trial is comparable to the averages across trials (Ego: 85%; Geo: 74%). This was similarly true for the first leave-card trials (Ego: 85%; Geo: 69% correct on first trial vs. Ego: 77%; Geo: 77% average). Thus, even if we look only at the first trials, the results still stand.

### 2.1.3. Discussion

These findings demonstrate that Tenejapan Tseltal speakers can keep track of and memorize the relationship between two objects (here, two dots on a card) with respect either to the environment or to themselves despite the absence of egocentric encoding in their linguistic repertoires. Unlike prior reports in the literature, these results offer no evidence of "a systematic downgrading of left/right asymmetries in Tenejapan conception" (Levinson, 2003, p. 153). Implicit encouragement from the task structure to solve the task egocentrically or geocentrically appears sufficient to bias Tenejapans' response style. Further, the data show that Tenejapans' dispreference for the egocentric solution, previously demonstrated through ambiguous spatial tasks (e.g., Brown & Levinson, 1993a), can be eliminated and in fact reversed. Specifically, consider the leave-card trials, in which the disambiguating act of carrying the box to the second table was removed from the situation. In these trials, participants were in principle free to interpret the instruction of finding the "same" card in any way they chose: Crucially, participants in the egocentric condition were now free to switch to a geocentric response in case this was their default preference for encoding spatial relationships. However, no such switch occurred. Despite the fact that the task had become more open-ended, letting participants select according to their own spontaneous preferences, those in the putatively dispreferred egocentric condition retained their egocentric pattern of responses. This pattern supports the hypothesis that participants factor in the prior context (such as cultural norms and instructions from previous tasks) to infer the intent of the experimenter in open-ended tasks, and it demonstrates the flexibility with which Tseltal speakers can reason about spatial relations.

One might attempt to dismiss the relevance of these results to the language-thought question by ascribing the outcomes to special strategies our subjects might have adopted. We briefly discuss such objections below before turning to the remainder of the experiments:

1. *Training effects*: Possibly, the Tenejapans' performance in the egocentric condition is the result of learning during performance of the experimental task rather than a straightforward reflection of their spontaneous and natural frame-of-reference reasoning. After all, participants

were allowed to open the box at the end of each carry-card trial to see if they responded correctly. From this feedback, they might learn how to adjust their strategy and respond correctly on the next trial. However, we found no learning adjustments or practice effects: The ability to use egocentric (left/right) relationships surfaced early in the experimental sessions and performance is the same even if we only consider the very first trial. Furthermore, there was no evidence that participants found the task difficult when the task was first introduced.

2. *Coping strategies*: Could Tenejapan participants have used alternative methods for solving the egocentric task that did not rely on true egocentric left/right concepts? One way of succeeding in the egocentric condition is to maintain visual fixation on the card (even if its face is covered) as it rotates, then simply pinpoint that which one had been gazing at. But if participants had employed such a strategy, their performance should have been impaired in the leave-card trials, in which they were prevented from constant visual monitoring of the display. Yet no such decrement in performance was found. Performance on leave-card trials is indistinguishable from that on the test trials both within and across participants (see again Fig. 3).

   Closely related to keeping one's eye on the stimulus is keeping one's finger (or other body-part, or item associated with one's proximity to the stimulus object) on it, maintaining and rehearsing this relationship as the stimulus object moves (''It's the dot near my finger/birthmark/torn sock''). Participants could have formed an association between the orientation of the target dot and a salient feature of their body, clothing, etc., and maintained this as they held the box and rotated with it. However this solution would have again failed blatantly on the leave-card trials, yet no decrement in performance was found for these sorts of trials.[7]

3. *The flip-the-response solution*: A final and extremely important idea is that the participants in fact encoded the display according to the geocentric machinery that their language typically encodes (e.g., ''The green dot is south of the yellow dot'') and then ''flipped'' this response after rotation (''Now the green dot is north of the yellow dot''). But if this two-step process had occurred, the flipping should have incurred some processing cost that would reveal itself in false starts, higher error percentages, or systematically slower responding in the egocentric condition relative to the geocentric condition. However, there was no telltale evidence by any such measures of performance in the pattern of results and therefore no evidence to support this conjecture.

### 2.2. Experiment 2: Solving mazes

We next tested Tseltal speakers' spatial reasoning in a more complex task, since task complexity has been claimed to increase reliance on culturally and linguistically dominant FoRs (see Haun, Rapold, Janzen, & Levinson, in press; Levinson et al., 2002). The idea is that when memory load is increased even slightly, participants revert to habitual (language-congruent) ways of coding spatial scenes in non-linguistic tasks. Experiment 2 followed the logic of Experiment 1 but implemented this logic through a more demanding spatial memory task.

This experiment adapted Brown and Levinson's (1993a) maze task. In the original version, participants memorized a path traversed by a figurine on the tabletop surface. The participants then identified the ''same'' path among several paths after turning 180° to face a second table. In our version, we increased task difficulty by asking participants to memorize a path traversed by a ball held by the experimenter and later recreate the original path on the second table (rather than select among several candidate paths). As in Experiment 1, the participants were implicitly cued to recreate the path using either egocentric, body-defined coordinates or geocentrically-defined coordinates to represent path-internal directional relations (e.g., turn left/downhill from point *x*), depending on how they carried the maze to the second table.

#### 2.2.1. Methods

*2.2.1.1. Participants.* The same 26 Tseltal speakers from Experiment 1 participated in this task. Participants were assigned to the same condition (egocentric/geocentric) as in Experiment 1. Experiment 2 was completed directly following Experiment 1.

*2.2.1.2. Stimuli.* For the test phase, a 25.4 cm. × 25.4 cm. evenly-gridded square maze (Fig. 4a) was constructed and laminated. A small ball was used during the experiment to demonstrate a motion path starting from the center of the maze. Test paths consisted of 1, 2 or 3 legs (Fig. 4b). We also constructed a simpler 17.78 cm. × 17.78 cm. square maze for the familiarization phase, which was used to demonstrate only 1-leg paths (Fig. 4c). Each maze had a cardboard maze cover.

The same two tables from Experiment 1 were used in the same locations (i.e., the tables were still aligned such that participants' left–right aligned with the uphill–downhill axis).

*2.2.1.3. Procedure.* A 6-trial familiarization phase using the simple maze preceded the test trials. During the first four familiarization trials, the experimenter demonstrated a straight path originating from the center of the maze

[7] Another related proposal (see e.g., Levelt, 2005) is that the egocentric condition can be solved entirely with an intrinsic frame of reference that is readily available in the Tseltal language, rather than a relative frame of reference that is not conventionalized in the language. However, the proposal fails logically. Representing the relation of two dots (e.g., a red dot and blue dot) using a coordinate system that is independent of the dot's own coordinates (i.e., the participant's body coordinates) necessarily requires a relative/three-place relation. Even if a Tseltal speaking participant used an intrinsic/two-place FoR mnemonic (''The red dot is near my birthmark''), the participant had to encode the blue dot's relation away from the birthmark (e.g., up or left). This requires a three-place relation because some third party besides the two dots necessarily supplies the direction and perspective.

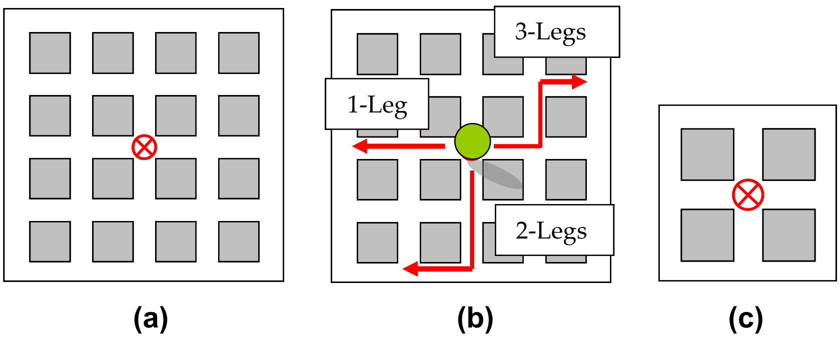



**Fig. 4.** Mazes used in the maze task (Experiment 2). Panel (a) depicts the 10″ × 10″ complex maze used in test trials. Panel (b) shows sample test paths. Panel (c) depicts the 7″ × 7″ simple maze used in training trials.

placed at the first table, such that there was one path in each of the four directions (up/east, down/west, left/north, right/south). Participants were then instructed to hold the maze according to the condition they were assigned to (egocentric or geocentric) and walk to a second table where they were asked to recreate the path on the maze (*pas-a, jich bit'il la j-pas nax* – 'do it, the same way that I just did'; alternatively, *pas-a, jich bit'il la j-pas lum ine* – 'do it, like I just did it over there'). In the egocentric condition, the maze was picked up by the participants as they rotated so that it also rotated 180° and was carried to the second table. In the geocentric condition, the participants first rotated 180° and then picked up and carried the maze to the second table so that the maze did not rotate even though the participants themselves turned. In both conditions, participants were asked to demonstrate the path with the ball on the maze at the second table. In the last two familiarization trials, a maze cover was introduced right before the maze was carried over to the second table. At the second table, the maze cover was lifted, and the participants then traced out the path with the ball. These additional two familiarization trials included one path on the saggital (up/east) and one path on the transverse (left/north) axis. In case of errors, which were extremely rare (see Results section and Fig. 5a), the experimenter demonstrated the correct path at the second table by tracing out the path with the ball. Participants in both conditions were encouraged to pick up the maze with both hands (with one hand on either side of the maze) for all trials.

The test phase involved the same rotation procedure but with the more complex maze and a maze cover that was decorated with a complex pattern of lines designed to block visual imagery or visual tracing of the path on the maze while it was being carried. Each participant was given 10 *test trials* (2 1-leg paths, 4 2-leg paths, and 4 3-leg paths; see Fig. 4b). We reasoned that, if Tseltal speakers have a tendency to encode spatial relations in line with the demands of their language, they should find the geocentric solution relatively easy, and easier than the egocentric solution. Furthermore, if task complexity increases reliance on culturally and linguistically dominant FoRs, as has been claimed, performance in the egocentric group should deteriorate with increasing number of legs, while performance in the geocentric group should be unaffected. During these carry-maze test trials, the experimenter traced out the correct path at the second table if the participants erred.

As in Experiment 1, participants were also tested on 10 *leave-maze trials* after the test trials were completed. For these, the participants were told to continue doing it "like they just did" but to leave the maze at Table 1 and recreate the path on an identical maze which had been placed at Table 2. Again, this manipulation removed the possibility of visually tracing the path on the carried stimuli, which is a strategy that could be easily employed by both the geocentric and the egocentric groups. No corrective feedback was given for the leave-maze trials.

Two sets of 10 paths each were created. One set was the mirror of the other such that "left" in Set 1 was replaced with "right" in Set 2, and so forth for the other directions. Half of the participants in each condition received Set 1 and half Set 2 during the test trials, and then the other set for the leave-maze trials. The paths were presented roughly in order of increasing number of legs, with the 1-leg trials interspersed with the 2-leg trials, and lastly the 3-leg trials given as a block (1-2-1-2-2-2-3-3-3-3).

At the end of the entire task, we administered a brief four-question language elicitation task. The experimenter demonstrated 1-leg paths from the center of the complex maze, once in each direction (up/east, down/west, left/north, right/south). For each direction, the participant was asked where the ball went (*Banti s-tojol* (lit. 'in a straight line towards what/where?')? *Banti bajt te pelota?* – '(Towards) which direction (lit. 'in a straight line towards what/where?')? Where did the ball go?').

*2.2.2. Results*

*2.2.2.1. Analyses of language assessment task.* We present the results of the language elicitation first in order to establish that this is indeed a linguistic population that prefers geocentric and landmark-based descriptions of motion paths. Each participant contributed 4 utterances, one for each direction, in response to the query "Which direction? Where did the ball go?". Thus for 26 participants, there was a total of 104 utterances. The overwhelming majority of the utterances (96%, or 100/104) made use of geocentric terms or stable landmarks. These terms include 30 references to the trajectory of the sun (*ta smalib k'aal* 'towards the sunset'; *ta slok'ib k'aal* 'towards the sunrise'),

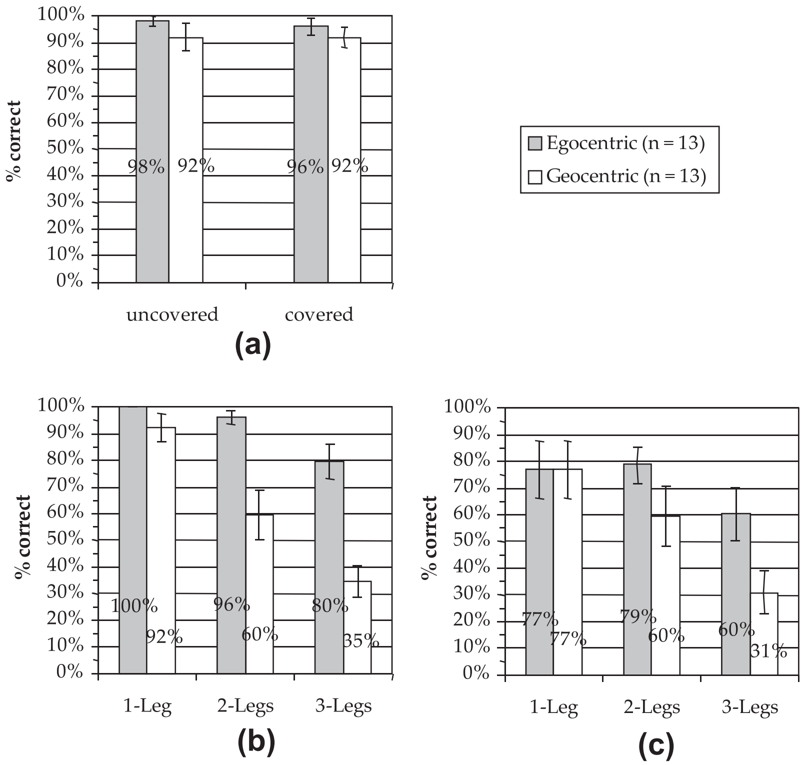



**Fig. 5.** Results for the tests trials of the maze task. Panel (a) shows the familiarization trials with the small maze, consisting of 4 uncovered trials and 2 covered trials. Panel (b) shows the test trials when participants carried the big maze from Table 1 to Table 2. Panel (c) shows the, "leave-maze" trials when participants left the big maze at Table 1. For both the test trials and, "leave-maze" trials, there were two 1-leg trials, four 2-leg trials, and four 3-leg trials. Error bars plot SE.

18 landscape-derived directional terms (*ta ajk'ol* 'towards the uphill'; *ta alan* 'towards the downhill'; *ta ch'entik* 'towards the cliffs'; *ta Tsontewits* 'towards the mountain Tsontewits'), 23 references to neighboring parajes or nearby towns (e.g., *ta Cañada* 'towards the Cañada (Chica or Grande)'; *ta Jobel* 'towards San Cristobal'), and 17 references to man-made landmarks such as roads, buildings (e.g., *ta carretera* 'towards the street'; *ta almacen* 'towards the store'; *ta mukinal* 'towards the cemetery', and 12 references to the Spanish cardinal terms (*ta norte/sur/este/oeste* 'towards the north/south/east/west'). The remaining four utterances, contributed by a single participant, referenced people in the testing room (*ta a-tojol* and *ta s-tojol ja'at* 'towards you'; *ta j-tojol* 'towards me'). Overall, the elicitation task revealed that participants typically talked about directions using locations and entities that remained stable with respect to the environment, and rarely talked about space in terms of other participants or themselves. None of the participants talked about directions towards the left or right.

*2.2.2.2. Analyses of maze task.* As in Experiment 1, analysis of the familiarization trials (see Fig. 5a) confirmed that the geocentric and egocentric groups were similar in terms of memory capacity and their ability to understand the task when it involved simple, 1-leg straight paths on a simple maze. *t*-tests yielded no significant difference between participants in the geocentric and egocentric condition for either the four uncovered familiarization trials (Geo: 92% correct and Ego: 98% correct, $t(24) = 1.5$, $p = .15$, $d = .59$) or the two covered familiarization trials (Geo: 92% correct and Ego: 96% correct, $t(24) = .59$, $p = .59$, $d = .23$). Performance was near-ceiling in both conditions. Only one participant (in the geocentric condition) made two errors out of 6-trials. The rest of the participants made one or no errors. Such near-ceiling performance provided no evidence that the participants in either condition thought the task was unnatural or difficult.

Results from the test and leave-maze trials are presented in Fig. 5b in terms of path complexity (number of legs in the motion path). A trial was counted as correct if the participant retraced the entire path correctly in line with the solution predicted by their assigned condition.[8] The percentage correct was entered into a 2 (Trial Type: Test, Leave-Maze) × 3 (Leg Number: 1, 2, 3) × 2 (Condition: Geocentric, Egocentric) ANOVA.

[8] In cases where participants did not correctly reproduce the entire path, their errors predominantly involved inserting or omitting a leg, or picking the wrong direction for a leg. A very small percentage of the trials involved reproducing the geocentric path when the egocentric one was requested (3% or 9 of 260 possible trials), or reproducing the egocentric path when the geocentric one was requested (8% or 21 of 260 possible trials). Notice that even if these last two tiny percentages are taken seriously, the greater proportion of substitutions in the geocentric condition runs counter to the geocentric linguistic tendency of Tseltal (also confirmed by these same participants on the elicitation task).

There was a Trial Type effect ($F(1,24) = 7.12$, $p = .01$, $\eta_p^2 = .23$), but no significant interaction effects with Trial Type ($p$'s > .20). The fact that no interactions with Trial Type were significant affirmed that the pattern of performance for the test trials and leave-maze trials was overall similar. However, the effect of Trial Type indicated that participants performed better when they carried the maze than when they left the maze on the first table. One possible explanation is that participants were visually tracing or visualizing the path (or at least its endpoint) while holding the covered maze. When this strategy was unavailable in the leave-maze trials, performance overall suffered.

Crucially, there was a main effect of Condition ($F(1,24) = 351.97$, $p < .001$, $\eta_p^2 = .94$), indicating that the egocentric condition was easier than the geocentric condition. There was also an effect of Leg Number ($F(2,48) = 39.46$, $p < .001$, $\eta_p^2 = .62$), with 1-leg paths being easier than 2-leg paths ($p < .001$) and 2-leg paths being easier than 3-leg paths ($p < .001$). The Leg Number $\times$ Condition interaction was also significant ($F(2,48) = 7.92$, $p = .001$, $\eta_p^2 = .25$), suggesting that, as the number of legs increased, so did the difference between geocentric and egocentric conditions.

Corroborating the Leg Number $\times$ Condition interaction, $t$-tests comparing the egocentric and geocentric condition for the test trials revealed that, while the difference was not significant for 1-leg paths (difference of 8%, $t(24) = 1.48$, $p = .15$, $d = .58$), the difference was significant for 2-leg paths (difference of 37%, $t(24) = 3.83$, $p = .001$, $d = 1.5$) and 3-leg paths (difference of 45%, $t(24) = 5.04$, $p < .001$, $d = 2.0$). For the leave-maze trials, the difference between the two conditions also increased as the number of path legs increased (difference of 0%, 19%, 30% for 1-, 2-, and 3-leg paths respectively). However, the difference was significant only for 3-leg paths ($t(24) = 2.3$, $p = .03$, $d = .9$), but not for the other paths ($p$'s > .05).

Trial-by-trial performance was examined for signs of improvement over the course of the experiment. Because the trials were more or less blocked by number of legs, we examined the effect of trial position within each leg number. For the 1-leg trials, whether participants answered correctly on each trial was entered into a logistic regression with 2 (Trial Number: 1, 2) $\times$ 2 (Trial Type: Test, Leave-Maze) $\times$ 2 (Condition: Egocentric, Geocentric). There was a significant effect of Trial Type (Wald, $\chi^2(1) = 6.25$, $p = .01$), with test trials being better than leave-maze trials (96% vs. 77% correct). No other significant effects were found to indicate improvement across trials ($p$'s > .14). The same analyses were also performed for the 2-leg trials as well as the 3-leg trials, with 4 (Trial Number: 1, 2, 3, 4) $\times$ 2 (Trial Type: Test, Leave-Maze) $\times$ 2 (Condition: Egocentric, Geocentric) logistic regression models. The two analyses, one for the 2-leg trials and one for the 3-leg trials, revealed effects consistent with and in the same direction as the previous ANOVA: There was an effect of Condition for both 2- and 3-leg paths (2-legs: Wald $\chi^2(1) = 9.31$, $p < .01$; 3-legs: Wald $\chi^2(1) = 18.64$, $p < .001$), an effect of Trial Type for the 3-leg paths ($p = .05$), and no other main or interaction effects (all other $p$'s > .12). Importantly, the fact that there was no main effect of Trial Number or interactions with that term means there was no hint of improvement across trials.

### 2.2.3. Discussion

This experiment produced two major findings. First, Tseltal speakers did not describe spatial relationships using Tseltal or Spanish words for *left* and *right*. Instead, as previously reported in many sources, they most often used the sun or features in the landscape to describe motion direction. Despite this linguistic preference, these same participants made fewer errors when they attempted to retrace motion paths along a maze in line with egocentric, body-defined versus geocentrically-defined axes, especially when the motion paths became more complex. This asymmetry between egocentric and geocentric perspectives occurred regardless of whether participants held the maze and transported it to the second table or not. In sum, the linguistic asymmetry between egocentric and geocentric FoRs did not give rise to a corresponding asymmetry in spatial reasoning in the Tenejapan population. If anything, the reverse was true.

These results broadly replicate and extend the findings from Experiment 1. First, Experiment 2 replicates Experiment 1 by showing that Tseltal speakers have no difficulty solving spatial problems requiring egocentric responses. Second, Experiment 2 confirms that the Tenejapans' preference for geocentric responses reported in previous literature could be flexibly changed. In the egocentric condition, the experimenter created a context in which the egocentric response was the expected correct answer. Participants then continued with the same egocentric responses at the very start of Experiment 2 and during the leave-maze trials although they were free to choose geocentric responses. That is, their preference for selecting the geocentric response on the open-ended, leave-maze trials had been (temporarily) altered given locally established expectations, supporting the conclusion that the previously exhibited geocentric preference was also governed by local (in this case cultural) expectations. Finally, Experiment 2 extends Experiment 1 with a more complex task. Particularly, Experiment 2's results show that *task complexity increases the disparity of reasoning in favor of egocentric solutions,* despite the fact that the habitual modes of speaking in the community tend strongly in the opposite direction.

As in Experiment 1, it is important to consider and exclude task-specific strategies that might allow Tenejapan participants to solve the egocentric version of this task without using relative (left/right) concepts.

1. *Training effects:* An alternative explanation of our findings is that participants in the egocentric condition succeeded only because they were trained. However, as indicated by Fig. 5a, the participants understood the task immediately during the training trials; percentage correct was extremely high. Analysis for improvement over trials yielded no significant trends. Furthermore, participants in the egocentric condition were almost always correct in the first place, so they rarely received corrective feedback. This is in contrast to participants in the geocentric condition who erred more frequently,

and thus could have benefited from watching the experimenter demonstrate the correct path. In sum, there was no indication that training or practice accounted for Tseltal speakers' performance in the egocentric condition.

2. *Coping strategies:* As in Experiment 1, it is an open possibility that participants retraced the visual path traversed by the figure or at least gazed at the path endpoint while they carried the maze to the second table (even if the maze was covered).[9] However, this explanation could only partially account for the higher performance on the egocentric condition. Specifically, when we experimentally disallowed such a strategy with the *leave-maze* trials, we still found more accurate responses in the egocentric condition than the geocentric condition as the number of legs increased. As before, there is also the possibility that participants were anchoring the direction of each path leg with respect to their own body-parts or other salient oriented features (clothing, etc.) to solve the task. But even if they attempted to do so, in this situation they would still need to code the relations of the legs with each other to solve the problem. Thus, in essence, they would have to code the entire path, made out of its multiple legs, using the relative FoR rather than two-place intrinsic FoR. Furthermore, just as in the *leave-card* trials of Experiment 1, this solution could not explain performance on the *leave-maze* trials of the present experiment. This is because the participants' contact with the maze was lost they moved over to the second table.
3. *Flipping:* As in Experiment 1, it is logically possible to first use geocentric (language-congruent) coordinates to encode the motion path in the egocentric condition ("The ball went one block uphill, two blocks towards the sunrise, then one more block downhill") and later convert this geocentric representation into an egocentric one by flipping the coordinate axes (e.g., by substituting 'uphill' for 'downhill'). This strategy should create more errors in the egocentric than the geocentric group as a result of the conversion cost; furthermore, such errors should increase as paths became more complex and the conversion process more demanding. However, neither of these predictions was supported by the findings: Participants were more accurate in the egocentric condition than the geocentric one, especially for longer motion paths.

Recall that an important motivation behind this experiment was to test the hypothesis that increasing task difficulty encourages language-congruent spatial reasoning (Levinson, 2003; Levinson et al., 2002). We embedded the spatial computations of directionality in a more complex task compared to that of Experiment 1. We also built a measure of complexity into the design of the maze task by including motion paths of different length and different numbers of turns (legs). However, as mentioned above, we found no evidence that task complexity leads participants to fall back on linguistically preferred (or 'habitual') patterns of spatial reasoning. In fact, the more complex motion paths led to lower performance in the geocentric but not the egocentric condition.

Importantly, other recent evidence points to a related conclusion: speakers of geocentric languages resort to egocentric reasoning for dealing with more complex spatial relationships such as those described by motion paths. Niraula, Mishra, and Dasen (2004) tested 6- to 14-year-old children who spoke Nepali (a geocentric language) on several spatial-reasoning tasks using the open-ended rotation paradigm of Brown and Levinson (1993a), Levinson (1996), Levinson (2003). When asked to reproduce a spatial array of three oriented objects (e.g., three animals in a row facing in a single direction), children produced geocentric solutions. Similarly, when asked to perform a version of the card task used in our Experiment 1, children gave predominantly geocentric responses. But when asked to recognize the complex path traversed by a moving object from among a set of alternatives, children gave more mixed (geocentric plus egocentric) responses.[10] Similar results have been obtained by Wassmann and Dasen (1998) with adults and children in Bali (cf. also Cottereau-Reiss, 1999). Thus, the difference in response preferences between speakers of different languages appears to diminish on more complex tasks.

As these authors observe, the most complex spatial configurations (e.g., the motion paths) in these tasks are also the most difficult to code verbally. If participants implicitly rely on verbal mediation to solve ambiguous tasks, as we have suggested, it makes sense that tasks which are hard to encode linguistically would rely less on spatial language. Importantly, increasing task complexity seems more likely to reveal common underlying mechanisms for representing spatial arrays (which may happen to be language-incongruent). In this case, when asked to recognize or recreate a path from memory at a distant second table, the egocentric representation (given by direct visual information) seems easier to process than the construction of geocentric representations for all language groups.

### 2.3. Experiment 3: Swiveling views

The present experiment required the use of spatial frames in object search and retrieval. We drew our inspiration from an episode reported in Brown and Levinson (1993b, p. 52) in which a Tenejapan was blindfolded, spun around 20 times in a darkened room and, still blindfolded and dizzy, was able to point in the direction of *batz'il alan*, or "true downhill" (approximately 15° west of north; see also Introduction to this paper). We contrasted egocentric and geocentric conditions, but using a within-subjects

[9] Notice that keeping an eye on the path endpoint does not guarantee that the original motion path can be retraced: there were multiple ways of reaching a certain point on the maze (see Fig. 4b) and a path needed to be retraced correctly in its entirety to be coded as correct.

[10] The Tenejapan studies originally reported in Brown and Levinson (1993a) and Levinson (1996), Levinson (2003) merely had participants select the correct path *endpoint* out of several possible choices. They did not require participants to actually *recreate* the entire path from scratch as we did here, or to identify an *entire* path as in Niraula et al. (2004). Their simpler maze task returned results similar to the 'animals in a row' and the card tasks: geocentric responses predominated over egocentric responses.

design. In the egocentric condition, participants were seated on a swivel chair that had two boxes, one to each side (left–right). In the geocentric condition, the boxes were not attached to the chair but were placed on the floor. On each trial, the experimenter hid a coin in one of the boxes. Then participants were blindfolded and spun slowly 360° plus an additional 90°, 180°, 270°, or 360°. Their task was to retrieve the coin once the blindfold was removed.

The aim of Experiment 3 was to test the hypothesis that Tseltal speakers have "impressive powers of mental rotation... because they construct at once a full 3D model of a scene, rather than hanging onto just one viewpoint" (Levinson, 2003, p. 346). Specifically, Levinson (2003) suggested that "Tzeltal speakers can rebuild an assemblage of arbitrary complexity under rotation" (p. 289), and that "absolute descriptions come without viewpoints. In a way, to think 'absolutely' one had better throw away visual memory: after all coffee-pot to left of cup becomes coffee-pot to right of cup from the other side of table – but coffee-pot to north of cup remains constant regardless of viewpoint." (p. 274). To infer how Tseltal speakers represented and remembered the location of the hidden coin after rotation, we planned to compare Tenejapans' accuracy and error pattern across the four final resting positions of the swivel chair. If Tseltal speakers habitually make use of geocentric encoding and "construct at once a full 3D model of a scene, rather than hanging onto just one viewpoint" as suggested above, then in the geocentric condition, they should have an equally easy time retrieving the hidden coin no matter what the position of the chair after rotation. That is, they would simply have to note the invariant location of the hidden coin (e.g., "the uphill box" or "the box near the table") and retrieve the coin. The rotation of the chair (i.e., the participants' own movement) does not affect the invariant geocentric relation that is encoded.

Similarly, Tseltal speakers might encode the boxes attached to the chair in the egocentric condition in geocentric terms (e.g., the "uphill box"; see Levelt, 2005 for a similar suggestion). In that case, they might have to compensate for how much they have moved from the initial facing direction when recalculating their position after rotation; the rotation of the chair should affect how well Tseltal speakers can retrieve the hidden coin in the egocentric condition. Specifically, Tseltal speakers in this condition should make more errors the more degrees they were rotated from the initial position because mental rotation would be required to align the starting and end positions.

### 2.3.1. Methods

*2.3.1.1. Participants.* Twenty-four Tseltal-speaking adults (15 women and nine men; mean age = 45.8 years; SD = 20.0; mean years schooling = 2.5, SD = 2.5), who had not participated in the previous experiments were recruited from the same Tenejapa population. They were tested individually in the same room used for our previous experiments.

*2.3.1.2. Stimuli.* The most important stimulus object for this experiment was the swivel chair in which the participants sat, while they solved the task of finding a hidden coin. In the egocentric condition, the chair had spokes to the left and right. Two identical boxes were attached to the spokes (see Fig. 6). Each spoke extended 61 cm. from the edge of the chair to the box. In the geocentric condition, the same chair was used but the spokes were removed. Instead, the boxes were placed on the floor to the left/uphill and right/downhill of the chair. Again, each box was at a distance of 61 cm. from the plane of the seat of the chair.

### 2.3.2. Procedure

Each participant was tested on *both* the egocentric and geocentric condition, with eight trials per condition. The trials for each condition were blocked and the order of the blocks counterbalanced. Participants sat on a swivel chair with two boxes, one to each (left–right) side of the participant. The initial position of the chair always faced east for each trial so that the left–right sides corresponded to north–south. On each trial, the experimenter pointed to one of the boxes and proceeded to hide a coin in that box. Then participants were blindfolded and spun slowly 360° plus an additional 90°, 180°, 270°, or 360°. In the egocentric condition, the boxes rotated with the chair and participant. In the geocentric condition, the boxes remained stationary (on the floor) while the subject was rotated. The final positioning of the chair was randomized with two trials per position for each condition. After the rotation stopped, the blindfold was removed and participants were asked to point to the coin's location (on a single try). The

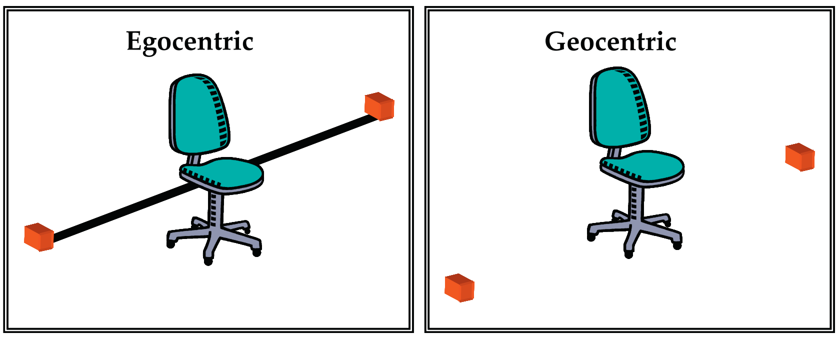



**Fig. 6.** Swivel chair set-up (Experiment 3).

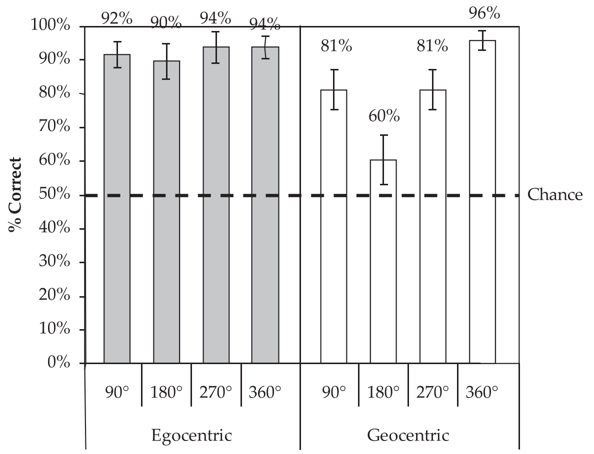



**Fig. 7.** Results from the swivel chair task (Experiment 3) broken down by degree for the two conditions: egocentric condition (gray bars) and geocentric condition (white bars). Error bars plot SE.

experimenter then opened the box with the coin to indicate whether participants were correct.

*2.3.3. Results*

Correct performance (defined as retrieval of the coin on the first try) was submitted to a 2 (Condition: Egocentric, Geocentric) × 4 (Degree: 90°, 180°, 270°, 360°) × 2 (Block Order: Egocentric first, Geocentric first) ANOVA, with Block Order as the only between-subjects measure (see Fig. 7). There was no main effect of Block Order or any interaction with that term ($p$'s > .21). However, there was an effect of Condition ($F(1,22) = 7.78, p = .01, \eta_p^2 = .26$). Performance on the egocentric condition was higher than on the geocentric condition (92% vs. 80% of correct responses).

There was also a main effect of Degree ($F(3,66) = 8.46, p < .001, \eta_p^2 = .28$) and an interaction between Degree and Condition ($F(3,66) = 3.96, p = .01, \eta_p^2 = .15$). In order to understand this interaction, we conducted pairwise $t$-test comparisons of the percentage correct for the four degrees within each condition. For the egocentric condition, the percentage correct for 90°, 180°, 270°, or 360° did not differ across trials (all $p > .16$; the corresponding percentages of correct responses were 91.7%, 89.6%, 93.8%, and 93.8%). Thus, there was no evidence that participants were reconstructing the location of the box using geocentric encoding. For the geocentric condition, the percentage correct was highest for 360° (95.8%), followed by 90° and 270° (both 81.3% correct), then 180° (60.4% correct). Performance on the 360° trials was significantly different from performance on the other trials (all $p < .05$). The 90° and 270° trials did not differ from each other ($p = 1.0$), but both differed from 180° trials (all $p < .03$). The results indicated that, whereas the ending position did not affect performance for the egocentric condition, it greatly affected accuracy for the geocentric condition. When the perspective matched that of the scene when the coin was hidden, as it was after a 360° turn, participants in the geocentric condition were the most accurate. When the perspective most mismatched the perspective of original encoding in number of degrees turned (i.e., after a 180° turn, with the two boxes to the two (now reversed left–right) sides of the participant), accuracy in the geocentric condition was the worst. Thus, the results provide evidence that reconstructing the location of the box in terms of an invariant relation with respect to the environment is dependent upon egocentric viewpoint information.

Finally, to examine the effect of practice, whether participants answered correctly on each trial was entered into an 8 (Trial Number: 1, 2, ... 8) × 2 (Condition: Egocentric, Geocentric) logistic regression. The effect of Condition was again significant (Wald $\chi^2(1) = 8.81$, $p < .01$), indicating that performance on the egocentric condition was better than the geocentric condition. There was no effect of Trial Number ($p = .07$), but there was a marginal effect of Trial Number × Condition (Wald $\chi^2(7) = 14.18$, $p = .05$). The marginal effect is likely to be spurious; when further examined with separate analyses of Trial Number for each condition, Trial Number only approached significance for the geocentric condition ($p = .06$) and was clearly not significant for the egocentric condition ($p = .63$, n.s.).

*2.3.4. Discussion*

This task was designed to compare egocentric to geocentric reasoning in the context of object search. Recall that Levinson (2003) suggested that "Tzeltal speakers can rebuild an assemblage of arbitrary complexity under rotation" (p. 289), and that "absolute descriptions come without viewpoints. In a way, to think 'absolutely' one had better throw away visual memory: after all coffee-pot to left of cup becomes coffee-pot to right of cup from the other side of table – but coffee-pot to north of cup remains constant regardless of viewpoint." (p. 274).

Nothing in the present findings offers support to the claim that egocentric reasoning has become hard for Tseltal speakers, that they fail (conceptually or perceptually) to extend the notion of left and right outside the compass of the body, that they "throw away" visual or kinesthetic memory for the positions of things, relative to their viewpoints. Tseltal speakers did not resort to geocentric encoding to solve the egocentric condition. Had they done so, they would have been affected by the degree of rotation in the egocentric condition. Instead, they were quite capable of encoding the invariant egocentric relationship between the box and themselves.

Most importantly, Experiment 3 provides new information regarding how Tseltal speakers reconstruct geocentric relations from memory. Tenejapans, by virtue of the language they speak, have not become viewpoint independent in their spatial reasoning or perception. On the contrary, to recover where something was hidden, they appeared to *rely on* egocentric visual information available at the time of hiding, for they found it harder to locate the box in absolute space when the view at search time increasingly differed in degrees displaced from the original view at hiding time.

Finally, the fact that performance is better on the egocentric condition than the geocentric condition in Experiment 3 is consistent with the pattern found in Experiment 2. In Experiment 4, we turned to the old 180° paradigm to see if we can replicate this difference using a search task that greatly increases the complexity of egocentric encoding compared to the swivel chair task.

### 2.4. Experiment 4: Relating cups

Modeled after prior tasks (Brown & Levinson, 1993a; Haun, Rapold, Call, Jenzen, & Levinson, 2006; Majid et al., 2004), this experiment required participants to move 180° from a first table where a triangular array of three cups was originally set-up, to a second table in which the same array was oriented to be either egocentrically or geocentrically consistent with the original. Participants saw a coin being hidden in one of two identical cups at the first table and had to retrieve the coin from the same cup at the second table by using the third, non-identical cup as a reference object. Thus, this task was unambiguous, i.e., again had a correct solution.

As in Experiment 3, and unlike Experiments 1 and 2, this task compared participants' ability to memorize spatial relationships using egocentric versus geocentric coordinates using a within-subjects design. However, the current task tested a more complex left–right relationship: whereas Experiment 3 tested the recall of a hidden object's location to the participant's immediate left or right, this new task tested the recall of a hidden object's location that could only be determined by distinguishing that location from a second location/object using the relationship of both to a third object. In the egocentric condition, this could most readily be accomplished by projecting the participant's own left–right axis onto the ground. In the geocentric condition, this could most easily be accomplished by anchoring a geocentrically-derived axis (e.g., uphill–downhill) onto the ground.

A language elicitation tailored to the task was carried out afterwards to see if the participants' choice of language to describe the display correlated with their performance. Participants were also tested for their comprehension of extended uses of *xin* and *wa'el* (the Tseltal words for left and right body-parts), as well as for their working knowledge of *izquierda* and *derecha* (the Spanish words for left and right). This assessment was conducted to see if linguistic knowledge of "left" and "right" was correlated with the ability to solve the task.

#### 2.4.1. Methods

*2.4.1.1. Participants.* Sixteen Tseltal-speaking women (mean age = 52.4 years, SD = 14.1; mean years schooling = .13, SD = .50) who had not participated in the previous experiments were recruited from the same Tenejapan population. Older women were recruited as census data show that they are more likely to identify as monolingual in Tseltal and to have lower levels of formal schooling, and hence to have lower levels of literacy, knowledge of Spanish, and exposure to mainstream Spanish-speaking Mexican culture (Instituto Nacional de Estadística Geografía e Informática (INEGI), 2005). Further, any women for whom it was found that they knew Spanish during the course of the post-task elicitation were replaced. For this final study, we therefore opted to be as conservative as possible in selecting our sample. We do not see the recruitment of an exclusively female population as an issue, since we have never found gender effects on any of our previous tasks. Each participant was tested individually in the same furnished room that had a large window with a view to the outside that had been used in the prior experiments. Each participant was paid 50 pesos for her time. As before, a short preliminary interview established that these individuals were mostly unschooled (15 out of the 16 participants reported having never attended school) and non-literate and knew little or no Spanish.

*2.4.1.2. Stimuli.* Three opaque plastic cups were mounted onto a white cardboard circle with a diameter of 50 cm. Each cup was positioned 20 cm from the center and arranged so that the cups formed an equilateral triangle (see Fig. 7). Two of the cups were yellow and the third ('reference') cup was red. Two tables were placed at a distance of approximately 4.6 m from each other and aligned so that the left–right axis of the participants when facing each table was aligned with uphill–downhill.

*2.4.1.3. Procedure.* The experiment consisted of a non-linguistic and a linguistic task administered in that order.

*Non-linguistic task.* The non-linguistic task involved a familiarization phase and a test phase. During the familiarization phase, the participant sat at one table facing the display (see Fig. 8). The participants watched as the experimenter hid a coin in one of the yellow cups. The entire display was then covered with a cardboard box. After a 30 s delay, the cardboard box was removed and the participants were asked to point to the location of the coin (*Banti ay te tak'in?* 'Where is the coin?'). There were four such practice trials, two trials in which the coin was hidden in the left/uphill yellow cup and two trials in which it was hidden in the right/downhill yellow cup.

The practice trials were followed by 16 test trials in which the participants again watched the experimenter hide the coin in one of the yellow cups (see Fig. 9). After the coin was hidden, the participants were instructed to remain facing the first table, while the experimenter moved the display to the second table out of view of the participants. At the second table, the experimenter oriented the display in one of two ways, consistent with either the geocentric perspective or the egocentric perspective (see Fig. 9). Specifically, for the geocentric perspective condition, the experimenter did not rotate the display, so that

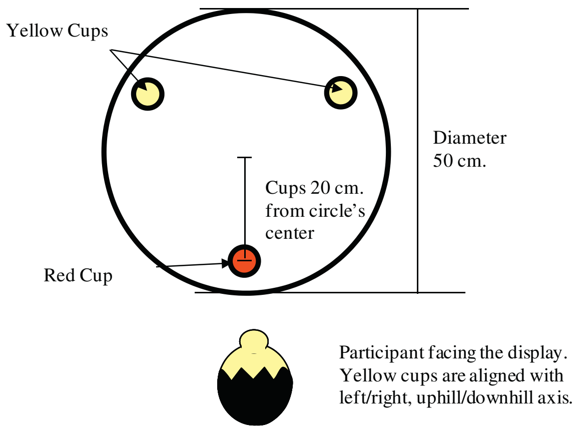
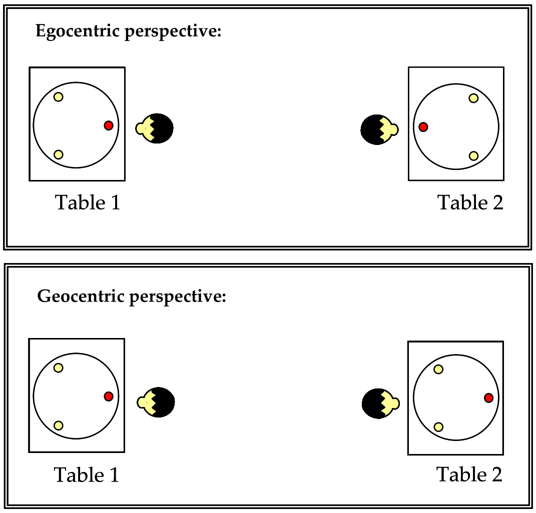



**Fig. 8.** Display set-up for the cup task (Experiment 4).




*Note: In both cases, the experimenter moves the display from Table 1 to Table 2 while participant faces Table 1. Then participants turns 180° to walk to Table 2.

**Fig. 9.** Egocentric and geocentric perspective for the cup task (Experiment 4).

the entire display retained the same geocentric orientation (i.e., the cups remained constant with respect to the uphill–downhill axis). For the egocentric perspective condition, the experimenter turned the display 180° so it was consistent with the perspective of the participants (i.e., the cups remained constant in terms of their left–right relationship to the participants). Following a 30 s delay, the participants were instructed to turn 180° and walk to the second table. At the second table, the participants had to point to the cup containing the coin. No directions were provided and participants were given no explicit instructions on how to solve the task. After pointing, the experimenter would lift the cup's lid revealing either the presence or the absence of the coin. If incorrect, the correct location was shown by the experimenter.

The 16 test trials were blocked by perspective, with eight trials in the geocentric and eight in the egocentric condition. Block order was counterbalanced. Within each condition, the coin was hidden under the left/uphill yellow cup in half of the trials and under the left/downhill yellow cup in the other half, with order of the two sides randomized.

*Linguistic task.* The linguistic task consisted of two subtasks: (a) an elicitation task seeking to determine how speakers would typically describe the display, and (b) a comprehension task seeking to determine whether participants understood Tseltal and Spanish left–right terms and whether they could interpret these terms in projective uses. For the elicitation task, using the display set-up for the non-linguistic task (see Fig. 8), a coin was first placed on each of the lidded yellow cups in turn and participants were asked "Where is the coin?" and then asked to describe "on which side of the red cup" the coin was, for a total of four trials.

Participants were next tested on comprehension of left–right terms under three conditions administered in the following order: LR (left–right) of Red Cup, LR of Self, and LR Body-Parts. For the first two conditions, the display with the three cups was used. For the LR of Red Cup condition, two identical coins were placed on each of the two yellow cups and participants were asked to point to the coin "to the left/right of the red cup."[11] For the LR of Self condition, they were asked to point to the coin, "to the left/right-hand of you."[12] For the LR Body-Parts condition, participants were asked to move their left/right arms and legs ("Raise you left/right-hand".)[13] For each condition, they were given four trials, two facing in one direction, and two with 180° rotation (rotation involved either walking to the opposite side of the table for the first two conditions, or turning around for the LR Body-Parts condition). The rotation was introduced to ensure that they were not simply mapping the left–right terms to the geocentric directions. After testing for the comprehension of Tseltal left and right terms, the same comprehension task was administered replacing the Tseltal terms with the Spanish terms for left (izquierda) and right (derecha).

Of the three LR uses in the comprehension task, only the LR Body-Parts is productive and canonical in Tseltal (Brown, 2006; Brown & Levinson, 1992; cf. Abarbanell, 2007); the other two are extended uses created for the purpose of this task that are not conventional in Tseltal. These two extended uses, LR of Red Cup and LR of Self, respectively contrasted what Levinson (1996) termed "relative" and "intrinsic" left–right. The relative relation is a 3-place relation. In this case ("The yellow cup is to the left/right of the red cup"), a *figure*, the thing to be located, (a yellow cup) is related to a *ground*, the reference object (the red cup) via the LR coordinates of a *third entity* (the participant).[14] The intrinsic relation is a 2-place relation involving just the *figure* and the *ground*. In this case ("The yellow cup is to my left"), the *figure* (a yellow cup) is related to the *ground* (the participant) via the coordinates of the *ground itself*.

### 2.4.2. Results

*2.4.2.1. Analyses of the linguistic task.* We again present the data from the Linguistic Task first. For the elicitation

[11] Ak'a ta ilel, banti ay-ϕ te tak'in ta s-wa'el yu'un te tsajal tasa-e?
Give'IMP PREP see, where EXIST-3A ART coin PREP 3E-right 3E-RELN ART red cup-CL

[12] Ak'a ta ilel, banti ay-ϕ te tak'in ta a-xin-k'ab a'w-u'un?
Give-IMP PREP see, where EXIST-3A ART coin PREP 2E-left-hand 2E-RELN?
'Show, where is the coin to your left-hand?

[13] Bech-a a-wa'el-k'ab.
Raise-IMP 2E-right-hand
'Raise your right hand.'

[14] We note that our use of the third person singular possessive prefix s-/x- (*[x]-xin* and *s-wa'el*) to refer to *the cup's* left and right for the relative form could be potentially confusing to a native Tseltal speaker, as this would normally imply the cup has a left or right side. While this is admittedly awkward, underscoring the difficulty of expressing relative left-right relationships in Tseltal, it allowed us to avoid the ambiguity that would have resulted had we used the first person possessive prefix instead (e.g., *ta j-wa'el*/*ta j-xin* 'to my right'/'to my left'). Had we done so, we would not be able to distinguish whether participants were interpreting this intrinsically or relatively. By using the third person possessive, we left it to the participants to decide what determines *the cup's* left and right.

sub-task, each participant responded to two questions of the type "Where is the coin?" and two questions of the type "On which side of the red cup is the coin?" for a total of 64 responses.[15] The 64 responses can be classified into three categories consisting of 3 (5%) egocentric responses, 22 (34%) geocentric or landmark responses, and 39 (61%) other responses. Importantly, two of the three egocentric responses, contributed by the same participant, contained the words *left* and *right* in Tseltal (i.e., *ay ta xin*, *ta wa'el*). The third response, by another participant, made use of *straight ahead of/in line with* (*s-tojol bojch* 'straight ahead of the cup'). Of geocentric or landmark terms, 14 referenced cardinal/landscape terms, two referenced nearby parajes or towns, and six referenced man-made landmarks (buildings, roads). Of the 39 "other responses", 18 were locative expressions (14 simple locatives: e.g., *ay ta vaso* 'on the cup', *ay ta mesa* 'on the table'; three relational noun locatives: *ta s-ts'eel* 'at its side'; 1 body-part locative: *ta [x]-xujk,* 'to the side of'), and 21 were deictic expressions (*li' e,* 'there', *tal ini*, 'coming here', or *in ta ba'ay,* 'there it is'). The deictic expressions provided no information regarding which frame-of-reference participants had in mind.

In summary, corroborating previous studies and Experiment 2, the linguistic elicitation found that Tseltal speakers made use of geocentric terms to reference locations of objects in small-scale space, and did so more frequently than egocentric terms. However, we also found two other equally frequent responses that were not in Experiment 2. Corroborating Brown (2006), participants used locatives and deictic expressions to describe a visible stationary object (the coin) when the reference object was in close proximity and had no intrinsic facets that could be used; however, no such responses were given to describe the heading direction of a moving object (the ball in Experiment 2). Although deictic directionals (e.g., *bel* 'going', *tal* 'coming') can be used with motion verbs to specify the direction of action in relation to the speakers' current location (Brown, 2006, p. 232), Experiment 2's elicitation focused speakers on the direction or landmark towards which the ball was heading from a given center.

For the comprehension sub-task, the data were coded for whether the participants performed the correct action. That is, in response to the experimenter's query, did the participants point to the correct coin for the LR of Red Cup or LR of Self tests or move the appropriate body-part for the LR Body-Parts test? Results are presented in Fig. 10. The percentage correct was entered into a 2 (Language: Tseltal, Spanish) × 3 (Sub-Test: LR of Red Cup, LR of Self, LR Body-Parts) ANOVA. The ANOVA returned a significant effect of Language ($F(1,15) = 16.40$, $p = .001$, $\eta_p^2 = .52$): participants were better when the left–right words were in Tseltal than in Spanish (79% vs. 57% correct respectively). Crucially, performance on Tseltal terms was different from the chance level of 50% ($t(15) = 5.22$, $p < .001$, $d = 2.7$) while performance on Spanish terms was no different from chance ($t(15) = 1.65$, $p = .12$, $d = .85$). This pattern held for every sub-test in both Tseltal (*t*-tests, $p < .01$, $d > 1.6$) and Spanish (*t*-tests, $p > .05$, $d < 1.0$). Furthermore, if correct performance on 75% or more of the trials is considered as the criterion for 'knowing' the Tseltal left–right terms, 11 of the 16 participants (or 69%) met this criterion, scoring on average 91% correct across all of the comprehension tasks (the remaining five participants scored on average 53% correct across these tasks). In contrast, only 2 of 16 participants scored 75% or above for the Spanish terms (average 92% correct).[16] The remaining 14 participants scored 52% correct.

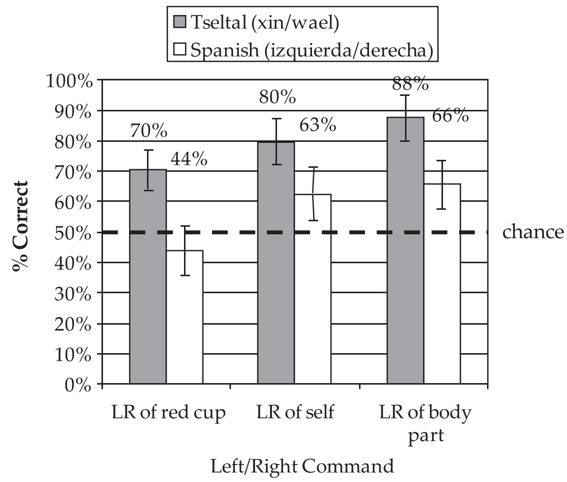



**Fig. 10.** Results for *left–right* comprehension task (Experiment 4). Error bars plot SE.

The ANOVA also revealed a main effect of Sub-Test ($F(2,30) = 3.96$, $p = .03$, $\eta_p^2 = .21$), with 57% correct responses for LR of Red Cup, 71% for LR of Self, and 77% for LR Body-Parts. Pair-wise *t*-tests with Bonferroni corrections suggested that performance on LR of Red Cup was lower than performance on LR Body-Parts ($p = .03$). No other comparisons were significant ($p > .19$). The observed difference is reasonable: in order to correctly interpret the expression" to the left/right of the red cup" in either Tseltal or Spanish, the participants had to realize that the intended left–right axis should be derived from their own left–right, and not the left–right of the experimenter (the speaker) or of the cup (which itself lacks a left–right axis). By contrast, computation of the relevant axis is most straightforward in the LR Body-Parts condition.

These findings can be summarized as follows: First, on the whole, these primarily monolingual Tseltal speakers had not adopted the Spanish terms for left and right into their working vocabularies and were not above chance in their comprehension of these terms. Second, these Tseltal speakers by and large knew the canonical uses of left–right terms for body-parts in their language, though some did not. Third, those participants who were above chance in their knowledge of how the Tseltal left–right terms apply to their bodies also (1) understood how the terms could be applied to objects immediately to their own left and

[15] Eight responses contained more than one type of expression (generally a deictic adverbial or directional paired with a more specific term, e.g., "Over there, towards the sunset."). In all cases, the more specific term (i.e., "towards the sunset") was coded.

[16] These two participants also scored above 75% on the Tseltal terms.

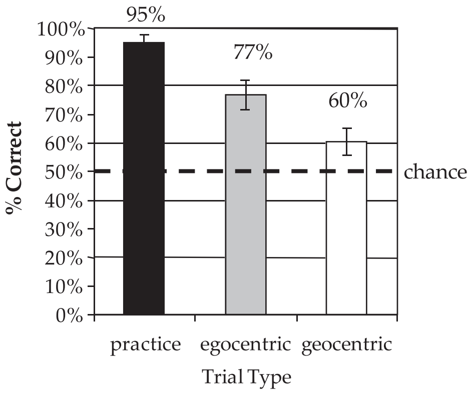



**Fig. 11.** Results for the (non-linguistic) cup task (Experiment 4). Error bars plot SE.

right, and (2) could guess how the terms might be used to relate two objects from their own viewpoint, despite the fact that these were novel uses of the terms.

*2.4.2.2. Analyses of the non-linguistic task.* Results from the non-linguistic task are presented in Fig. 11. Beginning with the familiarization (practice) trials, participants scored on average 95% correct, an indication that they understood the task.

For test trials, performance on the egocentric and geocentric conditions was 77% and 60% correct respectively. For both these conditions, this level of performance was above chance (2-tailed $t$-tests, $p < .05$). We conducted a 2 (Condition: Geocentric, Egocentric) × 2 (Block Order: Geocentric first, Egocentric first) ANOVA, with Condition as a within-subjects factor and Block Order as a between-subjects factor. The analysis yielded no effect of Block Order ($p = .74$) or Condition × Block Order interaction ($p = .32$). Only a main effect of Condition was significant ($F(1,14) = 16.95,\ p = .001,\ \eta_p^2 = .55$), with the egocentric condition leading to better performance than the geocentric condition. In other words, Tseltal speakers' memory for spatial locations was better when the position of the cups at the second table maintained the same alignment with respect to their own left–right axis than to the uphill–downhill axis derived from the environment. This finding is again consistent with Experiments 2 and 3: Performance is best when the spatial relations at recall align with the perspective from which the participants initially studied and remembered the spatial relations.

We also examined the data for trial order effects in a 2 (Condition: Egocentric, Geocentric) × 8 (Trial Number: 1, 2, 3, ... 8) logistic regression model. There was an effect of Condition, with egocentric being easier than geocentric (Wald $\chi^2(1) = 17.34$, $p < .0001$), but no effect of Trial Number (Wald $\chi^2(7) = 10.85$, $p = .15$, n.s.) and no Trial Number × Condition interaction ($p = .11$, n.s.). The lack of effect of Trial Number indicated that, if there was any learning occurring in task, it happened quickly and without further improvement as the number of trials increased.

*2.4.2.3. Relations between the linguistic and non-linguistic tasks.* Finally, we asked whether individual participants' language use and comprehension was in any way correlated with their performance on the non-linguistic task. To find out, we selected participants according to whether they used any geocentric or landmark terms in describing our displays for at least one of the four utterances they contributed. Eight of the 16 participants fell into this category. According to the view that habitual language use drives cognitive styles, the participants who used geocentric terms would have been more likely to have encoded the display geocentrically at the first table. If so, at the second table, they should have found the hidden coin easier to retrieve when the display maintained the same alignment with respect to the environment than when it rotated along with their own, egocentric perspective. However, these eight participants who used geocentric terms in their elicited descriptions performed better on the egocentric than the geocentric condition of the non-linguistic task ($M_{Ego} = 89\%$ vs. $M_{Geo} = 72\%$, $t(7) = 2.99$, $p = .02$, $d = 1.27$). The preference for geocentric terminology thus did not index better performance in the geocentric condition on the non-linguistic task. The other eight participants who did not use geocentric terms also showed better performance in the egocentric condition ($M_{Ego} = 64\%$ vs. $M_{Geo} = 48\%$, $t(7) = 2.55$, $p = .04$, $d = .92$). However, notice that performance by this group was worse than performance by those speakers who used geocentric language. These eight participants mainly consisted of those who gave the "other responses" in the language elicitation (e.g., "on the cup", "over there").[17] These descriptions alone were not useful for distinguishing between the cups and picking out one of them. The responses could either reflect a lack of motivation for doing well on the tasks. Alternatively, they might indicate reduced awareness of the pragmatic demands of these decontextualized tasks: these participants seemed not to understand why the experimenter was moving a coin between two yellow cups and asking for its whereabouts when it was in plain view, and as a result, they did not add disambiguating information to their responses (e.g., "on the uphill cup") over the course of the four trials. In general, these participants' responses were less "on-task" for both the non-linguistic and the linguistic elicitation tasks.

Next we asked whether language comprehension scores were in any way related to or predictive of non-linguistic test scores. A matrix of Pearson correlations was created to examine how percentage correct on the non-linguistic task (egocentric, geocentric, both egocentric and geocentric) was correlated with percentage correct on the comprehension task (total for Tseltal terms, total for Spanish terms, and each of the sub-tests within each language). The matrix yielded no significant correlations ($r$'s ranging from $-.36$ to $.48$, $p$'s > .05). Additionally, those eleven participants who scored 75% or higher on their comprehension of Tseltal left–right terms were comparable in their non-linguistic scores to the five participants who scored worse than 75% (for the *left–right* knowers: $M_{Ego} = 77\%$ vs. $M_{Geo} = 58\%$; for the non-knowers: $M_{Ego} = 75\%$ vs. $M_{Geo} = 65\%$). Corroborating this, a 2 (Condition: Geocentric,

[17] Five participants gave at least three deictic responses out of four possible responses. Two participants gave only locative responses. One gave two Tseltal left-right egocentric responses and two deictic responses.

Egocentric) × 2 (*Left/Right* Knowledge: Know *Left/Right*, Do Not Know *Left/Right*) ANOVA yielded an effect of Condition ($F(1,14) = 12.04,\ p < .01,\ \eta_p^2 = .46$) but no significant effect of *Left/Right* Knowledge ($p$ = .70) and no interaction ($p$ = .71). Thus, not knowing left–right expressions did not index poorer performance on the egocentric condition.

#### 2.4.3. Discussion

Using a modified 180° paradigm, Experiment 4 tested the possibility that Tseltal speakers' linguistic preference for describing scenes geocentrically could have a strong impact on their ability to encode the relationship between two objects with respect to their own body-defined axes compared to environmentally-stable coordinates. Unlike our previous studies (Experiments 1 and 2), participants here did not have to carry a spatial array from one table to the other. This feature of the task completely removed the possibility that task instructions or special strategies used while the array was being carried might influence participants' spatial encoding. This set-up also excluded the option of using (two-place) intrinsic FoRs to produce what looks like a (three-place) relative solution to a spatial task: it was insufficient simply to represent the cup with the hidden coin as being to the right (or left) of oneself in order to retrieve the coin at the second table: the relation between the cup with the coin and the red cup also had to be represented.

If participants adopted a geocentric encoding of the display at Table 1, in line with their language and in line with their preference on open-ended versions of such tasks, there would be a processing cost for translating the encoding to an egocentric one at Table 2 for the egocentric condition; in contrast, no such cost should be incurred in the geocentric condition. The data show, however, that performance was stronger in the egocentric compared to the geocentric condition. In other words, Tseltal speakers appear to have greater facility representing relationships between objects using egocentric, body-derived coordinates than geocentric, environmentally-stable ones. This pattern of behavior is inconsistent with the claim that speakers are biased to use linguistically dominant coordinate systems to encode everyday spatial representations in non-linguistic cognition. However, it is consistent with results from Experiments 2 and 3, according to which Tseltal speakers were better at adopting a perspective that aligned with their own body coordinates or the viewpoint in which they had originally encoded an array and showed no evidence of greater facility in constructing viewpoint independent representations.

A closer comparison between participants' linguistic performance and success on non-linguistic spatial tasks led to two further conclusions. First, production of geocentric terms did not correlate with better geocentric performance on the non-linguistic task. Second, comprehension of the Tseltal left–right terms (including their extended, unconventional uses) did not correlate with egocentric performance in the non-linguistic task (cf. also Niraula et al., 2004, on similar conclusions about the relationship between non-linguistic FoRs and use of spatial language in Nepali children). Taken together, these results support the position that the linguistic and non-linguistic FoRs are at least partially independent, and that linguistically dominant spatial encoding does not predict the ease with which spatial FoRs are recruited in spatial memory and inference.

## 3. General discussion

### 3.1. Summary of findings and conclusions

The four experiments reported here were designed to contribute to our understanding of how the formal resources and everyday use patterns of one's native tongue influence conceptual organization. Like prior investigators (e.g., Levinson, 2003), we focused attention on fundamental aspects of spatial reasoning in a Mayan population whose language (Tseltal) lacks – or customarily avoids – egocentric left–right spatial terminology. The overarching question was the degree to which the linguistic-terminological preferences of the language would influence behavior in non-linguistic spatial tasks. As in several earlier works, these new experiments studied spatial reasoning under rotation, where the choice of FoR will yield different solutions to the same puzzle: When one turns around, what is to one's East remains the same but what is to one's Left changes. Several cross-linguistic studies exploring how people recreate or identify rotated spatial arrays have found that under fully ambiguous circumstances – that is, where either FoR would provide an adequate solution to the spatial problem posed – participants' non-linguistic responses were strikingly correlated with the particular coordinate system favored in their spoken language (Pederson et al., 1998; Majid et al., 2004). The present experiments asked whether the findings would be the same for unambiguous spatial tasks.

Unambiguous (single-solution) tasks can reveal how adaptable individuals are when the task requires producing a spatial response that is less preferred or even unavailable in one's language. Each of our experiments included a condition in which the speakers of Tseltal (a language that frames spatial relations geocentrically) had to produce responses that matched the egocentric perspective. In these cases, representing the spatial relations geocentrically would have yielded a false conclusion as to the relative positions of dots on a card (Experiment 1), led participants down a false path through a maze (Experiment 2), or caused them to fail to find a hidden coin (Experiments 3 and 4). Furthermore, if linguistic preferences shaped spatial reasoning, Tseltal speakers' performance would be worse on the egocentric than the geocentric conditions.

Our experimental probes were designed to exclude artifactual interpretations of our results. First, we ensured through linguistic assessments that the population studied was essentially monolingual (potential participants with significant Spanish competence were excluded from the scored results) and unschooled (participants were nonliterate or semiliterate). As shown in the language elicitation results included here, the Tenejapan villagers who participated in the present studies were remarkably similar in their linguistic and socio-cultural profiles to those investigated in related contexts in the classic studies of

Brown and Levinson conducted two decades earlier in Chiapas (Brown & Levinson, 1993a; see also Abarbanell, 2007).

We followed the procedures and designs of earlier studies of Tseltal spatial reasoning to ensure that the same or closely related features of behavior previously argued to support a relativistic approach were broadly reproduced in the new probes (e.g., a rotated maze test, a rotated picture-card test, and so forth). Next, we tested participants in both geocentric and egocentric versions of each manipulation, using within-subject designs wherever possible (Experiments 3 and 4). Finally in Experiments 2 and 4 we provided tasks scaled for difficulty to see whether increases in task complexity would induce subjects to switch their strategic attack on the task, falling back on a hypothesized tendency to follow their language's spatial encoding for harder problems (as suggested by Levinson et al., 2002).

Our studies led to three major findings. First, the participating Tenejapan individuals did at least as well – usually better – in solving the spatial problems in the egocentric conditions where the linguistic categories of Tseltal mismatched (at least on the surface) the implied organization of the task itself compared to geocentric conditions. These findings, in combination with the error pattern across different degrees of rotation in the geocentric condition of Experiment 3, suggest that Tseltal speakers may at times rely on their egocentric perspective in solving spatial tasks in the geocentric condition. Second, variance in the use and comprehension of spatial terminology by individual Tseltal speakers does not correctly predict performance on (unambiguous) spatial tasks. Third, contrary to previous hypotheses (e.g., Levinson et al., 2002), performance on the egocentric condition remains solid with increasing task complexity, but performance on the geocentric condition dramatically plummets (see Experiment 2). Together these results strongly support the view that spatial reasoning is flexible and largely independent of the implied dictates of linguistic encoding.

The finding that Tenejapan Mayans are flexible in their spatial reasoning is not really surprising. After all, multiple FoRs are necessary to represent where things are in everyday life (Gallistel, 2002b). As Mou, Li, and McNamara (2008, p. 415) put it, "effective navigation requires people to keep track of objects in the environment that are stationary and objects in the environment that move with them." Furthermore, as the spatial cognition literature (studying English speakers) has shown, our representations of spatial scenes may often depend on the viewpoint from which we studied the scene (e.g., Burgess, Spiers, & Paleologou, 2004; Diwadkar & McNamara, 1997; Shelton & McNamara, 1997; Simons & Wang, 1998; Wang & Simons, 1999). Psychophysical and systems-electrophysiological evidence indicates that the brain routinely encodes position for action in multiple systems (Muller, 1996; Snyder, Grieve, Brotchie, & Andersen, 1998; Taube, Muller, & Ranck, 1990; cf. Gallistel, 2002a). Several systems of encoding locations that encompass both external and internal references are present in adults and even children (Newcombe & Huttenlocher, 2000). These observations, together with the experimental results reported here, can most naturally be explained by assuming that the linguistic encoding of spatial FoRs vastly under represents people's ability to think about where objects are located and how they move through space.

### 3.2. Gricean doubt: The influence of ambiguity

We turn now to the large and striking correlations between linguistic form and spatial reasoning that have been found repeatedly in ambiguous spatial-reasoning tasks, as described by Levinson and collaborators across a large variety of languages that vary in their typology, their geographical distribution, and the cultural practices of their native speakers (see particularly Levinson, 2003, for a summary and discussion of both informal and experimental findings). There are several ways to interpret such correlations. The first is that, much as Whorf suggested, specific structural and lexical features of individual languages come to be the frame and format for thought, invading all our reasoning. As Levinson (2003, p. 301) put it, "the imprint of language-specific categories will run deep in cognitive processes." In contrast, several investigators (including some of the present authors, e.g., Li & Gleitman, 2002) have presented evidence that favors, instead, the traditional hypothesis that language is more effect than cause of our thought; that is, that we talk the way we think. The idea from this point of view is that, owing to differences in the circumstances that populations find themselves in, they invent and use lexical and grammatical resources that most conveniently express these circumstances.

The present paper is an attempt to evaluate a more specific hypothesis about the striking correlations between language and spatial performance which is consistent with the second position. According to this hypothesis, listeners use differences in language patterns as a probabilistic basis for inferring how new words and sentences relate to new objects and events. This perspective starts with the obvious fact that the words and sentences we utter map only very approximately onto the thoughts we mean to express, a truism that requires humans to apply considerable inferential analysis to make sense of the speech of their interlocutors (Grice, 1989; Horn, 1972, 1989; Clark, 1992; Sperber & Wilson, 1995). Iconic cases are the easy interpretations of "Chomsky and Socrates are on the top shelf" (a locution common in libraries) and "The pastrami sandwich wants his check" (more common in restaurants).

As these examples imply, the response to linguistic ambiguity at every level of linguistic functioning is heavily influenced by plausibility considerations. But very often it is preferred linguistic usage (instead of or in addition to real-world probability) that contributes its own plausibility criteria: Listeners have the expectation that, all other things being equal, their interlocutors are speaking in ways generally preferred by the linguistic community (cf. Whorf (1956) on "façon de parler"). This line of reasoning is consistent with a long line of work showing that participants in experimental tasks engage in sophisticated pragmatic reasoning to reconstruct what the experimenter had in mind (see Politzer, 2004; Sperber, Cara, & Girotto, 1995; and other papers in Noveck & Sperber, 2004).

It is plausible, therefore, that when an experimental participant is faced with an ambiguous spatial task, he or she makes implicit reference to such design and typical usage factors to tip the scales, that is to make a judgment as to what the speaker meant. Thus when the experimenter after rotating the participant in a spatial task says "Make it the same," and there are at least two solutions, implicit understanding of how the particular language usually encodes spatial concepts will resolve Gricean doubt by defaulting to the most frequent option. This explanation makes sense of the fact that language-based preferences for one of these solutions appear when tasks are ambiguous but, as in the experiments presented here, disappear when they are unambiguous.[18] A closely related effect occurs in experiments in which the ambiguity is removed by changes in the task situation as contrasted with changes in the language usage that we just discussed. For instance, Li and Gleitman (2002) replicated Brown and Levinson's (1993) finding (for Dutch) that English speakers prefer to solve ambiguous table-top rotation tasks egocentrically (that is, language-congruently), but only if the participant had to move from the original (training) table to one that was at 180° remove (that is, behind them, much as shown in the set-ups in Fig. 9 of the present paper). The ambiguity arises in this case because there are two ways that the experimenter might have meant the edges of the second table to align with those of the first – egocentrically "the same" or geocentrically "the same." If we assume that the language-specific tendencies of participants are influenced by dominant linguistic usages, we should predict that this tendency will disappear with the ambiguity itself. Li and Gleitman showed just this: A new group of monolingual English-speaking participants whose 180° rotation was accomplished by their walking from one side of the training table to the opposite side of the same table now uniformly solved the same problem geocentrically. In the absence of doubt as to which edges of the table are to be aligned (after all, in this case there is only a single table and therefore only a single possible alignment), the tendency to respond in language-congruent ways is effectively removed.

Relatedly, because the task demands are ambiguous and open-ended, it is possible that altering the experimental contexts could effectively affect the likelihood of whether participants interpret the task as targeting egocentric or geocentric responses. In Experiment 1 and 2, prior unambiguous instructions (carry-box and carry-maze) set-up expectations that influenced how participants later chose to interpret the more open-ended versions of the tasks (i.e., the leave-box, leave-maze). These new data are consistent with other evidence showing that the preferences found by Levinson and colleagues could be shifted with slight changes in the testing context. For example, Cottereau-Reiss (1999) found that speakers of a geocentric language were more likely to recreate arrays of toy animals egocentrically when they themselves carried the animals to the second table than when the experimenter carried the toys. Danziger (2001) found that subtle instruction adjustments (e.g., "Remember where the animals are" vs. "Remember where the animals are looking") influenced whether intrinsic language speakers' respond geocentrically.

To accept the interpretations we have made, one need do little more than to acknowledge that people are responsive to probabilities in language use just as they are responsive to plausibilities in the world. These factors influence the interpretation both of situational ambiguities (two solutions for the same spatial problem) and of referentially ambiguous speech (two contextualized interpretations of "Make it the same"). Tests of linguistic relativity in other domains have offered additional strong evidence that language influences participants' responses on non-linguistic tasks primarily when stimulus objects are highly ambiguous and/or task instructions are open to linguistic reinterpretation; subtle changes to stimuli and/or instructions can easily make what appear to be cross-linguistic differences in object or event construal disappear (see Li, Dunham, & Carey, 2009 on the mass-count distinction; Papafragou & Selimis, 2010 on motion events). From this perspective, the language-congruent biases sometimes found in the language-and-thought literature are more likely to be influences of language on language than influences of language on thought itself.

[18] There are, in fact, two more precise ways of resolving 'Gricean doubt'. One possibility is that, to recover the experimenter's intent when uttering 'Make it the same', participants consult non-linguistic conventions/practices in the community about how spatial locations are encoded: on this reasoning, Tseltal participants would conclude that 'the same' refers to absolute FoR. Another possibility is that, in interpreting the experimental instructions, Tseltal participants match the phrase 'the same' to a specific verbal equivalent – which of course again points to the absolute FoR. The two ways of resolving the ambiguity in the interpretation of the instructions are not equivalent, since only the second one requires covert verbal encoding. Even though we have leaned towards the first way of understanding how 'Gricean doubt' might be resolved, our data at present cannot adjudicate between these two options. One way of doing so would be to include a verbal shadowing task: if implicit verbal encoding is taking place, then the language-on-thought effects should again disappear even from an ambiguous version of the task. If the Gricean effects are not necessarily tied to verbal encoding but still include a guess as to the most reasonable/plausible interpretation, then some of these effects might persist.

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