Unraveling the contribution of left-right language on spatial perspective taking

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We examine whether acquiring left/right language affects children's ability to take a non-egocentric left-right perspective. In Experiment 1, we tested 10-13 year-old Tseltal (Mayan) and Spanish-speaking children from the same community on a task that required they retrieve a coin they previously seen hidden in one of four boxes to the left/right/front/back of a toy sheep after the entire array was rotated out of view. Their performance on the left/right boxes correlated positively with their comprehension and use of left-right language. In Experiment 2, we found that training Tseltal-speaking children to apply left-right lexical labels to represent the location of the coin improved performance, but improvement was more robust among a second group of children trained to use gestures instead.

Keywords: linguistic relativity; coordinate systems; perspective-taking; gestures; Tseltal

1.0. Introduction

Although infants have complex expectations about the behavior of objects (e.g., Baillargeon et al., 1985), quantities (Wynn, 1992) and intentional agents (Woodward, 1998), there is no doubt that much of our knowledge is learned though cultural transmission. Language in particular plays a crucial role in acquiring information (e.g., see Harris, 2012, on children's knowledge acquisition through testimony). But can linguistic representations actually shape or even restructure core aspects of our nonlinguistic cognition (Whorf, 1941/1956)? The strongest version of this argument, linguistic determinism, has largely been discredited (but see research in the domain of learning natural numbers; Carey, 2009). Nevertheless, a growing body of work has argued for weaker effects (see Bowerman & Levinson, 2001; Gentner & Goldin-Meadow, 2003; Gumperz & Levinson, 1996; Malt & Wolff, 2010). In this paper, we present new evidence to bear on one of the most studied cases to emerge from this work: the coordinate systems, or frames of reference (FoR) speakers use when talking about locations and directions (e.g., Brown & Levinson, 1993a; Levinson, 2003; Majid et al., 2004; Mishra et al., 2003; Pederson et al., 1998).

To contextualize the present studies, we first present an overview of the arguments and evidence to date, which has focused primarily on speakers' ability to memorize small-scale spatial arrays from a viewer-centric versus an environment-centric perspective. We then present data from two new experiments in an area where linguistic frames of reference might be predicted to have an effect: the ability to take the non-egocentric left-right perspective of another entity. In Experiment 1, we used naturally-occurring variation in the acquisition of "left" and "right" among children in the Tseltal Mayan community of Tenejapa, Chiapas, Mexico, and found a direct correlation between knowledge of left-right language and performance on a non-egocentric left-right perspective-taking task. Our study is one of the first to directly test and demonstrate such a relationship. To understand the nature of this correlation (e.g., whether some children are better at perspective-taking and thereby at learning left-right language or whether learning left-right language actually leads children to be better at perspective-taking), in Experiment 2 we used a paradigm in which we trained children to use left-right language to label the sides of the relevant entity on the same perspective-taking task. Given the difficulty of acquiring left-right language, however, we also trained a second group of children to represent this relationship by gesturing with their own corresponding body parts. We found that training Tseltal-speaking children to use left-right language temporarily boosted their perspective-taking performance; However, the children who were trained to use gestures showed longer-lasting improvements. This concurs with studies showing that using gestures during instruction can promote learning (see Goldin-Meadow, 2016, 2018). Thus, while having left-right language may help, it is not necessary to represent non-egocentric left-right relationships and may not be as optimal as more embodied representations. These studies help advance our understanding of where and how language might affect nonlinguistic cognition in this and other domains.

A long-held assumption of Western thought was that children first encode spatial relationships egocentrically, with reference to their own bodies (Piaget, 1948/1955), and that all languages would therefore preferentially encode spatial information using body terms (Kant, 1768/1991; Hertz, 1907/1960; Lyons, 1977; Miller & Johnson-Laird, 1976; Piaget, 1948/1995; Clark, 1973; Taylor & Tversky, 1996; see Levinson, 1996). A large and influential body of cross-linguistic work, however, found systematic variation in the available or preferred frames of reference across languages (see Levinson, 2003; Levinson & Wilkins, 2006). A primary distinction is between languages that primarily use a geocentric or environment-centric perspective and those that use a viewer-centric perspective (see Shusterman & Li, 2016a, 2016b for an overview of FoR classifications). English-speakers, for example, typically use a viewer-centric system based on their own body axes (e.g., "left/right", "front/back"). The expressions are often egocentric, from the perspective of the speaker (e.g., "the cup *to my left* of the teapot"), and sometimes non-egocentric, from the perspective of another (e.g., "the cup *to your left* of the teapot"). In some languages, however, like Tseltal Mayan, which we work with here, speakers use fixed aspects of their environment (e.g., "the cup *downhill* from the teapot") and do not use terms like "left" and "right" projectively[1] (Brown, 2006; Brown & Levinson, 1992, 1993b). These cross-linguistic differences were shown to correlate with speakers' preferences on tasks where they were asked to find or make the same spatial array (Pederson et al., 1996; Majid et al., 2004) or to guess a spatial rule the experimenter had in mind (Haun et al., 2006). For example, when asked to recreate an array of toy animals after turning to face a new direction, speakers of viewer-centric languages like English and Dutch rotated the array along with their own (i.e., egocentric) body axes, while Tseltal-speakers maintained its geocentric orientation. These results, together with the prolonged acquisition of "left" and "right" by English-speaking children (Piaget, 1928; Rigal, 1994, 1996), have been taken as evidence that left-right concepts in particular are not saliently available (e.g., Brown & Levinson, 1992; Levinson, 2003). Rather, speakers may construct such a perspective as a result of language learning (Haun et al., 2006).

Li, Abarbanell, Gleitman, and Papafragou (2011), however, showed that Tseltal-speaking adults, similar to English-speakers, can easily reason about spatial relationships using their own egocentric left-right perspective, and sometimes even have an easier time taking the egocentric than the geocentric perspective. In one task, which is analogous to the

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[1] To be more precise, in limited cases, a Tseltal-speaker might say that one animate entity is literally 'at' or near-touching another animate entity's hand (e.g., 'the man is standing at the woman's right hand', from Brown & Levinson, 1992, p. 599). Nevertheless, such expressions are rare, and as Brown and Levinson note, they denote positions of topological adjacency rather than projective divisions of regions of space. A more recent elicitation study verified limited use of "left" and "right," with the few uses coming from younger bilingual speakers who often used the borrowed Spanish terms (left: *izquierda*, right: *derecha*; Polian & Bohnemeyer, 2011).

task we use here, Li et al.'s participants were seated in an office swivel chair. They watched as a coin was hidden in one of two identical boxes located to their left and right, and then were blindfolded and spun 360° plus an additional 90°, 180°, 270°, or 360°. The blindfold was then removed and they were asked to retrieve the coin. The boxes were either attached to the chair so they rotated with the participant (egocentric condition) or placed on the floor so they remained stationary (geocentric condition). Tseltal-speakers performed *better* in the egocentric condition and the errors they made in this condition were invariant of the degree of rotation. In contrast, in the geocentric condition participants made the most errors when the chair was rotated 180°, that is, when the visual representation of the environment was the most mismatched from the perspective in which they initially saw the coin being hidden. This pattern suggests that Tseltal-speakers preferred to encode the location of the coin using egocentric coordinates, and then used this relation to retrieve the coin once rotated. Thus, language may not necessarily override the primacy of an egocentric perspective, at least not in this scenario where the coin was hidden in close proximity to the participant.[2]

Nonetheless, spatial language can have some impact on spatial cognition (Landau et al., 2010). Left-right language can serve as a useful tool for encoding spatial relationships, making the relationship explicit and more memorable (Dessalegn & Landau, 2008; Hermer-Vazquez et al., 1999, 2001; Shusterman et al., 2011; Pyers et al., 2010; Ratliff & Newcombe, 2008). For example, all adult speakers of Nicaraguan Sign Language, a sign language undergoing creolization, were above chance at retrieving a hidden object located to the left/right of a distinct colored wall in a rectangular room after being disoriented; However, later-generation speakers who had developed a consistent way of labeling left/right

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[2] See also Li et al.'s (2011) cups task (Exp. 4). Although the interpretation of these findings has been debated (see Bohnemeyer & Levinson's (2011) response), more recent studies that aim to reconcile seemingly conflicting sets of findings suggest that the nature of the task is more influential in determining which FoR is recruited or more heavily weighted across language groups (see Li & Abarbanell, 2018, 2019 in response to Haun et al., 2011, 2006 respectively).

performed significantly better than those who did not have such consistent conventions. Thus, although learning left-right language is not needed to successfully retrieve an object hidden to the left/right of a distinct landmark, it is extremely helpful.

In sum, studies of the effect of variations in FoR on cognition support the view that learning left-right language has only a limited impact on egocentric spatial perception (see also Gallistel, 2002; Newcombe, 2017; Landau et al., 2010; Ünal & Papafragou, 2016). In the present paper we therefore extend this work by asking what role learning spatial language has on *non-egocentric* viewer-centric perspectives. As mentioned, viewer-centric perspectives can be distinguished by either the speaker's egocentric perspective or the addressee's perspective. Prior studies such as those reviewed above have primarily focused on the relationship between learning left-right language and reasoning about egocentric left-right (for a few exceptions on learning left-right language and solving tasks that could potentially involve reasoning about non-egocentric left-right relations, see Hermer-Vazquez et al., 2001's Experiment 3 with six-year-olds, and Pyers et al., 2010's rotated box task with adult Nicaraguan Signers). As we discuss next, however, it is important to distinguish between egocentric and non-egocentric left-right language and cognition. It is possible that learning left-right language may have the most impact on reasoning at the non-egocentric level.

The acquisition of linguistic frames of reference suggests that it is the non-egocentric viewer-centric perspective, and especially that of non-egocentric left-right that is difficult to acquire (Shusterman & Li, 2016a, 2016b). In contrast to terms like "front" and "back" which are acquired comparatively early in development (Johnston, 1988; Johnston & Slobin, 1979; Kuczjac & Maratsos, 1975; Levine & Carey, 1982), "left" and "right" are notoriously difficult for English-speaking children to acquire, and their acquisition follows a developmental pattern. Children begin by labelling the left and right sides of their own bodies at about 5-to-6 years of age, but it is not until they are approximately 11 years-old that they acquire the full use of these terms, including the ability to take the left-right perspective of another person or entity that may not coincide with their own (e.g., "the cup to the right of the teapot *from your perspective*"; Piaget, 1928; Rigal, 1994, 1996). Further, while distinguishing one side of one's body from the other is based in proprioception and has been shown in prelinguistic infants and many other species (Corballis & Beale, 1976; 1983), identifying left-right from another person's perspective requires additional spatial abilities. It requires knowing the conventions for how one's own left-right is to be mapped onto other bodies or entities and may require mental rotation if the orientation of that entity does not match one's own. It is possible, therefore, that less salient uses of left and right such as the ability to take a non-egocentric left-right perspective is facilitated or at least strengthened by language.

In line with this prediction, Lasky, Romano and Wenters (1980) tested for the age at which children can solve a non-egocentric left-right task using a turntable apparatus which had two hiding locations at the left and right sides of a central reference object (a face painted on the turntable). The child watched as an object was hidden in one of the locations. The apparatus was then occluded and rotated. The occluder was then removed and the child had to retrieve the hidden object by using the reference object's left and right. The age at which children were able to solve this task at above chance level was around 10 years-old, the same age children typically acquire non-egocentric left-right language (Rigal, 1996).

In Experiment 1, we therefore tested the relationship between children's left-right language and their ability to solve a similar non-egocentric left-right task using a within-subjects design, as no prior studies have directly tested this relationship. In pilot work, we (Abarbanell & Li, 2009) tested Tseltal-speaking adults who do not use left-right language for spatial reference on the same apparatus that we use here (Figure 1) and found that many performed at chance level, raising again the possibility that the acquisition of left-right language promotes the development of non-egocentric left-right perspective-taking skills.

However, the majority of the adults had little to no formal schooling. A long line of cross-cultural work has argued for the effects of formal schooling on the ability to understand and do well on decontextualized tasks (e.g., Cole et al., 1971; Luria, 1971). Individuals with formal schooling are better at understanding instructional discourse and using strategies to organize information (Cole, 2005; Rogoff, 1981). Thus, lack of schooling may explain the Tseltal-speaking adults' performance. Researchers comparing psychological processes across schooled and traditionally unschooled populations have therefore taken to testing children. Due to increasing education rates in many regions, their educational experiences tend to be more similar than that of adults across cultures (e.g., Haun et al., 2011).

In the present study, we therefore tested 10-13 year-old Tseltal-speaking school children, the age that English-speaking children acquire non-egocentric left-right language and can solve a similar non-egocentric left-right perspective-taking task. In contrast to the adult Tseltal-speakers, the children are exposed to Spanish terms for "left" and "right" at school. However, our previous work with similar-aged Tseltal-speaking children has shown that many have not yet mastered even their egocentric use (Abarbanell, 2010; Li & Abarbanell, 2018). They therefore provide an opportunity to disentangle the contribution of the acquisition of left-right language from the development of more general cognitive skills. One possibility is that non-linguistic developmental changes, such as increases in working memory, underlie children's improvement in perspective-taking tasks as well as their acquisition of non-egocentric left-right language by allowing for the development of related spatial skills such as translation and mental rotation (Hale, 1990; Kail et al., 1980; Willis & Schaie, 1988). Testing Tseltal-speaking children of this same age range who, because of the more limited use of left-right terms in their community, do not necessarily have left-right language, will allow us to understand the observed correlation in English-speaking children.

To maximize the variability in left-right language, we tested Tseltal-speaking children from two different regions in Tenejapa, which is a rural municipality in the Chiapas highlands: one group from the somewhat more urbanized municipal center and one from a rural region just outside of the center. Children in both regions are acquiring Spanish in school, a language that, like English, favors viewpoint-dependent language. They are also learning the Spanish left-right terms at school. Children in the municipal center, however, are likely to have even more exposure to Spanish outside of school. The municipal center is the point of departure and entry for taxis going to and from the nearest cosmopolitan center of San Cristobal de Las Casas, at a distance of approximately 29 km. It therefore has more interface with mainstream Spanish-speaking Mexican culture than the outlying regions. Moreover, in contrast to other regions of Tenejapa that are almost exclusively Tseltal, the center has a small population of native Spanish-speaking Ladinos[3] whose families have resided there for generations. In addition to exposing the Tseltal-speaking children in the center to more Spanish, this provided a third, ideal Spanish-speaking comparison group.

We therefore tested three comparison groups, all of the same age and level of schooling but predicted to vary in their exposure to and understanding of “left” and “right”. The two groups of Tseltal children are of the same ethnolinguistic group and therefore share the same language and broader culture but were predicted to differ in their exposure to left-right language. These two groups, however, also differ in their exposure to community-level factors that may also promote left-right knowledge and use, such as cars and roads.[4] The two center groups, in contrast, are different ethnolinguistic groups and therefore differ in their language and broader culture while residing in the same community and sharing the same

[3] Ladinos is regional term for *mestizos*, native-Spanish speakers that are of mixed Spanish and Indigenous descent. About 12% of the center’s nearly 2,000 residents are native-Spanish speaking Ladinos (INEGI, 2010).

[4] The municipal center is the only community in Tenejapa to have three main streets. Rural communities are connected to the municipal center via a paved road but houses within these regions are typically connected via dirt paths.

general environment. The Ladino children even attend the same primary school as their Tseltal-speaking neighbors where they are in the same classes. By testing all three groups we therefore hoped to be able to tease apart the contribution of knowledge of left-right language from other cultural and community-level factors that might also contribute to the children's performance on our non-egocentric perspective-taking task.

For all three groups, we assessed the children's performance on a non-egocentric perspective-taking task in which the children had to retrieve a coin they had previously seen hidden to the left or right of a central reference object after the entire array had been rotated out of the children's view. We then assessed the children's understanding and use of left-right language and asked whether it was correlated with their performance on the perspective-taking task and whether such a correlation would hold even controlling for the children's ethnolinguistic group (Tseltal or Spanish) and community (rural or municipal center). If so, this would be the first study to demonstrate such a relationship using a within-subjects design and would suggest that there may be a causal relationship between the two.

2.0. Experiment 1

2.1. Participants, Materials and Methods

We tested three groups of children: 30 Tseltal-speakers residing in a rural region just outside of the municipal center of Tenejapa (Tseltal Rural: 13 girls, M_{age} = 11.40 years), 27 Tseltal-speakers residing in the municipal center (Tseltal Center: 16 girls, M_{age} = 11.65 years), and 23 native Spanish-speakers residing in the municipal center (Spanish: 13 girls, M_{age} = 11.68 years).

The Tseltal Center and Spanish children were in the same 5th and 6th grade classes and showed no difference in their academic performance[5]. The more rural Tseltal children were

[5] The children's grade point average, provided by their teachers, did not differ between the two groups (Spanish: 82.99 vs. Tseltal: 83.17 (on a 100-point scale); Mann-Whitney U = 193.50, p = .57, exact sig. 2-tailed).

recruited from two neighboring communities, or *parajes,* and attended two different primary schools. These schools have the same general curriculum and format as the school in the center, and all of the schools have a similar reputation. Instruction in all schools is primarily in Spanish, almost exclusively so by the 5th and 6th grades. While all of the Tseltal-speaking children were therefore acquiring Spanish in school, their home language and the dominant language in the community is Tseltal.

Similar to Lasky et al. (1980), we used a turntable apparatus. Rather than a 2-dimensional face, however, ours had a toy sheep (measuring 5.5 x 2.3 x 3 cm) as the center reference object. Rather than two hiding locations, our apparatus had four identical square lidded boxes (6 x 6 x 4 cm) for hiding coins. These were attached to the ends of rods that extended 26 cm from the front, back, left, and right of the sheep such that the boxes and sheep rotated together (see Figure 1). Boxes were included on the front-back axis as well as left-right to be able to assess whether children would at least attend to the correct axis.

[Figure 1 near here]

The experiment consisted of a coin search task followed by language assessment tasks, which were ordered so that exposure to the language tasks would not affect children's coin search strategy.

2.1.1. Coin Search Task

The coin search task, as noted, made use of the turntable apparatus (see Figure 1a). At the start of each trial, the turntable was oriented so the child and sheep shared the same facing direction (see Figure 1b). To familiarize the children with the apparatus, the experimenter first pointed out the sheep and the four boxes, opening each and noting they were empty. The experimenter then showed the child how the turntable rotated, with the boxes moving together with the sheep. After rotating the turntable back to its initial orientation, the experimenter hid a coin in the box to the right of the sheep and, pointing to its side, explained, "I'm putting the coin on *this side* of the sheep" (*Ya kotses te tak'in ta xujk ine yu'un te tunim chij"*). All of the children were tested in their native/home language. The child was asked to point to the box where the coin was hidden to ensure that she or he had attended to and encoded its location. The experimenter then rotated the turntable 90° counterclockwise while the child watched, and then asked the child to point again to the location of the coin. The box was then opened to verify if the child's answer was correct. The turntable was returned to its initial orientation and the procedure was repeated with the coin hidden in the box to the front of the sheep. The children then received two more Familiarization trials with the coin hidden to the left and then the back of the sheep, only now they covered their eyes while the turntable was spun 90° counterclockwise and then opened their eyes to retrieve the coin. Almost all children succeeded on these familiarization trials (M = 97.50% correct).

The children were next given 8 Test trials, four on each left-right side or one trial per side for each rotation (90°, 180°, 270°, and 360°). The trials were blocked by side and counterbalanced, with the order of rotation randomized within each block. Each trial began with the sheep facing as in Figure 1b. On hiding the coin, the experimenter pointed to the side of the sheep and said, "I'm putting the coin on *this side* of the sheep", thereby drawing the children's attention to the relevant dimension. The children then covered their eyes while the apparatus was spun, and then opened their eyes and were asked to retrieve the coin. If correct on the first try, they got to keep the coin.

2.1.2. Language Tasks

The coin search task was followed by four language tasks, each serving a slightly different function: a language elicitation task, two tests of non-egocentric left-right language comprehension (Other Pointing and Other Labeling tasks), and one test of egocentric left-right language comprehension (Self task).

The first task, *the language elicitation*, was designed to see whether children would spontaneously use left-right language to describe the relationship between the coin and the sheep. First, the sheep was placed in its initial starting position as in Figure 1b, and a coin was placed on top of the box to the front of the sheep. In order to elicit how the children would describe the sides of the sheep, we asked, "Where is the coin *from the sheep*?" (*Banti ay te tak'in yu'un te tunim chij?*). The children were then given three more trials with the coin placed to the back, left, and then right of the sheep. Each child, therefore, received a total of four such elicitation trials. We were primarily interested in seeing whether the children would use left-right terms, and if so, whether they would map them correctly and whether they would use the Tseltal or Spanish terms.

The next two tasks, *Other Pointing* and then *Other Labeling*, focused on children's knowledge of non-egocentric uses of "left" and "right," that is, language that describes the relation needed to succeed on the coin search task. Both tasks examine the children's ability to correctly map left-right terms onto another entity when rotated at different orientations but did so using slightly different means.

For the *Other Pointing task*, the children covered their eyes while the apparatus was spun to a new orientation. The experimenter then placed a coin each on top of the boxes to the left and right of the sheep. The children opened their eyes and the experimenter said, "There are two coins. Which one is located to the left/right of the sheep?" (*Ay cheb tak'in. Ba junuk ay ta s-izquierda/s-derecha yu'un te tunim chij?*), and the children were prompted to point to the correct coin. The children received 8 Pointing trials, or one trial per side at each rotation (90°, 180°, 270°, and 360°), blocked by side and counterbalanced, with the order of rotation randomized within each block. We used the Spanish terms for "left" and "right" since, in consultation with teachers and parents while designing the study, teachers report that they teach them in school while the Tseltal terms are rarely if ever used (cf., Brown, 2006;

Brown & Levinson, 1992). Additionally, Abarbanell (2010) found that when similar-aged Tseltal-speaking children used left-right terms on a referential communication task in which they were paired with a Tseltal-speaking peer, they always used the Spanish terms which they incorporated into their otherwise Tseltal discourse. Similar borrowings were noted among some of the Tseltal-speaking adults in Tenejapa studied by Polian and Bohnemeyer (2011) and have been observed for other spatial terms in other Mesoamerican languages (Hernández-Green et al., 2011). We added the third person possessive prefix in Tseltal (*s-*) to emphasize that we were referring to the sheep's left/right and not the child's – a construction that was spontaneously used by some of the children in Abarbanell's (2010) sample.

For the *Other Labeling task*, which was administered after the Pointing task, the same procedures were followed except that a coin was placed on top of only one left/right box on each trial, and the children were asked, "On which side of the sheep is the coin?" (*Ta ba xujk ay yu'un te tunim chij?*). The children had to produce the correct response ("left" or "right"). If the children produced another (non-left-right) response, they were prompted by the experimenter, "On its left or its right of the sheep?" (*Ta s-izquierda o ta s-derecha yu'un te tunim chij?*) The children received 8 such trials, or one trial per side at each rotation, with the sides pseudo-randomized so they would be difficult to predict.

Lastly, the *Self task* tested the children's ability to map "left" and "right" to the sides of their own bodies using simple commands, e.g., "Raise your right hand" (*Becha a-k'ab ta derecha a'wu'un*) or "Move your left leg" (*Tija te a'wakan ta izquierda a'wu'un*). The children received 8 such trials, two on each left/right side with the child standing facing toward the experimenter, and two on each side with the child facing away.

2.2. Results

Our intent in testing the three groups of children was capture variation in their understanding and use of left-right language in order to be able to test for a correlation between such language and the children's performance on the coin search task. We therefore look first at the children's left-right language, examining their spontaneous use followed by their left-right comprehension. We then examine the relationship between this language and the children's performance on the coin search task.

2.2.1. Spontaneous Left-Right Use: Language Elicitation

Recall that our main goal for the elicitation was to see if the children would spontaneously use left-right terms to describe the relationship between the coin and the sheep, and if so, if they would they use the terms on the correct axis (i.e., left-right and not front-back) and the correct side. Each child produced four responses to the question, "Where is the coin *from the sheep*?", one response each for the sheep's front, back, left and right sides. Table 1 shows the total percent of children who used left-right terms in each group followed by the percent of children who used these terms correctly (no incorrect use). To provide more details on how the children erred, we also list the percent of children who used these terms incorrectly on the left-right axis and on the front-back axis. Fisher's exact tests confirmed that the Spanish-speaking children were more likely to use left-right terms and to use them correctly than both groups of Tseltal-speaking children (p's $\leq .01$) who did not differ from each other in their pattern of use (p's $\geq .07$).

A second point to note is that all of the Tseltal-speaking children who used left-right terms did so by using the Spanish terms, *"izquierda"* and *"derecha"*, with one child explicitly specifying the sides of the sheep by affixing the third person possessive prefix in Tseltal to the Spanish terms (*"ta s-derecha", "ta s-izquierda"*). We emphasize again that at this point the experimenter had not used any left-right terms. Further, the children used the Spanish terms even though the task had been conducted entirely in Tseltal and almost all other elicitations from the Tseltal-speaking children consisted of Tseltal terms used in Tseltal locative expressions. This finding concurs with our arguments above and supports our decision to use the Spanish left-right terms with this population. The children who did not use left-right terms primarily used non-left-right intrinsic expressions for the sides of the sheep such as 'at its side' or 'at its stomach'.

[Table 1 near here]

2.2.2. Left-right Language Comprehension: Self and Other Tasks

Next, we compared the three groups' understanding of left-right uses, contrasting their responses on egocentric uses (the Self task) with non-egocentric uses (Other Pointing and Other Labeling tasks). See Figure 2 for the breakdown by task and group. Performance across the three tasks was highly correlated (r's > .56; p's < .001). An ANOVA with language tasks (Self, Other Pointing, Other Labeling) as a within-subjects factor and group (Tseltal Rural, Tseltal Center, Spanish) as a between-subjects factor found a main effect of group ($F(2,77) = 6.42$, $p = .003$, $\eta_p^2 = .14$), a main effect of task ($F(2, 154) = 9.82$, $p < .001$, $\eta_p^2 = .11$), and no interaction ($F(4, 154) = 0.93$, $p = .45$, n.s.). To make sense of the task effect, we conducted paired t tests with Bonferroni corrections ($\alpha = .02$). Percentage correct on the Self task (77.81% correct) was significantly higher than the Other Pointing (64.69% correct; $t(79) = 4.09$, $p < .001$, $d = .43$) and the Other Labeling task (68.59% correct; $t(79) = 2.95$, $p = .004$, $d = .30$). As expected, then, children were better on egocentric than non-egocentric uses. Lastly, the Other Pointing and Other Labeling tasks did not differ from each other ($t(79) = 1.29$, $p = .20$, n.s.). In further analyses, we therefore collapsed these into a single left-right Other score by taking the average of the two scores.

Comparing across groups ($\alpha = .02$), Spanish-speaking children scored slightly higher overall than the Tseltal-speaking children in the municipal center ($M_{\text{SPANISH}} = 83.33\%$, $M_{\text{TSELTAL CENTER}} = 71.45\%$, $t(48) = 1.81$, $p = .08$, $d = .52$), and statistically higher than those from the more rural parajes ($M_{\text{TSELTAL RURAL}} = 59.44\%$, $t(51) = 3.62$, $p = .001$, $d = 1.02$). The

Tseltal-speaking children in the municipal center were slightly better than the rural group ($t(55) = 1.79$, $p = .08$, $d = .48$).

[Figure 2 near here]

2.2.3. Relationship between Language and Cognition

We next examined how well performance on the coin search task was predicted by knowledge of left-right language (Table A.1, Appendix A shows the correlation of each language measure with the coin search). We first look at the correlation of the children's coin search performance with their use of left-right terms on the language elicitation task. Independent-samples *t* tests confirmed that children who used left-right terms on the elicitation did significantly better on the coin search task than children who did not use such terms (69.79% correct vs. 57.37%; $t(78) = 2.21$, $p = .03$, $d = .53$). This effect was even greater if we restrict our analysis to only those children who used left-right terms correctly compared with children who used them incorrectly or did not use them at all (77.89% correct vs. 57.84%; $t(78) = 2.93$, $p = .004$, $d = .87$; see also Figure A.1, Appendix A).

Next, we looked at the relationship between the coin search and the left-right language comprehension measures. We first looked separately at the children's understanding of egocentric left-right language, as measured by the Self task, and their understanding of non-egocentric left-right language, as measured by the combined Other tasks (the average of the Pointing and Labeling tasks). Figure 3 plots the relationship between these language measures and the coin search task. Both language measures were positively correlated with performance on the coin search (Self: $r = .31$, $p = .005$; Other: $r = .27$, $p = .02$).

To explore the causal direction of this language-cognition correlation, we divided the children into passers and non-passers on the coin search and language tasks, looking separately at the egocentric (Self) vs. non-egocentric (combined Other) left-right language tasks. The criterion for "passing" each task was set at the minimum number of correct answers required to reach $p < .05$ by binomial distribution. Chance was set at the more stringent 0.50 level for the coin search task (as well as the language tasks for which there were only two possible responses) assuming that children would search on the correct, left-right axis. See the vertical and horizontal lines in Figures 3a and 3b that divide the children into four groups: those who passed both coin search and language, those who did not pass either, those who passed only on the coin search, and those who passed only on the language. Of interest are the latter two disconcordant groups. If cognition leads language, where being able to reason about others' left-right leads children to work out the non-egocentric uses of left-right terms, we should see that there are many more children who pass the coin search despite lacking the language than the reverse. If language leads cognition, where language learning leads to greater sensitivity to left-right relationships and the subsequent deployment of these relationships in problem-solving, we should find many more children who pass the language measures without passing the coin search. The results, as seen from Figure 3, support the latter. More children passed the Self task and failed the coin search ($N = 34$) than vice-versa ($N = 3$; Figure 3a). Likewise, more children passed the Other tasks and failed the coin search ($N = 24$) than vice-versa ($N = 7$; Figure 3b; McNemar tests, p's $< .001$). This relationship held for each group of children (see Table B.1, Appendix B for the breakdown by group).

We also examined whether children's spontaneous use of left-right terms on the elicitation task preceded their likelihood of deploying left-right relations in solving the coin search task. If so, we might expect to find more children who spontaneously produced left-right language and could not pass the coin search task than those who failed to spontaneously produce left-right language and could pass the coin search task. However, there was no clear relationship (McNemar tests, *p's* $> .06$) (see Figure A.1, Appendix A for all children and Table B.2, Appendix B for the breakdown by group). Although there were children who used left-right terms on the elicitation and did not pass the coin search, there were also children who did not spontaneously use left-right language but did very well on the coin search task. We note, however that whereas the self and other tasks directly assessed the children's understanding of left-right language, the elicitation task did not. There may have been children who, despite having learned left-right language, did not use it during the elicitation due to community norms and preferences for describing space. Thus, the elicitation may be less predictive of the children's coin search performance than the other language tasks.

[Figure 3 near here]

Lastly, we asked whether this relationship holds even controlling for the children's general ethnolinguistic group and community in a linear regression model. Given the high correlation and non-independent nature of Self and Other language measures ($r = .66$; $p < .001$), we first created a composite left-right language measure by taking the average of the Self and the Other language measures, which we then entered into our model to predict children's performance on the coin search task (see Figure 3c for the relationship). We then controlled for ethnolinguistic group (Tseltal = 0, Spanish = 1) and community (rural = 0, municipal center = 1; see Figure A.2, Appendix A for how each control individually relates to coin search scores). We also included a variable for whether the children used LR terms on the elicitation task (no = 0, yes = 1) to see whether such spontaneous deployment predicted performance apart from the children's scores on the language measures.[6] The strongest predictor of coin search performance was the composite language score (ß = .23, p = .05), followed by community (ß = .19, p = .14, n.s.), LR use on the elicitation task (ß = .14, p =

[6] Recall that many children who spontaneously used "left" and "right" terms did not use the words correctly. Their use, however, may be an indicator of whether the child was sensitive to the demands of the task even though s/he may not have correctly mapped those terms. We thereby included this variable but excluded the related variable of whether children correctly used these terms. Those who correctly used the terms also scored high on the language tasks, especially on the Other tasks. Thus, the term is highly correlated with the language tasks and does not add new information not captured by the composite language score.

.28, n.s.), and ethnolinguistic group (ß = -.05, p = .71, n.s.). The overall fit of the model was significant ($R^2 = .15$; $F(4,79) = 3.37$, $p = .01$). Importantly, even controlling for community and ethnolinguistic group, knowledge of left-right language was a significant predictor of coin search performance, while spontaneous use of left-right terms on the elicitation was not.

2.3. Discussion

In Experiment 1, we tapped children with variability in their exposure to left-right language, and hence variability in their mastery of such language. This variability allowed us to explore the necessity of language in promoting reasoning about non-egocentric left-right relationships. In doing so, we found a significant positive relationship between left-right language and task performance on a non-egocentric left-right perspective-taking task. This held for the children's use of left-right terms in their spontaneous elicitations as well as for their performance on our left-right Self and Other tasks. While this correlation has been suggested by previous studies that separately tested language (Rigal, 1994) and cognition (Lasky et al., 1980), this is one of the first studies to directly test the relationship using a within-subjects design and find such a result. Moreover, knowledge of left-right language was shown to predict coin search performance even controlling for community and ethnolinguistic group. Although our analysis does not rule out the possibility that other factors that vary at these levels may also promote task performance, our results support the hypothesis that left-right language in particular plays a causal role in children's acquisition of non-egocentric left-right perspective-taking skills over and above the contribution of such other factors.

Dividing the children into passers and non-passers on the language and coin search tasks, we found that there were many more children who passed the language tasks but did not pass the coin search task than vice-versa (see Figures 3a and b), and this relationship held across all three groups (see Appendix B). This shows that children's knowledge of left-right language outpaces the likelihood of spontaneously deploying this relationship in spatial problem-solving. Moreover, we note that the children's spontaneous use of "left" and "right" on the elicitation task was not a significant predictor of task performance in our regression model. This suggests that knowing to deploy these terms descriptively does not mean that children know to deploy them for problem solving (see also Miller et al., 2017; Miller et al., 2020 for a similar finding). There were some children, however, who passed the coin search task but did not pass the language tasks, indicating that while left-right language may help, it is not necessary to succeed on such a task.

In sum, while not deterministic, our results strongly suggest that there is a causal relationship between left-right language acquisition and task performance. How might language help on non-egocentric left-right perspective-taking tasks such as this? At a minimum, language focuses speakers' attention on certain distinctions, making them more salient than they would otherwise be. Such priming effects may underlie many of the weaker effects of language on cognition to have been demonstrated (e.g., Boroditsky, 2011; Landau et al., 2010; Wolff & Holmes, 2011). In our task, knowledge of left-right terms may have drawn the children's attention to the relevant dimension of the task – a notion that was suggested by the greater tendency of the rural Tseltal-speaking children to incorrectly search for the coin on the front-back axis (although we note that this could also have been due to other community-level factors).

Lexical labels also serve a mnemonic function that makes it easier to encode and retrieve spatial information. Studies suggest that language may allow for more efficient representations by compressing complex information, such as the cardinalities of large sets, into easy to encode and process lexical units (Frank et al., 2008; Spaepen et al., 2013). Simple lexical items like "left" and "right" become increasingly complex and abstract over development from labeling the sides of one's body, to regions of space around one's body, to regions of space around a ground object that is separate from one's body. Having a lexical label for each side may therefore make it easier for participants to encode and retrieve the coin's location, provided that they are able to correctly and consistently map these terms – a notion that was supported by the correlation between performance on the coin search task and our left-right Self and Other language tasks.

Acquiring lexical labels for "left" and "right' may also draw children's attention to left-right asymmetries more generally and help them extend, via analogy, such egocentric use of left-right to non-egocentric left-right concepts (Gentner, 2003). The use of left-right terms might facilitate task performance, for example, by highlighting the analogy between the children's own left-right and that of the sheep. This in turn might prompt the children to imagine their own body rotating and then to map this transformation onto the sheep.

In sum, there are three levels at which left-right language might help: first, by drawing attention to the relevant distinction; second, by serving as semantic packages for encoding and retrieving complex spatial relationships like non-egocentric left-right; and third, by facilitating mental rotation via an analogical mapping between egocentric and non-egocentric perspectives.

In Experiment 2, we therefore set out to establish whether there is a causal relationship between the acquisition of left-right language and task performance by explicitly teaching the children left-right terms and training them to apply them to the coin search task. One problem with such an approach, however, is the difficulty of mapping these terms consistently and correctly, as seen in the prolonged time period required for children to learn "left" and "right" (Rigal, 1994). This would make it difficult for the children to benefit from such instruction in a single testing session. The elicitation and language tasks in Experiment 1 confirmed that many Tseltal-speaking children were still confused about the use of "left" and "right" even from an egocentric perspective despite being exposed to these terms in school.

We also noted that while language may help, it may not be necessary to develop non-egocentric left-right concepts; Some of the children in our sample passed the coin search but not the language tasks. Notably, Li and Abarbanell (2018) found that similar-aged Tseltal-speaking children who had not yet acquired the use of left-right terms, were able to recreate complex arrays of objects from an egocentric left-right perspective when instructed using "this side" rather than "left" and "right". We therefore also asked whether training the children to use a nonlinguistic representational system such as gesture might be more advantageous than lexical labels for representing the relationship of the coin to the sheep.

It is possible that lexical labels are more economical and effective than gestures for encoding and retrieving complex spatial information. Alternatively, having the children gesture by moving their own arm/hand to mark the side of the sheep where the coin is hidden would draw attention to the relevant dimension of the task and provide them with a means for encoding and recalling the coin's location while avoiding the difficulty of learning left-right language. Moreover, we note that gestures are inherently spatial (McNeill, 1992) and are particularly suited for representing spatial information (e.g., Emmorey et al., 2000; Schaal et al., 2005; So et al., 2015). In particular, studies suggest that gestures may improve performance on mental rotation tasks. Ehrlich, Levine, and Goldin-Meadow (2006) found that the more gestures children produced when asked to explain how they solved a spatial transformation task involving translation and mental rotation, the better their task performance. They noted that the children often conveyed strategies in gesture that were not expressed in their speech. Similarly, Chu and Kita (2008) found that adults who used gestures when verbally describing solutions to a mental rotation task showed a greater abstraction of physical (agentive) action on the objects being rotated in both gesture and speech, reflecting an internalization of motor strategies and greater efficiency in problem solving. In our task, having the children move their own arms/hands might be better suited than lexical labels for highlighting the analogy between the children's own left-right and that of the sheep which in turn might facilitate their mental rotation of this relationship, as noted, by imaging their own rotation and then translating this onto the sheep.

It is possible, however, that neither modality – language nor gesture – will improve coin search performance as any advantages conferred may require more practice than a single training session. In Experiment 2, we therefore tested a new sample of Tseltal-speaking children who did not initially succeed on a pretest of the coin search task under two new conditions: a Language condition where we trained the children to recognize and label the location of the coin with respect to the sheep using left-right terms, and a Gesture condition, where we trained them to do so by moving their own corresponding arms/hands. For both groups, we asked whether the training improved the children's performance above that of a Control group that received no training but was given the same number of coin search trials as the other two groups. If so, this would support the hypothesis that left-right language and/or a nonlinguistic representational system such as gestures can play a causal role in promoting nonegocentric perspective-taking skills. Further, comparing performance between the Language and the Gesture groups will allow us to see whether lexical labels confer an advantage over a more direct or embodied representation or vice versa.

3.0. Experiment 2

3.1. Participants, Materials and Methods

3.1.1. Participants and Pretest

The same coin search task from Experiment 1 was used as a Pretest, or baseline, to test a new group of same-age Tseltal-speaking children for Experiment 2. We tested only children in the municipal center as the population there is greater and there were therefore more children to select from of this age range. On the basis of the Pretest, we kept children who scored less than 75% correct on the Pretest trials to test for the effect of training.[7] Of 54 children tested, 31 children (57.41% of the children) scored less than the 75% cut-off and were thereby included in Experiment 2. These children were randomly divided into three groups: a Control group (11 children: 6 girls; M_{age} = 11.57), a Language group (9 children: 4 girls; M_{age} = 11.84), and a Gesture group (11 children: 5 girls; M_{age} = 12.18).

3.1.2. Instructional Phase

After the Pretest trials there was an instructional phase (see Figure 4 for a diagram of the order of the tasks) where the children were taught to label the left and right sides of the sheep, and then introduced to the analogy of relating their own left-right sides with the sheep's left-right sides using either left-right terms or arm/hand movements for the Language and Gesture groups respectively (see Appendix C for the full transcript).

Both language and gesture manipulations were designed to draw attention to the relevant dimension of the sheep and to reinforce the processes of translation and mental rotation from the children's perspective to that of the sheep. For the Language group, the experimenter first asked, "Do you know which is your left/right hand? Raise your left/right hand." Any errors were corrected. The experimenter then pointed to the analogous sides of the sheep and explained, "The same as the sheep. This is his left/right side of the sheep," and pointing to the box at each side, "and this box is on his left/right side of the sheep." To ensure that the children understood that this referred to the sheep's left/right and not their own, the experimenter placed a coin on top of the box to the left/right side of the sheep in the starting position so that its left/right was aligned with that of the child, and asked which side of the sheep the coin was on. Any errors were corrected. Without removing the coin, the

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[7] We chose 75% correct as our cut-off since the lowest number of trials to reach a binomial probability < .05 is 5 out of 8, assuming the probability of success on a single trial is .25 based on all four boxes. Assuming a probability of .50 based only on left-right axis, the lowest number of trials correct would be 7 out of 8. We therefore chose 6 out of 8 as our cut-off point as an intermediary between the two.

experimenter rotated the apparatus 90° while the child watched and again asked what side of the sheep the coin was on. This was repeated for each of the four orientations. If the child made a mistake, the experimenter explained that the side of sheep had not changed; the apparatus had just turned. This procedure was repeated for the other side.

The Gesture group received a similar introduction but the children were trained to use arm/hand movements to label the sides of the sheep. The experimenter first explained that the children have two sides of their body, "this side" and "this side", touching each arm in turn. The children were then asked to raise each arm/hand[8] in turn while the experimenter pointed to the analogous side of the sheep and said, "The same as the sheep. This is *this side* of the sheep," and pointing to the corresponding box, "and the box over here is on *this side* of the sheep." A coin was then placed on top of the left/right box and the children were asked to raise their arm/hand that was the same as that side of the sheep. Without removing the coin, the question was repeated with the apparatus turned to each of the four orientations and was then repeated for the other side. Any errors were corrected as for the Language group. We note that the experimenter used both language and gestures in the instructions for both groups: The experimenter gave verbal instructions and pointed to the sides of the sheep. The crucial difference is that for the Language group, the children were trained to use *left-right lexical labels* to encode which side of the sheep the coin was on, while the children in the Gesture group were trained to use *arm/hand movements* instead.

The Other Pointing and Other Labeling tasks, which correlated with the children's performance on the coin search task in Experiment 1, were next adapted to reinforce the application of the left-right lexical labels or arm/hand movements to the sheep and the turntable apparatus. For the Language group, these trials were identical to those from

[8] In Tseltal, the same word, *k'ab*, is used for both hand and arm.

Experiment 1 except the children were given feedback after each trial. The Gesture group used arm/hand movements as described above rather than left-right terms. For the Pointing trials, a coin was placed on top of each left/right box. The experimenter then tapped one of the child's arms and asked, "Which of these coins is on *this side* of the sheep?" (*Ba junuk ay ta xujk ine yu'un te tunim chij?*). For the Labeling trials, a coin was placed on only one left/right box, and the experimenter asked, "*Raise your hand*, on which side of the sheep is the coin?" (*Becha a-k'ab, ta bi sk'ab ay yu'un te tunim chij?*).

3.1.3. Practice Phase (Applying Instruction to Coin Search Task)

While the instructional phase focused on introducing the children to labeling the left and right sides of the sheep using lexical labels or arm/hand movements, the practice phase that followed reinforced the application of left and right concepts for solving the coin search task. Children in both groups received 8 Practice trials where they were prompted to apply the cue they had just learned to the coin search task. For the Language group, on hiding the coin the experimenter said, "I'm hiding the coin on this side of the sheep. On which side of the sheep did I put the coin?" They were further prompted if needed, "On its left or its right?" Any errors were corrected. They were prompted to name the side again prior to retrieving the coin. For the Gesture group, on hiding the coin the experimenter said, "I'm hiding the coin on this side of the sheep. Raise your hand, on which side of the sheep did I put the coin?" They were prompted again prior to retrieval (also see Appendix C for transcript).

3.1.4. Post-test and Language Assessment

The Practice trials were followed by 8 Posttest trials identical to the Pretest trials where no prompts or cues were used. These were followed by a language assessment phase that consisted of the language elicitation and the left-right Self task from Experiment 1.

The Control group received no additional instructions, cues, or prompts, but instead were given the same number of coin search trials in three identical blocks: 8 Pretest, 8

Practice, and 8 Posttest trials. These trials were followed by the language assessment phase that consisted of the language elicitation, the left-right Other tasks (Pointing and Labeling) without any instruction or feedback, and the left-right Self task.

[Figure 4 near here]

3.2. Results

We first explored whether children improved on the coin search task as the result of the training. Then we examine the effectiveness of the instructional trials, followed by their performance on the language tasks. Figure 5a plots the improvement on the coin search task across blocks: pre-test versus practice and post-test. Independent-samples t-tests of the pre-test scores confirmed that the three groups were equivalent at the start of the task (M_{CONTROL} = 54.55%, M_{LANGUAGE} = 41.67%, M_{GESTURE} = 50.00%; all *p*'s > .07). We then calculated the gains on the Practice over the Pretest, and the Posttest over the Pretest for each child and compared the average gains across the three groups (Practice-Pretest: M_{CONTROL} = 5.68%, M_{LANGUAGE} = 38.89%, M_{GESTURE} = 26.14%; Posttest-Pretest: M_{CONTROL} = 14.77%, M_{LANGUAGE} = 27.78%, M_{GESTURE} = 38.64%). One-sample *t* tests comparing the average gains for each group against 0, revealed significant gains on both the Practice and Posttest trials for the Language (*p*'s < .01) and Gesture (*p*'s < .001), but not the Control group (*p*'s > .05). A 2(Gain Type: Practice-Pretest, Posttest-Pretest) x 3(Condition: Control, Language, Gesture) ANOVA[9] confirmed that there was a main effect of Condition ($F(2, 28) = 6.24$. $p = .006$, $\eta_p^2 = .31$) that varied by the type of Gain ($F(2, 28) = 4.06$, $p = .03$, $\eta_p^2 = .23$). Overall, both the Language (33.33%) and the Gesture (32.39%) groups showed greater gains than the Control (10.23%) (post-hoc analyses with Bonferroni corrections, p's < .02). One-way ANOVAs

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[9] We also ran the same analysis with the Self task scores as a covariate. This was the one measure of left-right knowledge that was given across the three groups. We used it to control for effects of left-right knowledge on coin search performance. The results remain the same with a main effect of Condition ($F(2, 27) = 6.95$, $p = .004$, $\eta_p^2 = .34$) and a Condition x Gain Type interaction ($F(2, 27) = 3.92$, $p = .03$, $\eta_p^2 = .23$). No other effects were significant (*p*'s > .18).

confirmed that the effect of Condition was significant for each type of gain: Practice-Pretest ($F(2,28) = 8.40$, $p = .001$, $\eta_p^2 = .38$); Posttest-Pretest ($F(2,28) = 3.60$, $p = .04$, $\eta_p^2 = .21$. Post-hoc analyses with Bonferroni corrections, however, showed that while both the Gesture and Language group had greater gains than the Control group on the Practice trials (p's = .04 and .001 respectively), only the Gesture group showed greater gains on the Posttest (p's = .04 and .53 respectively). In sum, while both types of training were effective, the gesture training appeared to be more robust: When the children were prompted by the experimenter to apply their newly learned strategy to the task, both groups showed significantly greater gains than the control. When this prompting was taken away, however, only the Gesture group continued to show significantly greater gains. The Language group seemed to revert back to whatever strategy they had previously used.

3.2.1. Performance on the Instructional Trials

We next explored the children's performance during the instructional period (see Figure 4 for where the Instruction phase occurred in the procedure) to examine the effectiveness of teaching children how to think about the sides of the sheep. Recall that the structure of these trials was parallel for the Language and Gesture groups: Both groups were taught and tested on how to represent the left and right sides of the sheep, but the Language group did so using left-right terms while the Gesture group used arm/hand movements. Both groups received feedback if they responded incorrectly. The Control group did not receive any training but were tested in the same modality as the Language group at the very end of the experiment and received no feedback as in Experiment 1. As such, the Control group served as a baseline comparison. Figure 5b plots the results for the two tasks by condition. An ANOVA with Task (Other Pointing, Other Labeling) by Condition (Control, Language, Gesture) yielded no main effects (p's > .21) or interaction ($p = .80$). Thus, the benefit of instructions was not initially observed during the instructional phase despite gains on the practice and post-test trials of the coin search. Noteworthy, children in the Gesture condition did score the highest, though not significantly higher than the other two groups (Combined Other Score: $M_{GESTURE}$ = 81.82% correct vs. $M_{LANGUAGE}$ = 68.06% vs. $M_{CONTROL}$ = 67.05%). It is also worth noting that the Language group did no better than the Control on these tasks, even though they were given direct instruction on the use of left-right terms and feedback after each trial, testifying to the difficulty of acquiring these terms.

3.2.2. Language Task Performance

We next examined children's understanding of left-right language via the language elicitation and left-right Self language tasks, both of which were given at the end of all tasks for all three groups. Recall that the children in Experiment 2 were selected on the basis of their low coin search score on the Pretest, and it is likely that these children would also have low left-right scores. However, the Language group was trained to use left-right terms to label the sides of the sheep. Given that the language instructions did improve these children's performance on the coin search task, at least during the Practice trials, we thereby expect this group to use these terms more frequently and accurately on the elicitation task and to show the most improvement on the Self task. The overall distribution of the children's responses for the elicitation task is presented in Table 2. As expected, all of the nine children in the Language group used "left" and "right". Fisher's exact test confirmed that this was significantly higher than in either of the other two groups (p's < .001). None of the children in the Gesture group and only one child in the Control group used these terms, and that child did so incorrectly. Similar to Experiment 1, the children in the Control and Gesture groups mostly used intrinsic non-left-right terms to describe the location of the coin ("at its side", "at its ribs"). However, while almost all of the children in the Language group mapped "left" and "right" correctly on the left-right axis, some also used these terms on the front-back axis. The emphasis on these terms during the task may have prompted the children to overextend them

– a notably higher proportion did so than in the Control group (Fisher's exact test $p = .02$). Nevertheless, it demonstrates that despite direct instruction in the use of "left" and "right", many children were still unsure of the exact nature and extent of their use.

[Table 2 near here]

The left-right Self task provides further evidence that the Language group did not robustly learn "left" and "right". Recall that this task, which was given at the end of the experiment for all three groups, tested the children's ability to respond to simple commands about their own left and right. A one-way ANOVA showed no effect of Condition ($p = .79$) and all three groups were at chance ($M_{\text{CONTROL}} = 68.18\%$, $M_{\text{LANGUAGE}} = 61.11\%$, $M_{\text{GESTURE}} = 56.82\%$; all p's > .15). Further, we note that the children's performance on this task was not correlated with their gains on the Practice (Practice-Pretest) or the Posttest (Posttest-Pretest) trials (p's > .25). That is, the children's knowledge of egocentric left-right language was not associated with the effectiveness of the Language or the Gesture training. These difficulties with left-right language in turn may help to explain the differential effectiveness of each type of training, as we explore in the discussion.

[Figure 5 near here]

3.3. Discussion

Experiment 1 revealed a robust positive correlation between left-right language and performance on the coin search task. Moreover, our analysis suggested that the acquisition of left-right language actually leads cognition in this case. This is not to say that left-right language is necessary for children to perform well on such tasks, nor is it the only factor that can affect performance, but our data suggest that language can play a role in promoting nonegocentric left-right perspective-taking skills. In Experiment 2, we further explored the causal nature of this relationship. First, we asked whether directly instructing children in the meaning and use of left-right terms on the coin search task would improve task performance.

Second, we asked whether language would have an advantage over a more direct, embodied representational system such as gestures that might be better suited for representing and manipulating spatial information. The left-right Pointing and Labeling trials from Experiment 1 were used to train the children in the Language and Gesture groups in Experiment 2 to identify, label and track the left and right sides of the sheep. Children in the Language group were trained to use left/right lexical labels and in the Gesture group to move their own corresponding arms/hands. Surprisingly, despite receiving direct instruction and feedback on these trials, neither group showed significantly better performance on these tasks when compared with the Control group, attesting to the difficulty of robustly acquiring these mappings. Nevertheless, both groups showed significantly greater gains on the coin search than the Control, which received only additional practice with the task. The Language and Gesture groups, however, benefitted differently from their respective training. The children who were trained to use left-right lexical labels showed greater gains only on the Practice trials immediately following the instructional period, where they were explicitly prompted to apply their newly learned strategy. When these prompts were taken away on the Posttest trials, they showed no difference in performance over the Control group. In contrast, the children who were trained to use arm/hand movements showed significantly greater gains on both Practice and Posttest trials; they continued to improve even after the explicit prompts to gesture were taken away.

Although left-right language may help children attend to and encode nonegocentric left-right relationships, if they do not already have a stable mapping of these terms, they may need more than one training session to fully benefit from their use. The cognitive cost of having to track which side of the sheep was labeled “left” or “right”, which are essentially arbitrary mappings, may have prompted children in the Language group to revert back to not using the taught strategy on the Posttest trials. In contrast, the children in the Gesture group did not have to contend with such potentially confusing left-right language. The children in the Language group did use left-right terms on the elicitation task, and most mapped them correctly on the left-right axis; however, many children also used these terms to describe the boxes to the sheep's front and back. Despite direct training, they were unsure of the exact nature and extent of the use of these terms. That the Language group was at chance on the left-right Self task just like the Gesture and Control groups, provides further evidence of the difficulty of acquiring these terms. It could be the children needed more input than just a single training session; they may also have needed more explicit and transparent instructions that these are body-derived terms and not just oppositional terms along an axis (see Appendix C and contrast Language vs. Gesture's Mapping on Self of the instructional phase).

In sum, our Gesture training, in contrast to our Language training, was better retained, concurring with other studies in the literature that suggest that gestures are more effective than language for representing spatial information, particularly for mental rotation tasks (e.g., Chu & Kita, 2008; Ehrlich et al., 2006). In the next section, we discuss some of the reasons why gestures – particularly the arm/hand movements by the children to highlight the analogous relationship on the sheep – may be more effective than lexical labels for representing and retaining this type of information.

4.0. General Discussion

The present studies make a new contribution to an ongoing debate regarding whether and how the spatial frames of reference used by a language community shape speakers' nonlinguistic spatial representations. Prior work, as noted in the introduction, has primarily focused on viewpoint-dependent language and egocentric representations (e.g., Haun et al., 2011; Li et al., 2011; Li & Gleitman, 2002; Pederson et al., 1998), or left-right language and egocentric left-right representations (Dessalegn & Landau, 2008; Hermer-Vazquez et al., 2001; Pyers et al., 2010; Ratliff & Newcombe, 2008; Shusterman et al., 2011). The present studies extend this work by focusing on left-right language and non-egocentric left-right representations. Our findings support the hypothesis that left-right language can promote cognitive development at later stages of acquisition involving non-egocentric left-right relationships, although it is not necessary and may not be the most efficient system.

In Experiment 1, we made use of naturally-occurring variation in the understanding of “left” and “right” among Tseltal- and Spanish-speaking children in the municipality of Tenejapa, Chiapas, Mexico, who were comparable in their age and educational experiences but were expected to vary in their exposure to “left” and “right”. The children’s performance on the coin search task correlated strongly with their use and understanding of left-right language, as measured by post-task language elicitation and comprehension tasks. A regression analysis retained our left-right combined language measure as a significant predictor of coin search performance, even controlling for ethnolinguistic group and community. Moreover, we found that more children could be considered to have ‘passed’ the left-right language tasks and ‘failed’ on the coin search than vice-versa, suggesting that language learning leads task performance in this case. In other words, there were many children who could correctly identify and label the sides of the sheep and yet did not think to use that relationship to solve the coin search task. Given the isomorphic nature of the language (Other Pointing/Labeling) tasks and the coin search task, this finding shows that independent of the possibility that language learning could give rise to new capacities or tools to reason about others’ left or right, deployment of such capacities in problem solving is promoted and made salient by the frequent use of left-right language.

In Experiment 2, we directly tested the causal nature of this relationship using a training study in which we compared children who were trained to use left-right lexical labels versus arm/hand movements to see whether language has an advantage over a nonlinguistic representational system such as gestures. We hypothesized that there were three levels at which the acquisition of left-right language might have an effect: by drawing children's attention to the relevant dimension of the task, by providing a mnemonic for remembering and recalling the location of the coin, and by drawing an analogy between the children's left-right and that of the sheep. This last level was predicted to be particularly useful for promoting mental rotation of the child's own perspective to match that of the sheep. Our instructions (see Appendix C) provided training at all three levels: we pointed out the sides of the sheep, taught the children to represent the left/right sides of the sheep using lexical labels or arm/hand movements, and explicitly emphasized the connection between the children's left/right sides and those of the sheep. We also demonstrated the rotation of these left/right representations together with the rotation of the sheep.

While lexical labels might be efficient for representing complex information, gestures were predicted to be better suited for representing spatial information and assisting with mental rotation. Tellingly, both types of training were effective on the Practice trials, suggesting that either type of representation helps. When explicitly prompted to use their newly learned strategy, both groups showed significant gains in performance when compared with a control that was simply given additional practice with the task. At a minimum, as noted, both types of training drew attention to the relevant dimension of the task. On the Posttest trials, however, when the experimenter stopped explicitly prompting the children to apply the newly taught strategy, only the Gesture group continued to show significant gains. The Language group seemed to stop applying this strategy as their performance looked no different from that of the Control. This suggests that these representation were functioning as more than just an attention-directing device.

One reason the gesture training may have been more effective than using left-right lexical labels concerns the difficulty of learning left-right terms. Even other species such as rats have been shown to be capable of distinguishing left from right (see Corballis & Beale, 1976, 1983). Mastery of left-right language, however, is a separate skill (Sholl & Egeth, 1981; Maki et al., 1979). As noted, mapping essentially arbitrary terms consistently and correctly to each side of one's body takes time even for English-speaking children to master and continues to be a source of confusion for many adults (Wolf, 1973). It is important to distinguish, therefore, between studies that test children's left-right language vs. those that assess their nonlinguistic left-right cognition. For example, as mentioned previously, Li and Abarbanell (2018), found that by tapping children on each side of their body and referring to each side as "this side" rather than "left" or "right", 10-12 year-old Tseltal-speaking children were able to reproduce a previously memorized array of toy animals using their own left-right perspective after turning to face a new orientation. Despite being at chance on a left-right language assessment, their performance was no worse than that of same-age English-speaking children. Haun et al. (2011), who tested Hai//om-speaking children on a similar task – Hai//om is a Namibian language that, like Tseltal, prefers a geocentric reference system – likely underestimated their ability for using an egocentric left-right reference frame by using the lesser-used and underdeveloped Hai//om left-right terms in their instructions. In the present study, we tried to avoid this problem by using the Spanish terms for "left" and "right" which the children are taught in school, and our training taught and reinforced their meaning and application to the coin search task. Nevertheless, the children likely required more than a single training session to master and effectively deploy these terms. While the training for the Language condition was not entirely ineffective, the training for the Gesture condition – similar to the "this side" instructions in the animals task just mentioned – avoided this difficulty and was therefore better retained.

Our training for the Gesture group, however, went beyond simply instructing the children that there are two sides to their bodies and that this is similar to the sheep; the children were trained to actually move their own arm/hand as an embodied representation of this relationship. There are other reasons why gestures may be more effective than lexical labels for representing nonegocentric left-right relationships. Gestures, as previously noted, can convey information that is not encoded in speech and are particularly suited for representing spatial information or information that may be spatially expressed (Goldin-Meadow, 2003; Goldin-Meadow et al., 1993). Gestures may also serve as a link between implicit and explicit knowledge (McNeill, 1992). Children often begin expressing new strategies for problem solving in their gestures, which may indicate readiness to learn a new concept (Alibali, 1999; Church & Goldin-Meadow, 1986; Perry et al., 1988; Perry & Elder, 1997). Accordingly, people solving problems involving spatial transformations are shown to frequently gesture (Trafton et al., 2006), which helps bring implicit knowledge into active use. For example, the number of gestures children produced when explaining their solutions to a transformation task involving translation and mental rotation was found to be correlated with their performance (Ehrlich et al., 2006). The children frequently conveyed strategies in their gestures that were not conveyed in speech, and children who performed better on the task often referred to movements in their gestures and not in their speech.

Both gestures and lexical labels could serve as means of cognitive offloading, however gestures, being inherently spatial, are a better medium for working out spatial problems and may make lower demands on working memory when compared with speech (Goldin-Meadow et al., 2001; Wagner et al., 2004). Thus, gestures could lead to better retention and retrieval than lexical labels, as evident by the continued gains among the gesture but not the language group on the posttest trials in Experiment 2. Moreover, the embodied nature of gestures likely made the instruction for our Gesture condition more informative and transparent of the spatial computation that children should use to solve the coin search task. In our task, during the Instruction phase, we explicitly demonstrated that the labels (whether lexical or gestural) remained invariant with the sides of the sheep as it was rotated into different orientations by having the child either say which side of the sheep the coin was on or by raising the arm/hand on the corresponding side of his or her own body. The latter may be better suited for activating one's own body-based representation of the relevant relationship which may help children imagine or even mimic their own rotation with the sheep.

As Chu and Kita (2008, p. 721) note, gestures can enrich people's motoric experience, providing a "vivid first-hand experience of the nature of a problem". Lexical labels, in contrast, are abstracted from such motor strategies and may therefore be less effective for developing mental rotation skills. In addition, moving one's arm breaks the visual symmetry in a way that lexical labels cannot provide, just as putting a bracelet or other markers on one hand helps children remember which side is "left" or "right" (see Exp. 6, Shusterman & Li, 2016a; Newcombe & Huttenlocher, 1992). Such hypotheses fit in with theories of the embodied nature of cognition which posit that cognition is deeply rooted in the body's interaction with the world (Chu & Kita, 2008; Goldin-Meadow, 2016).

These benefits, importantly, do not result in actual changes in perception, but rather enhancements in specific aspects of cognitive processing through practice, the freeing up of working memory, and facilitating some form of analogical mapping through the use of body-based representations.

5.0 Summary

What is the relationship between spatial language and spatial cognition? Despite linguistic communities converging upon different means to communicate about space, results from a variety of studies now demonstrate that learning linguistic frames of reference is unlikely to alter basic spatial perception (Li et al., 2011; Li & Abarbanell, 2018, 2019; Gallistel, 2002; Newcombe 2017; Landau, Dessalegn, & Goldberg, 2010; see however Levinson, 1996, 2003; Majid et al., 2004; Lupyan, 2012 for alternative views). Nevertheless, learning spatial language may help speakers hone in on the dimension of relevance others have in mind for similarity judgment and analogical reasoning (e.g., Li & Gleitman, 2002; Loewenstein & Gentner, 2005; Haun et al. 2006). It may even highlight and make explicit an otherwise non-prominent relationship to consider for problem-solving (e.g., Dessalegn & Landau, 2008; Shusterman et al., 2011). The present work focuses on left-right language and adds to the body of research on language and cognition in an important way by suggesting the level and types of information where language might be predicted to have an effect – not by restructuring basic perceptual processes as some researchers have argued, but by extending these processes to novel contexts and domains where they are less readily given by our embodied cognition. Our findings show that learning left-right language promotes awareness of non-egocentric left-right relationships and can serve as a tool for encoding and assisting in cognitive processing. However, our findings also show that language may not necessarily be the most optimal system to do so.

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References

Abarbanell, L. (2010). *Words and Worlds: Spatial Language and Thought among the Tseltal Maya of Chiapas, Mexico*. Unpublished doctoral dissertation. Harvard University Graduate School of Education.

Abarbanell, L. & Li, P. (2009). Spatial frames of reference and perspective taking in Tseltal Maya, *Proceedings of the 33rd Annual Boston University Conference on Language Development*. Somerville, MA: Cascadilla Press.

Alibali (1999). How children change their minds: strategy change can be gradual or abrupt. *Developmental Psychology, 35,* 127-145.

Baillargeon, R., Spelke, E.S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition, 20*, 191-208.

Bohnemeyer, J. & Levinson, S.C. (2011). Framing Whorf: A response to Li et al. (2011). Unpublished manuscript. https://cse.buffalo.edu/~rapaport/575/S11/Bohnemeyer_Levinson_ms.pdf

Boroditsky, L. (2011). How language shapes thought: the languages we speak affect our perceptions of the world. *Scientific American,* February, 2011, 63-65.

Bowerman, M. & Levinson, S.C. (2001). *Language acquisition and conceptual development*. Cambridge, UK: Cambridge University Press.

Brown, P. (2006). A sketch of the grammar of space in Tzeltal. In S. C. Levinson, & D. Wilkins (eds.), *Grammars of space* (pp. 230-272). Cambridge, UK: Cambridge University Press.

Brown, P. & Levinson, S.C. (1992). 'Left' and 'right' in Tenejapa: investigating a linguistic and conceptual gap. *Z. Phon. Sprachwiss. Kommun.forsch (ZPSK), 45*(6), 590-611.

Brown, P. & Levinson, S.C. (1993a). *Linguistic and nonlinguistic coding of spatial arrays: Explorations in Mayan cognition.* Nijmegen: Cognitive Anthropology Research Group at the Max Planck Institute for Psycholinguistics.

Brown, P. & Levinson, S.C. (1993b). "Uphill" and "downhill" in Tzeltal. *Journal of Linguistic Anthropology, 3*(1), 46-74.

Carey, S. (2009). *The origin of concepts.* Oxford, UK: Oxford University Press.

Chu, M. & Kita, S. (2008). Spontaneous gestures during mental rotation tasks: insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General, 137*(4), 706-723.

Church, R.B. & Goldin-Meadow, S. (1986). The mismatch between gesture and speech as an index of transitional knowledge. *Cognition, 23*, 43-71.

Clark, H. (1973). Space, time, semantics and the child. In T. Moore (ed.), *Cognitive development and the acquisition of language* (pp. 27-63). New York: Academic Press.

Cole, M. (2005). Cross-cultural and historical perspectives on the developmental consequences of education. *Human Development, 48*, 195-216.

Cole, M., Gay, J., Click, J.A., & Sharp, D.W. (1971). *The cultural context of learning and thinking.* New York, NY: Basic Books.

Corballis, M.C., & Beale, I.L. (1976). *The psychology of left and right.* Hillsdale, N.J.: L. Erlbaum Associates.

Corballis, M.C., & Beale, I.L. (1983). *The ambivalent mind: the neuropsychology of left and right.* Chicago: Nelson-Hall.

Dessalegn, B. & Landau, B. (2008). More than meets the eye: The role of language in binding and maintaining feature conjunctions. *Psychological Science, 19*(2), 189-195.

Ehrlich, S.B., Levine, S.C., & Goldin-Meadow, S. (2006). The importance of gesture in children´s spatial reasoning. *Developmental Psychology, 42*(6), 1259-1268.

Emmorey, K., Tversky, B. & Taylor, H.A. (2000). Using space to describe space: perspectives in speech, sign, and gesture. *Spatial Cognition and Computation, 2*, 157-180.

Frank, M.C., Everett, D.L., Fedorenko, E., & Gibson, E. (2008). Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition, 108*(3), 819-824.

Gallistel, C.R. (2002). Language and spatial frames of reference in mind and brain. *Trends in Cognitive Sciences, 6*(8), 321.

Gentner, D. (2003). Why we're so smart. In D. Gentner & S. Goldin-Meadow (eds.), *Language in mind: advances in the study of language and thought.* (pp. 195-235). Cambridge, MA: MIT Press.

Gentner, D., & Goldin-Meadow, S. (eds.) (2003). *Language in mind: advances in the study of language and thought.* Cambridge, MA: MIT Press.

Goldin-Meadow, S. (2003). *Hearing gesture: how our hands help us think.* Cambridge, MA: Harvard University Press.

Goldin-Meadow, S. (2018). Taking a hands-on approach to learning. *Policy Insights from the Behavioral and Brain Sciences*, 5(2), 163–170.

Goldin-Meadow, S. (2016). Using our hands to change our minds. *Wiley Interdisciplinary Reviews: Cognitive Science*, 8(1-2), 1-6. doi: 10.1002/wcs.1368.

Goldin-Meadow, S., Alibali, M.W., & Church, R.B. (1993). Transitions in concept acquisition: using the hand to read the mind. *Psychological Review, 100*, 279-297.

Goldin-Meadow, S., Nusbaum, H., Kelly, S.D., & Wagner, S. (2001). Explaining math: gesturing lightens the load. *Psychological Science, 12*(6), 516-522.

Gumperz, J.J., & Levinson, S.C. (eds.) (1996). *Rethinking linguistic relativity*. Cambridge, UK: Cambridge University Press.

Hale, S. (1990). A global developmental trend in cognitive processing speed. *Child Development*, 61 (3), 653-663.

Harris, P.L. (2012). Trusting what you're told: how children learn from others. Cambridge, MA: Harvard University Press.

Haun, D. B. M., Rapold, C. J., Call, J., Janzen, G. & Levinson, S. C. (2006). Cognitive cladistics and cultural override in Hominid spatial cognition. *Proceedings of the National Academy of Sciences of the USA, 103*(46), 17568-17573.

Haun, D. B. M., Rapold, C. J., Janzen, G., & Levinson, S. C. (2011). Plasticity of human spatial memory: Spatial language and cognition covary across cultures. *Cognition*, *119*(1), 70-80.

Hermer-Vazquez, L., Moffet, A. & Munkholm, P. (2001). Language, space, and the development of cognitive flexibility in humans: the case of two spatial memory tasks. *Cognition, 79*(3), 263-299.

Hermer-Vazquez, L., Spelke, E.S., & Katsnelson, A.S. (1999). Sources of flexibility in human cognition: Dual-task studies of space and language. *Cognitive Psychology, 39*(1), 3-36.

Hernández-Green, N., Palancar, E.L., Hernández-Gómez, S. (2011). The Spanish loanword *lado* in Otomi spatial descriptions. *Language Sciences, 33*, 961-980.

Hertz, R. (1907/1960). *Death and the right hand*. Glenco, IL: Free Press.

Johnston, J. R. (1988). Children's verbal representation of spatial location. In J. Stiles-Davis, M. Kritchevsky, & U. Bellugi (Eds.), *Spatial cognition: Brain bases and development* (pp. 195-205). Hillsdale, NJ: Lawrence Erlbaum Associates.

Johnston, J. R., & Slobin, D. I. (1979). The development of locative expressions in English, Italian, Serbo-Croatian, and Turkish. *Journal of Child Language*, 6(3), 529-545.

Kail, R., Pellegrino, J., Carter, P. (1980). Developmental changes in mental rotation. *Journal of Experimental Child Psychology*, 29 (1), 102-116.

Kant, I. (1768/1991). On the first ground of the distinction of regions in space. In J. van Cleve & R.E. Frederick (eds.), *The philosophy of left and right: incongruent counterparts and the nature of space* (pp. 27-34). Dordrecht: Kluwer.

Kuczjac, S. A. & Maratsos, M. P. (1975). The acquisition of front, back and side. *Child Development*, 46(1), 202-210.

Landau, B., Dessalegn, B., & Goldberg, A.M. (2010). Language and space: Momentary interactions. In P. Chilton and V. Evans (Eds.), Language, cognition and space: The state of the art and new directions. Advances in Cognitive Linguistics Series (Ed, V. Evans, B. Bergen, J. Zinken). London: Equinox Publishing.

Lasky, R.E., Romano, N., & Wenters, J. (1980). Spatial localization in children after changes in position. *Journal of Experimental Child Psychology*, 29(2), 225-248.

Levine, S. C. & Carey, S. (1982). Up front: The acquisition of a concept and a word. *Journal of Child Language*, 9(3), 645-657.

Levinson, S.C. (1996). Frames of reference and Molyneux's question: cross-linguistic evidence. In P. Bloom, M.A. Peterson, L. Nadel, & M.F. Garrett (eds.), *Language and space* (pp. 109-169). Cambridge, MA: The MIT Press.

Levinson, S.C. (2003). *Space in language and cognition: Explorations in cognitive diversity.* Cambridge, UK; New York: Cambridge University Press.

Levinson, S.C., & Wilkins, D. (2006). *Grammars of space.* Cambridge: Cambridge University Press.

Li, P. & Abarbanell, L. (2018). Competing perspectives on frames of reference in language and thought. *Cognition*, 170, 9-24.

Li, P. & Abarbanell, L. (2019). Alternate spin on phylogenetically inherited spatial reference frames. *Cognition,* 191, 103983. https://doi.org/10.1016/j.cognition.2019.05.020

Li, P., Abarbanell, L., Gleitman, L., & Papafragou, A. (2011). Spatial reasoning in Tenejapan Mayans. *Cognition, 120*(1), 33-53.

Li, P. and Gleitman, L.R. (2002). Turning the tables: Language and spatial reasoning. *Cognition*, *83*(3), 265-294.

Loewenstein, J. & Gentner, D. (2005). Relational language and the development of relational mapping. *Cognitive Psycholo*gy*, 50*, 315-53

Lupyan, G. (2012). Linguistically modulated perception and cognition: the label feedback hypothesis. *Frontiers in Cognition*, 3(54). doi:10.3389/fpsyg.2012.00054

Luria, A.K. (1971). Towards the problem of the historical nature of psychological processes. *International Journal of Psychology, 6*, 259-272.

Lyons, J. (1977). *Semantics, Vols. I and II*. Cambridge: Cambridge University Press.

McNeill (1992). *Hand and mind: what gestures reveal about thought.* Chicago: University of Chicago Press.

Majid, A., Bowerman, M., Kita, S., Haun, D., & Levinson, S. (2004). Can language restructure cognition? The case for space. *Trends in Cognitive Science*, 8(3), 108-114.

Maki, R.H., Grandy, C.A., & Hauge, G. (1979). Why is telling right from left more difficult than telling above from below? *Journal of Experimental Psychology: Human Perception and Performance, 5*, 52-67.

Malt, B.C. & Wolff, P. (2010). *Words and the mind: how words capture human experience.* Oxford: UK: Oxford University Press.

Miller, G.A., & Johnson-Laird, P.N. (1976). *Language and perception*. Cambridge, MA; Belknap Press of Harvard University Press.

Miller, H. E., Vlach, H. A., Simmering, V. R. (2017). Producing spatial words is not enough: Understanding the relation between language and spatial cognition. *Child Development*, 88(6), 1966-1982.

Miller, H. E., Andrews, C. A., Simmering, V. R. (2020). Speech and gesture production provide unique insights into young children's spatial reasoning. *Child Development*. https://srcd.onlinelibrary.wiley.com/doi/abs/10.1111/cdev.13396

Mishra, R.C., Dasen, P.R., & Niraula, S. (2003). Ecology, language, and performance on spatial cognitive tasks. *International Journal of Psychology, 38*, 366-383.

Newcombe, N. S. (2017). Cognitive development in comparative perspective: exploring the role of language acquisition in spatial, quantitative, and memory development. In Call, J., Burghardt, G.M., Pepperberg, I.M., Snowdon, C.T., & Zentall, T. (Eds.), *APA Handbook of Comparative Psychology: Vol. 1, Basic Concepts, methods, Neural Substrate, and Behavior* (pp. 403-425). Washington, DC: APA Books.

Newcombe, N. S., & Huttenlocher, J. (1992) Children's early ability to solve perspective-taking problems. *Developmental Psychology, 28* (4), 635-643

Pederson, E., Danziger, D., Wilkins, S., Levinson, S., Kita, S., & Senft, G. (1998). Semantic typology and spatial conceptualization. *Language, 74* (3) (1998), 557-589

Perry, M., Church, R.B., & Goldin-Meadow, S. (1988). Transitional knowledge in the acquisition of concepts. *Cognitive Development, 3*(4), 359-400.

Perry, M. & Elder, A.D. (1997). Knowledge in transition: adults; developing understanding of a principle of physical causality. *Cognitive Development, 12*, 131-157.

Piaget, J. (1928). *Judgment and reasoning in the child.* London: Rutledge & Kegan Paul.

Piaget, J. (1948/1995). The child's conception of space. In H. Gruber, & J. Vonèche, (Eds.), *The essential Piaget: an interpretive reference and guide* (pp. 576-642). Northvale, NJ: Jason Aronson Inc.

Polian, G. & Bohnemeyer, J. (2011). Uniformity and variation in Tseltal reference frame use. *Language Sciences, 33*, 868-891.

Pyers, J., Shusterman, A. Senghas, Spelke, E., A., & Emmorey, K. (2010). Evidence from users of an emerging sign language reveals that language supports spatial cognition. *Proceedings of the National Academy of Sciences*, *107*(27), 12116-12120.

Ratliff, K.R. & Newcombe, N.S. (2008). Reorienting when cues conflict. *Psychological Science, 19*(12), 1301-1307.

Rigal, R. (1994). Right-left orientation: Development of correct use of right and left terms. *Perceptual & Motor Skills, 79*(3), 1259.

Rigal, R.. (1996). Right-left orientation, mental rotation, and perspective-taking: When can children imagine what people see from their own viewpoint? *Perceptual & Motor Skills*, *83*(3): 831-843.

Rogoff, B. (1981). Schooling and the development of cognitive skills. In H.C. Triandis & A. Heron (Eds.), *Handbook of cross-cultural psychology, Vol. 4*. Rockleigh, NJ: Allyn & Bacon.

Schaal, A.G., Uttal, D.H., Levine, S.C., & Goldin-Meadow, S. (2005, May). *Children's gestures provide insight into their representations of space.* Poster presented at the annual meeting of the Midwestern Psychological Association, Chicago.

Sholl, M.J. & Egeth, H.E. (1981). Right-left confusion in the adult: a verbal labeling effect. *Memory and Cognition, 9*, 339-350.

Shusterman, A., Lee, S. A., & Spelke, E. S. (2011). Cognitive effects of language on human navigation. *Cognition, 120*, 186-201.

Shusterman, A. & Li, P. (2016a). Frames of reference in spatial language acquisition. *Cognitive Psychology. 88*, 115-161.

Shusterman, A. & Li, P. (2016b). A framework for work on frames of reference. In: Barner, D. and Baron, A., (Eds.), Core Knowledge and Conceptual Change, Oxford University Press.

So, W., Shum, P.L., & Wong, M.K. (2015). Gesture is more effective than spatial language in encoding spatial information. *The Quarterly Journal of Experimental Psychology, 68*(12): 2384-2401.

Spaepen, E., Coppola, M., Flaherty, M., Spelke, E., Goldin-Meadow, S. (2013). Generating a lexicon without a language model: Do words for number count? *Journal of Memory and Language*, 69(4), 496-505.

Taylor, H.A., & Tversky, B. (1996). Perspective in spatial descriptions. *Journal of Memory and Language, 35*(3), 371-391.

Trafton, J.G., Trickett, S.B., Stitzlein, C.A., Saner, L., Schunn, C.D., & Kirschenbaum, S.S. (2006). The relationship between spatial transformations and iconic gestures. *Spatial Cognition and Computation, 6*, 1-29.

Ünal, E., & Papafragou, A. (2016). Interactions between language and mental representations. *Language Learning, 66*, 554-580.

Wagner, S.M., Nusbaum, H. & Goldin-Meadow, S. (2004). Probing the mental representation of gesture: Is handwaving spatial? *Journal of Memory & Language, 50*(4): 395-407.

Woodward, A.L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition, 69*, 1-34.

Whorf, B.L. (1941/1956). The relation of habitual thought and behavior to language. In J.B. Carroll (Ed.) *Language, thought and reality: selected writings of Benjamin Lee Whorf.* Cambridge, MA: MIT Press.

Willis, S. L. & Schaie, K. W. (1988). Gender differences in spatial ability in old age: Longitudinal and intervention findings. *Sex Roles*, *18*(3), 189-203.

Wolf, S. M. (1973). Difficulties in Right-Left Discrimination in a Normal Population. *Archives of Neurology*, *29*(2), 128-129.

Wolff, P. & Holmes, K.J. (2011). Linguistic relativity. *Wiley Interdisciplinary Reviews: Cognitive Science, 2*(3), 253-265.

Wynn, K. (1992). Addition and subtraction by human infants. *Nature, 358*, 749-750.

Tables

Table 1. The percent of children in each language group that used left-right terms on the elicitation task in Exp. 1. Also showing the percent who used these terms correctly (no incorrect use), and the percent who used them incorrectly on the left-right axis and on the front-back axis.

	% of children who used LR terms	**% who used LR terms correctly (no incorrect use)**	**% who used LR terms incorrectly on LR axis**	**% who used LR terms incorrectly on FB axis**
Spanish (*N*=23)	**65.22**	43.48	17.39	8.38
Tseltal Center (*N*=27)	**25.93**	3.70	18.52	7.81
Tseltal Rural (*N*=30)	**6.67**	6.67	0	0

Table 2. The percent of children in each condition that used left-right terms on the elicitation task in Exp. 2. Also showing the percent who used these terms correctly (no incorrect use), and the percent who used them incorrectly on the left-right axis and on the front-back axis.

	% of children who used LR terms	**% who used LR terms correctly (no incorrect use)**	**% who used LR terms incorrectly on LR axis**	**% who used LR terms incorrectly on FB axis**
Control (*N*=11)	**9.1**	**0**	9.1	9.1
Gesture (*N*=11)	**0**	**--**	--	--
Language (*N*=9)	**100**	**33.3**	11.1	66.7

Figures

a) b)

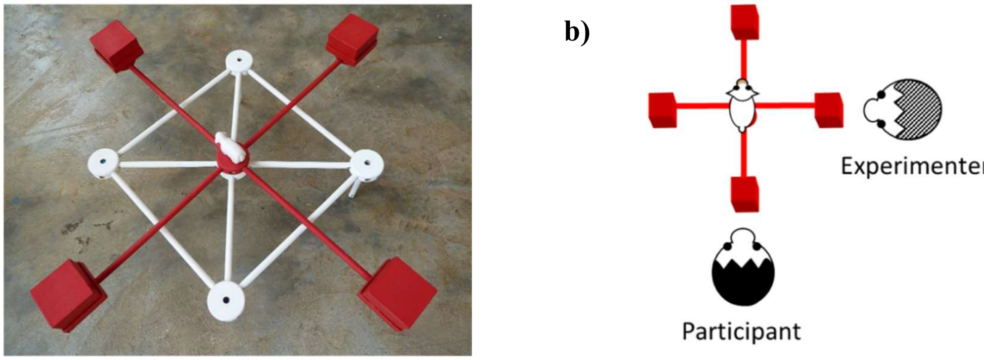

Figure 1. The apparatus and experimental set-up, showing (a) a photograph of the apparatus and (b) the position of the Experimenter and Participant.

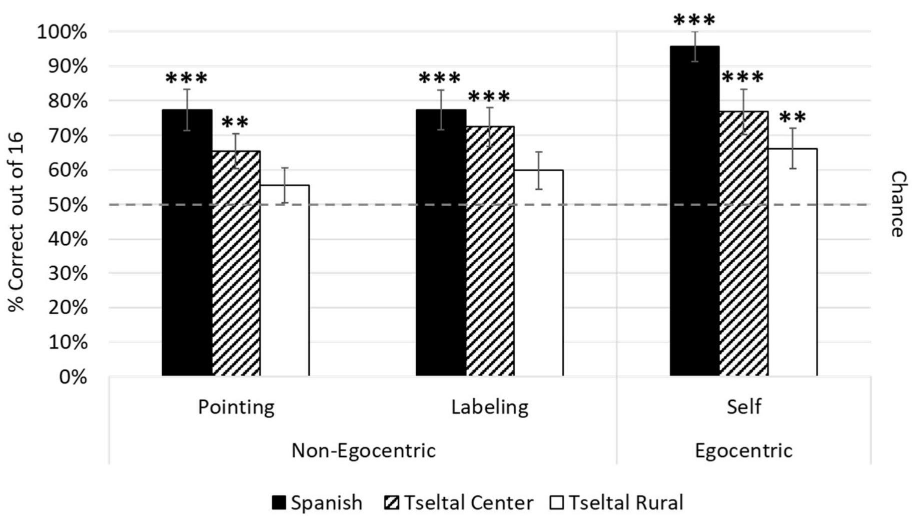

Figure 2. Percent correct on the Language Tasks for the Spanish, Tseltal Center, and Tseltal Rural groups in Experiment 1. Asterisks show significance above chance at the .50 level (*$p \leq .05$; ** $p \leq .01$, *** $p \leq .001$). This is the more stringent level of chance, assuming that the children would search for the coin on the left-right axis and not on the front-back axis.

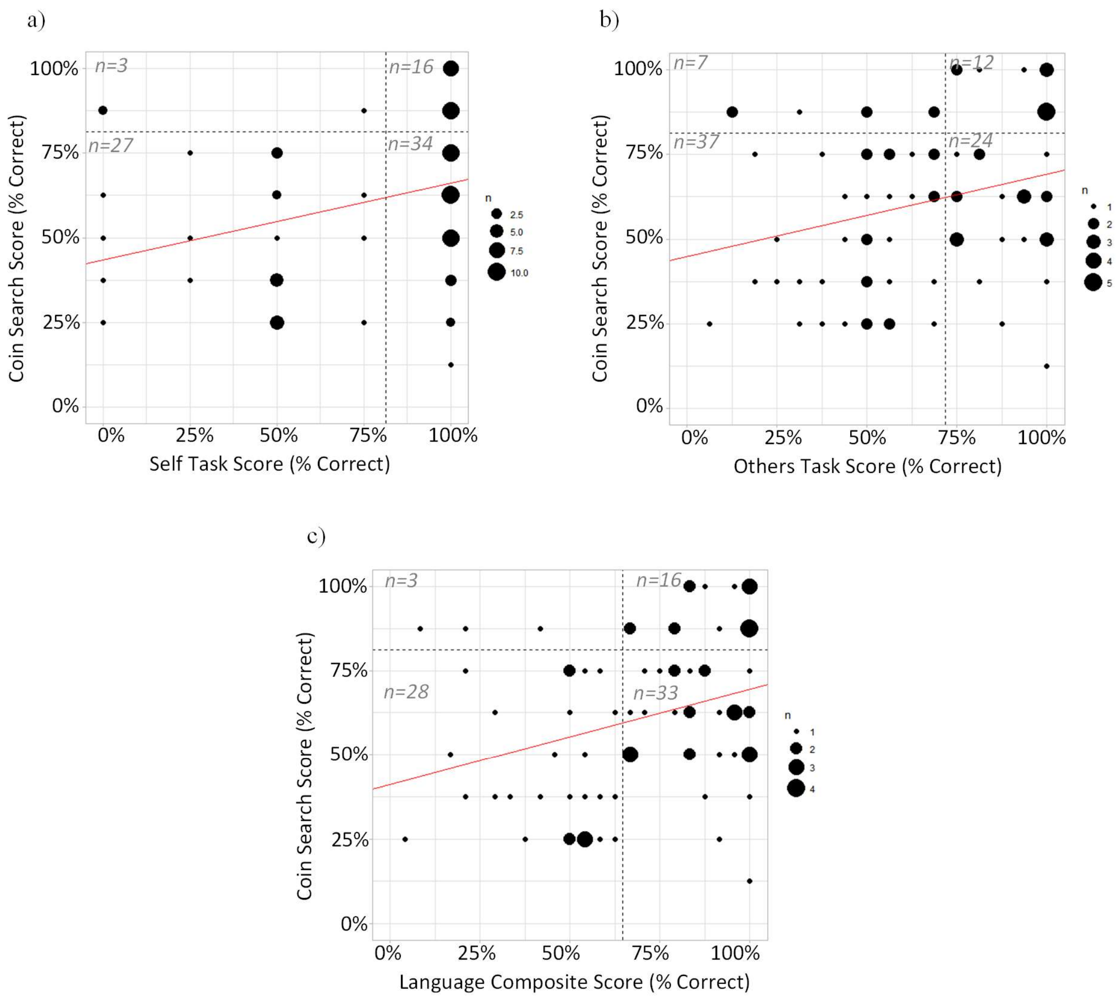

Figure 3. Relationship between coin search and left-right language comprehension when tested on (a) Egocentric left-right (Self Task) and on (b) Non-egocentric left-right (combined Other Pointing and Other Labelling Tasks) and on (c) Egocentric and Non-egocentric left-right combined (combined Self, Other Pointing, and Other Labelling tasks). The regression lines show a positive correlation when regressing language on coin search for all children tested. Children were further classified into four quadrants (see dashed lines) on the basis of those who passed or did not pass the respective tasks to show that there were more children who passed the language and did not pass the coin search than vice versa. See text for what constitutes passing.

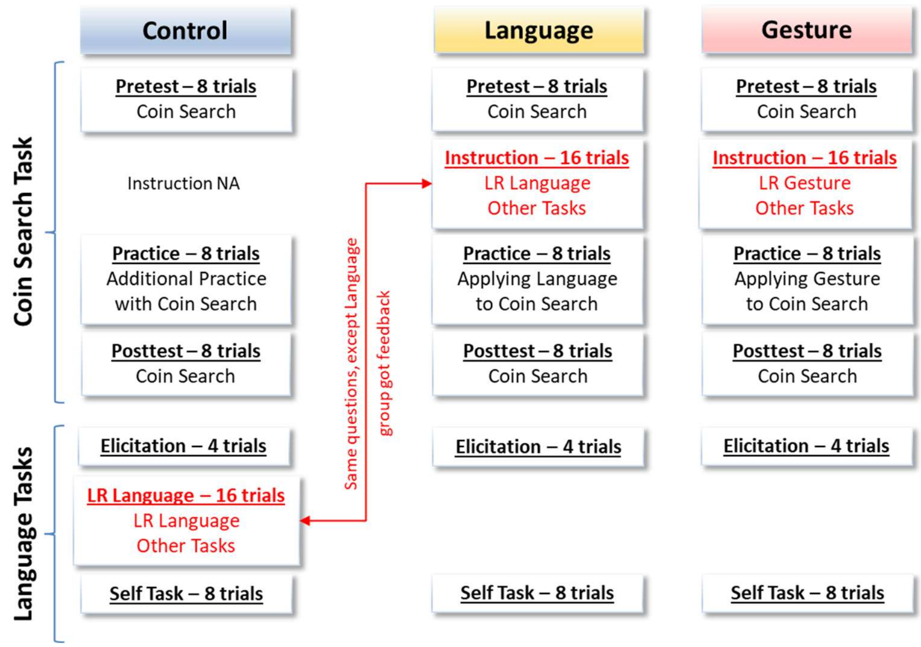

Figure 4. Order of tasks for Experiment 2.

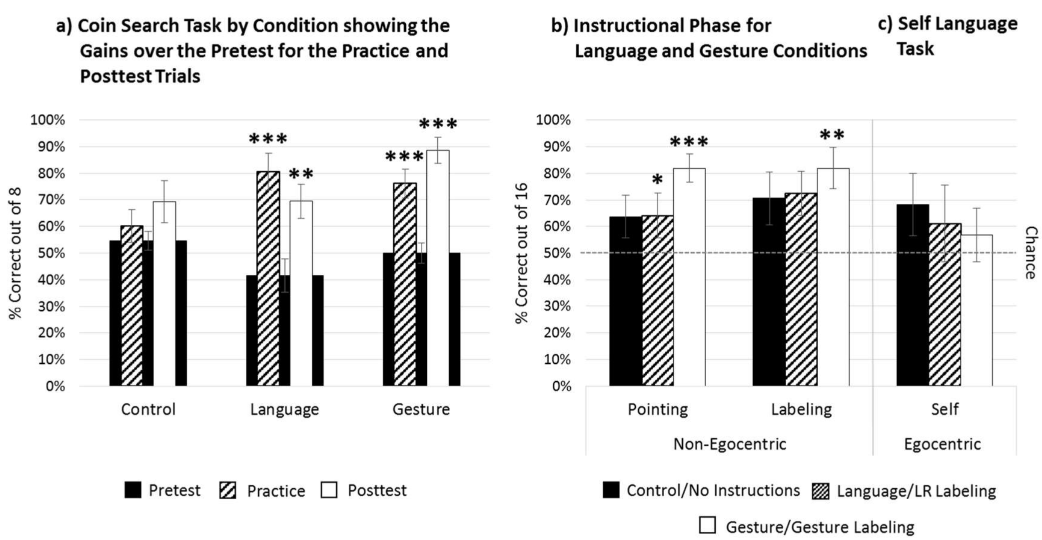

Figure 5. Showing a) the percent correct by Condition for the coin search task in Experiment 2, highlighting the gains between the Practice and Posttest over the Pretest trials; and b) the percent correct on the Non-Egocentric (Other Pointing, Other Labeling) left-right language tasks by Condition; and c) the percent correct on the Egocentric (Self) left-right language task by Condition. Asterisks in a) indicate a significant gain over 0. Asterisks in b) indicate significance when compared with chance = 50% (*$p \leq .05$; ** $p \leq .01$, *** $p < .001$). The error bars in a) show the standard errors from a 3(Condition: Control, Language, Gesture) x 3(Trial Type: Pretest, Practice, Posttest) ANOVA.

Appendix A
Experiment 1: Predicting Coin Search Task Score

To examine the relationship between left-right language and performance on the coin search in Experiment 1 ($N = 80$), we ran bivariate correlations between the children's performance on each language measure and their coin search scores. As shown in Table A.1, each listed language measure was positively correlated with the coin search (p's $< .05$).

Table A.1. Relationships between the coin search task and the various language tasks in Experiment 1.

				Language Tasks			
				Spontaneous Elicitation		Comprehension Tasks	
			Coin Search Task	Used "left" and "right"	Used "left" and "right" correctly	Self Task	Other Tasks
		Coin Search Task		$r = .243$ $p = .03$*	$r = .315$ $p = .004$**	$r = .311$ $p = .005$**	$r = .267$ $p = .017$**
Language Tasks	Spontaneous Elicitation	Used "left" and "right"			$r = .673$ $p < .001$***	$r = .261$ $p = .02$*	$r = .192$ $p = .088$
Language Tasks	Spontaneous Elicitation	Used "left" and "right" correctly				$r = .172$ $p = .13$	$r = .306$ $p = .006$**
Language Tasks	Comprehension Tasks	Self Task					$r = .656$ $p < .001$**
Language Tasks	Comprehension Tasks	Other Tasks					

Figure A.1 below plots the distribution of individuals' performance on the elicitation task in relation to their coin search score. To see the distribution of Self and Other vs. coin search, see Figure 3 in the main text.

a) b)

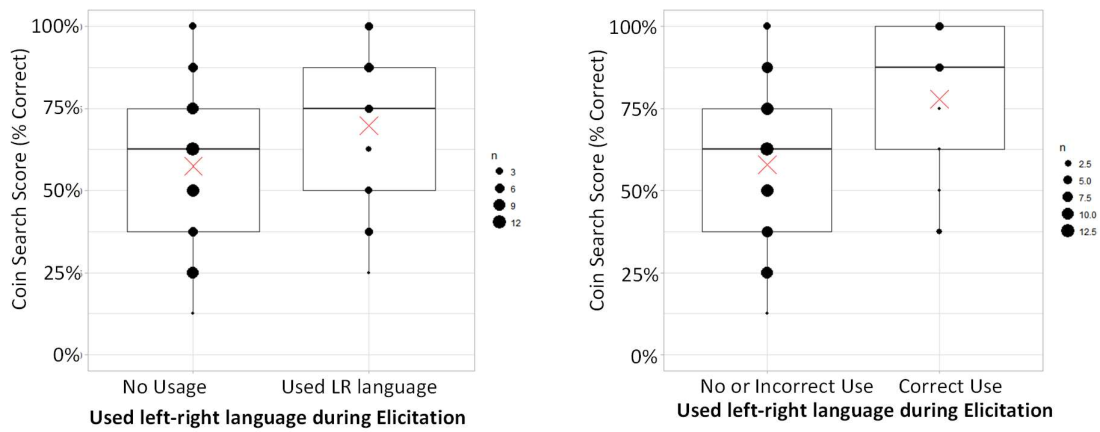

Figure A.1. Boxplots that show the relationship between coin search score and (a) whether children produced any left-right language during elicitation and (b) used them correctly. X marks the means. The number of participants with each coin search score is represented by the size of the dots, with bigger dots for greater number of participants.

Figure A.2 shows how the control variables in the regression analyses related to the coin search for Experiment 1. As can be seen from Figure A.2.a, on average, children in the Town Center (Spanish group and Tseltal Center group) scored higher on the coin search task than the rural children (Tseltal Rural group; $t(78) = 2.75$, $p < .01$). As can be seen from Figure A.2.b, whether the children spoke Tseltal or Spanish did not predict coin search score ($t(78) = 1.66$, $p = .10$, *n.s.*).

a) b)

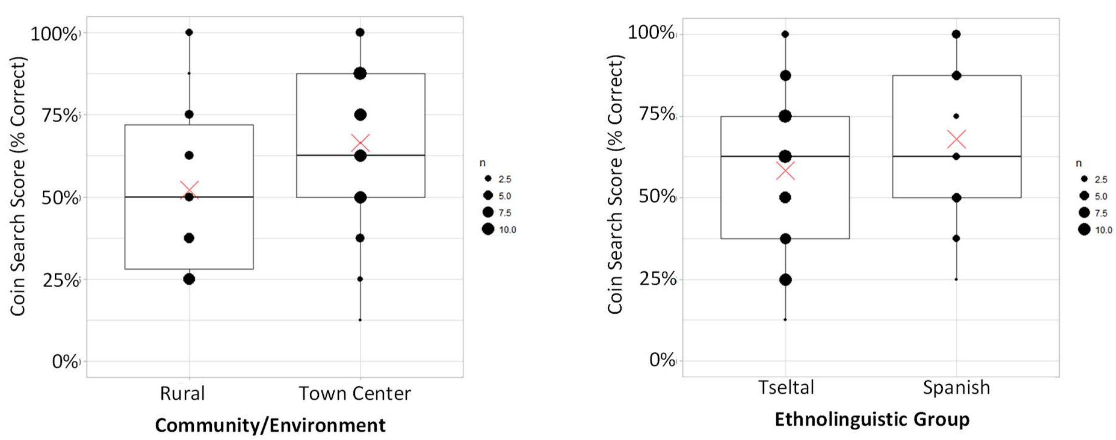

Figure A.2. Boxplots that show the relationship between coin search score and (a) community/environment of residence and (b) ethnolinguistic background. X marks the means. The number of participants with each coin search score is represented by the size of the dots, with bigger dots for greater number of participants.

Appendix B
Experiment 1: Coin Search vs. Language Displayed by Group (Spanish, Tseltal Center, Tseltal Rural).

While the main text reported the matrix of number of passers and non-passers for the coin search vs. number of passers and non-passers for the language tasks (see e.g., Figure 3 in the main text), we provide the breakdown by the three groups of children in Table B.1. All three groups and for both sets of language tasks (Egocentric and Non-Egocentric), there were always more children who passed the language tasks before passing the coin search task than vice versa (McNemar tests, p's < .001). Table B.2 shows that there was no clear relationship for the children's spontaneous use of left-right language on the elicitation task (McNemar tests, p's > .06).

Table B.1. The relationship between the 'passers' and 'non-passers' on the coin search and a) Egocentric left-right language (Self Task) and b) Non-egocentric left-right (combined Pointing and Labelling Other Tasks) results for each group of children. See main text for what constitutes passing.

			a) Egocentric LR Language (Self Task)		**b) Non-Egocentric LR Language (Other Tasks)**	
			Non-Passers	**Passers**	**Non-Passers**	**Passers**
Coin Search	**Spanish (*N*=23)**	**Passers**	0	9	3	6
		Non-Passers	1	13	5	9
	Tseltal Center (*N*=27)	**Passers**	2	4	3	3
		Non-Passers	9	12	12	9
	Tseltal Rural (*N*=30)	**Passers**	1	3	1	3
		Non-Passers	17	9	20	6

Table B.2. The relationship between the 'passers' and 'non-passers' on the coin search and a) any LR use vs. no LR use on the elicitation task and b) correct LR use vs. no or incorrect LR use for each group of children. See main text for what constitutes passing.

			a) Any LR Use (Elicitation Task)		**b) Correct LR Use (Elicitation Task)**	
			None	**Any**	**None/Incorrect**	**Correct**
Coin Search	**Spanish (*N*=23)**	**Passers**	2	7	3	6
		Non-Passers	6	8	10	4
	Tseltal Center (*N*=27)	**Passers**	4	2	5	1
		Non-Passers	16	5	21	0
	Tseltal Rural (*N*=30)	**Passers**	3	1	3	1
		Non-Passers	25	1	25	1

Appendix C
Experiment 2: Transcript for the Instructional Phase and Practice Trials for the Left-Right Language Training vs. Gesture Training

	LR Language Training	Gesture Training
Instructional Phase		
Mapping on Self	Do you know which is your right hand? Raise your **right hand**. And which is your **left hand**? (*correct if needed*)	Do you know there are two sides of your body? There is **this side** here, and **this side** here. (*taps each arm*)
Analogy to Other	Raise your **right hand**. The same as the sheep. This is **his right side** of the sheep (*pointing to the right side of the sheep*),	Raise your arm/hand on **this side** (*taps right arm*). The same as the sheep. This is **this side** of the sheep (*pointing to the right side of sheep*)
Spatial reference	And the box over here (*pointing to the box to the right*), it's on **his right side** of the sheep.	And the box over here (*pointing to the box to the right*), it's on **this side** of the sheep.
Rotation	Now, I'm putting the coin on top of this box (*puts coin on top of right-hand box*).	Now, I'm putting the coin on top of this box (*puts coin on top of right-hand box*).
	On which side is it from the sheep?	Raise your arm/hand, on which side is it from the sheep?
	(*Rotates apparatus 90° in view of participant*) Now, on which side it is from the sheep?	(*Rotates apparatus 90° in view of participant*) Raise your hand, on which side of the sheep is it?
	(*Repeats for 90°, 180°, 270°, and 360°*)	(*Repeats for 90°, 180°, 270°, and 360°*)
Repeated for Other Side	And this side here? (*pointing to the left side of the sheep*). What is it called?	And raise your other arm (*taps left arm*). Which of his sides is the same?
	And the box here (*pointing to the box to the left*), it's on his **left side** of the sheep.	And the box here (*pointing to the box to the left*), it's on **this side** of the sheep.
	Now I'm putting the coin on top of this box… (*the rest of the script above is repeated*)	Now I'm putting the coin on top of this box… (*the rest of the script above is repeated*)
Practice Trials		
On Hiding Coin	I'm hiding the coin on this side of the sheep. Which side of the sheep did I put the coin? (*If needed*) On its left or its right? (*Correct if needed*)	I'm hiding the coin on this side of the sheep. Raise your hand; on which side of the sheep did I put the coin? (*Correct if needed*)
On Retrieval	On which side of the sheep did I place the coin? Where is the coin?	Raise your hand; On which side of the sheep did I place the coin? Where is the coin?