Frames of reference in spatial language acquisition

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Abstract

Previous research shows that languages differ in how they encode spatial frames of reference. However, it is unknown how children acquire the particular frame-of-reference terms used in their language. We created a word-learning paradigm to investigate children's acquisition of novel spatial frame-of-reference terms. In five experiments, we contrasted children's acquisition of novel word pairs meaning left-right and north-south. We examined children's initial hypotheses about the meanings of these terms and the relative ease of learning left-right and north-south meanings. We found that four-year-old English-speaking children interpreted ambiguous spatial terms as having environment-based meanings akin to north and south, and that they readily learned and generalized north-south meanings. Further, when learning left-right meanings, children benefit from input emphasizing body parts. We conclude that environment-based conceptual representations of space exist prior to language learning and support language acquisition. These studies provide the first direct evidence that children invoke geocentric representations in spatial language acquisition. (152 words)

1. Introduction

1.1. Background

How does language acquisition interact with conceptual development? Amid a resurgence of exploration and debate about the Whorfian hypothesis (Whorf, 1956; Boroditsky, 2003; Wolff & Holmes, 2011; Gleitman & Papafragou, 2005; Bloom & Keil, 2001; Pinker, 2007), the domain of spatial cognition has provided fertile ground for examining language-thought interactions (e.g., Hespos & Spelke, 2004; Bowerman & Choi, 2003; Pyers, Shusterman, Senghas, Emmorey, & Spelke, 2010; Shusterman, Lee, & Spelke, 2011; Bloom, Peterson, Nadel, & Garrett, 1996). The development of frame-of-reference (FoR) concepts represents one particularly interesting case study. Languages vary widely in the availability and frequency of FoR terms (Levinson, 1996; 2003; Pederson et al., 1998; Majid, Bowerman, Kita, Haun, & Levinson, 2004). For example, whereas English prefers egocentric terms (“left”, “front”) for describing small-scale tabletop arrays, some languages (e.g., Tseltal, Haillom, Guugu Yimitirr) dis-prefer or even lack such terms and prefer geocentric (sometimes called ‘absolute’) terms instead (“north,” “uphill”).

How do children acquire frame-of-reference concepts? Early philosophers (Kant, 1768) and developmental researchers (Acredolo, 1977; Piaget, 1928) argued that children’s spatial representations are primarily egocentric. The reports of cross-linguistic variations in spatial language, especially the evidence that several linguistic and cultural societies preferred to use absolute FoR terms, raised questions about whether egocentric FoRs are truly more natural or cognitively primitive than absolute FoRs (Majid et al., 2004. Furthermore, a number of studies indicated relationships between the dominant FoRs in language and the availability of FoR representations in non-verbal cognitive tasks (Pyers et al., 2010; Haun et al., 2006; Haun &

Rapold, 2009). These findings have raised a number of questions. First, what are the conceptual origins of these FoR representations: how robustly are they represented in children prior to substantial input from their culture? Second, how does experience with language and culture interact with any early-arising conceptual representations? Finally, what are the reasons underlying the co-variation between dominant FoRs in language and thought across different cultures?

1.2. Frames of Reference

Frame-of-reference concepts are complex, abstract mental structures. A frame of reference (FoR) is a coordinate framework that organizes a set of spatial relations. This coordinate framework can be derived from any entity or set of entities in the world onto which axes may be imposed. The entities providing the axes can be things that move (object-based FoR) or stationary entities anchored to earth (environment-based FoR).

Object-based FoRs support axes such as *front*/*back* or *left*/*right*. Within the object-based FoR, researchers distinguish between egocentric (one's own left) versus non-egocentric object (some other girl's left or the ship's left) frames. Traditionally researchers single out the egocentric frame as a privileged FoR because this is the frame by which we receive sensory information from the world and by which our muscular actions are specified, and refer to all other frames as allocentric, or other-centered. Environment-based allocentric FoRs, such as rooms, buildings, and local terrain, provide axes such as *window-side*/*wall-side*, *front/back*, and *uphill/downhill*.

In addition to the entities that define the coordinate axes, FoRs vary in their scope – the scale of space to which they apply. In principle, one can refer to locations inside or outside of the entities defining the frame, covering regions of space varying dramatically in size. For instance, terms like *left* and *right* can be used to refer to the left and right sides of a person's body, limiting the scope to the body. They can also be used to refer to other objects, not only immediately off to the left and right sides of the person (e.g., the box to the person's left), but also of locations miles away from the person; for example, for a person standing facing north in New York, California is to the person's left. In practice, the scope is often restricted for various reasons and often depends on the FoR. For practical reasons, it is difficult to think about and extend a frame of reference defined by a building in New York to talk about locations and relations of entities in California; it is also typically not useful or necessary to think about such relations.

The scope covered by FoRs in the world's languages is often additionally influenced by the conventions of one's linguistic community. For example, Brown and Levinson (1993) describe Tseltal Mayans who refer to spatial locations with the terms meaning *uphill* and *downhill*, derived from the terrain of the local environment. The *uphill-downhill* terms, derived from the important hill on which they reside, are also used to refer to entities off and beyond the hill. In contrast, terms like *uptown* and *downtown* for Manhattan are restricted in scope to the island itself even though in principle the terms could be extended to talk about locations off and beyond the island.

A well-known taxonomy of spatial frames of reference terms comes from a survey of over twenty languages by Levinson and colleagues from the Max Planck Institute at Nijmegen (Levinson, 1996; 2003). They suggest that three kinds of FoRs (*intrinsic*, *relative*, and *absolute*) can classify the world's languages. In this taxonomy, the three kinds of frames differ in how they talk about a *figure* object (i.e., the entity to be located) in relation to a *ground* object (i.e., the reference entity) via a *viewpoint* (i.e., the entity that defines the coordinate system). Levinson defines *intrinsic* frames as binary relations, involving a figure and a ground/viewpoint. The ground and the viewpoint are one and the same. An example would be "the cup is to the left of me," where the figure, *cup*, is related to the ground/viewpoint, *me*. *Relative* frames differ from *intrinsic* frames because they describe ternary relations, where the relation between the figure and ground is specified by a third party's viewpoint. An example would be "the cup is to the left of the saucer," where the figure, *cup*, is related to the ground, *saucer,* via some third party's viewpoint, such as the *speaker* or the *addressee's.* Thus, *relative* frames expand the instances covered by the *intrinsic* frames by allowing the ground to be another entity besides the one that defines the coordinate system. Finally, *absolute* frames are reserved for relating the figure to the ground via the viewpoint of an environment-based frame. However, in order to qualify as an absolute frame, the region of space covered by the frame must be infinite. Therefore, environment-based FoRs with scope restrictions (like Manhattan's uptown-downtown example) are classified by Levinson as intrinsic, not absolute.

Levinson's taxonomy glosses over some distinctions that may be important in considering the acquisition of FoRs in children. For example, the *intrinsic* category collapses across the child's left hand, and objects to the left of the child. However, children might find it easier to apply the term "left" to their own bodies than to objects next to them, having not realized that such words can be extended beyond a location on a person's body. This suggests that these two uses should be distinguished. One way to think about it is that both uses rely on a body-based FoR but differ in their scope (bounded by the body, extended beyond the body).

Furthermore, the *intrinsic* category under Levinson's taxonomy also applies to larger FoRs such as a building or a room (e.g., door side, window side), contrasting with cardinal directions (north, south). However, it seems possible that children would treat the intrinsic FoR of their own body differently from the intrinsic FoR of a room. Thus, for purposes of understanding children's acquisition of spatial reference frames, it is useful to first consider which entities children can conceive as the source of a coordinate framework, and second to consider the scope to which they are willing to apply this framework.

In the current series of experiments, we introduce novel spatial words to children, and contrast their acquisition of body-based (left-right) and environment-based (north-south) frames of reference. Here, we are using the term "body-based" to refer to the reference frame defined by the child's body, and the term "environment-based" to refer to any frame of reference that is fixed to the ground as opposed to a viewer. These frames of reference differ by definition on the coordinate framework used and, in practice, on the characteristic of scope. The body-based, or egocentric, frame of reference is defined using the body and tends to cover a scope restricted to some (usually visible) distance from that body. The environment-based, or geocentric, frame of reference is defined by the earth and covers a wider scope. We hope that our data can begin to address two separate questions: first, whether children spontaneously construe novel spatial words in terms of a body-based or environment-based frame of reference, and second, whether and how children constrain the scope over which to apply these frames of reference.

1.3. Developmental Origins of Spatial Frame-of-Reference Concepts

Where do FoR concepts come from? One possibility is that spatial representations might be linguistically or culturally derived, with children growing up in an absolute-language speaking community learning one set of spatial concepts and children growing up in a relative-language community learning another. On this view, children may need to construct conceptual representations of space in a slow, effortful, and language-dependent manner from cultural and linguistic input in their communities (Brown & Levinson, 2000; Levinson, 2001; de Leon, 2001; Bowerman & Choi, 2003).

Evidence for the language-dependent and effortful view of language acquisition comes from previous observational studies on the acquisition of frame-of-reference terms. On the basis of children learning relative languages, Piaget argued that children first apply spatial terms to their own bodies. However, children acquiring absolute languages do not show this pattern (deLeon, 1994, 1995; Brown & Levinson, 2000). In fact, language-specific developmental trajectories are evident quite early in the acquisition process. In Brown and Levinson's description of the acquisition of absolute spatial reference terms in Tseltal, 2-year-olds know the words "uphill" and "downhill" as places, but do not use them relationally. By 3;6, productive relational use of these terms in constructions like "X is uphill of Y" is observed in speech samples. It is not until 7 or 8 that Tseltal speaking children are as successful as adults at giving spatial commands to others for manipulating tabletop objects (Brown & Levinson, 2000; for characterizations of spatial language acquisition in other absolute languages, see de Leon, 1994, 1995).

Studies exploring the acquisition of relative spatial terms reveal a similar pattern of partial early acquisition followed by protracted elaboration that lasts several years. For instance, the initial mapping of the words *left* and *right* to the child's own body parts can be successfully taught to children as young as four years old over the course of a single training session (Shusterman & Spelke, 2005). However, learning to apply the terms *left* and *right* to other people's viewpoints is extremely protracted with the acquisition of a full-fledged, adult-like meaning for these terms taking several years (e.g., Irwin & Newland, 1977; Piaget & Inhelder, 1967; Rigal, 1994; 1996). In sum, the acquisition of FoR terms follows a protracted time course for both absolute and relative languages, with key differences in their respective acquisition patterns (Rigal, 1994, 1996; Piaget, 1928, 1948; deLeon, 1994, 1995; Levinson, 2001, 2003; Brown & Levinson, 2000).

Additional arguments that experience plays a major role in the development of spatial FoR concepts comes from reported correlations between spatial language and performance on non-verbal tasks (Haun et al., 2006; Haun et al. 2011; Pyers et al, 2010; Levinson, 2003; Majid et al., 2004; Pederson et al., 1998; Pyers et al., 2010; Shusterman & Spelke, 2005; but see Li & Gleitman, 2002; Li, Abarbanell, Gleitman, & Papafragou, 2011; Abarbanell, Montana, & Li, 2011). For example, Haun et al (2006) used an implicit spatial learning task to see whether participants would recognize a pattern in which hidden objects preserved either egocentric or geocentric relations across two arrays. Speakers of Hai||om, an absolute-FoR language in Namibia, performed much better at learning the pattern when geocentric spatial relations were preserved rather than egocentric ones, while the reverse was true for speakers of Dutch, a relative language. The findings led researchers to argue that language learning "seems to play an important role in this divergent specialization of the intellect" (Haun et al, 2006).

The findings of language-specific trajectories in learning spatial words and in solving non-verbal tasks is consistent with the claim that FoR representations are acquired through experience with culture and language. However, these findings do not address whether or how innate conceptual precursors might interact with language experience in shaping adult FoR representations. To address the possible role of conceptual precursors in spatial FoRs, Haun et al (2006) tested German-speaking 4-year-olds, who likely had not acquired left-right language, and three non-human species of great apes on modified versions of the same implicit spatial learning task described earlier. Both children and apes successfully learned a pattern across two arrays in which hidden objects maintained geocentric/allocentric relations, but not when the hidden objects maintained egocentric relations. This pattern contrasted with adult Dutch speakers mentioned above, who successfully learned the egocentric pattern. From these findings, Haun et al. concluded that humans and other species share a conceptual representation of space that supports geocentric FoR. Learning an absolute language capitalizes on these universal representations, while learning a relative language increases the salience of the egocentric FoR, creating cross-cultural variations in thought.

Although many developmental psychologists had presumed egocentric representations precede allocentric representations (Piaget, 1928; Acredolo, 1977), recent studies lend support to the idea that allocentric frames of reference are available quite early in development (Nardini, Burgess, Breckenridge, & Atkinson, 2006; Huttenlocher & Presson, 1973). A large literature on cognitive maps in animals also suggests that neural representations, most importantly hippocampal place cells, contain allocentric codes of the environment (Knierim, Kudrimoti, & McNaughton, 1995; O'Keefe & Nadel, 1978), raising the possibility that allocentric representations shared across species are recruited for learning geocentric language.

Is there similar evidence for egocentric representations that could support the acquisition of relative languages? Studies on the neuroscience and psychology of spatial representation suggest that egocentric representations exist alongside allocentric representations during development; in fact, egocentric and allocentric representations are often not mutually exclusive, and can even support each other within a single task context (e.g., Nardini et al., 2006; Huttenlocher & Presson, 1973; Wang & Spelke, 2002).

For example, in a developmental version of the Simons and Wang (1998) task, children were asked to remember an array of objects on a round table (Nardini et al, 2006). Children then either walked to a new position at the table (yielding a novel presentation of the array in a body-based frame of reference, but a consistent presentation in a room-based frame of reference), or stayed in place while the table rotated (novel body-based and room-based presentations), or walked to a new position as the table rotated (novel room-based but consistent body-based presentations). A control group walked and then returned to the original position. Overall, 3- to 6-year-old children benefited from consistency in either the room- or body-based frames of reference, in a way that suggested an additive effect of consistency with egocentric and allocentric memory representations.

A growing consensus in the literature suggests that organisms entertain multiple representations of space simultaneously (Burgess & O'Keefe, 2003; Colby, 1998; Newcombe & Huttenlocher, 2000; Landau & Stecker, 1990). Given the evidence from the developmental and animal literatures, then, language acquisition could build on all, some, or none of these conceptual representations. It is impossible to know *a priori* which spatial representations come into play for children learning new words. In the current experiments, we ask whether and how underlying spatial representations could influence and support the process of language acquisition.

1.4. The Present Studies

The findings from developmental and comparative studies provide a glimpse at the link between evolutionary and cultural forces on human language and conceptual representation (Gentner, 2007). They raise the hypothesis that children invoke innate conceptual representations in the process of acquiring meanings for spatial terms. To date, however, no studies have directly tested this hypothesis in order to see how conceptual precursors affect the course of word learning (Majid et al, 2004).

To examine the development of FoR language and concepts, we designed a word extension task and training protocol. The design allowed us to examine (1) children's biases in their initial acquisition of these spatial terms, (2) their patterns of learning when given structured input and feedback about word meanings, (3) and their spontaneous generalization of these terms to novel situations. Like Haun et al. (2006), we tested 4-year-olds. We tested English-speaking children, who are not attuned to their linguistic community's FoR preferences (Haun et al., 2006), and who do not yet fully know the FoR words being tested (Shusterman & Spelke, 2005; Shusterman, Lee, & Spelke, 2011), although they likely have some partial knowledge about spatial FoR terms (e.g., that "left" and "right" are opposite directional terms; Dessalegn & Landau, 2008).

If language learning capitalizes on specific conceptual precursors, then we expect to see systematic biases in children's initial interpretations of novel words. If children's biases are geocentric, as predicted by Haun and colleagues' cross-species and cross-cultural findings, then we expect children to interpret novel FoR words as meaning north-south, and to learn north-south meanings for novel spatial terms more readily than left-right. If children's early spatial representations are egocentric, as suggested by previous developmental research (Piaget, 1948; Acredolo 1977), then we expect the reverse pattern.

Alternatively, both FoRs could be equally privileged and recruited for word learning. Then we might expect some children to favor egocentric interpretations while others geocentric interpretations, but for children to learn both kinds of FoR words equally well when given disambiguating input.

Finally, if FoR concepts initially emerge from language learning, then we do not expect any regularities in children's initial hypotheses about the novel words, and we expect children to have difficulty learning the meanings of the words with such minimal input.

2. Experiment 1: Left-Right Body-Based vs. Environment-Based FoR

In Experiment 1, we introduced children to novel spatial terms (e.g., This wall is to the "ZIV" of you). The script did not differentiate between a left-right and a north-south interpretation of the novel words. We assessed children's initial interpretations of the terms and ease of learning left-right or north-south meanings when given feedback consistent with only one of those interpretations.

2.1. Experiment 1 Methods

2.1.1 Participants. 20 children (mean 4;7, range 4;2-4;11, 8F) recruited from the local community were tested in a multi-part study that took around 25 to 35 minutes to complete. The experimenter always faced the children when introducing the novel words and asking questions (Figure 1a and 1b). Participants received a small prize and travel reimbursement.

2.1.2. Training environment. The training room was 11x12 feet and furnished (Figure 1).

2.1.3. Pretest (8 trials). On each trial, identical boxes were placed on either side of the child. Children were given directions with the novel words "ZIV" or "KERN" (e.g., "The prize is in the box on the ZIV side"). Children indicated a box, which was then set aside to be opened after the pretest. No feedback was given. The child faced east for the first four trials and west for the last four, with "ZIV" requests for half the trials and "KERN" for the other half.

2.1.4. Word introduction. Children were then given instructions about the meaning of novel spatial terms in language that referred to both the environment and the child (e.g. "This *wall* is to the ZIV of *you*"; see Appendix A for complete script). The script was ambiguous about whether the words meant something like north-south or left-right. Children faced only one direction during this portion because turning would disambiguate the intended reference.

Seven *probe* questions tested whether children were paying attention (e.g., "Everything that way is ZIV of you. Can you point to the ZIV?"). Two *object-switch* questions tested whether they could apply the terms to new toys placed on their ZIV and KERN sides. Children received corrective feedback if needed.

2.1.5. Bias test (4 trials). Next, we turned the children 180 degrees and asked about new toys placed on their ZIV and KERN sides ("Can you show me the toy on the ZIV side?"). This manipulation revealed whether children mapped the novel terms onto their bodies or to the environment (Figure 1b)[1]. No feedback was given. Children completed four trials to assess how consistently they mapped the novel words when the relation between their body and the environment changed. The first two trials were in the center of the room and the second two trials were in the corner of the room. The purpose of changing locations was to assess whether children used *themselves* as the origin of the spatial relation (with ZIV extending in one direction and KERN in the other from their body) or *the center of the room* as the origin (with both toys either in the ZIV or KERN half of the room).

[1] The "geocentric" pattern is consistent with children mapping the novel terms to frames of reference established by stationary entities in the environment (e.g., the cabinet, the wall) or even cardinal directions. The "egocentric" pattern is consistent with children mapping the novel terms to their own left and right as well as the possibility of the experimenter who always faced them. However, further series of studies reported in Li, Shusterman, & McNaughton (under revision) showed that same-age children rarely preferred to map left-right terms to a FoR established by another person's body over their own. In fact, children have difficulty identifying the left or right sides of another individual after the individual moves in tasks where they have to track which pocket, left or right, of the individual contained a hidden coin.

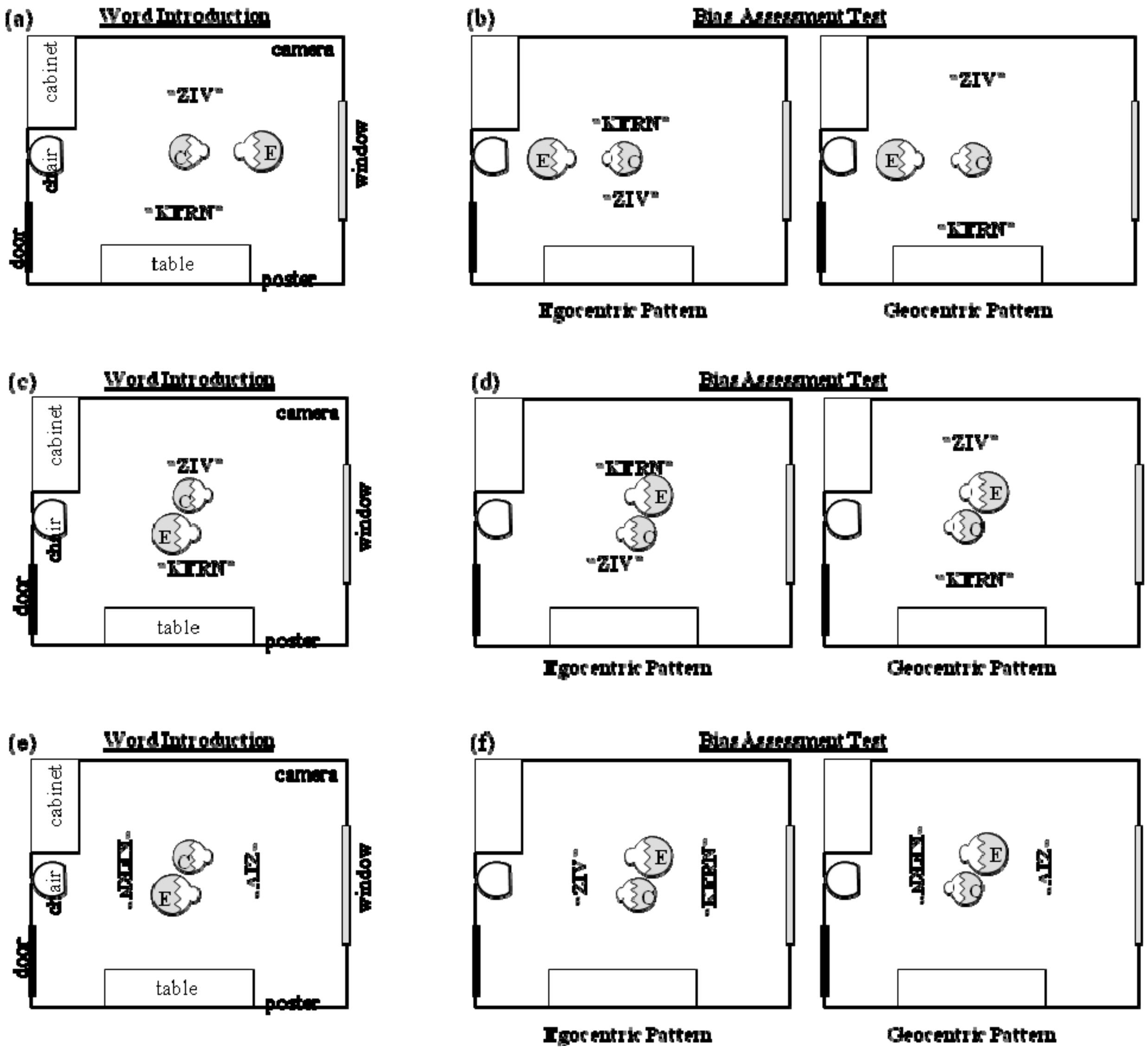

Figure 1. Experimental design and bias assessment diagram. (a) Set-up for word introduction and (b) predicted response patterns for geocentric and egocentric biases in Experiments 1-3, with positions of child (C) and experimenter (E). (c) Set-up for word introduction and (d) predicted response patterns in Experiment 1b. (e) Set-up for word introduction and (f) predicted response patterns in Experiment 4.

2.1.6. Structured feedback session (maximum 24 trials). Children received feedback to disambiguate the novel words' meanings. Half of the children received feedback consistent with left-right meanings and half with north-south. As before, identical boxes were placed on either side of the child, and the experimenter used "ZIV" or "KERN" to disclose the prize's location. Children were immediately allowed to open the box that they chose. Correct boxes contained prizes. Incorrect boxes were empty. Trials were blocked in 6-trial sets. Children turned 180-degrees between each block. Feedback ended after eight consecutive correct responses, with a maximum of 24 trials.

2.1.7. Post-test (8 trials). Children received a Post-test, structured like the Pretest with no feedback, to see whether they had learned the intended word meanings.

2.1.8. Left-right comprehension (8 trials). After the experiment, children were tested for their knowledge of the real words "left" and "right." The test was identical to the Pre- and Post-Tests, except real words replaced "ZIV" and "KERN." The left-right comprehension test served to verify whether children at this age could correctly identify "left" and "right," and to rule out the possibility that prior knowledge of left-right meanings contributed to how children interpreted and learned these novel words.

2.2. Experiment 1 Results

2.2.1. Pretest and word introduction. Children did not know the intended meanings of the words on the pretest (55% correct, $t[19] = 0.87$, $p > .1$, $d = .2$). After the initial word introduction, children were highly accurate on the probe (98% correct, $t[19] = 34.87$, $p < .0001$, *d* = 8.00) and object-switch trials (object-switch: 90% correct, $t[19] = 6.84$, $p < .001$, $d = 1.54$), indicating that they were paying attention.

2.2.2. Bias test. For each child, we calculated the percentage of trials out of four in which they gave an answer consistent with a geocentric interpretation. The two trials at the center of the room and the two trials at the corner were combined since performance did not differ between them ($t[19] = 0$, $p = 1$; Wilcoxon $Z = -1.38$, $p = .89$; MH std = .94, $p = 1$; ns).[2] Children gave geocentric responses 70% of the time, significantly above 50% chance ($t[19] = 2.32$, $p < .05$, $d = .52$; Wilcoxon $Z = -2.13$, r=.48, $p < .03$). Twelve of 20 children gave predominantly geocentric responses (3 or 4 geocentric responses out of 4 trials), and 4/20 children gave predominantly egocentric responses (Figure 2a); this distribution is non-normal (Shapiro-Wilk $W = .74$, $p < .01$), suggesting that children were non-random in their responses. The majority, as can be seen from Figure 2a, gave geocentric responses across all four trials.

2.2.3. Structured feedback and posttest. On all measures, north-south (NS) meanings were easier to learn than left-right (LR). Learning north-south required fewer feedback trials to criterion than learning left-right (16 vs. 23 trials, $t[18] = 2.78$, $p = .01$, $d = 3.95$; MW$U = 25$, $p = .03$). Post-test scores were higher for children learning NS than LR (86% vs. 56%, $t[18] = 2.218$, $p < .05$, $d = .99$; MW$U = 24.5$, $p < .05$; Figure 3a). Children were above chance for NS ($t[9] = 4.796$, $p = .001$, $d = 1.5$), but not LR ($t[9] = .557$, $p > .1$, $d = .18$).

2.2.4. Left-right comprehension. Sixteen of the twenty children were tested on the left-right comprehension test. Average percent correct was 65%, marginally close to being above 50% chance ($t[15] = 1.912$, $p = .08$, $d = .5$). There was no correlation between participants' "left" and "right" comprehension scores and their preference for the geocentric response on the

[2] We supplement t-tests with non-parametric tests whenever the distribution is non-normal and/or the sample size small. The marginal homogeneity test (MH) was conducted using SPSS version 16.

bias assessment trials (r=.16, p = .57), suggesting that knowing "left" and "right" did not influence participants' tendency to respond either egocentrically or geocentrically.

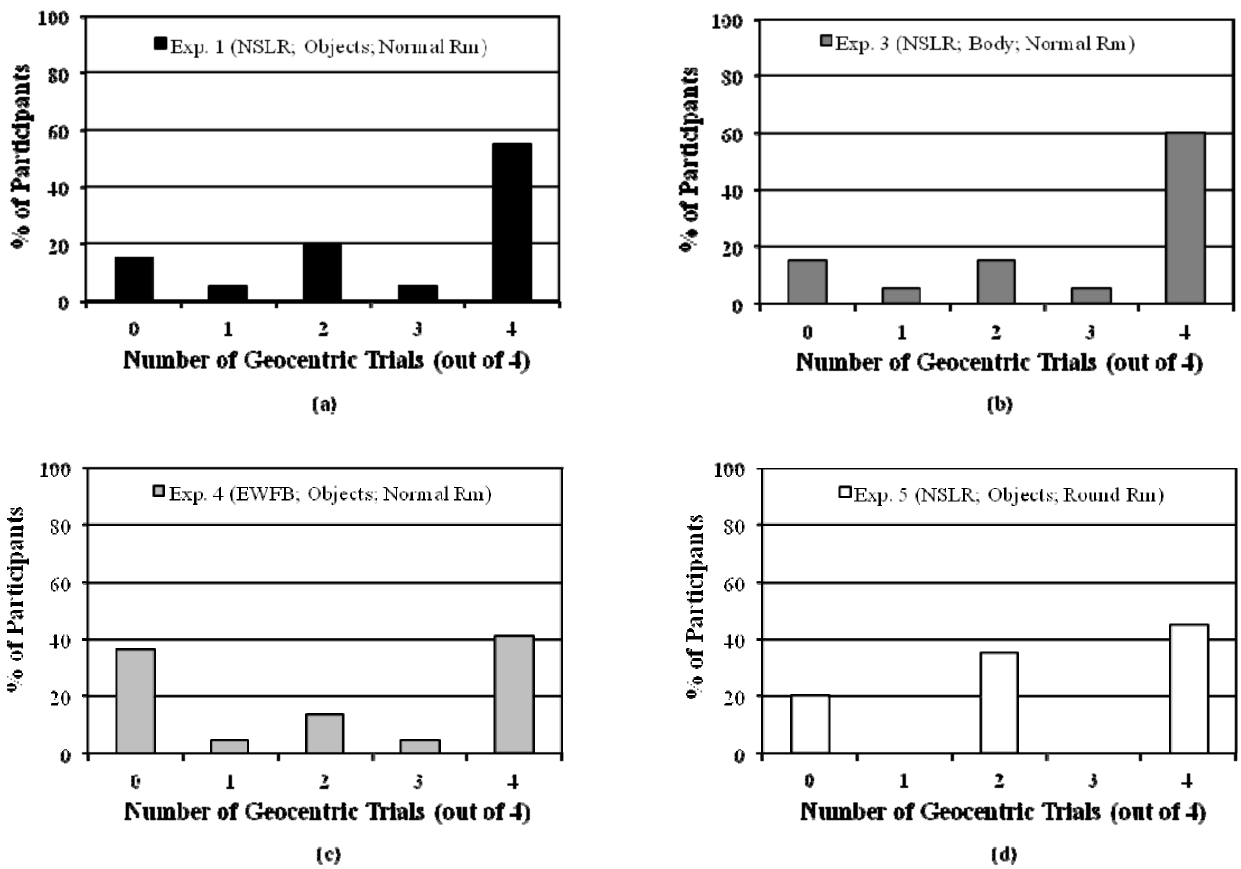

Figure 2. Experiments 1 and 3-5 Bias Assessment results after 180-degree turn. Bars represent percent of participants giving geocentric responses on 0, 1, 2, 3, or 4 out of 4 possible trials.

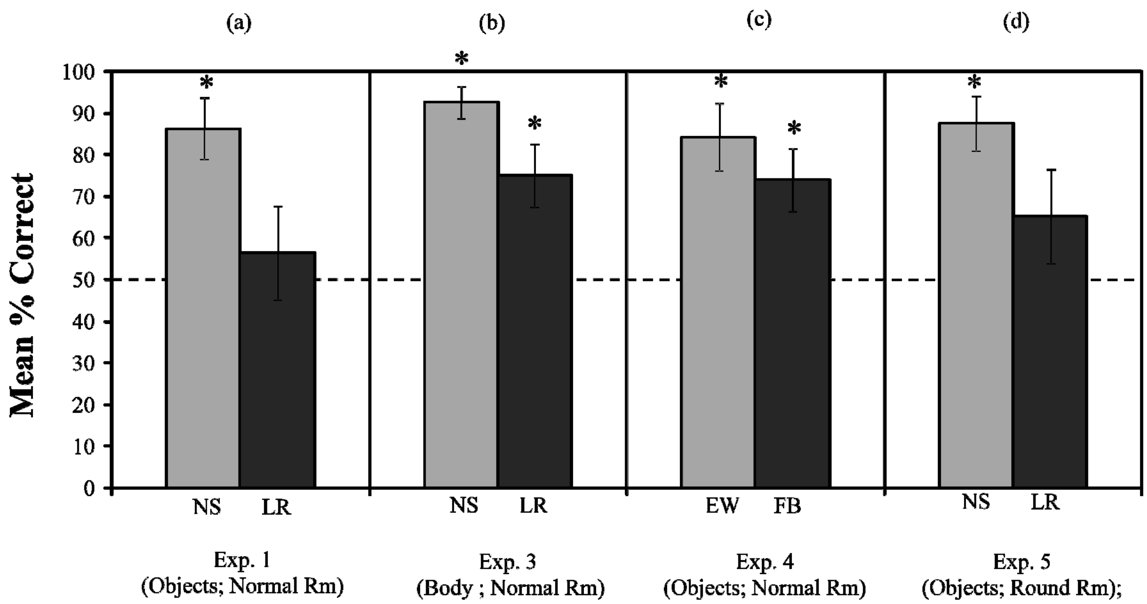

Figure 3. Experiments 1 and 3-5 Post-Test scores. Light bars for children in egocentric conditions and dark bars for children in geocentric conditions.

2.3. Experiment 1 Discussion

Experiment 1 tested children's initial mapping of novel spatial words and their subsequent learning through structured feedback. The bias assessment task revealed that children had a preference to attribute environment-based meanings rather than body-based meanings to the novel spatial words. One potential problem, however, was that children always sat across from the experimenter. Body-based interpretations would thus be ambiguous about whether they referred to their own left-right or the experimenter's left-right. Might children have avoided body-based interpretations because they noticed that the terms are ambiguous, and hence they preferred the unambiguous environment-based interpretation that would be identical from both people's perspectives? We conducted a short follow-up (Experiment 1b) to assess whether remove the conflict between perspectives would shift children's interpretations.

An additional twelve children (mean 4;7; range 4;0-4;11; 6F) were recruited and tested on the Word Extension and Bias Assessment portion of the study. The experimenter always stood to the right of the child and faced the same direction as the child when asking questions (Figures 1c & 1d). Objects placed to the left of the child were therefore also to the left of the experimenter. Similarly, objects to the right of the child were to the right of the experimenter. If conflict in perspective led children to prefer an environment-based interpretation, this set-up, which involved a shared perspective between the child and experimenter, should have encouraged body-based interpretations by reducing environment-based interpretations.

The twelve children performed well-above chance on the probe questions and object-switch questions (99% and 96% correct), indicating they were paying attention to the experimenter. Importantly, these children gave geocentric responses 77% of the time ($t[11] = 2.40$, $p < .05$) for the bias assessment trials. Nine out of 12 children gave predominantly geocentric responses (3 or 4 geocentric responses out of 4 trials) and 1/12 gave predominantly egocentric responses. The children's response pattern did not differ from the previous twenty children's (MW$U = 106.5$, $p = .55$, ns; $t[30] = .5$, $p = .62$, ns), indicating that facing direction of the child and the experimenter could not account for the response preference.[3]

These results show that children have a preference to interpret novel spatial terms as referring to the environment and not to their own bodies. Children were also highly successful at learning environment-based meanings, consistent with their initial hunches. By contrast, they had difficulty learning egocentric meanings. These results indicate that children might generally privilege geocentric FoR, as suggested by Haun et al. (2006) and provide the first direct evidence that children invoke their environment-based representations of space in spatial word learning.

However, it is possible that children's success at learning environment-based meanings in Experiment 1 falls short of abstract and adult-like concepts such as *north* and *south.* For instance, they could have taken the novel terms to be adjectives describing the position of particular walls in the training room, applying a narrow scope to the spatial terms, not as terms specifying cardinal directions with a wide scope. Experiment 2 was undertaken to test the limits of children's environment-based meanings by asking how children apply these words in novel situations.

3. Experiment 2: Extending Scope and Contexts for Environment-Based FoR

3.1. Experiment 2 Rationale and Methods

Experiment 2 asked how abstractly children construed the environment-based meanings of novel terms. We used a shortened version of Experiment 1's training protocol (excluding pre- and post-tests) to induce fast-mapping of the terms "north" and "south," determined through pilot studies to be novel to children this age, with 12 children (mean 4;5, range 4;4-4;11, 4F). Three generalization tests (Figure 4a-c) followed the training protocol:

3.1.1. New facing direction test (4 trials). Children faced north or south and were asked to point to the north and south, requiring them to point forwards or backwards. This contrasted with training, when children had only pointed to the sides, and tested the possibility that children developed a low-level sensorimotor response to hearing the novel words.

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[3] See footnote 1 for another reason why we think the child is unaffected by the perspective of the experimenter.

3.1.2. New origin test (8 trials). Children had to transfer the origin of the coordinate system from their own bodies to a stuffed animal. Children sat with the animal next to them. Identical toys were placed on the animal's left and right sides, and the experimenter asked children had to indicate the toy to the north or south of the animal. Critically, although all three toys were on the same side (north or south) of the child, only one toy was to the north or south of the animal. Thus, if children responded without considering the new origin, they would respond correctly only 50% of the time.

3.1.3. New Environment test (8 trials). Children were led outside the training room to see whether they could track north and south after losing perceptual contact with the training environment. Children were asked to point to north and south after each of four movements: after moving to the hallway just outside of the training room and turning to look into the training room; after turning in place 180-degrees to look away from the training room; after walking 13 feet up the hall; and after turning 180-degrees again, resulting in 8 trials total.

3.2. Experiment 2 Results

As in Experiment 1, children mapped the terms with above-chance accuracy on the probe (97% correct, $t[11] = 20.77$, $p < .0001$, $d = 5.88$), and object switch (90%, $t[11] = 6.917$, $p < .0001$, $d > 10$) trials (Figure 4d, black bars). Combining trials in the center and corner of the room, which did not differ significantly from each other ($t[11] = .692$, $p = .504$; Wilcoxon Z = .480), children selected the geocentric response on 79% of trials, compared to 50% chance, $t(11) = 4.841$, $p < .001$, $d = 1.25$. Nine of 12 children gave predominantly geocentric responses, and 0/12 gave predominantly egocentric responses. Thus, as in Experiment 1, children spontaneously interpreted and rapidly learned environment-based meanings.

Furthermore, children robustly generalized the geocentric meanings to new contexts (Figure 4d, gray bars). In the New Facing Direction test, children performed well above chance, with chance defined as 25% for each of the four walls, 83% correct; $t(11) = 6.205$, $p < .0001$, $d = 1.00$. In the New Origin test, children also performed above chance, with chance defined as 50% for choosing between the two identical toys, 84%; $t(11) = 4.861$, $p < .001$, $d = 1.42$.

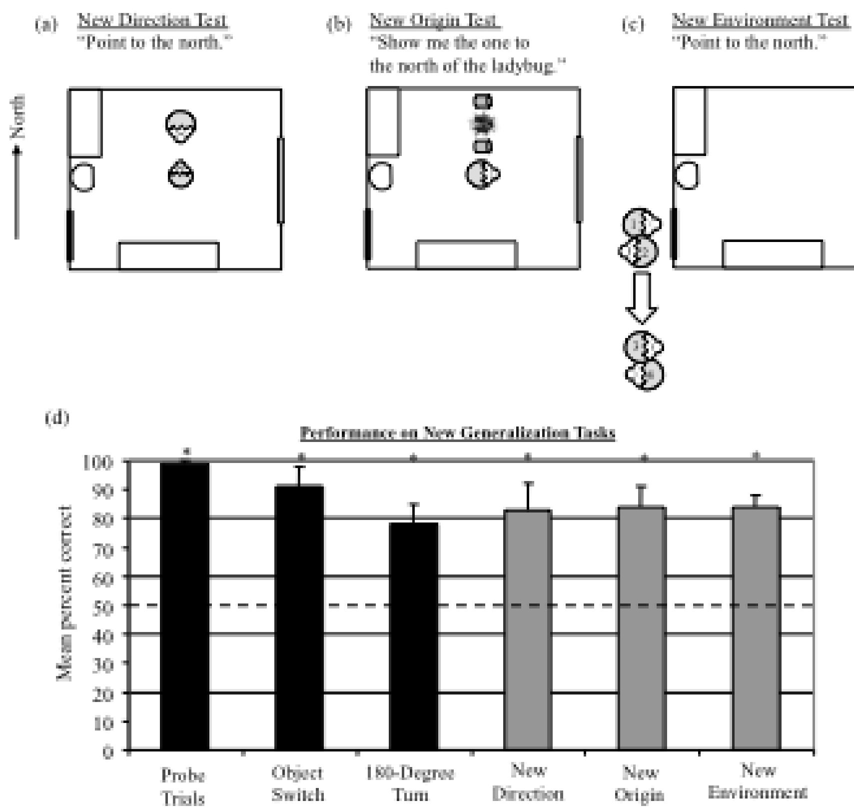

Figure 4. Experiment 2 design and results. (a) New Direction Test; (b) New Origin Test; (c) New Environment Test. Heads in the schematic for the New Environment Test represent each of the four locations from where the child was asked to point to the north and south. (d) Percent correct responses. Black bars: Replication of Experiment 1. Gray bars: Accuracy on three generalization

tests. (New Environment bar includes angled and straight points if children pointed to the correct side; see Results in section 3.2. for further explanation.)

In the New Environment test, children were taken outside the training room. For two trials, they looked into the room from just outside the doorway. We wondered whether children would point at an angle towards the walls in the room, as though *north* and *south* were adjectives describing particular walls, or whether they would point straight out their sides as one might for cardinal directions. The responses were mixed: seven children pointed straight, four children pointed to the walls, and one child did both. On the two subsequent trials, when turned away from the room, children lost perceptual contact with the training room. At this location, facing away from the room, 2/12 children pointed (slightly backward) toward the walls, 9/12 pointed straight, and one child gave a mixed response. After moving up the hallway, 12/12 of the children pointed in cardinal directions straight out to their sides for all four trials.

Collapsing across all eight trials, and only counting responses as correct if the children pointed straight, mean accuracy was 70%, well above a conservative chance level of 50%, $t(11) = 3.402$, $p < .01$, $d = .99$. Including angled pointing responses, mean accuracy was 84%, $t(11) = 8.421$, $p < .0001$, $d = 2.43$, indicating that children were tracking directions even after losing perceptual contact with the training environment, moving a substantial distance, and turning several times.

3.3. Experiment 2 Discussion

Experiment 2 replicated the geocentric bias and illuminated children's interpretation of these terms. In the New Direction test, children were accurate at pointing when facing untrained directions, eliminating the possibility that they developed a simple association between the novel words, visual cues, and a sensorimotor response (e.g., when I see the cabinet and hear "north," extend my right hand).

In the New Origin test, children had to suppress any tendency to focus on their body and had to transfer the coordinate origin to an animal besides them. A request for "the toy to the north of the bear" had only one correct answer, even though half the time *both* toys, as well as the bear, were on the north side of the child, and half the time *neither* was on the north side of the child. Previous work distinguishing absolute from intrinsic FoR suggests that absolute FoR terms are defined by abstract, flexible relations (Levinson, 2003). Children's success at this relational test indicates they quickly developed meanings for the terms consistent with theoretical descriptions of absolute FoR.

In the New Environment test, children demonstrated an impressive ability to maintain an internal sense of the directions without direct visual aid from the training environment, even after substantial movement and turning. This finding distinguishes between two possibilities raised in Experiment 1: children are predisposed to rely on generally geocentric representations of space, not representations of local environments.

A few children initially indicated the walls of the room when asked to point, as though the terms referred concretely to the walls and not to abstract cardinal directions. However, within just a few trials down the hallway, and with no corrective feedback, all children updated their interpretation in favor of cardinal directions. Other than this hint that children's initial interpretations were limited in scope, the speed with children adjusted their interpretations, and their overall success on all the three tasks, suggests that children's initial interpretations of the novel words were indeed geocentric—abstract, flexible, and broad in scope.

Having established that children prefer environment-based interpretations of the novel words over body-based meanings, we next asked about the robustness of this preference under various input conditions (Experiments 3 to 5).

4. Experiment 3: Body-Focused Input

In Experiments 1 and 2, children showed a readiness to adopt an environment-based frame of reference for objects next to them. Speakers of absolute languages are reported to use absolute terms even to refer to their bodies (Haun & Rapold, 2009; Majid et al., 2004). Experiment 3, therefore, tested whether children's preference for environment-based terms would be observed even if the terms were taught and tested on their own left and right sides of their bodies, rather than on separate objects. In this case, the environment-based representation that they entertained in Experiments 1 and 2 would have to compete with a sensorimotor experience of their own bodies.

4.1. Experiment 3 Methods

A new group of 20 children (mean 4;7, range 4;1 to 4;11, 9F) was introduced to ZIV and KERN on their own bodies ("This is your KERN arm"). The task was identical to Experiment 1, except children received instructions to "wiggle" or "point to" their body parts instead of choosing toys or boxes (e.g., "Can you raise your ZIV arm?"; see Appendix A for instructions). In the feedback session, children were enthusiastically praised after a correct answer or corrected after a wrong answer. As in Experiment 1, half of the children received left-right feedback and half received north-south feedback.

4.2. Experiment 3 Results

4.2.1. Pretest and word introduction. Children performed at chance on the pretest (48% correct, *t*[19] = -0.567, *p* = .61, *d* = .14, n.s.) when they were asked to "wiggle" or "point to" their body parts using the terms ZIV and KERN. After a brief introduction to these terms, they answered the probe (99%, *t*[19] = 49.0, *p* < .0001, *d* = 4.32) and switch (from arms to legs, 88%, *t*[19] = 6.097, *p* < .0001, *d* = 1.34) questions with high accuracy.

4.2.2. Bias test. Results did not differ between the center versus corner of the room (*t*[19] = 0, *p* = 1; Wilcoxon Z = -.138, *p* = .89; MH std = .935, *p* = 1; n.s.), so responses were combined. When asked to "wiggle" or "point to" their body parts, children selected geocentric meanings 72.5% of the time, well above 50% chance (*t*[19] = 2.592, *p* < .02, *d* = .58; Wilcoxon Z = -2.32, *p* = .02, r = .52). Thirteen of 20 children gave predominantly geocentric responses, and 4/20 gave predominantly egocentric responses (Figure 2b). This distribution was non-normal (Shapiro-Wilk W = .711, *p* < .01) and similar to the proportion of geocentric responses in Experiment 1 (Exp. 2: 72.5% vs Exp. 1: 70.0%, *t*[38] = .204, *p* = .84, *d* = .06; MW*U* = 191.5, *p* = .82, n.s.).

4.3.3. Structured feedback and post-test. Children in the north-south (NS) and left-right (LR) conditions required similar number of feedback trials to criterion (NS: 15.6 vs. LR: 16.4, *t*[18] = 2.67, *p* = .79, *d* = .38; MW*U* = 44, *p* = .67, n.s.). Both groups performed above chance on the post-test (NS: 92.5%, *t*[9] = 11.129, *p* < .0001, *d* = 3.54; LR: 75%, *t*[9] = 3.254, *p* = .01, *d* = 1.04). The NS group was marginally better than the LR group on the post-test (*t*[18] = 2.040, *p* = .06, *d* = .96; Figure 3b). Comparing post-test performance in this body-oriented instruction to Experiment 1's object-oriented instruction, a 2-way ANOVA on the post-test, with Instruction (Exp. 1 or Exp 3) and Terms (NS or LR) as between-subjects factors revealed a main effect of Terms ($F[1,36] = 8.74$, $p < .01$, $\eta_p^2=.20$) and no effect or interaction with Instruction (p's > .13, n.s.).

4.3.4. Left-right comprehension test. Children scored on average 58.8% correct on the comprehension task, not different than 50% chance ($t[19] = 1.11$, $p = .28$, $d = .25$). There was an almost significant negative correlation between participants' "left" and "right" comprehension scores and their preference for the geocentric response on the bias assessment trials (Pearson's r = -.43, $p = .06$), suggesting children who know "left" and "right" are less likely to give geocentric responses. Thus, a mutual exclusivity word-learning strategy cannot explain children's preference for geocentric interpretations. If anything, children who knew "left" and "right" were more likely to attribute egocentric, not geocentric, interpretations to the novel terms.

4.4. Experiment 3 Discussion

Surprisingly, children exhibited the environment-FoR preference just as strongly with reference to their bodies (Experiment 2) as to objects (Experiment 1). Thus, a typical child, having heard one arm labeled as her "ZIV arm," would turn 180-degrees and spontaneously decide that that the same arm was now the "KERN arm." These findings suggest that children are quite attuned to a non-egocentric spatial concepts from a young age—even if they are being raised in an English-speaking environment in which relative spatial terms like *left* and *right* dominate.

Unlike Experiment 1, we found moderate success on learning left-right meanings despite children's initial preference to map words onto environment-based meanings. With feedback, children were able to benefit from the stable mapping between egocentric spatial terms and sides of their bodies.

Although these data demonstrate that children more easily map spatial terms to environment-based representation than to body-based representation, the environment-based interpretations emerged in a context where the two main FoRs were an asymmetrical environment (a normal room with windows and furniture) and a symmetrical body axis (the child's left-right). Thus, it is possible that children found it easier to map directional terms to a marked, asymmetrical referent rather than an unmarked, symmetrical one. Experiments 4 and 5 addressed this possibility. In Experiment 4, children were tested on their front-back axis, pitting two asymmetric FoRs against each other. In Experiment 5, children were tested on their left-right axis but in a completely symmetrical room, pitting two symmetrical FoRs against each other.

5. Experiment 4: Front-Back Body-Based vs. Environment-Based FoR

The purpose of Experiment 4 was to see whether children's preference for geocentric interpretations would arise only when they had to consider their own symmetrical left-right axis, or whether such interpretations would also arise if the words were applied their front-back axis. Children were introduced to novel spatial terms ZIV and KERN (e.g., This wall is to the "ZIV" of you). The procedure was identical to Experiment 1 with two exceptions. First, words were introduced on the front-back/east-west axis instead of the left-right/north-south axis. Second, the experimenter always stood to the side of the participant, instead of in front of her, when placing the objects (in order to avoid reaching around the child and to avoid a possible interpretation of near/far from the experimenter; Figures 1e and 1f). Participants were 22 children (mean 4;5, range 4;0-4;10, 8F) recruited from the local community.

5.1. Experiment 4 Results

5.1.1. Pretest and Word introduction. Children did not know the intended meanings of the words on the pretest (51% correct, *t*[21] = 0.169, p-.87, *d* =.04), but were highly accurate on the probe (95% correct, *t*[21] = 16.554, $p < .0001$, *d* = 3.52) and object-switch trials (object-switch: 89%, *t*[21] = 5.923, $p < .0001$, *d* = 1.26), indicating they were paying attention.

5.1.2. Bias test. Performance did not differ between the two trials at the center of the room and the two trials at the corner (*t*[21] = .624, *p* = .54; Wilcoxon Z = -.557, *p* = .58; MH std = .632, *p* = .53, n.s.), so combined responses were analyzed. Children gave geocentric interpretations 52% of the time (compared to 50% chance: *t*[21] = .234, p =.82, *d* = .05; Wilcoxon Z = -.242, *p* = .81, r = .51, n.s.). Ten of 22 children gave predominantly geocentric responses (3 or 4 geocentric responses out of 4 trials), and 9/22 children gave predominantly egocentric responses. This distribution was non-normal (Shapiro-Wilk W = .76, $p < .01$; Figure 2c), with children split between either predominantly choosing geocentric responses or egocentric responses. However, this pattern was not significantly different from Experiment 1 when children's left-right axis was used (*t*[40] = 1.35, *p* = .18, *d* = .42; *MWU* = 172.5, *p* = .20).

5.1.3. Structured feedback and post-test. All measures indicated that front-back (FB) and east-west (EW) meanings were equally easy to learn. Both required similar number of feedback trials to criterion (FB: 15.5 vs. EW: 16.9 trials, *t*[20] = .654, *p* = .65, *d* = .19; MW*U* = 53.5, *p* = .65). Post-test scores were similar for children learning FB and EW (74% vs. 83%, *t*[20] = .933, *p* = .36, *d* = .40; MW*U* = 44.5, *p* = .27; Figure 3); both scores were above chance (FB: *t*[10] = 3.139, *p* = .01, *d* = .95 and EW: *t*[10] = 4.242, *p* = .002, *d* = 1.24). Comparing post-test performance in this EW-FB axis to Experiment 1's NS-LR axis, a 2-way ANOVA on the post-test, with Axis (EW-FB or NS-LF) and Terms (Geo or Ego) as between-subjects factors revealed a main effect of Terms (F[1,38] = 5.37, $p < .03$, $\eta_p^2=.12$) and no effect or interaction with Axis (p's > .38, n.s.).

5.2. Experiment 4 Discussion

In Experiment 4, children were presented with novel spatial terms along their front-back axis rather than their left-right axis. The script was identical to Experiment 1, ensuring that any difference in children's bias or learning would be due to the particular axis chosen and no other experimental variables. In this case, no strong preference for the geocentric interpretation was observed; children were equally likely to select egocentric interpretations as geocentric ones. Similarly, children were easily able to learn both geocentric (east-west) or egocentric (front-back) meanings. These results suggest that the tendency toward geocentric interpretations of novel terms observed in Experiments 1, 2, and 3 is specific to the left-right axis.

These findings suggest that symmetry plays a role in shaping how children encode frames of reference. In the current experiment, two asymmetrical FoRs were pitted against each other – the front-back axis of the child's own body and the landmark-rich testing room. Both FoRs were robustly accessible to children for word-learning.

Importantly, in the context of two competing asymmetrical frames of reference, children did not switch to an overall preference for the egocentric interpretation. This is striking because the front-back axis is a very salient asymmetry. The two objects were presented in front of and behind the child: one was in front of them and visible, and the other was behind them and out of sight. Therefore, in addition to the body-based spatial interpretation of the novel terms, children could have mapped ZIV and KERN onto meanings like "the one I can see" and "the one I can't see." Despite this salient perceptual asymmetry, children were split in their initial interpretations, with approximately half of them still choosing the geocentric interpretation.

The learnability of the front-back frame of reference matches the learnability of an east-west frame-of-reference, but does not trump it. This provides a metric for the availability of geocentric representations in young children – environment-based representations seem to be approximately as salient and available as one's own front and back. Front-back concepts are already available by the age of two years (Levine & Carey, 1982). Thus, the fact that the two conditions are fairly equal in difficulty suggests that geocentric representations are readily available for word learning and perhaps for other tasks, since they compete on equal footing with well-established front-back representations.

Experiment 4 demonstrated that both body-based and environment-based FoR are easily and equally available to children when they are matched for symmetry, in that both reference frames were asymmetrical. This raised the question of whether children's frame-of-reference concepts, both body and environment, are rooted in perceptual input or abstract mental models of space. Experiment 5, therefore, tested the possibility that children's ability to invoke environment-based representations was due to external perceptual cues in the environment – notions like "poster-side" or "window-side" – rather than truly abstract geocentric concepts.

6. Experiment 5: Impoverished Cues for Environment-Based FoR

6.1. Experiment 5 Rationale and Methods

Experiment 5, using a round room, tested children's bias in an environment with no perceptual cues that could highlight the asymmetry of the environment and consequently cue children to the asymmetry of the directional terms. If children in the previous experiments had mapped the terms directly to features in the environment, the availability of geocentric representations should disappear in a featureless room. On the other hand, if children had mapped the terms to conceptual representations of geocentric directions, they should continue to demonstrate a readiness to interpret the terms geocentrically in their initial bias and in their subsequent acquisition of north/south meanings.

Furthermore, a featureless room might diminish the relative salience of the environment-based frame, enabling children to focus on the body-based frame and possibly acquire Left-Right terms. Indeed, prior studies show that features of the environment affects spatial reasoning (Restle, 1957; Acredolo, 1977; 1978; 1979). In particular, Acredolo (1977) demonstrated that 4-year-olds more often respond egocentrically when searching for hidden objects in featureless rooms, and have to be reminded of their changed location in the room to take into account geocentric relations (Acredolo, 1977).

The procedure was identical to Experiment 1, but in a landmark-free environment (an all-white, soundproof, symmetrically lit, 10' round room). To minimize distractions in this sparse environment, we used small compact envelopes holding pictures instead of small boxes holding toys. Twenty new children (mean 4;7; range 4;2 to 4;11; 11F, 9M) were tested. As in Experiment 1, each child received feedback consistent with left-right or north-south interpretation for the novel words ($N = 10$ for each group).

6.2. Experiment 5 Results

6.2.1. Pretest and word introduction. Replicating Experiment 1, children's pretest performance was at chance, 47% correct ($t[19] = -.82$, $p = .42$, $d = .18$, n.s.). Children learned the terms quickly, with above chance performance on the probe trials, 97% correct ($t[19] = 28.687$, $p < .0001$, $d = 6.4$), and on the object switch trials, 90% correct ($t[19] = 5.812$, $p < .0001$, $d = 1.30$.

6.2.2. Bias test. After turning 180 degrees, children's performance did not differ between the trials in the center and at the side of the room (*t*[19] = .37, p = .72; Wilcoxon Z = -.378, p = .71; MH std = .378, p = .71), so we collapsed the bias measures. Children gave geocentric responses 62.5% of the time. The bias in the round room was not significantly different from 50% chance (*t*[19] = 1.422, p = .17, *d* =.32; Wilcoxon Z = -1.387, p = .17, r = .31) nor from the 70% geocentric responses observed in the normal room in Experiment 1 (*t*[38] = .61, p = .55, *d* =.20.; *MWU* = 179, p = .57, n.s.). 9/20 children responded geocentrically, and 4/20 egocentrically (Figure 2d), resulting in a non-normal distribution (Shapiro-Wilk W = .78, $p <$ .01).

6.2.3. Structured feedback and post-test. The north-south (NS) group required fewer feedback trials than left-right (LR) group (NS: 13 trials vs LR: 19 trials, *t*[18] = 2.142, p = .04, *d* =1.04, *MWU* = 25, p = .06). Children in the NS condition scored slightly higher than the children in the LR condition (NS: 88% correct vs. LR: 65% correct; one-tailed *t*[18] = 1.70, p = .05, *d* =.80; one-tailed *MWU* = 35, p = .09; Figure 3d). Children in the NS performed significantly above chance (*t*[9] = 5.582, $p <$ .0001, *d* =1.77), while children in the LR did not (*t*[9] = 1.328, p = .21, , *d* =.43 n.s.). Comparing post-test performance in this feature-free room to Experiment 1's feature-rich room, a 2-way ANOVA on the post-test, with Room (Round or Normal) and Terms (LR, NS) as between-subjects factors revealed a main effect of Terms (F[1,36] = 7.67, p < .01, η_p^2=.18) and no effect or interaction with Room (p's > .60, n.s.).

6.2.4. Left-right comprehension. This group of children scored statistically higher than chance on left-right comprehension (65% correct, *t*[18] = 2.54, p = .021, *d* = .58). However, left-right knowledge was not correlated with a tendency to give geocentric responses for the bias assessment trials, Pearson's r = -.13, p = .13. Including all the children from Experiments 1, 3, and 5, for whom we assessed biases on the NS-LR axis, we found no correlation between percent correct on left-right comprehension and geocentric response (n = 55, Pearson's r = -.21, p = .12). This is true even if we take into consideration of the possibility that some children consistently mis-mapped left-right with right-left, Pearson's r=-.12, p = .40. Futhermore, for children assigned to the LR-feedback conditions, comprehension of real left and right was not correlated with the number of trials they needed during structured feedback (n = 29; Pearson's r = -.15, p = .42) nor how well they learned the novel terms when they were reinforced as meaning left and right (n = 29; Pearson's r = .21, p = .28). Therefore, children's comprehension of left-right was not predictive of how they interpreted the novel words or how well they subsequently learned the meanings of these novel words.

6.3. Experiment 5 Discussion

The initial bias in a featureless room was 62.5%—not significantly different from chance nor from the robust preference for geocentric interpretations observed in Experiment 1. In the post-test, the NS group outperformed the LR group both in needing fewer trials to criterion and in their final percent correct. Moreover, the lack of perceptual features in the environment did not help children focus on a body-based frame of reference more easily learn left and right. Thus, the impoverished testing environment had little or no effect in promoting "left" and "right" as candidate word meanings.

We conclude that an environment devoid of landmarks and other asymmetries does not significantly attenuate the preference for or hinder the learning of geocentric meanings. This is quite remarkable, given that in order to keep track of absolute directions in a featureless room, the children must be able to keep track of their own movement and turns since no other information is available for mapping the terms. The finding suggests that children engage a geocentric representation of the environment even in the absence of external perceptual cues, and that they rely on internal mental models of space rather than external cues in generating potential referents for directional terms.

Experiments 4 and 5 were designed to challenge the interpretation that children are biased to interpret novel spatial words geocentrically. Experiment 4 pitted geocentric representations against a highly salient asymmetry on the body, the front-back axis, and Experiment 5 removed any environmental cues that might have provided support for environment-based meanings. In both cases, the preference for geocentric interpretations was diminished compared with its strength in Experiments 1-3, when it was presented in the context of a feature-rich environment and contrasted with the left-right axis. Nevertheless, in both cases, many children showed an initial preference for the environment-based meaning, and children readily learned the environment-based meanings when given feedback. Together, Experiments 4 and 5 highlight the resilience of children's geocentric FoR representations – they are apparent even when pitted against the child's own front-back axis, and even with no perceptual supports.

7. General Discussion

Five experiments tested children's initial interpretations about novel spatial terms and the ease of learning these terms. In all experiments, many children interpreted the novel spatial terms with an environment-based frame of reference. They readily learned environment-based interpretations when given brief, structured feedback. Moreover, they inferred a great deal of information about the terms with very little exposure. They knew how to apply the terms to new facing direction, to new reference objects, and to new origins. Their ability to reason about environment-based FoR was based on abstract, conceptual representation of space and not on concrete features of the room (Experiments 2 and 5). They readily extended the meanings of the terms to cardinal directions to compute novel spatial relations both inside and outside of the scope of the training room. The acquisition process documented in these experiments suggests that children "fast-mapped" geocentric meanings of novel spatial terms (Carey & Bartlett, 1978).

Of course, there are many ways in which children's semantic acquisition was not complete or truly "geocentric." Understanding the basis of geocentric terms requires further learning and conceptual development. For instance, understanding the true meanings of *north* and *south* requires an understanding that the earth is a sphere, a concept that is acquired long after four years of age (Vosniadou & Brewer, 1992). Furthermore, when children learn geocentric terms in a linguistic community rather than in an artificial training study, children need to learn the conventions how their language communities derive and use geocentric terms. Communities vary in how geocentric terms are derived (e.g., "north", "seaward"), so children need to learn which elements are relevant to their language, especially if the word's origin provides no clues. Children also have to learn conventions about the scope of space to which these words apply (e.g., "uphill/downhill" in Tseltal Mayan extend beyond the hill, but "uptown/downtown" in Manhattan does not extend beyond the island). Thus, even with a predisposition to understand that spatial terms might be geocentric, children in real language learning situations likely need to revise their initial lexical concept in order to accommodate cultural conventions and conceptual change (Brown & Levinson, 2000; de Leon 2001).

Nonetheless, what children surmised about the words' initial meanings is quite impressive. There was no evidence for slow and effortful learning. On the contrary, children's inferential machinery and spatial intuitions are rich enough to support spontaneous generalization of the new terms to novel circumstances. Our findings are consistent with Nardini et al.'s (2006) and Haun et al's (2006) conclusions that geocentric representations of space are readily available to children, and provide the first direct evidence that children's language acquisition draws upon these precursors.

What is the relative status of egocentric versus geocentric representations? Haun et al (2006) suggested that there is an inherited bias for allocentric/geocentric representations, and that children will experience "relatively greater difficulty of acquiring a predominantly egocentric coding system" because they have to override the initial bias (p. 17572). Indeed, the four-year-olds in the present study, like Haun et al.'s, are from a culture that promotes relative concepts and has relative language, and yet children appear to have less difficulty with geocentric reference frames than with egocentric ones. In three of our five experiments (Experiments 1-3), the majority of children showed a strong preference for the environment-based interpretation; they did not even favor egocentric left-right interpretations when the spatial words had been used to describe body parts (Experiment 3). In Experiments 4 and 5, children showed a slightly attenuated preference for environment-based interpretation, but nonetheless seem to more easily learn the environment-based meanings when given disambiguating feedback.

We consider several possibilities of why geocentric FoRs might be privileged or readily invoked in word-learning situations. We appeal to reasons that pertain to communicative situations, general cognitive predispositions, or both. A first possibility is that, in a communicative setting, assuming a geocentric FoR eliminates the problem of deciding whose perspective – the speaker's or the listener's – takes precedence. The follow-up to Experiment 1 (set-up Figures 1c & 1d) demonstrated that sharing the same perspective as the experimenter did not increase children's likelihood to attribute body-based meanings to the novel words. This and the other five reported experiments do not, however, offer any evidence in favor of or against the idea that children's bias toward environment-based interpretations arises more generally as a result of considering the perspective of the experimenter. Another related possibility is that when referencing and locating something in space, it is preferable to choose a FoR using entities anchored to earth rather than entities that move to guarantee that an object can always be found (Haun et al.2006; Gentner, 2007). Hence, when forced to choose, children privilege or weigh more heavily geocentric relations over object-centric relations. Future studies can further test this idea by contrasting whether children more easily learn word meanings consistent with FoRs derived from earth-anchored entities than entities that move.

One of our experiments, however, already suggests that children do not always privilege geocentric FoRs over egocentric (object-centric) FoRs. In Experiment 4, when novel words were introduced along children's sagittal axis, half of the children favored egocentric front-back meanings over geocentric meanings. It is conceivable that learning words consistent with "front" and "back" – words which 4-year-olds know –led more children to consider front-back meanings. It is well documented that children have front-back concepts early in development. For instance, even before acquiring the words "front" and "back," two year-old English-learning children correctly oriented people, animals, and objects so that they faced forward in a parade or so that their fronts faced each other in a tea party scenario (Levine & Carey, 1981). Likely, the problem with egocentric FoR is specific to left and right relations.

A possibility, then, is that the advantage for geocentric FoRs may be specific to situations where geocentric relations are pitted against egocentric left-right. Psychologists have long noted that we have particularly poor perceptual memory for left-right orientation of visual information, and some have suggested that this is linked to our bilateral symmetry and wiring of our brain (e.g., Corballis & Beale, 1976; Dehaene, 2009). Therefore, given difficulties in reasoning about left-right, children find it difficult to learn “left” and “right” language. A challenge to the idea that left-right concepts are undeveloped, however, is that children do show sensitivity to left-right relations in many tasks, such as spatial reorientation (e.g., Lee & Spelke, 2010).

We consider another alternative to explain the specific difficulty children have with left-right relations. The left-right axis is a secondary axis whose differentiation is dependent on the primary front-back axis. Figuring out the meaning of the two symmetrical sides, “left” or “right”, therefore, requires noticing how these words are linked to the front-back axis, an axis that was not mentioned at all in the discourse. This added level of relational complexity might make it harder for a child (listener) to correctly identify the intended meaning of the experimenter (speaker). Indeed, the same reason may explain why in geocentric languages, where the environment is rarely symmetrical, there are often no distinct labels for the two sides of the secondary axes (e.g., Tseltal Mayan has “uphill” and “downhill,” but lacks distinct terms for the two sides of the crosshill axis).

How then do children figure out left-right meanings? Our findings suggest that egocentric left-right relations are less prominent but can be drawn out through emphasis on the body, by capitalizing on the proprioceptive or kinesthetic differences felt from moving the left and the right sides of the body (Experiment 3). Specifically, the physical movements we demanded of the children (“Raise your ZIV/KERN arm”) helped them learn to associate the novel words to their left and right sides through physical movements. This finding aligns with clinicians’ success in using associated motor memory that differentiates two sides to train children on left-right discrimination (Jeffrey, 1958; Greenspan, 1973). In a recent follow-up with four-year-olds, we made use of the same methodology presented here to further explore under what circumstances children can acquire left-right meaning. We found that egocentric left-right language can easily be learned the body is explicitly emphasized as the source of the words' meanings ("Your body has two sides: a ZIV side and a KERN side"; Li, Shusterman, & McNaughton, under revision).

Where do all these studies leave us? Recall that our inquiry began with the observation that language communities vary greatly in the stock of FoR terms for talking about space, and that many researchers have reported evidence for language shaping our spatial cognition (Levinson, 1996). Given such striking variations in language and thought, we asked how is it that children come to learn the FoR terms in their language. We focused on children's acquisition of two contrasting types of reference systems – an environment-based ("geocentric") coordinate system and a body-based ("egocentric") coordinate system. Like Haun et al (2006), we wondered what cognitive capacity children bring to learning the spatial words. Our findings support Haun et al's (2006) hypothesis that geocentric representations of space are readily available, and provide the first direct evidence that children's language acquisition draws upon these precursors. However, our findings, contrary to Haun and colleagues, suggest that egocentric representations are also readily available for children to explore. The difficulty in learning meanings for "left" and "right" may not lie in learning egocentric uses of "left" and "right", but rather figuring non-egocentric uses of "left" and "right" (i.e., another person's left and right side). In other work from our laboratory, we are currently exploring the cognitive capacity that children bring to learning non-egocentric uses of left and right, a situation that children find quite challenging (see Li, Shusterman, & McNaughton, under revision for a start; also Piaget, 1928). These and future studies will help to articulate the interaction between conceptual precursors and linguistic input, and illuminate how language acquisition acts as a bridge between universal representations on the one hand, and cognitive and linguistic diversity on the other.

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APPENDIX A: Word introduction script

** Probe (training) trials.*
*** Object switch trials.*

ALL CHILDREN:
This way is ZIV. This wall is the ZIV wall. It is on the ZIV side of the room.
**Can you tell me which side of the room that wall is on?*
Remember? This wall is to the ZIV of you. Everything that way is ZIV of you.
**Can you point to the ZIV?*

This way is KERN. This wall is the KERN wall. It is on the KERN side of the room.
**Can you tell me which side of the room that wall is on?*
Remember? This wall is to the KERN of you. Everything that way is KERN of you.
**Can you point to the KERN?*
**Can you point to the ZIV?*

OBJECTS GAME (Experiment 1):
This toy is on the ZIV side of you.
This toy is on the KERN side of you.
**Can you show me the toy on the ZIV side?*
**Can you show me the toy on the KERN side?*
***Can you show me the toy on the KERN side?*
***Can you show me the toy on the ZIV side?*

BODY GAME (Experiment 3):
This arm is on the ZIV side of you. It is your ZIV arm.
This arm is on the KERN side of you. It is your KERN arm.
**Can you raise your ZIV arm?*
**Can you raise your KERN arm?*
***Can you shake your KERN leg?*
**Can you shake your ZIV leg?

Figure Captions

Figure 1. Experimental design and bias assessment diagram. (a) Set-up for word introduction and (b) predicted response patterns for geocentric and egocentric biases in Experiments 1-3, with positions of child (C) and experimenter (E). (c) Set-up for word introduction and (d) predicted response patterns in Experiment 1b. (e) Set-up for word introduction and (f) predicted response patterns in Experiment 4.

Figure 2. Experiments 1 and 3-5 Bias Assessment results after 180-degree turn. Bars represent percent of participants giving geocentric responses on 0, 1, 2, 3, or 4 out of 4 possible trials.

Figure 3. Experiments 1 and 3-5 Post-Test scores. Light bars for children in egocentric conditions and dark bars for children in geocentric conditions.

Figure 4. Experiment 2 design and results. (a) New Direction Test; (b) New Origin Test; (c) New Environment Test. Heads in the schematic for the New Environment Test represent each of the four locations from where the child was asked to point to the north and south. (d) Percent correct responses. Black bars: Replication of Experiment 1. Gray bars: Accuracy on three generalization tests. (New Environment bar includes angled and straight points if children pointed to the correct side; see Results in section 3.2. for further explanation.)