“Put your left arm in, and shake it all about”:
The role of the body in children’s acquisition of spatial terms

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Abstract

Languages make use of different coordinate systems (north-south, left-right) to describe spatial relationships. Previous studies (Shusterman & Li, under review; Haun et al., 2006), exploring how children learn a range of spatial expressions available in the world’s languages, showed that 4-year-old children have greater difficulty learning “left” and “right” body-based frame of reference than “north” and “south” environment-based frames of reference. By using a novel word extension and word-learning paradigm, three experiments in this paper explored the difficulties four- and five-year-old children face in learning body-based frames of reference words. Experiment 1 explored the circumstances under which children can successfully learn “left” and “right” spatial expressions when the novel words are introduced on the child’s body. Experiment 2 assessed how easily children can extend their newly learned spatial words to novel circumstances. Experiment 3 tested whether children can learn to talk about the left and right sides of a doll. The results have implications for how children learn body-based frames of reference and speak to the availability of different frames of reference in thought.

Keywords: Frames of reference, language acquisition, left-right vs. front-back, linguistic relativity, spatial cognition
Every day we use spatial language, but we do not normally think about the different types of spatial expressions available to us. Consider a child hearing a novel spatial expression for the first time (“The apple is ziv of the doll”). There are numerous meanings that the child could attribute to the novel spatial word “ziv.” For example, the speaker could mean the apple is to the North of the doll. In this case, the speaker would be using an environment-based (or geocentric) frame of reference, where he is describing the relationship between the doll and the apple using a constant fixture of the environment (the North Pole). Environment-based expressions have the same meaning no matter how the speaker and the object to which the speaker is referring are oriented (if we turn the speaker, the doll, or both, the doll will still be North of the apple). However, the speaker could also describe the position of the doll using an expression with an object-centered frame of reference, where the meanings of the expressions depend on the orientation an object not anchored to earth (e.g., the doll or the speaker).

Surveying over twenty languages, Levinson and colleagues from the Max Planck Institute at Nijmegen observed there is considerable cultural variation in the conventions that speakers choose to adopt for talking about spatial relations (Levinson, 1996; 2003). For example, cultures may adopt different features of the environment (e.g., the slope of the mountain, the direction of river drainage; “the cow is uphill of house”) or different features of objects (e.g., nose, front; “the cow is at the nose the house”) as conventions. Some cultures may have only one convention (e.g., only one set of environment-based frames of reference terms), while other cultures have more than one. Cultures that have several conventions also differ in which conventions they use most frequently. Some favor environment-based conventions while others favor object-centered ones. Given this tremendous variation, how do children learn the meanings of spatial words in their language?

Variation in frame-of-reference terms across languages

The current studies investigate children’s ability to learn frames of reference words in languages. To set up our study, we must first introduce some terminology regarding the range of reference frames that are discussed in the literature and highlight the cross-linguistic variations that appear in the world’s
languages. Cognitive psychologists studying spatial cognition often single out *egocentric* frame of reference as a special type of object-centered frame of reference, and refer to all other frames of reference as *allocentric* frames of reference. The egocentric frame of reference may hold a privileged status in cognition because it is the perspective from which one takes in information about the world and plans one’s own movements through space. In this paper, we will divide object-centered frames of reference into two types: *egocentric*, where the expression changes its meaning depending on the orientation and position of the speaker, and *non-egocentric*, where the expression changes its meaning depending on the orientation of an object other than the speaker. Because the term *allocentric* often refers to viewpoint-independent reference frames (e.g., bird’s-eye view), and it is ambiguous whether this terms refers to another person’s perspective, we instead focus on the distinction between egocentric (the child’s perspective) versus non-egocentric (any other perspective). The distinction between egocentric and non-egocentric object-centered frame of reference may matter in children’s acquisition of spatial words.

In the linguistics literature, Levinson (1996; 2003) observed that the world’s languages can be classified into three kinds of frames of reference: *relative*, *intrinsic*, and *absolute*. These three frames are often equated with egocentric, non-egocentric object-centered, and geocentric frames, respectively (Majid et al., 2006). However, the taxonomy is actually not the same (Watson, Pickering, & Branigan, 2006; Newcombe and Huttenlocher, 2000). Levinson’s taxonomy focuses not just on the choice of *perspective* (coordinate system), but also on the *figure* (i.e., the entity to be located) and *ground* (i.e., the reference entity) mentioned in the linguistic expression. He defines relative frames as *ternary* relations, where the relation between the figure and ground is specified by a third party’s perspective. 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 body coordinates (e.g., the speaker’s left). In intrinsic frames, the ground doubles as the entity providing the perspective (coordinate system). Intrinsic frames are thus *binary* relations, involving a figure and a ground/perspective. An example would be “the cup is to my left,” where the
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figure (cup), is related to the ground/perspective (me). Therefore, relative and intrinsic frames both make use of object-centered coordinate systems, but differ in the number of participants (i.e., three vs. two, respectively). Finally, absolute frames are reserved for relating the figure to the ground via an environment-based perspective. Therefore, absolute frames are more-or-less equivalent to geocentric frames.

Levinson and colleagues have found that there are languages that have intrinsic frames of reference, but lack relative frames of reference. In contrast, languages that have relative frames of reference always have intrinsic frames of reference. One possibility for explaining why some languages never develop relative frames of reference is that reasoning about relative frames of reference requires its learner or speaker to make a big conceptual leap from intrinsic frames of reference, and this is why relative expressions do not surface in all the worlds’ languages.

Another possibility, separate from difficulties in computing relative frames of reference, is that adding relative frame of reference expressions to a language introduces ambiguities. For instance, in a language that exclusively uses intrinsic frames of reference and lacks relative frames of reference, the expression “the ball is to the right of the girl” is unambiguous: The ball is on the side of the girl determined by the right side of her body. However, in a language with relative frame of reference, such an expression could be ambiguous between the intrinsic meaning and the relative one (girl’s right or someone else’s right). Since the speaker must craft expressions such that the listener can infer the speaker’s intended meaning, perhaps it is simpler if languages do not make use of relative frame of reference expressions, when intrinsic or geocentric frames of reference are available, sufficient and unambiguous for indicating directions and locating objects.

We might also expect that communities are driven to develop conventions to reduce the ambiguity when using relative frames of reference. For example, some languages might always use the speakers’ perspective in relating the figure to the ground, while others might make use of the perspective of an imaginary listener who is facing the speaker to relate the figure to the ground (Levinson, 2003).
Sometimes the developed conventions differ depending on the particular coordinate axes (front-back vs. left-right). These various instantiations can be seen respectively in languages such as Hausa, Tamil, and English, when these languages locate a figure relative to a non-fronted object (i.e., an object that has no fronts, such as a ball; see Figure 1 for example; Levinson, 2003). In Hausa, one can think of the coordinate system of the speaker being projected onto the ball to determine front-back and left-right. In Tamil, one can think of the coordinate system as being rotated onto the ball so that the front-back and left-right relation is from the perspective of someone imaginary facing the speaker. In English, determining left-right is a direct projection just like in Hausa, but determining front-back is a rotation like Tamil.

Figure 1. Examples of different relative frame of reference conventions. In the examples, the speaker faces a ball that is serving as the ground object. (a) depicts an imagined translation of the speakers’ coordinates onto the ball. (b) depicts a translation and rotation of the speakers’ coordinates onto the ball, thus the ball is imagined to be facing the speaker. (c) depicts a system in which the convention for the left-right axis differs from the convention for the front-back axis. In this example, the left-right axis is not rotated while the front-back axis is rotated.
Egocentric left and right

Previous research suggests that both children and primates find it easier to learn to use environment-based frames of reference than object-centered ones (Haun, Rapold, Call, Janzen, & Levinson, 2006). For both four-year-olds and several genera of great ape, it was easier to learn where to find a hidden target if its location was given by an environment-based rule (e.g. the target is under the cup to the North) than when it was given by an egocentric rule (e.g. the target is under the cup on my left) (Haun et al., 2006; Gentner, 2007).

The study by Haun et al. (2006) only compared subjects’ ability to apply environment-based and egocentric rules where the egocentric rule is based on conceptions of “left” and “right” (e.g. the target is under the cup on my left). However, it is possible that not all egocentric spatial relations are equally hard to learn: it might be easier for children (and apes) to learn a rule that uses “front” and “back” (e.g. the target is under the cup in front of me) than a rule that uses “left” and “right.” Children seem to have a concept of “front” and “back” early in development. They even seem able to intuitively understand the concepts front and back before they even know the words (Levine & Carey, 1981). In Levine & Carey’s study, two year-olds were unable to verbally identify the fronts and backs of people, but they correctly oriented objects so that they faced forwards in a parade or so that their fronts faced each other in a tea party scenario. In comprehension studies, Kuczjac and Maratsos (1975) showed that by five years of age, children have almost adult-like mastery of “front” and “back.” When asked to identify an object’s parts, children were also able to correctly point at the “front” and “back” about 6 months before they could point to its “sides.” Shusterman and Li (under review) also substantiated the fact that “front” and “back” are easier to learn than “left” and “right” using a novel word extension/word learning paradigm. By contrast, children seem to struggle with the concept of “left” and “right.” They do not consistently apply the terms correctly to their own bodies until around six or seven years of age and they do not have full adult mastery of these words until after nine years of age (Rigal, 1994; Piaget, 1928). Thus, four-
year-olds might be able to use an object-centric frame of reference along the front-back axis even
though they cannot do so for the left-right axis.

Why do “left” and “right” pose such difficulty relative to “front” and “back”? The left-right axis
is less salient than the front-back axis in a number of ways. First, humans face and walk forwards rather
than sideways, so the front/back axis may be more salient because it also determines what we see
(versus what we can’t see) and where we are going (versus where we are coming from).

Second, humans’ front and back sides are physically different from each other, while our left and
right sides are symmetrical. The left-right axis is, therefore, a secondary axis to the front-back axis; one
must first know which sides are front and back in order to determine which sides are left and right. On
these grounds, it is logical that children acquire front-back terms before left-right terms, because
learning left and right presupposes sensitivity to front and back: Understanding labels on the secondary
left-right axis requires that children first notice the primary front-back axis\(^1\).

Third, humans may in general have particularly poor perceptual memory for left-right orientation
of visual information, even in adulthood (e.g., Corballis & Beale, 1976; Dehaene et al, 2006; Gutowski,
2006). This may be true of our visual system for reasons that may or may not be connected to our
bilateral symmetry.

The low salience of the left-right axis could affect children’s acquisition of left-right spatial
terms in several ways. One possibility is that children’s left-right concepts are relatively weak or
undeveloped, making it difficult for children to reason about them for purposes of word learning.
Certainly, there are many non-linguistic tasks in which children clearly show very little sensitivity to
left-right relations, such as map use (Shusterman, Lee & Spelke, 2008) and memory for picture
orientation (Gutowski, 2006).

\(^1\) Similarly, often the secondary axis is left undifferentiated among geocentric terms in languages (e.g., a language
might have “uphill” and “downhill,” but not terms to differentiate the sides of crosshill), possibly because the
success of adopting and conventionalizing words for the sides of the second axis may in general be less successful
than if the words named for the sides of the primary axis.
A challenge to the idea that left-right concepts are undeveloped is that children do show sensitivity to left-right relations in some navigation tasks: after becoming disoriented (through turning in place), they detect and use left-right relations in the shape of the boundary (e.g., Lee & Spelke, 2010) and possibly other features of the environment (Nardini, Atkins, & Burgess, 2008; Twyman, Friedman, Spetch, 2007; but see Wang, Hermer & Spelke, 1999). Nevertheless, the representations that support their successful use of left-right relations when they are disoriented may not be accessible for purposes of word learning.

A second possibility is that children are less likely to entertain a secondary axis as the source of possible meanings for the novel words. That is, whereas children might be able to entertain left and right concepts in reasoning about space, they might not assume that different words would label identical looking sides.

An outstanding puzzle, then, is explaining how children do eventually learn “left” and “right.” Do they have the ability to entertain such concepts at all as possible referents for spatial terms, at an age where they seem to find it quite easy to learn environment-based meanings or front-back meaning? If the difficulty lies in the low salience of the left-right dimension, then a teaching method that increases this salience might enhance children’s learning of these terms. Furthermore, if the difficulty lies in the fact meanings tied to a secondary axis are dis-preferred relative to meanings tied to a primary axis, then a teaching method that emphasizes the sides of the body (secondary axis) and rules out a competing geocentric or primary axis interpretation, should help them zero in on the body as the source of the meaning of left and right.

Previous work has provided hints that the acquisition of “left” and “right” is made less difficult when the words are systematically introduced on the child’s own body. Shusterman & Li (under review) found that, when the experimenter introduced the terms using body-centric phrases (e.g., “this your ziv

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2 This possibility applies to Haun et al. (2006)’s studies as well: children (and apes) may have been unlikely to entertain the secondary axis as a possible hypothesis for the rule governing the hiding game.
four-year-olds were eventually able to learn left-right meanings for parts of their body after playing a game in which children were asked to raise, wiggle, or touch different left and right sides of their bodies. Children learned that their ziv (left) arms were still their ziv (left) arms and had not become their kern (right) arms after they turned 180 degrees.

_Beyond the body: the problems of extension, translation, and rotation in learning left and right_

In order to flexibly use these words in the way that adults conventionally do in English and other “relative” languages, it is critical to realize that the meanings of these terms are not limited to the borders of one’s own body. “Left” does not just mean a certain side of one’s body; rather, “left” also means in the direction of the coordinate axes set up by one’s body (i.e., a leftward direction). This might be called the problem of _extension_ because the meaning of left and right is extended beyond the body.

Furthermore, the egocentric axes set up by one’s body can be applied onto another object through _translation_. In the example “the cup is to the left of the saucer,” the speaker’s left-right axes can be imposed onto the saucer, which serves as the ground in the spatial relation. This might be called the problem of _translation_ because the left-right relation is defined by transferring the body’s coordinate axes a certain distance, without rotating them, to the new ground object.

Lastly, “left” can refer not just to coordinates set up by one’s own body, but any entity to which a front-back axis can be ascribed. These left-right axes may be rotated with respect to the speaker’s own left and right, such that the intended meaning of the speaker’s “right” is actually on the listener’s left. This might be called the problem of _rotation_.

In the current studies, we systematically explore whether these problems create difficulties for children acquiring left and right, and what input conditions can help them to overcome them.

Experiment 1 takes on the problem of extension. While almost all languages surveyed have words to describe the “left” and “right” hands, not all languages extend these meanings to describe objects at people’s sides (e.g., the box to his left; Levinson, 2003, p. 83). Thus it is plausible that children might understand that body parts can be labeled with these terms without understanding that the
terms can be used to describe locations beyond their bodies. Indeed, in a neutral script that did not emphasize their bodies, four-year-old did not easily learn that body part terms could refer to objects at their sides (Shusterman & Li, under review).

In Experiment 1, we explored whether children could be taught this more general meaning by emphasizing that the meaning of the words is body-centric, i.e. associated with sides of the body. In addition to body-centric instructions, we used a bracelet to make the child’s left and right sides physically different and break the symmetry between the left and right sides. Placing a bracelet on one arm might help the child to realize that his ziv arm is always his ziv arm no matter where he turns, because the bracelet is still on the same arm.

In Experiment 2, we addressed the problems of translation and rotation, two problems raised by the relative frame of reference. Because relative frames of reference involve computing relationships with three objects, rather than the two used in intrinsic frames of reference, relative frames of reference are computationally more difficult than intrinsic ones. Intrinsic frames include those that refer to the parts of the body (the left side) as well as extensions of this reference frame (to my left). Relative frames, however, always require translation to another ground object, and can also require rotation to a different perspective. One question is whether children can flexibly extend simple egocentric spatial terms to novel contexts in a relative frame of reference.

In Experiment 2, therefore, we explored whether children could easily expand their newly learned ziv and kern meanings to talk about a figure and ground from their own perspective. We assessed how children interpret relative frame of reference expressions such as (“Which envelope is to the ziv of the cup?”). Do they systematically choose an appropriate option? If they are systematic, do they prefer an interpretation that aligns with a direct projection like Hausa or a rotated projection like Tamil?

Finally, in Experiment 3, we addressed the problem of rotation. We asked whether children could learn labels for, or even attend to, the left and right sides of a doll. In other words, can they learn
the non-egocentric sense of left and right, when given consistent and structured input emphasizing the body-centric origins of these terms? Previous work suggests that the mental rotation involved in computing and attending to the left-right axes of other objects is a relatively difficult spatial problem both for children and adults (e.g., Dehaene et al., 2006; Piaget & Inhelder, 1971). Nevertheless, it might be easier for children to learn if they are given clear information about how to apply left-right spatial terms to non-egocentric origins.

In all of the studies, we test 4- and 5-year-olds, following Shusterman and Li (under review), and use a structured input method to understand children’s interpretations of novel words. We systematically varied the input children received about the novel spatial words and tested how they learned and extended these meanings. Specifically, we directly compared children’s ability to learn spatial terms depending on the reference axes (front-back vs left-right), type of spatial relations (intrinsic vs. relative), and egocentricity (own vs. other’s left-right). We also gave feedback to guide them toward specific intended meanings to see which meanings were learnable, under what input conditions.

Experiment 1

The goal of Experiment 1 was to explore whether children could learn egocentric spatial terms not just on their own bodies, but to describe separate objects at their left or right sides. The primary strategy was to emphasize from the outset that the meaning of the novel words is body-centric, i.e. associated with sides of the body. In addition to body-centric instructions, we gave the child a bracelet to wear on just one hand, in order to differentiate and break the symmetry between the left and right sides. The bracelet was removed after a few turns.

Children were tested in one of two settings in order to explore whether perceptual cues in the environment would have an impact on children’s ability to learn frame-of-reference terms: a typical asymmetrical room with furniture, objects, and a window creating a rich external environment, or in an empty, symmetrical, round, all-white room, creating a spare external environment. The purpose was to
see whether the different settings would influence word acquisition; for example, the rich setting might create an environment-based frame of reference that would compete with the body-based frame of reference we were teaching.

**Methods**

**Participants.** 20 four-year-old children (mean 4;6, range 4;2–4;10; 9F) recruited from the local community were tested. Participants received a small prize and travel reimbursement.
Testing environments. Following Shusterman and Li (under review), half of the participants were tested in a 11x12 feet furnished room (see Figure 2a). The other half of the participants were tested in an unfurnished, 12.5 ft-diameter, circular room with white walls, symmetrical lighting, and a plain gray floor. The walls consisted of adjoining panels, one of which was a hidden door that remained closed during testing.

Pretest (8 trials). Children were introduced to a sticker hunting game. On each trial, identical-looking envelopes were placed on the left and right sides of the child. Children were told that one envelope contained a sticker and one did not. They were given directions with the novel words “ziv” or “kern” (e.g., “The sticker is in the envelope on the ziv side”). They indicated which envelope by pointing. However, they were not allowed to open the envelopes until the end of the game. Thus, no feedback was given as to whether they were correct. 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 in a fixed pseudorandom order (ABBABAAB). The Pretest verified that children could not intuit the meanings of the novel words in the absence of any instruction.

Word introduction (9 trials). Children were given instructions about the meaning of novel spatial terms. The script emphasized that the meaning of the terms was associated with a particular side of the child’s body (e.g. “this is your ziv side” and ”this is your ziv arm”; see Appendix A). This body-centric meaning of the terms was further emphasized by putting a bracelet on one of the child’s arms and explaining that the side with the bracelet was the ziv arm.

Objects were then placed at the child’s side and labeled as “on your ziv side” or your kern side.” Seven probe questions (e.g., “Can you raise your kern arm?”) tested whether children were paying attention. Two object switch questions tested whether they could generalize the terms to new toys placed on their ziv and kern sides. They received corrective feedback if they erred or did not respond.

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 (Figure 2b) or to the environment (Figure 2c). No feedback was given in response to the children’s choices.

**Structured Feedback Session (maximum 24 trials).** Feedback was given to disambiguate the novel words’ meanings. All children received feedback consistent with “ziv” and “kern” meaning “left” and “right.” Identical-looking envelopes were placed on either side of the child, and the experimenter asked the child to point the envelope on the “ziv” or “kern” side. After each trial the envelope was opened to show the child if they were correct. The correct envelope contained a sticker and the incorrect one did not.

The child turned 180 degrees every six trials. The bracelet was removed from the child’s wrist at the end of the eighth trial, and remained off for the rest of the experiment. The number of feedback trials ended either when children got eight trials in a row correct or continued until twenty-four trials were reached.

**Posttest (8 trials).** Children received a Posttest, structured like the Pretest with no feedback, to see whether they had learned the intended word meanings. At the end of the Posttest, they were allowed to open the envelopes.

**Real word test (8 trials).** Following the Posttest, children were also tested on their knowledge of the real words “left” and “right.” The test was structured like the Post- and Pretest, but with real words. This test checked whether the children participants know “left” and “right,” and whether having prior knowledge of “left” and “right” could affect their interpretation and learning of “ziv” and “kern.” It should be noted that across several experiments, Shusterman and Li (under review) found that children’s response or ability to learn ziv and kern was not correlated with their knowledge of the meanings of the words “left” and “right.”

**Results**

**Pretest and Word introduction.** We found chance performance on the pretest (50% correct,
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where correct is defined as consistent with “ziv” being left and “kern” being right. \( t(19)=0.03, p=.97, \) (ns). Children learned the words quickly, performing above chance on the probe trials (89% correct, \( t(19)=12.91, p<.001 \)) and the object-switch trials (95%, \( t(19)=13.08, p<.001 \)).

Bias test. 3 of 20 children gave predominantly geocentric responses (3 or 4 geocentric responses out of 4 trials), and 9 of 20 children gave predominantly egocentric responses (Figure 3, left bar).

Results are compared with those from Shusterman and Li, who ran the same experiment in the same two rooms using non-body-centric language (neutral condition). In their study, the spatial words were introduced in a neutral manner without emphasis being placed on the body (“This way is ziv. This wall is on the ziv side of the room. Everything this way is to the ziv of you.”). They found that 12 of 20 children gave predominantly geocentric responses and 4 of 20 children gave predominantly egocentric
responses (Figure 3, right bar).

![Bar graph showing comparison of geocentric responses for body-centric vs. neutral instruction, divided by testing room for Experiment 1. Error bars = SE.](image1)

**Figure 4.** Comparison of geocentric bias for body-centric vs. neutral instruction, divided by testing room for Experiment 1. Error bars = SE.

In a 2 Instruction (body-centric, neutral) x 2 Room (round, rectangular) ANOVA with the percentage of environment-based responses as the dependent variable, we did not find a main effect of Room ($F(1, 36)=.164, p=.69$, ns) nor of Room x Instruction ($F(1,36)=1.473, p=.23$, ns). We did find a

![Bar graph showing comparison of number of trials to criterion for body-centric vs. neutral instruction, divided by testing room for Experiment 1. Error bars = SE.](image2)

**Figure 5.** Comparison of number of trials to criterion for body-centric vs. neutral instruction, divided by testing room for Experiment 1. Error bars = SE.
main effect of Instruction (F(1,36)=8.018, p< .01, \( \eta_p^2 = .182 \); Figure 4), indicating that the children were less likely to have an environment-based response when given body-centric instructions.

**Structured Feedback and Posttest.** Children learned left-right meanings significantly faster in the body-centric instruction condition than in the neutral instruction condition (Figure 5). In the body-centric condition, they reached the criterion for successful learning (8 correct answers in a row) after 16.05 trials compared to 21.45 in the neutral condition. In a 2 Instruction (neutral, body-centric) x 2 Room (round, rectangular) ANOVA with the number of trials to criterion as the dependent variable, we did not find a main effect of Room (F(1, 36)=1.225, p=.28, ns) or of Room x Instruction (F(1,36)=.428, p=.52, ns). We did find a main effect of Instruction (F(1,36)=7.379, p=.01, \( \eta_p^2 = .17 \)), confirming that when the instruction was body-centric, children reached criterion earlier.

![Graph](image)

*Figure 6. Comparison of post-test score for body-centric vs. neutral instruction, divided by testing room for Experiment 1. Error bars = SE.*

Posttest scores were higher for children in the body-centric condition than in the neutral condition, 82% vs. 61% (Figure 6). This finding is supported by a 2 Instruction (neutral, body-centric) x 2 Room (round, rectangular) ANOVA with the percentage correct as the dependent variable. There was
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no main effect of Room (F(1, 36)=.469, p=.50, ns) nor of Room x Instruction (F(1,36)=.07, p = .79, ns). There was a main effect of Instruction (F(1,36) = 5.20, p = .029, ηp^2=.13). Thus, the context in which the word is introduced (neutral vs. body-centric) affects children’s acquisition of left-right meanings: body-centric language helps children latch onto the body-centric meanings of novel left-right terms. As in Shusterman & Li (under review), the testing space did not affect word learning.

**Real word test.** Children scored 58% percent correct on their knowledge of the real words “left” and “right,” which was not above chance of 50% (t(19) = 2.04, p = .06, ns). Only five of the children scored 75% or higher. The percentage correct did not correlate with performance on the bias assessment scores (i.e., % trials choosing geocentric response; Pearson’s r=.074, p=.76), number of trials to criterion scores during structured feedback phase (r=.136, p=.57), or posttest scores (r=-.025, p=.92). Thus, like previous studies, the current test indicate that most children at this age do not know the meanings of the words “left” and “right.” Furthermore, their “left” and “right” knowledge does not fully explain their interpretation or learning of “ziv” and “kern,” our stand-ins for those real words.

**Discussion**

Prior studies demonstrated the difficulty of learning egocentric “left” and “right” in contrast to learning egocentric “front” and “back” and environment-based terms like “north” and “south.” Four-year-olds’ success at this task therefore suggests two important conclusions. First, it demonstrates how even though children have strong tendency to use environment-based frames of reference along the left-right axis, they can be taught egocentric “left” and “right.” This ability to learn left and right meanings begins to explain how it is possible that some cultures adopt such a frame of reference in their linguistic repertoire, and thus how children cope with such a range of linguistic diversity.

Second, this experiment, in conjunction with Shusterman and Li’s (under review) previous findings, provides suggestive evidence about the mechanism that children use to learn the egocentric frame of reference. It seems likely that when children are initially introduced to words with egocentric
meanings (e.g., “Get the plate on your left”) they often mistakenly interpret them as environment-based terms. The current results show that children can, however, realize that these terms are body-based if they are explicitly used to describe their own bodies. They can learn to associate physical and proprioceptive differences with the meanings of egocentric terms such “my left” and “my right.” They might notice that when they turn around the words tied to these physical differences (such as the bracelet or one’s dominant hand) turn with them. Since “left” is defined by a physical difference (such as the bracelet or one’s dominant hand), the terms can no longer be interpreted to have an environment-based meaning since the hand with the bracelet will not always be in a consistent position relative to the environment, such as the North side, the downhill side, or the side near the window.

It remains to be seen whether this account adequately describes children’s learning of left and right under more natural conditions. Even so, the successful learning observed here implies at least two mechanisms that are likely to support the acquisition of left and right: proprioceptive cues that break the symmetry of the body, and constancy of the terms while the body is rotated. This account also echoes common methods that adults use to teach children left and right (such as telling them that they write with their right hand), and common reports by children about how they learned left and right (such as noting which arm they broke or which hand has a prominent freckle).

One question that is not answered here is whether children’s learning of the word meanings were supported by the bracelet, the body-based instructions, or both. In Shusterman and Li (under review), children were successful at learning labels for the left and right sides of their own bodies without the aid or mention of a bracelet after playing a long dance game involving shaking and moving body parts (“Can you shake your ziv leg.”). However, most of these children did not spontaneously extend these terms to objects next to them. In the current study, by contrast, children quickly figured out the body-based meanings and learned the extended left-right meaning as well – applying the novel terms to objects at their sides. Thus, the bracelet and the body-based instructions in the current case might have supported children in realizing that the terms were not limited to describing parts of their own bodies.
The bracelets might have also lowered the working memory demands of the task, enabling the children to remember more easily which was the ‘ziv’ side and allowing them to benefit more rapidly from the instructions and feedback.

In sum, Experiment 1 revealed that egocentric left and right were not too difficult for children to quickly acquire, and that children quickly solved the problem of extending these terms beyond their own bodies. Experiment 2 explored the generality of their newly learned word meanings.

**Experiment 2**

Experiment 2 served as a replication and extension of Experiment 1. In contrast to Experiment 1, children were *only* introduced to ziv and kern on their bodies; they were not given any cues that ziv and kern could apply beyond their own bodies. We used a similar script to introduce ziv and kern as body-centric terms and then assessed how flexibly children could use these terms in two generalization tests.

In the *intrinsic trials*, children heard these novel words in intrinsic frames of reference expressions for the first time (e.g., the sticker to the ziv of you). We assessed how easily they used these words to pick out objects to their sides. In the *relative trials*, we tested how children spontaneously interpreted relative frame-of-reference expressions of the form “X is to the ziv of Y”, where Y is another entity other than the child.

We used two different types of relative trials. Half of the children were asked to interpret relative expressions using a non-fronted object – a cup – to see whether they could impose axes onto the cup, and whether they would follow a standard convention for doing so (e.g., transferring their own egocentric axes onto the cup). The other half of children were asked to interpret relative expressions using a fronted object – a doll – to see whether children would integrate the doll’s axes into their interpretations of these expressions. In some of the trials, the doll’s frame of reference was in conflict with the child’s axes (e.g., the doll’s left was on the child’s right). Thus, these extension trials would allow us to see whether the doll’s axes would influence the child’s choices in interpreting the novel
word meanings. If children’s responses changed with the doll’s turn, then it would imply that they considered that the doll also had a ziv and a kern side like themselves. If children’s responses differed between the cup and the doll condition, it would imply that they were sensitive to the doll’s orientation in computing the meanings of ziv and kern. Thus, the two tests in Experiment 2 assessed how readily children solved the problems of extension beyond their own body (intrinsic trials) and translation to a new coordinate origin (relative trials).

Methods

Participants. 30 children (mean 5;0, range 4;0-5;9; 14F) were recruited from and tested at the Museum of Science, Boston. The children were tested individually in a corner of an exhibit hall. An additional 3 children were tested, but excluded because they scored 0% correct on the last two memory check trials (see Memory Check Trials below).

Word introduction (8 trials). Children were introduced to novel spatial words, ziv and kern, using a script that closely followed the word introduction of Experiment 1 (see Appendix B). However, unlike Experiment 1, the novel words only referred to a side or a body part of the child (e.g., “This is your ziv hand”). They were not used in examples as directional terms to describe locations of objects outside the child’s own body. This word introduction phase provided no demonstrating examples like “This toy is to the ziv of you.”

Altogether, children answered eight questions involving body-parts during the Word Introduction. Four were probe questions that tested whether they paid attention (“I am putting a bracelet on your ziv hand…. Which hand did I put the bracelet on – ziv or kern?”). Four were body-switch questions to see whether children could extend the novel terms to new body parts (e.g., “Can you raise your ziv leg?”). If the children erred or did not respond, the experimenter gave corrective feedback.

Intrinsic language trials (8 trials). On each trial, the experimenter placed two identical-looking envelopes, one on each side of the child. The child was told that one of the two envelopes contained a
sticker inside. The experimenter then asked the child to point to the envelope with the sticker (“The sticker is on the ziv side. Can you show me the envelope on the ziv side?”). The dependent measure was which envelope the child chose. After 4 such trials, the child was turned 180-degrees and tested on 4 more trials. The turn manipulation revealed whether the child mapped the novel terms onto their body or to the environment. The child was allowed to open the envelopes for the first two trials. For all remaining trials, including the relative language trials below, the child was asked to refrain from opening any envelopes. The experimenter kept the selected envelopes in a pile to be opened after the experiment.

Figure 7. Testing for systematic relative frames of reference interpretations of ziv and kern in Experiment 2. (a-c) depicts the setup of the envelopes and cup in relation to the child during test. (d-e) depicts two possible interpretations for ziv and kern when the cup and envelopes are placed in front of the child.
Relative language trials (12 trials). Children were randomly assigned to the Fronted Object or Non-Fronted Object condition (n=15 in each). In the Non-Fronted condition, the object was a red cup, a “non-fronted” object that lacks a front-back axis. For each trial, two identical-looking envelopes were placed on the sides of the red cup and the child had to identify the envelope from the experimenter’s use of ziv and kern (“The sticker is on the cup's ziv side. Can you point to the envelope on the cup’s ziv side?”). In these sentence frames, the cup was the ground object and the envelope with the sticker was the figure object.

See Figure 7 for the general set-up of the child, ground and figure objects. In all cases, the experimenter sat facing the same direction as the child, but slightly behind to one side. The envelope-cup-envelope array was placed in three different positions. For the first four trials, the cup was placed directly in front of the child (Figure 7a). For the next four trials, the cup and the two envelopes were all lined up on the child’s left side (Figure 7b). For the last four trials, the cup and envelopes was lined up on the child’s right (see Figure 7c).

In the Fronted condition, the instructions were identical to the Non-Fronted condition with a few exceptions. A doll, which has a front-back axis, replaced the cup. For all three positions (Figure 7a-c: directly in front, to the left, and to the right of the child), the doll initially faced the same way as the child. Halfway through each set of four trials, the experimenter turned the doll to face the opposite direction of the child, and indicated the turn (“Look. I am turning the doll.”). Children then answered queries about ziv and kern (“Can you point to the envelope on the doll’s ziv side?”).

Memory check (4 trials). At two different points in the experiment, children were polled to see if they still remembered how the novel words referred to their own body. The first time was in the middle of the intrinsic language test, right after the child turned 180-degrees. The second time was at the end of the experiment. Each time, the children were asked to raise their arms (“Can you raise your ziv arm?”), once for ziv and once for kern. The order for ziv or kern was counterbalanced across children. No feedback was given.
The purpose of the memory check was to verify that children had learned ziv and kern during the Word Introduction phase. If children failed the memory check, there was no reason to expect that they would be systematic on the novel extensions of the spatial words. In line with Experiment 1, which showed children were able to fast-map and maintain these new words, the average percentage correct for the memory trials was high (91.7% correct, $t(32)=13.01, p < .001$). With the exception of three children out of 33 tested, all children scored at least 75% correct on these four trials. The three children reversed ziv and kern at the second time point, scoring 0%, while the other children score 100%. Because we were interested in how children who had learned the words as body parts extended these words to novel situations, we excluded these three children from analyses.

**Results**

**Word Introduction.** Children learned the words quickly, performing above chance on the probe questions (96.7% correct, $t(29)=23.55, p < .0001$) and body-switch questions (88.3%, $t(29)=11.50, p < .0001$).

**Intrinsic Language Trials.** Children correctly indicated the envelope to their immediate left and right sides with “ziv” and “kern” 95% of the time, compared to 50% chance ($t(29)=24.23, p < .0001$). Further analyses divided the four trials prior to the 180 degree turn and the four trials after the turn (Figure 8a). Performance was 95% for both sets of trials ($t(29)=.00, ns$). As the high percentages correct suggest, children were almost always correct, even on the very first trials. Thus, as in Experiment 1, children were easily able to extend the terms ziv and kern to objects at their sides.

**Relative Language Trials.** Analyses of the relative language trials assessed how children interpreted the novel terms. Did they systematically project their own axis onto the ground object (as in Figure 7d) or did they rotate their axis (as in Figure 7e)? Did those exposed to a fronted ground object (doll) consider the orientation of the doll?
As a first pass, disregarding the type of ground object used, the children were typed according to whether they applied their own axis directly onto the ground object (Figure 7d, no rotation) or rotated their own axis and applied it onto the ground object (Figure 7e, rotation) for each of the three placements of cup/doll and envelopes shown in Figures 7a-c. The first three columns of Figure 9 show the results for the three positions. To be typed, children had to respond in the same way for at least 3 out of the 4 trials tested in each position. Those who did not meet this criterion were considered “Untypable.” Finally, children were typed for their consistency across all twelve relative trials. Here, they were typed two ways, using both a relaxed criterion (Figure 9, column 4) and a stringent criterion (Figure 9, column 5). The relaxed criterion typed children’s application of their own axis as rotated or not rotated if they were consistent on at least three-quarters of the trials (i.e. at least 9 out of 12 trials). To meet the stringent criterion, children needed to give a consistent response on at least 11 out of 12
trials. As indicated by all columns of Figure 9, the majority of the children transferred their own axis, without rotation, to reliably interpret relative uses of ziv and kern. Impressively, at least half of them did so consistently across all twelve trials regardless of whether the ground object was either in front or to one side of them.

![Graph showing children's biases to interpret ziv and kern on relative trials](Figure 9)

To address whether children considered the orientation of the ground object, the percentage of trials in which children applied their own axis directly onto the ground object was entered into a 2 Ground Object (cup, doll) x 3 Position ANOVA. There was no effect of Position (F(2, 56)=.53, p=.59, ns). Relevantly, no difference was found between the fronted and the non-fronted reference objects that
we used – the doll and the cup – suggesting that children did not consider the orientation of the doll in their responses (Ground Object: F(1, 28)=.49, p=.49, ns; Ground x Position: F(2, 56)=.33, p=.72, ns). However, we also examined this question more closely by focusing on the fifteen children in the doll condition. We compared the six trials in which the doll faced the same direction as the child with the six trials in which the doll faced the opposite direction from the child. Figure 10 plots the distribution of children’s responses by how many times they applied their own axis without rotation onto the ground object. As can be seen from Figure 10, where the two distribution curves sit on top of each other, there was no difference across the two types of facing directions (Wilcoxon signed-ranks, Z = -.17, p = .86).
When the child and the doll faced opposite directions, the majority of the children still interpreted ziv and kern with respect to themselves rather than with respect to the doll.

Finally, taking the direct projection of one’s own axis onto the ground object as the “correct” response, performance on the relative trials was contrasted with performance on the intrinsic trials. Performance was worse on the relative (relative: 82% “correct” vs. intrinsic: 95% correct, t(29)=12.718, p < .0001). The relative trials required children to consider translational movement, because the center of the coordinate system was not their own body but rather a separate object (i.e. the ball or the doll). Nonetheless, for the relative trials, the majority of the children projected their own axis onto the ground object above chance (81.7% correct, t(29) = 6.831, p < .0001). This suggests that upon learning how the novel words refer to their bodies, English-speaking children have reasonable intuitive guesses as how these words can be used in relative frame of reference expressions: they directly project their own left-right axis onto the new ground object.

Discussion

The Word Introduction phase of the current experiment replicated Experiment 1 by demonstrating that children can learn novel words ziv and kern as body parts, and then extend the words to other body parts. In addition, whereas children were given two instances of how to extend ziv and kern to the sides of themselves in Experiment 1, the current experiment asked whether they could spontaneously do so without any prior examples. Indeed, they could, suggesting that there were no major conceptual barriers to doing so. Experiment 2 further tested whether children could spontaneously understand and interpret relative uses extending the novel terms to new ground objects. We found that children were not random in their responses or confused by the expressions. As a group, they overwhelmingly and consistently adopted their own body’s coordinate system and applied it directly onto the ground objects in order to select the correct (ziv or kern) figure objects.

The tendency of children to project, rather than rotate, their own axis onto a ground object
Learning “Left” and “Right” directly in front of them (Figure 7a, d) agrees with developmental studies of how children learn body-centric words like “left,” “right,” “front,” and “back” under natural circumstances (see Levinson, 2003 for a review). These studies show that children learning languages that have rotated axes as conventions often go through a stage in which they do not rotate the axes. For example, in learning relative uses of “front” and “back,” many English-learning children do not correctly adopt the convention of rotating the front-back axis when using a non-fronted object as the ground to talk about other objects (as in Figure 1c, English example). Instead they first project their own front-back axis on to the cup (as in Figure 1a, like Hausa), only later adopting the traditional convention. Together, these results suggest that children do not have a problem computing relative relationships when their own perspective is involved. Rather, they may struggle with computing spatial relationships that require axis rotation and learning how such relationships are conventionalized in their language.

The results of Experiments 1 and 2 demonstrated that children do not have much difficulty with two of the three problems of left-right relations: extension beyond their own body and translation to a new coordinate origin. Experiment 2 further demonstrated that English-speaking children are not naturally inclined to rotate the coordinate axis when project novel terms to the left-right sides of a doll or a non-fronted object. In other words, they seem to intuitively adopt the Hausa or English convention of direct translation, and do not adopt the Tamil conventions for rotating the left-right axis. In Experiment 2, children ignored the doll’s left-right axes, but they were not given any particular reason or motivation to attend to the doll’s orientation; they essentially treated the doll just like the cup. Nevertheless, it is possible that children can solve the problem of rotation too, if they are given sufficiently structured input that clearly demonstrates this convention. Experiment 3 tested this possibility.

**Experiment 3**

Experiment 3 tested children’s spontaneous intuitions about and ability to learn words for a non-egocentric object-centered frame of reference. In Experiment 2, children did not rotate their own left-
right axis and apply it to another object. However, they were not given any explicit instruction or reason to do so. Therefore, in Experiment 3, we taught them the novel terms directly on the doll. The goal was to extend the results of Experiments 1 and 2, which demonstrated that children could use the egocentric object-centered reference frame (their own axes applied to another object), to see if they could also learn a non-egocentric object-centered frame of reference (learning another object’s axes). In comprehension studies, Rigal (1994) showed that children first identify the left and right sides of themselves at seven years old, but fail to identify the left and right sides of people facing them until nine years old (see also Piaget & Inhelder, 1971).

It is important to keep in mind that our studies are word-learning studies exploring the input conditions under which children can learn different meanings. Under natural learning conditions, there are at least two reasons why non-egocentric left and right might be difficult to acquire. First, parents may tailor their child-directed speech to talk about the child’s left and right more than any other kinds of left and right, realizing that there are often ambiguities as to whose left or right is being talked (see Schober, 2009; Martin & Seras, 2006). Indeed, more advanced speakers often tailor their spatial language to the level of the listener (Schober, 2009) and English-speaking children more often hear left-right language applied to themselves than to others (Martin & Seras, 2006). Second, children may not be conceptually ready to learn non-egocentric uses. Computing another person’s (or object’s) left-right requires one either to mentally rotate one’s own axes and apply them to another body, or to construct a truly “object-centered” mental representation that includes the left-right axis of that object. Either way, computing another person’s left and right seems to require spatial skills that are not required for determining one own’s left and right.

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3 Same possibility may apply also to the input of front and back. Kucjaz and Maratsos (1975) found that comprehension of others’ “front” vs. “back” comes in after child’s own “front” vs. “back” despite the fact children know how to determine the front and back of animals and can line them up in a parade (Levine & Carey, 1982).
The structured introduction of the novel spatial terms allowed us to see whether children can learn the words on a doll when given clear instructions. We used the body-centric script that was successful in Experiment 1, but with reference to the doll instead of the child’s own body. Critically, the experimenter and the child sat facing the same direction, to minimize the number of perspectives that the child would have to consider. Experiment 3A therefore tested children’s initial interpretations of new spatial terms introduced on the left-right axis of a doll (“The doll has a ziv side and a kern side.”). The left-right instruction condition was contrasted with a front-back training condition. By comparing children’s interpretations for the left-right and the front-back axis, we could determine which response patterns were specific to the non-egocentric object-centric frame of reference and which were specific to the left-right axis within this frame of reference. In Experiment 3B, we gave a subset of the participants from Experiment 3A follow-up training, to see whether a series of structured feedback trials would help children to learn non-egocentric left and right. In Experiment 3C, we used a spatial memory rather than a word-learning task to see whether children’s response patterns were due to conceptual as opposed to linguistic limitations.

Experiment 3A

Methods

Participants. 55 children (mean 4;9, range 4;0-5;11; 33F) were tested. Children were assigned to either the LR (left-right) condition or the FB (front-back) condition, with 27 and 28 children in the two respective conditions. With the exception of eight participants who were tested in the laboratory (same 11x12 furnished room as Experiment 1), all participants were tested on a small stage in the corner of an exhibit hall at the Museum of Science, Boston. Those tested in the laboratory were given a prize and travel reimbursement for participating. Those tested at the museum were given stickers.
(a) Position 1: Initial Position. Introduce ZIV/KERN

(b) Position 2: Doll turns 180°. Query ZIV/KERN.

(c) Position 3: Child moves behind doll, a 180° turn. Query ZIV/KERN.

Figure 11. Facing directions of the doll and child within testing environment for Experiment 3A’s left-right condition: (a) Initial facing direction, (b) doll turns, and (c) child turns. Boxes indicate the frames of reference that correspond to each possible response pattern. Thus, egocentric, (non-egocentric) object-centered, and geocentric frames of reference each correspond to a unique pattern of responses in Positions 2 and 3.
Figure 12. Facing directions of the doll and child within testing environment for Experiment 2B’s front-back condition: (a) Initial facing direction, (b) doll turns, and (c) child turns.
**Word introduction (9 trials).** Children were given instructions about the meaning of novel spatial terms while they sat facing the same direction as the doll (See Appendix C). For the children in the left-right condition, the doll was in front of the child so that ziv and kern were aligned with both the child’s and the doll’s left and right (see Figure 11a). For the children in the front-back condition, the doll was to the right of the child so that ziv and kern were aligned with both the child’s and the doll’s front and back (see Figure 12a). Body-centric language was used to explain the terms, e.g. “This is the doll’s ziv side.” Seven probe questions (e.g., “Can you point to the doll’s ziv arm?”; Appendix C) tested whether children were paying attention. Two object switch questions tested whether they could generalize the terms to new toys placed on the doll’s ziv and kern sides.

**Bias test (12 trials).** The bias test assessed whether children mapped the novel terms onto the doll’s body (i.e., object-centered frame), to the environment (geocentric frame), or to their own bodies (egocentric frame). The bias was determined by comparing how the children interpreted ziv and kern before and after the doll and the child each moved. Their movements dissociated the three different frames of reference (see Figure 11 for left-right condition and 12 for front-back condition).

For each trial, the child was asked about a set of two identical toys, one placed on each side of the doll (“Can you show me the toy on the ziv side?”). No feedback was given by the experimenter to support or oppose the child’s response. For the first four trials, the child and doll faced the same direction as the word introduction phase (Figure 11a for LR and 12a for FB). Then the experimenter turned the doll 180-degrees (Figure 11b and 12b) and asked about new toys placed on the doll’s ziv and kern sides for four trials. Finally, the experimenter turned the child 180-degrees and asked the same question with new objects for four last trials (Figure 11c and 12c).

**Results**

For the word introduction trials, performance on the probe questions was very high (89% correct), as was performance on the object switch trials (84% correct). Comparing the FB and LR
conditions, the scores on the probe questions (FB: 87% vs. LR: 92% correct; t(53) = 1.01, p = .32, ns) and the object switch questions (FB: 82% vs. LR: 85% correct; t(53) = .31, p = .42, ns) did not differ, indicating that the two groups were comparably attentive to the task. All scores were above 50% chance (t-tests, FB: t(28) > 4.36, LR: t(27) > 5.47, p’s < .001).

For the bias assessment trials, children were classified either as Egocentric (self-centric), Object-centered (doll-centric), or Geocentric (environment-centric), if they gave at least eleven responses out of twelve consistent with one of those frames of reference. They were otherwise classified Untypable (Figure 13). Although the novel words were introduced in doll-centric sentences, the LR and FB groups differed in their tendencies to attribute doll-centric (i.e., non-egocentric object-centered) meanings to ziv and kern. 46% of the FB children interpreted the novel words with respect to the doll, compared to 11% of the LR children (Fisher’s exact p = .007). The LR group tended to interpret the novel words with an

![Figure 13. Children typed by their biases for interpreting ziv and kern when introduced on either LR sides or FB sides of a doll (Experiment 3A).](image-url)
environment-based frame of reference, while the FB group rarely did so (LR: 44% vs. FB: 7%, Fisher’s Exact p = .002). Rarely did children in either group consider egocentric meanings (FB: 4% vs. LR: 11%, Fisher’s Exact p = .35, n.s.).

**Discussion**

With a doll-centric introduction on a doll’s front-back axis, children preferred to use the doll’s frame of reference in ascribing meanings to novel spatial terms (in other words, the non-egocentric object-centered meaning). In contrast, with an identical introduction on the left-right axis, children interpreted the novel words as having geocentric meanings, despite the fact that the instructions emphasized the doll and the doll’s body. Thus, like Shusterman and Li (under review), we see a difference between the front-back and left-right axis when interpreting novel spatial words, and a tendency to assume a geocentric interpretation when learning terms for the left-right axis.

**Experiment 3B**

The word introduction in Experiment 3A left the interpretation of the meanings up to the children. The data suggest that children tend to spontaneously construe terms along the left-right axis as having geocentric meanings. Experiment 3B explored whether these children could learn non-egocentric meanings of “left” and “right” if they received structured feedback. A subset of the children tested in Experiment 3A participated in a follow-up feedback training session to see whether they could over-ride their initial interpretations and learn the doll’s left and right. The feedback session emphasized the same body-centric script that was successful for teaching egocentric left-right in Experiment 1, but focused on the doll’s body instead of the child’s.
Methods

Participants. 8 children (mean 4;6, range 4;3-4;10; 4F) from experiment 3A participated in a structured feedback study and post-test. These children were all tested in the 11x12 furnished laboratory room of Experiment 1 for both portions of the experiment (3A and 3B).

Structured Feedback Session (maximum 24 trials). Feedback was given to disambiguate the novel words’ meanings. Children received feedback consistent with the words meaning “left” and “right.” Identical-looking envelopes were placed on the left and right sides of the doll. One contained a sticker and one was empty. The experimenter used “ziv” or “kern” to disclose the location of the hidden sticker (“The sticker is on the doll’s ziv side”). Children chose an envelope and were allowed to open it immediately. Correct envelopes contained stickers. Incorrect envelopes were empty. Trials were blocked in 6-trial sets. The doll turned 180-degrees between each block (Figure 11a vs. 11b). At each turn, experimenter would bring to the children’s attention that the doll was being turned (“Look! I am turning the doll.”). Feedback ended after eight consecutive correct responses, or after 24 trials, whichever came first.

Posttest (8 trials). A Posttest assessed whether the children learned doll-centric meanings (i.e., the doll’s left and right). For the first four trials, the child and the doll sat as they did during the Word Introduction phase (Figure 11a). For the last four trials, the doll was turned 180 degrees (Figure 11b). For each trial, identical-looking envelopes were placed at the sides of the doll, and the child had to point to the envelope indicated by the experimenter (“The sticker is on the doll’s ziv side”). The children were told that they would not open the envelopes until the very end.

Results

During the structured feedback trials, no child gave eight correct answers consecutively, so all children completed all 24 trials. On average, children scored 54% correct on the Posttest, not
significantly different from 50% chance ($t(7)=.41; p = .69, ns$). Thus there was no evidence that children learned the non-egocentric meanings of “left” and “right.”

**Discussion**

Although four-year-olds can be taught egocentric left-right when the body-centric meanings of the terms are emphasized (Experiment 1), they seem to be unable to learn non-egocentric left-right even when the body-centric meanings of the terms are emphasized (Experiment 3A and 3B). This difference in performance parallels the late acquisition of non-egocentric left-right in typical development, and suggests that there is some kind of additional ability required for non-egocentric left-right that is not required for egocentric left-right.

Experiments 3A and 3B show that children have difficulty learning words for the left and right of another entity, but this could be a failure to understand the communicative intent of the speaker rather than a conceptual problem. In Experiment 3C, we explored whether children have difficulty conceptually representing the left and right sides of another object (a doll). Instead of a word extension task, we used a spatial memory task in which children had to track coins hidden in the doll’s left or right pockets.

**Experiment 3C**

**Methods**

**Participants.** Forty-six children who completed Experiment 3A, but not 3B, participated in Experiment 3C. Children were assigned the same conditions they were assigned to for Experiment 3A; 19 of the children were in the LR condition, and 27 in the FB condition.

**Procedure.** Children were introduced to a doll with two empty pockets. For the children in the FB condition, the pockets were on the front and back of the doll. For children in the LR condition, the pockets were on the left and right of the doll. For each trial, children watched as the experimenter hid a coin in one of the pockets. Children were told to remember where the coin was hidden. Children then
Learning “Left” and “Right” 40

closed their eyes and counted with the experimenter to five. Finally, with eyes opened, the children were asked to point to the pocket with the hidden coin. The experimenter then opened the pocket(s) to reveal whether the correct pocket was chosen.

There were six trials. For the first pair of trials (Position 1), the doll remained stationary. For the second pair (Position 2), the doll was turned 180 degrees after the child opened their eyes. For the final pair (Position 3), the child moved 180 degrees to the other side of the doll after opening their eyes. Note that the orientation and movement of the doll and child for the three positions mirrored that of Experiment 3A (see Figures 11 and 12).

Results

Figure 14 plots the results of the coin search for the LR and FB group by position. Correct score was entered into a 2 Condition (LR, FB) x 3 Position (1, 2, 3) ANOVA, with Position as a within-subjects factor. The analysis revealed significant effect of Condition, with FB condition outperforming LR condition (93% vs. 77% correct; F(1, 44) = 19.76, p < .001, $\eta_p^2 = .31$). There was also a main effect of Position (F(2, 88) = 9.734, p < .001, $\eta_p^2 = .18$) and Position x Condition interaction (F(2, 88) = 14.148, p < .001, $\eta_p^2 = .24$). Specifically, whereas there was no effect of Position for the FB group (t-tests, p > .43), the LR group’s Position 1 (100% correct) was better than Position 2 (58%; t(18) = 6.10, p < .001) and Position 3 (74%; t(18) = 3.75, p = .001). Position 2 and 3 did not differ statistically (p = .14), but t-tests against chance indicates that percentage correct is above chance for Position 3 (t(18) = 3.38, p < .01), and not Position 2.

Crucially, the fact that children performed worse on Position 2 is consistent with their difficulty in representing left or right sides of other objects. For Position 1, neither the child nor the doll moved, so children do not necessarily have to represent the sides of the doll to succeed. They could remember the coin’s location with respect to the environment (e.g., next to the window) and with respect to themselves (e.g., their left). For Position 3, only the child moved. Again, children could rely on the coin’s location
with respect to the environment, without relying on the doll’s left or right, to successfully retrieve the coin. For Position 2, the doll moved and so the coin’s location remained invariant only with respect to the doll. It is only by noting the facing direction of the doll and identifying the left or right side that the child can succeed at retrieving the coin.

Revealingly, children’s chance performance on Position 2 (58% correct) is better than what is expected had they had entirely disregarded the doll’s movement. That is, if they noted the relation of the coin either with respect to the environment or with respect to their own perspective, and did not factor in the doll’s rotation, they would have always chosen the incorrect location (e.g., the side next to the window) and therefore be below chance. The 58% correct does not arise because of children who were always correct or always incorrect. The majority of the children (12 out of 19) scored exactly 50% correct. This suggests that although four-year-olds, as a group, appreciate that the location of the coin is tied to the doll, they have difficulty tracking the coin’s change of location when the coin is either in the left or right pocket.

![Figure 14. Children’s ability to retrieve a hidden coin from the doll’s left-right pockets vs. the doll’s front-back pockets (Experiment 3C). See Figures 11 and 12 for the 3 positions. Error bars = SE.](image)

_T-tests against chance (50% correct): * p < .01; ** p < .001_
Discussion

This coin search task is not about word learning and guessing the communicative intent of the experimenter. It is a task that has a right and wrong answer. Here, we find that children had no problems retrieving coins on the doll’s front-back axis. In contrast, children struggled with non-egocentric left-right. Because the set-up and procedure was directly analogous to the word-learning task in Experiment 3A, the failure to represent the doll’s left and right in the non-linguistic task is revealing. Since they have difficulty tracking left and right of the doll in Experiment 3C, it is logical that they would not even consider (Experiment 3A) or learn (Experiment 3B) non-egocentric object-centered left-right language (i.e., the doll’s left and right).

These data begin to explain why is it that children always start by learning the words “left” and “right” as applied to their own body before they ever learn how to talk about other’s “left” and “right.” Our experiments provide evidence that inability to correctly point to the “left” or “right” of other people (Rigal, 1994) has to do with the fact that children cannot represent those relationships. Other research suggests that this ability to compute other people’s left and right may take several years to develop (Lasky, Romano, & Wenters, 1980; Li, Shusterman, & Bogsted, 2007). Lasky et al. set up a tabletop display in which there was a clown face painted in the center, and one hiding place to each side of the clown’s face. Children who lost visual contact with the display could not locate an object hidden to either the left or right side of the clown at above chance level until about nine years of age. Interestingly, this is around the age Rigal (1994) reported that children learn the language for talking about other people’s left and right. It is possible that by first learning how “left” and “right” applies to one’s own body, and then hearing how the same words are used on other people’s body (e.g., the doll’s) lead children to draw the connection that they can reason about other people’s left and right sides. For example, it is possible that pointing out to young children that other people have left and right sides just like themselves could effectively help them solve non-verbal tasks such as Lasky and colleagues’ as well as learn words for non-egocentric left and right.
General Discussion

The strategies and conventions that communities converge upon to talk about space vary greatly (Levinson, 1996), with some preferring geocentric (absolute) frames of reference and other preferring object-centered (relative) frames of reference. These cross-linguistic variations have served as the starting point of many inquiries into the relationship between language and thought in adult-speakers (e.g., Pederson et al., 1998; Li and Gleitman, 2002, Levinson, et al. 2002). Of late, researchers have wondered how children come to learn the spatial reference systems of their native language (e.g., Mandler, 1996; Bowerman & Choi, 2003; Majid et al., 2004; Haun et al., 2006), asking to what extent are children ready to learn the range of spatial words in the worlds’ languages and to what extent does learning spatial words drive them to restructure spatial concepts. The current experiments add to several recent studies on spatial frames of reference to address these questions (Haun et al., 2006; Shusterman & Li, under review; Majid et al., 2004; Dasen & Mishra, in press).

These recent studies support the position that cognitive precursors allow children to easily learn geocentric meanings, contrary to older literature suggesting that children are predominantly egocentric and have difficulties considering alternative frames of reference (Piaget, 1928; Acredolo 1978). In particular, Shusterman and Li (under review) found that four-year-old children participants were readily able to fast-map novel spatial words to geocentric meanings, and that they understood the novel geocentric words in new linguistic expressions and in new test environments. For example, when taken outside the testing room and down the hall to a new environment, the children correctly tracked the absolute directions specified by the words; they pointed reliably in the directions requested by the experimenter (“Which way is ziv?”). Thus, young children are well-equipped to learn words derived from geocentric coordinates.

The case of children’s learning object-centered frames of reference (e.g., “to the left/front”) has proven to be somewhat more complicated. Some recent studies have been taken to suggest that children
have great difficulty learning object-centered frames of reference. Advocates for this position include Haun et al. (2006), who found that participants, across several great ape species (including four-year-old human children), were generally better at guessing rules that respected environment-based frames of reference than egocentric object-centered frames of reference. Haun et al. concluded:

> All genera prefer environment- to self-centered processing of spatial relations…. This inherited bias can be overridden by cultural preference, as in our own preference for egocentric or relative spatial coding. Nevertheless, overriding the bias might be of some cost; thus, the theory makes predictions about the relatively greater difficulty of acquiring a predominantly egocentric coding system. (p. 17572)

In support of their conclusion, Haun et al. went on to note that whereas children in communities preferring geocentric terms begin using geocentric expressions at four years and master the expressions by seven years, children in egocentric/relative communities do not master left-right expressions until they are eleven years old.

The current data suggest that children are more equipped to break into a system of relative spatial language than Haun et al.’s argument implies. While children do have difficulty learning the full-blown left-right system used in relative languages, they are readily able to learn egocentric object-centered meanings like “to the right of me” and “to the right of the cup” so long as they do not have to engage other perspectives or use mental rotation. Thus, there is more to the picture than overcoming an evolved bias that favors geocentric concepts.

Using a word learning paradigm, we controlled the input children were exposed to for learning novel spatial words. We varied whether the novel words were introduced on the children themselves or on other entities, thus distinguishing between two types of object-centered frames of reference – egocentric versus non-egocentric. We also varied whether the axis from which the novel words were derived is primary (front-back) or secondary (left-right). These subtle experimental variations reveal more nuanced patterns about children’s readiness to learn different frames of reference.

Our data indicate that not all types of object-centered frames of reference expressions are difficult to learn. First, children easily learn meanings for the front-back axis even when they struggle to
learn meanings for the left-right axis. Shusterman and Li (under review) showed that children learned *ziv* and *kern* to refer to the location of object in front of and behind themselves, but not to the left or right of themselves, when given neutral instructions. Experiment 3 in this paper extends this finding, showing that children could learn words for object located at the front and back of a doll, but not to the left and right of that doll. Thus, for both egocentric (i.e., the child’s own body) and non-egocentric (i.e., the doll) object-centered frames of reference the front-back axis is much more salient than the left-right axis, and front-back concepts are much more available for word learning. These word-learning findings show that the advantage for learning “front” and “back” relative to “left” and “right” exist when input conditions are equated. Thus, contrary to Haun et al, children do not struggle with egocentric or object-based reference frames per se; if this were the case, one would expect that they would struggle with left-right and front-back relations equally. However, the difficulties appear to be specific to left and right.

Furthermore, in a non-verbal spatial memory task where they had to remember the location of hidden coins on either the front-back or left-right sides of a doll, children were much more successful when the coin was on the doll’s front or back. These data also confirm the intuition that front and back is conceptually easier than left and right, and align with the observation that the vocabulary for “front” and “back” is learned earlier than “left” and “right” (Johnston 1988, Kucjaz & Maratsos 1975, Johnston & Slobin 1979).

Second, our data indicate that even left and right are not impossible for children to learn, although the full-blown adult meanings of these terms seem to be beyond their reach. Four- and five-year-old children can, given the right input, robustly and quickly learn egocentric left and right word meanings. Although Shusterman and Li (under review) showed that the secondary (left-right) axis may not be as salient as the primary (front-back) axis in word learning, Experiments 1 and 3 demonstrated that four- and five-year-old children are nonetheless quite capable of entertaining egocentric left-right concepts. When explicitly told that their body had two sides, a *ziv* side and a *kern* side, the children in our study now interpreted and learned the novel words as meaning their own left or right sides.
Furthermore, they extended these newly learned egocentric body terms consistently in new contexts, not only to pick out objects to their immediate sides, but also to pick out figure objects in relation to another ground object besides themselves. Thus, four- and five-year-old children are capable of understanding both intrinsic and relative frames of reference when using their own left and right sides as the coordinate axis.

In contrast, four- and five-year-old children seem incapable of figuring out non-egocentric left-right language. The children in our study did not entertain left-right meanings when the novel words were introduced on another entity’s left and right sides using body-centric language (“The doll has a ziv side and a kern side.”). Their failure to entertain such meanings also contrasted with their overwhelming preference to adopt front-back meanings when the words were introduced on the doll’s front and back (Experiment 3A). Furthermore, they could not learn the left-right meanings despite being given clear disambiguating feedback as to which sides were “ziv” and “kern” when the doll turned in front of them (Experiment 3B). In this manipulation, the children never heard contradicting or confusing input — that is, the novel words always applied exclusively to the doll’s left or right — and yet they could not figure out the meanings. Therefore, the difficulty in acquiring left-right terms cannot be fully explained by the fact that the input children hear will sometimes be contradicting or confusing. Nor can this difficulty be explained by adults’ tendency to tailor their speech to the perspective of the child: the children in Experiment 3B were extensively and systematically exposed to non-egocentric uses of left and right, but were unable to benefit from this structured input.

Intuitively, figuring out the meaning of “left” and “right” on the basis of one’s own body ought to be easier than the meaning of “left” and “right” of another person. First, proprioception gives a sense of one’s own left and right and may allow children to first associate “left” and “right” with the sides of their own body. On the other hand, children have no proprioceptive sense of another person’s left and right. Unlike front and back, there are no visually salient cues that distinguish the left and right sides of another person or other symmetrical entity. Consequently, children must rely on mental rotation to align
their own left and right with the other entity’s (or otherwise construct a truly object-centered spatial schema of that object) in order to determine which is “left” and which is “right.”

Given the complexity of the relation children must track, it is perhaps not surprising that children never consider the non-egocentric left-right meanings in the language learning tasks (Experiment 3A and 3B). However, the problem runs deeper than figuring out a non-transparent relationship between language and concepts. In our non-linguistic version of the task (Experiment 3C), where children had to retrieve a hidden coin, they could not figure out the location of the coin hidden to the doll’s left or right pockets when the doll moved (see also Lasky, Romano, & Wenters, 1980). Thus, our data indicate that four- and five-year-old children appear to be truly unready to think about or learn non-egocentric left and right language.

Our finding that egocentric left-right is privileged over non-egocentric left-right matches the developmental progression reported by Rigal (1994) in English- and French-speaking children from New Zealand and France. Both groups of children progressed similarly in their comprehension of “left” and “right” expressions. Rigal generalized that between five and seven years of age, children first figure out how the words map onto their bodies (e.g., “left eye”), and they correctly learn to identify the left and right sides of people facing the same directions as themselves (e.g., “left of the boy”). Between eight and eleven years of age, they learn to identify the left and right sides of people facing them, and work out how to talk about entities to the left and right sides of these people. We hypothesize that during this last period, children also work out the conventions of their language, such as whether the axis is rotated or not. We also predict that improvement in children’s ability to solve conceptual tasks requiring non-egocentric left-right, such as mental rotation, will be related to the acquisition of language for non-egocentric left and right.

Our data, however, leave unanswered how children eventually come to be ready to learn non-egocentric uses of left-right. Martin and Seras (2006) suggest that improvements in one’s ability to reason about the perspective of another person and to perform mental rotation is necessary for the
success in learning the full extent of left-right use. Several studies show that these abilities may undergo substantial development in childhood. For example, mental rotation speed and accuracy continue to improve into teenage years (e.g., Hale, 1990; Kail, Pellegrino, & Carter, 1980; Willis & Schaie, 1988). Such improvements in mental rotation abilities may allow children to grasp how language is used to describe the left-right sides of other people or objects.

It is equally possible that language learning can lead children to analyze, via analogy, relations that they would not otherwise compute (see Gentner, 2003, for a proposal). Perhaps, having first figured out how “left” and “right” apply to their own body, children begin considering the notion that other people have “left” and “right” sides as well. Consequently, they learn to encode such spatial relations that they normally would not consider. If so, we might expect that adult speakers of languages lacking left-right frames of reference would not necessarily notice and make use of left-right relations of other objects in solving spatial tasks, like the nonlinguistic task of Experiment 3B. There is some evidence this is the case; in a similar set-up to Experiment 3C, Abarbanell and Li (2009) showed that not all adult speakers of Tseltal, a language that lacks left-right spatial language, make use of a toy animal’s left-right to correctly retrieve a hidden coin.

Additionally, we might also expect that children would have greater difficulty figuring out left and right meanings when the convention of the target language is to describe objects’ locations using the speakers’ perspective rather than the addressee’s perspective. The child (addressee) in this case has to learn non-egocentric left-right language without getting the extra input to support mastery of egocentric left-right language. Indeed, for many sign languages, including American Sign Language (ASL), constructions are typically signed from the perspective of the signer and not the addressee (Emmorey, Klima, & Hickok, 1998). Children learning ASL acquire left and right language much later than English-speaking children (Martin and Seras, 2006), suggesting that learning egocentric left-right language first might be important to facilitate non-egocentric left-right language.
Finally, if we believe that language is the product of successful communications between speakers and listeners, our studies make predictions about the kinds of languages that appear in the world as well. With respect to object-centered frames of reference, our findings predict that the use of front and back axis for talking about space will be much more prevalent than the use of left and right across the world’s languages. That is, one might find that some languages lack the projection of left and right body terms to talk about space, but that most languages include terms for projecting the front and back of the body. More fine-grained analyses of the word’s languages will determine whether this prediction bears out. By examining how children acquire spatial words online, as we have done in these experiments, we can begin to uncover the intricate relationship between linguistic conventions, language acquisition, and cognitive development.
References


Appendix A

Script for Experiment 1

**Introduction: (child facing east)**

Your body has two sides— a ZIV side and a KERN side. This is your ZIV side and this is your KERN side.

This whole side of your body is your ZIV side. So this is your ZIV arm, because it is on the ZIV side of your body. Look at this hand. This is your ZIV hand because it is on the ZIV side of your body. I’m going to put this bracelet on your ZIV hand, so your ZIV hand has a bracelet.

Which hand did I put the bracelet on—the ZIV hand or the KERN hand? (Question 1)

Can you wave your ZIV arm? (Question 2)

This whole side of your body is your KERN side (*gesture*). So this is your KERN arm, because it is on the KERN side of your body. Look at this hand. This is your KERN hand, because it is on the KERN side of your body. I do not have a bracelet for your KERN hand, so your KERN hand does not have a bracelet.

Which hand does not have a bracelet—the ZIV hand or the KERN hand? (Question 3)
Can you wave your KERN arm? (Question 4)
Can you wave your ZIV arm? (Question 5)

This toy is to the ZIV of you.
This toy is to the KERN of you.
Can you show me the toy on the ZIV side? (Question 6)
Can you show me the toy on the KERN side? (Question 7)

Can you show me the toy on the KERN side? (Object switch Question 1)
Can you show me the toy on the ZIV side? (Object switch Question 2)
Appendix B
Script for Experiment 2

Introduction: (child facing east)

Your body has two sides – a ZIV side and a KERN side. This is your ZIV side and this is your KERN side.

This whole side of your body is your ZIV side. So this is your ZIV arm, because it is on the ZIV side of your body. Look at this hand. This is your ZIV hand because it is on the ZIV side of your body. I’m going to put this bracelet on your ZIV hand, so your ZIV hand has a bracelet.

Which hand did I put the bracelet on—the ZIV hand or the KERN hand? (Question 1)
Turn in a circle while you wave your ZIV arm. (Question 2)

This whole side of your body is your KERN side (gesture). So this is your KERN arm, because it is on the KERN side of your body. Look at this hand. This is your KERN hand, because it is on the KERN side of your body. I do not have a bracelet for your KERN hand, so your KERN hand does not have a bracelet.

Which hand does not have a bracelet—the ZIV hand or the KERN hand? (Question 3)
Turn in a circle while you wave your KERN arm. (Question 4)

Let’s see you raise your KERN leg. (Body switch Question 1)
Let’s see you pull your ZIV ear. (Body switch Question 2)
Let’s see you pull your KERN ear. (Body switch Question 3)
Let’s see you raise your ZIV leg. (Body switch Question 4)
Appendix C

Script for Experiment 2

**Left-Right Introduction:** *(child facing east)*

Uniqua has two sides – a ZIV side and a KERN side. This is Uniqua’s ZIV side, so this is her ZIV arm. Can you tell me which arm this is? (Question 1)

This toy is on the ZIV side of Uniqua, and that wall is to the ZIV of Uniqua too. Everything on this side is to the ZIV of her.
Can you point to Uniqua’s ZIV arm? (Question 2)

This is Uniqua’s KERN side, so this is her KERN arm. Can you tell me which arm this is? (Question 3)

This toy is on the KERN side of Uniqua, and that wall is to the KERN of Uniqua too. Everything on this side is to the KERN of her.
Can you point to Uniqua’s KERN arm? (Question 4)
Can you point to Uniqua’s ZIV arm? (Question 5)
Can you show me the toy on Uniqua’s KERN side? (Question 6)
Can you show me the toy on Uniqua’s ZIV side? (Question 7)

Can you point to the toy on Uniqua’s ZIV side? (Object switch Question 1)
Can you point to the toy on Uniqua’s KERN side? (Object switch Question 2)

**Front-Back Introduction:** *(child facing east)*

Uniqua has two sides – a ZIV side and a KERN side. This is Uniqua’s ZIV side, so this is the ZIV side of her head. Can you tell me which side of Uniqua’s head this is? (Question 1)

This toy is on the ZIV side of Uniqua, and that wall is to the ZIV of Uniqua too. Everything on this side is to the ZIV of her.
Can you point to the ZIV side of Uniqua’s head? (Question 2)

This is Uniqua’s KERN side, so this is the KERN side of his head. Can you tell me which side of Uniqua’s head this is? (Question 3)

This toy is on the KERN side of Uniqua, and that wall is to the KERN of Uniqua too. Everything on this side is to the KERN of her.
Can you point to the KERN side of Uniqua’s head? (Question 4)
Can you point to the ZIV side of Uniqua’s head? (Question 5)
Can you show me the toy on Uniqua’s KERN side? (Question 6)
Can you show me the toy on Uniqua’s ZIV side? (Question 7)

Can you point to the toy on Uniqua’s ZIV side? (Object switch Question 1)
Can you point to the toy on Uniqua’s KERN side? (Object switch Question 2)