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Spatial Language and the Embedded Listener Model in Parents' Input to Children

Katrina Ferrara, Malena Silva, Colin Wilson, Barbara Landau

Department of Cognitive Science, Johns Hopkins University

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Abstract

Language is a collaborative act: To communicate successfully, speakers must generate utterances that are not only semantically valid but also sensitive to the knowledge state of the listener. Such sensitivity could reflect the use of an "embedded listener model," where speakers choose utterances on the basis of an internal model of the listener's conceptual and linguistic knowledge. In this study, we ask whether parents' spatial descriptions incorporate an embedded listener model that reflects their children's understanding of spatial relations and spatial terms. Adults described the positions of targets in spatial arrays to their children or to the adult experimenter. Arrays were designed so that targets could not be identified unless spatial relationships within the array were encoded and described. Parents of 3–4-year-old children encoded relationships in ways that were well-matched to their children's level of spatial language. These encodings differed from those of the same relationships in speech to the adult experimenter (Experiment 1). In contrast, parents of individuals with severe spatial impairments (Williams syndrome) did not show clear evidence of sensitivity to their children's level of spatial language (Experiment 2). The results provide evidence for an embedded listener model in the domain of spatial language and indicate conditions under which the ability to model listener knowledge may be more challenging.

Keywords: Spatial language; Parental input; Embedded listener model; Audience design; Spatial development

1. Introduction

According to a long tradition of research on language use, speakers adapt their utterances to the communicative needs of their listeners (e.g., Clark & Carlson, 1982; Clark, 1991, 1996; Schober & Clark, 1989). Evidence for this process of *audience design* has

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Correspondence should be sent to Katrina Ferrara, Department of Cognitive Science, Johns Hopkins University, 237 Krieger Hall, 3400 North Charles Street, Baltimore, MD 21218. E-mail: ferrara@cogsci.jhu.edu

been found in the choices speakers make about whether to refer to an entity (e.g., Lockridge & Brennan, 2002), how to formulate referring expressions (e.g., Clark & Marshall, 1981; Fussell & Krauss, 1992), how to address listeners with less technical knowledge (e.g., Isaacs & Clark, 1987), and other aspects of linguistic expression. Audience design is related to the notion of communicative efficiency, according to which speakers make linguistic choices that enhance unexpected parts of their message while reducing or compressing parts that can be more easily predicted by the listener (see Jaeger & Tily, 2011 for a recent review). Both audience design and communicative efficiency rest on the assumption that speakers select modes of expression on the basis of internal (or "embedded") models of listeners. While originally thought to include only a discrete common ground (as assumed by the speaker), the embedded model has recently been elaborated to a fine-grained, probabilistic representation of what listeners know and expect (e.g., Frank & Goodman, 2012; Gahl & Garnsey, 2004; Golland, Liang, & Klein, 2010; Levy & Jaeger, 2007).

In spite of their intuitive appeal, it has proven difficult to provide evidence that unambiguously supports embedded listener models. One complication is that the same factors that make utterances more difficult for listeners to understand—such as longer linguistic dependencies (e.g., Gibson, 1998) and lower contextual predictability (e.g., Hale, 2003)—also pose difficulties for speakers themselves (e.g., Cook & Stevenson, 2009; Hawkins, 1994; Schnadt & Corley, 2006). Avoidance of difficult structures may therefore reflect processing limitations internal to the speaker's own production system rather than listener-oriented accommodations (e.g., Ferreira & Dell, 2000; MacDonald, 2013). Furthermore, there is limited direct evidence that speakers track listener knowledge separately from their own, and make use of it in determining their productions (e.g., Tanenhaus, 2013). In ordinary conversation with other adults, speakers may be too constrained by the demands of time and their own processing limitations to expend much effort to help the listener.

Testing an embedded listener model is especially relevant to questions about the nature of linguistic input to children and its role in supporting language learning. Many studies have asked whether parental input to young children varies in ways that predict children's language growth. Findings have generally supported the conclusion that parental utterances to young children have properties that are distinct from utterances directed to adults. For example, speech to infants tends to show extreme intonational excursions (Fernald & Mazzie, 1991) and productions that are especially close to the centers of vowel categories (Fernald & Kuhl, 1987; but see Cristia & Seidl, 2013; McMurray, Kovack-Lesh, Goodwin, & McEchron, 2013). Utterances by mothers to their young children tend to include many question forms and few declaratives, possibly providing the information necessary to learn auxiliary forms (Newport, Gleitman, & Gleitman, 1977). The adult use of word forms also shifts with age in child-directed speech (e.g., Gallaway & Richards, 1994; Snow & Ferguson, 1977). Furthermore, when adults introduce new objects or words to children, they do so using both speech (Clark & Wong, 2002) and gestures that are differentially optimized to the age of their child (Clark & Estigarribia, 2011). More broadly, work inspired by sociocultural theory has focused on child problem solving to investigate the ways in which mutual interactions between adults and children scaffold the development of children's participation in specific cultural and institutional contexts (Crowley et al., 2001; Rogoff, 1990, 1998).

These studies show that parent utterances and interactions with children often differ from those directed to adults, but they do not answer the specific question of whether these properties are driven by parents' use of an embedded listener model. Moreover, although there is now compelling evidence that the amount and quality of input to young children are correlated with their vocabulary growth (Cartmill et al., 2013; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Weisleder & Fernald, 2013), even within the domain of spatial language (Pruden, Levine, & Huttenlocher, 2011), we do not know whether variation in parental input is caused by internal constraints of time and energy, or variation in the degree to which the parent has an accurate model of the child listener.

In this study, we provide evidence that speakers—in particular, parents—do take into account the needs of the listener when communicating spatial information to their young children. Our focus on spatial language is designed to highlight the disparity between speaker and listener knowledge. Children of the ages studied here have incomplete mastery of the mapping between spatial concepts and relational terms, with horizontal terms (*left/right*) posing particular difficulty and showing a protracted developmental trajectory (Harris, 1972; Johnston & Slobin, 1979; Mandler & Day, 1975). If adults avoid certain spatial terms when communicating with children, but not when speaking to another adult under matched circumstances, this would indicate listener-oriented shaping of linguistic choices in the spatial domain. We will show that there are striking differences in the patterns of spatial language use in speech directed to children versus speech directed to adults. Our results will also show a correlation between spatial term avoidance on the part of parents and independently assessed mastery of spatial terms on the part of their children. This provides detailed support for audience design in the communicative interaction studied here.

Beyond their relevance for understanding audience design, spatial expressions are a natural part of a speaker's communicative toolkit for object identification and location. Even when locatives are not necessary to distinguish a target, spatial relations are used quite frequently by adults when describing the location of an object within a scene (Viethen & Dale, 2008). However, the accessibility of this toolkit is not equivalent for listeners of all ages, as mastery of certain spatial terms (i.e., *left/right*) is not evident until mid-childhood. In principle then, descriptions of spatial relations offer one key illustration of a case in which speech to adults could meaningfully differ from that adapted to children. If parent speakers truly are spontaneously adopting an embedded listener model (Golland et al., 2010), then we should observe dramatic variation in the type of spatial terms they opt to use when speaking to their young children, who are just beginning to master the mapping between spatial concepts and relational terms, relative to when speaking to adults. In particular, parents should avoid horizontal terms in favor of vertical and other expressions that are more likely to be understood by their children. For example, if a child's missing shoe is located *under* the bed and to the *left* of the bookcase, a parent will choose to instruct his or her child to look "under the bed," rather than "to the left of the bookcase."

The example above recruits an additional element of a landmark (bed or bookcase) to define a spatial relationship between the target (in this case, the missing shoe) and another salient item in the room. Research has demonstrated that young children rely on proximal landmarks when remembering and communicating about locations (Acredolo, 1978; Acredolo & Evans, 1980; Allen & Kirasic, 1988; Craton, Elicker, Plumert, & Pick, 1990; Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Overman, Pate, Moore, & Peuster, 1996; Plumert, Haggerty, Mickunas, Herzog, & Shadrick, 2012; Sluzenski, Newcombe, & Satlow, 2004). Parents apparently reflect this preference when giving directions to their 2- and 3-year-olds to find a hidden object, as they prefer to relate a target container to whatever is closer, either themselves or a distinguishing object present in the room. This preferential weighting could indicate sensitivity to children's skills. Alternatively, it could reflect the parent's own internal biases of spatial representation, in which the landmark closer to the target is considered more significant and for that reason is more often selected as a reference object. Plumert et al. (2012) specifically found individual variation in whether mothers preferred to use proximal personal references when the target container was both close to themselves and close to the external landmark, which suggests that some mothers may have been more sensitive to their child's level of understanding than others. But without the inclusion of an adult comparison group, it is difficult to tease apart whether parents' descriptions are formulated in recognition of their young child's spatial abilities, or as a reflection of their own representational biases.

Several key elements must necessarily be established to determine whether an individual parent's usage of certain spatial terms is appropriately tuned to meet her own child's level of linguistic and cognitive knowledge at the optimal level. First, we must establish specific, testable questions about possible and optimal preferences that are situated within a theory of what we know to be characteristic of young children's spatial representational capacities. Second, the experimental task must both measure parents' spatial term preferences, and compare these preferences to those that are demonstrated when speaking to a conversational partner who is not a young child (a comparison often incorporated in early studies of "motherese," e.g., Newport et al., 1977). Finally, to establish a connection between adult language and the knowledge of individual children, an independent measure of each child's spatial term competence must be compared to the spatial language used by her parent.

This study was designed in light of the three key elements outlined above. We developed a "language game" in the spirit of those that have previously been used to elicit referring expressions generated by an adult speaker to an adult listener (e.g., Viethen & Dale, 2008). Just as in these previous studies, success hinges on the speaker's ability to communicate referential identity in a way that the listener can comprehend. In the current situation, however, the listener imposes a complex set of constraints that are different from those of the speaker (namely, an immature spatial term vocabulary). Rather than gathering parents' descriptions for an undistinguished range of object types and spatial relationships, the stimulus set was constructed to embody generalizations from the literature on spatial representation and its development in children. We provided arrays that allow for alternative spatial descriptions of the target item, to determine whether adults show systematic biases in describing arrays to children in comparison to other adults.

The design of the arrays was guided by two primary generalizations. The first is the well-known asymmetry between the vertical versus horizontal axes in both linguistic and non-linguistic representation. Many studies have shown an advantage for the vertical axis. For example, among adults, confirming spatial relationships along the vertical axis is faster than for the horizontal axis (Carlson-Radvansky & Logan, 1997; Logan, 1995; Logan & Sadler, 1996), consistent with H. Clark's (1973) hypothesis that the gravitational axis is primary in human spatial representation (see also Sholl and Egeth, 1981). This vertical axis bias holds for tasks tapping memory for location and linguistic labeling of locations among adults (Hayward & Tarr, 1995) and children (Landau & Hoffman, 2005). In light of this strong asymmetry, we predict that parents who adopt an embedded listener model will prefer to use more vertical than horizontal terms when describing targets to their children—even in contexts where each type of term would serve to uniquely distinguish a target item within an array. The second generalization is less well documented, but plausible. Spatial terms representing so-called topological spatial relationships, such as *in* and *on*, are acquired particularly early by children (Bowerman, 1989; Clark, 1974; Johnston, 1988; Johnston & Slobin, 1979), far before mastery of terms that represent locations along an axis, such as *left* and *right* (Harris, 1972), or *above* and *below* (Clark, 1972; Kuczaj & Maratsos, 1975). On the basis of this evidence, we predict that parents who adopt an embedded listener model will prefer to use topological terms when describing item positions to children. In the Methods section, we detail the design of the specific arrays along with our associated predictions for spatial term use.

Testing whether a parent possesses an embedded listener model of her own child requires the final step of evaluating the child's own competence in the use of spatial terms. We independently tested children's mastery of key spatial terms, and then asked whether parents' demonstrated spatial term biases correlate with their own child's knowledge. This allows us to at least partly disentangle internal representational biases on behalf of the parent from adjustments in spatial term descriptions that were made in an effort to meet the knowledge level of the particular child.

When applied to the experimental context just described, the strongest version of the embedded listener model would maintain that parents always adjust their spatial language descriptions in precisely the right ways to meet the individual needs of their own children. However, previous research has shown that the spatial abilities of both speakers and listeners can have an impact on success in language tasks involving ambiguous spatial arrays. Schober (2009) tested speakers and listeners who were identified as having either high or low scores on a test of mental rotation ability. High-ability speakers were more likely to take their partner's perspective, and low-ability speakers were more likely to produce descriptions that were unintelligible to the listener. In comparison to high-ability matched pairings, "mixed" pairings (e.g., a low-ability speaker paired with a high-ability speaker, or a high-ability speaker paired with a low-ability speaker) also resulted in a higher number of speaker descriptions that were incomprehensible to the listener. Thus, it is important to test the embedded listener model against a full range of possibilities. To accomplish this, a great deal of variation among the listener population would be required. As typically developing 3- and 4-year-old children may be largely similar to one another in terms of their understanding of descriptions of various spatial relationships, we also examined a group in which the expected level of expertise may be essentially deficient.

In Experiment 2, we tested parents of individuals with Williams syndrome (WS), a neurodevelopmental disorder characterized by the deletion of approximately 25 genes on chromosome 7q11.23 (Morris, 2006). WS is associated with mild to moderate mental retardation (Mervis & Morris, 2007) and is accompanied by a unique cognitive profile that includes severe impairment in a range of spatial functions, coupled with strikingly fluent and well-structured language (Bellugi, Wang, & Jernigan, 1994; Musolino, Chunyo, & Landau, 2010). Studies of a broad range of spatial functions indicate that adolescents with WS perform similarly to typically developing children of approximately 4 years of age. For example, WS adolescents' and adults' performance in orientation discrimination and integration tasks aligns with typically developing 4-year-olds (Palomares, Landau, & Egeth, 2009), as does object recognition (Landau & Hoffman, 2012; Landau, Hoffman, & Kurz, 2006) and visual-manual action tasks such as posting a card through a slot (Dilks, Hoffman, & Landau, 2008). Within the spatial domain, the pattern of developmental arrest appears in many tasks and subdomains, with the details of performance and error patterns identical to those of typically developing children who are much younger in chronological age (Landau & Hoffman, 2012).

Studies specifically focusing on spatial language production by individuals with WS have shown that, compared to typically developing mental age matches, they produce proportionally fewer appropriate axial terms (e.g., *above*, *below*, *left*, *right*) when asked to describe the location of a dot in relation to a square (Landau & Hoffman, 2005). Instead, they tend to produce terms that encode contact or proximity, such as *touching* or *near*. These results indicate that communicating aspects of spatial relationships may be a particularly challenging task for a parent of a child with WS, especially in cases where proximity terms are not sufficient to disambiguate the location of a target. Given their child's known spatial deficit, parents of WS individuals may struggle to appropriately calibrate their spatial descriptions to include terms that are understandable by their child. Alternatively, some WS parents may attempt to compensate for their child's known limitations by providing over-informative descriptions that contain more spatial descriptions than necessary, which in turn burdens the listener with the responsibility of determining which aspects of the instruction are truly relevant and which are not. Although research suggests that typically developing adult comprehenders reject or penalize over-informative utterances (Davies & Katsos, 2009; Engelhardt, Bailey, & Ferreira, 2006), the process of sifting through a description for relevant information, on top of comprehending the spatial semantic content of the description itself, may be especially difficult for people with WS.

2. Experiment 1

2.1. Method

2.1.1. Participants

There were two groups of participants recruited from Baltimore, MD, and the surrounding areas. The first included 16 typically developing (TD) children (aged 3.5–4.5 years, 8 males, $M_{\text{age}} = 4.08$ years) and their parents (2 males). This group was recruited via parent groups and preschools local to Johns Hopkins University. The second participant group consisted of 16 students recruited from the Johns Hopkins University community (6 males). We will refer to this group to as “adults” or “adult speakers” throughout this paper. All child and adult participants were tested in our lab on the Johns Hopkins University campus.

2.1.2. Design and procedure

The communication task involved paired dyads of players who were assigned different roles. For parent–child dyads, the parent was assigned the role of the speaker and the child was assigned the role of listener. For adult–adult dyads, the student participant was assigned the role of the speaker and the experimenter played the role of the listener.

The two players viewed identical spatial arrays on separate computer screens, except for the fact that, on the speaker’s screen, the target shape was outlined in bold. Screens were arranged so that speaker and listener could see only their own screen. A black visual barrier was erected between the speaker and listener so that it was not possible for them to view one another’s faces during the task (Fig. 1). Dyads were instructed that they would see a series of item arrays, and that the speaker should describe the target shape (bolded on her screen) to the listener so that she could pick it out on her own screen. For parent–child dyads, these instructions were provided in the example of an “I spy” game, in which the parent speaker could say “I spy. . .” and then fill in the blank with his or her description of the target item. Speakers were told that they could describe the target in whatever terms they deemed most appropriate and effective. They were explicitly asked not to use hand gestures, and they were not provided with feedback about their interlocutor’s choices.

2.2. Stimuli

The communication task was divided into two parts. In Part 1, arrays were designed such that speakers could use a variety of spatial terms to describe the location of the target. In Part 2, we sought to constrain the set of appropriate terms to only those referring to the horizontal axis of space (e.g., *left/right*), arguably the terms that would be least likely to be fully acquired by the TD child or WS listeners.

All arrays were constructed so that the target could not be located simply by describing its individual featured properties (e.g., “a yellow triangle”). Rather, successful location required describing its spatial relationship with some other object in the array (e.g., “the

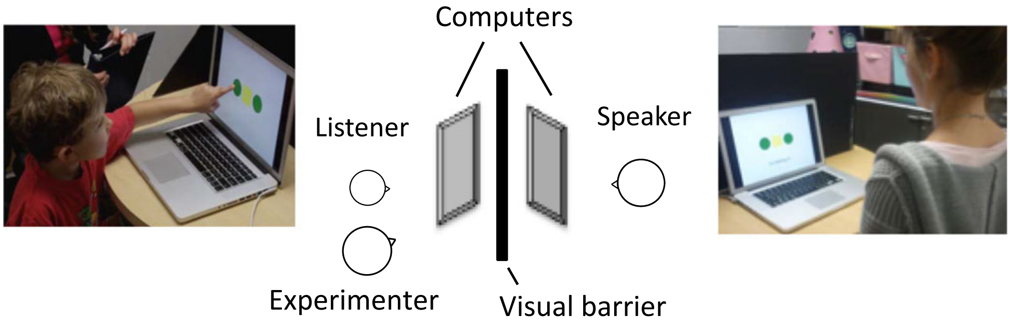

Fig. 1. Illustration of the communication task from the perspective of a child listener (left) and a parent speaker (right). The parent is describing the target, which is bolded on her screen, and the child is responding by pointing to the object he believes is the target. Screens were located across from each other with a panel in between so that speaker and listener would see only their own screen.

yellow triangle that is above the green circle"). Part 1 arrays included four types, each of which clearly afforded several options for describing the target and its location (see Fig. 2). Vertical versus Horizontal arrays pitted vertical axis descriptors against horizontal axis descriptors. For example, when presented with the array in Fig. 2A, speakers could describe the target (bolded yellow triangle) as *above* a green circle (vertical axis term), or to the *right* of a green circle (horizontal axis term). Vertical versus Proximity arrays pitted proximity (*near*, *far*) against the vertical axis (*above*, *below*), and Proximity versus Horizontal arrays pitted proximity (*near*, *far*) against the horizontal axis (*left*, *right*). For example, speakers could describe the green triangle target in Fig. 2B as either *far* from the blue circle or *below* the blue circle. Vertical versus Enclosure arrays pitted descriptions of enclosure (*in*, *out*) against the vertical axis (*above*, *below*). Six arrays were constructed for each type by varying geometric shapes and colors, for a total of 24 trials per participant in Part 1.

Part 2 arrays were designed to encourage the use of horizontal terms by eliminating vertical- and proximity-based spatial relations internal to the arrays that could identify the target shape (see Fig. 3). For example, the bolded yellow circle in Fig. 3A ("Horizontal, Vertical") could be described as the one on the *right* to differentiate it from the other circle, which is also *on top* of the rectangle. There were four trials for the three array types shown in Fig. 3, each portraying different sets of geometric figures and colors, for a total of 12 trials per participant in Part 2.

2.2.1. *Coding and measures for spatial description data*

Each experimental session was videotaped and later transcribed for manual coding. We developed a coding scheme to analyze the different types of spatial expressions that speakers offered to their listeners. The coding scheme included six different spatial expression categories: **vertical** expressions that identified one direction within the vertical axis (e.g., *up/down*, *above/below*), **horizontal** expressions that did so for the horizontal axis (e.g., *left/right*), descriptions of **proximity** (e.g., *near/far*, *close to*, *next to*), and

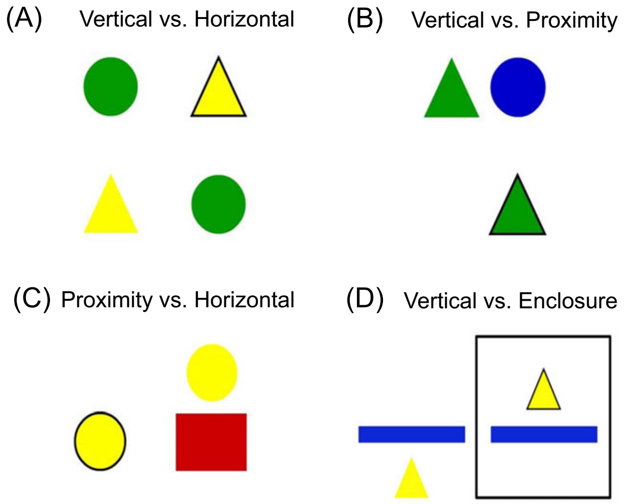

Fig. 2. Four stimulus array types used in Part 1. Array 2A pits vertical descriptions against horizontal descriptions, Array 2B pits vertical descriptions against descriptions of proximity, Array 2C pits descriptions of proximity against horizontal descriptions, and Array 2D pits vertical descriptions against descriptions of enclosure (see text for further detail).

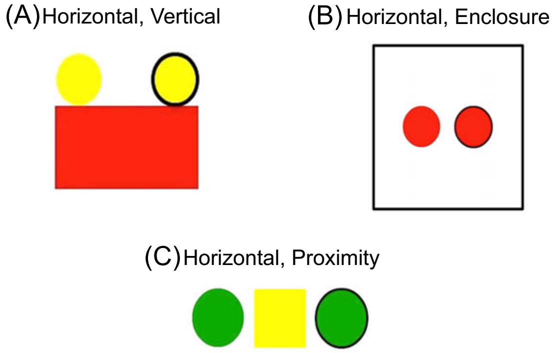

Fig. 3. Three stimulus arrays used in Part 2, in which horizontal descriptions must be used to identify one of two identical shapes. Array 3A depicts both horizontal and vertical relationships, although only horizontal terms are uniquely informative. Similarly, Array 3B depicts horizontal and enclosure relationships, and Array 3C depicts both horizontal and proximity relationships (see text for further detail).

descriptions of **enclosure** within a black outline (as in Fig. 3B, e.g., *in*/*out*). Table 1 provides a list of the spatial expression categories and examples of the specific expressions participants used. A single utterance could be coded to contain more than one spatial category. For example, the utterance "The one that is down and to the right" would be coded as containing two different kinds of spatial expressions, because it contains an expression that belongs to the vertical category (*down*) and an expression that belongs to

Table 1
Spatial word types and common qualifying expressions

Spatial Expression Type	Example Expressions
Vertical	*on top*, *on the bottom*, *above*, *below*, *upper*, *under*, *underneath*, *higher*, *lower*
Horizontal	*left*, *right*, *left side*, *right side*, *left corner*, *right corner*
Proximity	*next to*, *closest to*, *near*, *far. almost touching*, *by itself*
Enclosure	*inside*, *outside*, *in*, *out*, *within*
External	*the door*, *the shelf*, *her* (referring to the experimenter), *passenger side of the car*, *hand you throw a ball with*, *your thumb-sucking hand*
Ordinal	*first*, *second*, *third*, *first one*, *number one*, *number two*

the horizontal category (*right*). Descriptively, in Part 1 TD parents used on average 1.19 spatial expressions that belonged to different categories, whereas WS parents used 1.21, and adults speaking to the adult experimenter used 1.18. A mixed-effects linear regression with random participant intercepts revealed that there were no significant differences among the groups in the number of different spatial expression categories that were used (Adult: $\beta = 0.03$, $SE = 0.05$; WS: $\beta = -0.01$, $SE = 0.04$).

For Part 2 arrays, we observed that parents often described the spatial location of targets relative to items in the surrounding environment (e.g., the door to the testing room, the experimenter seated on the child's right side). To include these responses in our coding system, we designated these as **external** terms (i.e., using a reference object or relationship in the world outside the array shown on the computer screen). In Part 2, parents sometimes also adopted a counting strategy in which they relied on children's prior knowledge of numerical ascension (smallest numbers starting on the left, increasing in numerosity to the right). Western preschool children spontaneously map numbers onto space when presented with a visuospatial task (de Hevia and Spelke, 2009), and they display an intuition of the left-to-right organization of numerical magnitude that is favored in Western culture (Dehaene, Bossini, & Giraux, 1993; Opfer, Thompson, & Furlong, 2010). When parents used number as a means of conveying spatial location, these terms were coded as **ordinal**. In Part 2, TD parents used an average of 1.65 spatial expressions that belonged to different categories, WS parents used 1.31, and adults speaking to the adult experimenter used 1.09. A mixed-effects linear regression revealed a significant effect of group (Adult: $\beta = -0.25$, $SE = 0.08$; WS: $\beta = -0.04$, $SE = 0.07$). The number of different spatial expression categories used by parents of TD children was significantly greater than those used by WS parents ($\beta = 0.33$, $SE = 0.13$, $p < .05$ by Tukey's HSD test) and also adults ($\beta = 0.54$, $SE = 0.14$, $p < .01$). The difference between WS parents and adults was not significant ($\beta = 0.21$, $SE = 0.13$). We return to the root of the difference between TD parents and the other groups in the discussion. For a complete list of the different spatial descriptions offered by participants, see the Appendix.

Subsequent to data coding, we tabulated the spatial expression types for each utterance in Part 1 and Part 2. Immediate repetitions of the same spatial term were not counted (e.g., for the utterance "It's on the top, on the top, did you hear me?," "on the top" would be given a count of 1). For visualizing relative frequencies of spatial expression categories, counts were converted to proportion of each spatial expression type per trial. For example, if on one trial a speaker generated the utterance "It's on the top left," the vertical category (*top*) would receive a proportion score of 0.5, and the horizontal category (*left*) would receive a proportion score of 0.5. To characterize the variation and relative amount of spatial language elicited by each array, the proportions specific to each array were averaged across trials (e.g., proportions for all trials for the Vertical versus Horizontal array were averaged, etc.).

To assess reliability, a second coder analyzed a random selection of 20% of the transcripts. The proportion of utterances on which the two coders agreed was calculated for each spatial term category. Agreement exceeded 92% for all spatial term categories.

2.3. Results

Initial analyses revealed that parent speech to males versus females did not significantly differ in terms of overall length or quantity of spatial terms. Thus, the analyses reported below are collapsed across listeners' gender. Most children were quite accurate in selecting the target shape based on their parent's descriptions in Part 1, but there was substantial variability in Part 2, which required choosing an item based on its horizontal relationship with the reference object. On average, children correctly selected the target shape on 84% of the trials in Part 1 (range = 58–100%, *SE* = 3%). If children selected a shape in the array at random, they would have been accurate on 25%–33.3% of the trials (two Part 1 arrays contained four possible shape choices [chance = 25%], and the other two contained three possible shape choices [chance = 33%]). The accuracy with which children selected the target shape was significantly greater than chance (33%), $t(15) = 14.22$, $p < .001$. In Part 2, children correctly selected the target shape on an average of 75% of trials (range = 8%–100%, *SE* = 6%), which is significantly above chance (33%), $t(15) = 6.13$, $p < .001$. Thus, for both Part 1 and Part 2 arrays, children correctly selected the target shape at rates above chance.

We first considered each array type separately to test our predictions about parents' biases in use of spatial term descriptions to their children. These analyses were performed on the raw spatial expression counts, using binary or multinomial logistic regression where appropriate. In Part 1, analyses only included counts for a given spatial expression type that had non-zero frequencies for all groups, to avoid artifacts due to data sparsity and separation. In Part 2, all expression types observed in the experiment were included in the analyses, due to our interest in discovering whether parents are able to incorporate creative alternative descriptions and avoid using solely horizontal terms that their child may not understand. For all analyses, parents speaking to their TD children served as the reference level for the group factor, and the reference level for response was the **vertical** spatial expression type (the only type that was observed for all array types in all groups). This provides explicit comparisons of the two other groups to the TD group: adults speaking to a fellow adult experimenter (Experiment 1) and parents speaking to WS children (Experiment 2).

Instead of relying on traditional point estimates, we report results from mixed-effects Bayesian analyses in which model coefficients are sampled from the posterior distribution defined by the data and a standard prior distribution (Hadfield, 2010). Analyses included random intercepts for participants and, as noted above, were performed separately for each array type (random slopes were not included as there were no within-participant factors). Post hoc analyses were performed by calculating HPDIs (highest posterior density intervals) on the probabilities predicted by the omnibus analyses (Kruschke, 2011). Due to the large number of comparisons involved, the alpha level for all post hoc tests was chosen to be 0.99. We report results for arrays in Part I first, followed by arrays in Part 2.

2.3.1. Part 1 arrays

The proportions of spatial expression terms for Vertical versus Horizontal arrays are shown in Fig. 4, Experiment 1, for both parent speakers (to TD child listeners) and adult speakers (to the experimenter). (This and subsequent figures also include results from Experiment 2.)

As can be seen, there are large differences in the distribution of spatial expression choices between the parent and adult speakers. Parents showed a strong preference to describe the target to their child in terms of its relationship to another object along the vertical axis. In contrast, adult speakers described the target to the experimenter by using terms that represented the spatial relationship with another object along either vertical or horizontal axis. The difference in frequency of horizontal term usage was statistically

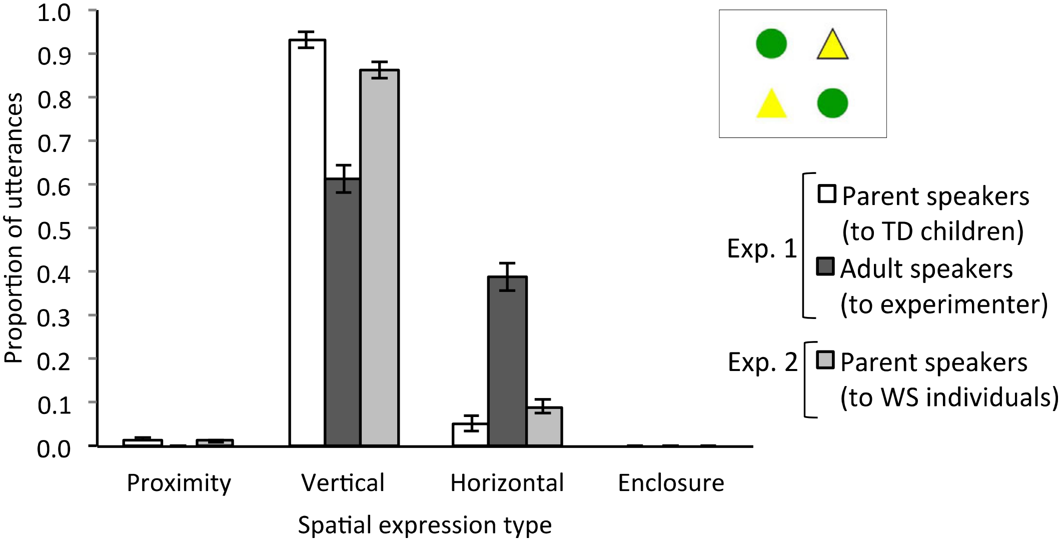

Fig. 4. Proportion of utterances containing spatial word types for Vertical versus Horizontal arrays, which were designed to compare use of vertical terms (e.g., *above/below*) with use of horizontal terms (e.g., *left/right*). Error bars show standard error of the mean for response proportions.

confirmed by a binary logistic regression (horizontal vs. vertical), ($\beta = 3.87$, $p < .001$). The positive sign of the coefficient in this case indicates that adults speaking to the adult experimenter used higher rates of horizontal terms relative to parents of TD children. The results for this array type are consistent with the embedded listener model, which predicts that parents speaking to their children (but not adults speaking to the adult experimenter) should actively avoid horizontal terms if they have the choice, due to difficulties that their children may have with assigning *left* or *right* to the correct side of the horizontal axis.

To evaluate the relative frequency of spatial expression types used by a particular group, we computed post hoc within-group pairwise comparisons (using HDPIs). These confirmed that parents speaking to TD children used significantly more vertical than horizontal expressions ($p < .001$). In contrast, the proportion of vertical and horizontal expressions did not differ for adults speaking to the experimenter ($p = .14$). This provides a clear instance in which spatial language is substantially modified by the interlocutor.

Fig. 5 shows the distribution of spatial expression types for Vertical versus Proximity arrays, which were designed to pit vertical terms (*above/below*) against terms representing proximity (*near/far*). The distributions for the TD and adult groups are largely similar to one another: Both show an almost complete preference to describe the target in terms of its relationship to another object along the vertical axis, rather than its proximity to another object. Binary logistic regression (proximity vs. vertical) indicated that vertical terms were used significantly more often by parents than adults ($\beta = -2.70$, $p < .05$). The negative sign of the coefficient in this case indicates that adults addressed lower rates

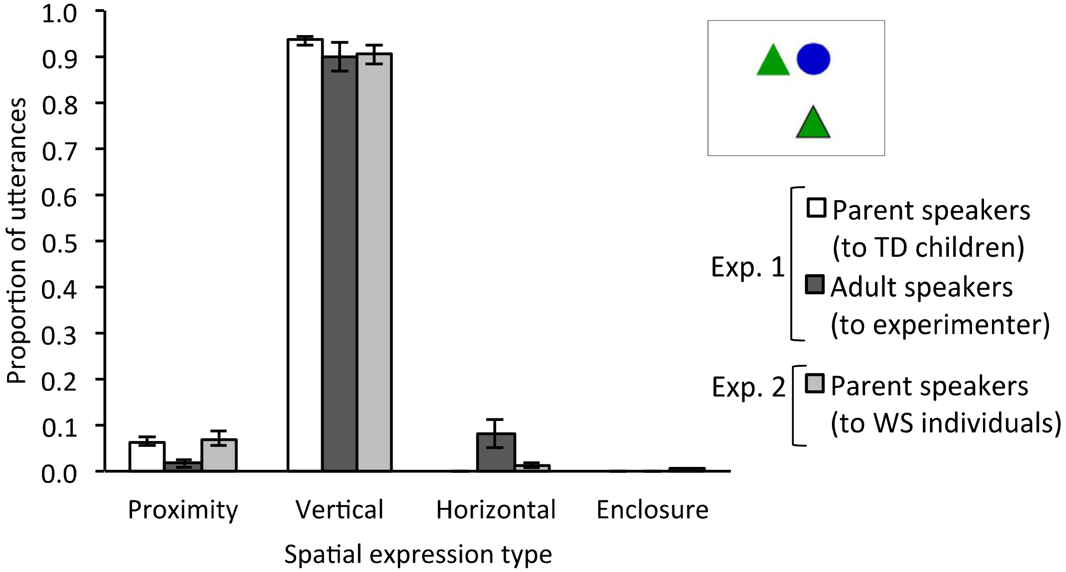

Fig. 5. Proportion of utterances containing spatial word types for Vertical versus Proximity arrays, which were designed to compare use of vertical terms (e.g., *above/below*) with use of terms encoding proximity (e.g., *near/far*).

of vertical terms to the experimenter than TD parents addressed to their children. Post hoc within-group comparisons showed that both adults and parents of TD children chose vertical terms significantly more often than horizontal terms ($p < .001$ for both groups). Thus, again, the vertical bias is evident—this time in both groups of speakers. Still, we see differences across the two groups, with adult speakers using horizontal spatial terms about 10% of the time, and parent speakers avoiding these altogether. Instead, parent speakers used terms representing proximity to another object 7% of the time.

Fig. 6 shows the data for Proximity versus Horizontal arrays, which were designed to pit horizontal terms (*left*, *right*) against proximity expressions (*near*, *far*). Here again we observe a striking contrast between parent and adult speakers. Parents often described the target in terms of proximity, using *far away from* or *close to* another object. In contrast, adult speakers described the target to the adult experimenter in terms of its relationship to another object along the horizontal axis, using *left/right*. Both groups occasionally employed vertical terms, which can be used to differentiate the two identical objects (e.g., by saying it is *on the bottom* or *below* the other circle). These uses of vertical axis terms to describe relationships that do not fall directly along the vertical axis of the reference object are relatively infrequent (Hayward & Tarr, 1995), but listeners can pragmatically infer the location of the target simply by looking at the array and ruling out other options. The fact that parent speakers used vertical terms in these contexts highlights their reluctance to use horizontal terms such as *left/right*. A multinomial logistic regression (with response types proximity terms, horizontal, and vertical) confirmed that adults used horizontal terms significantly more than

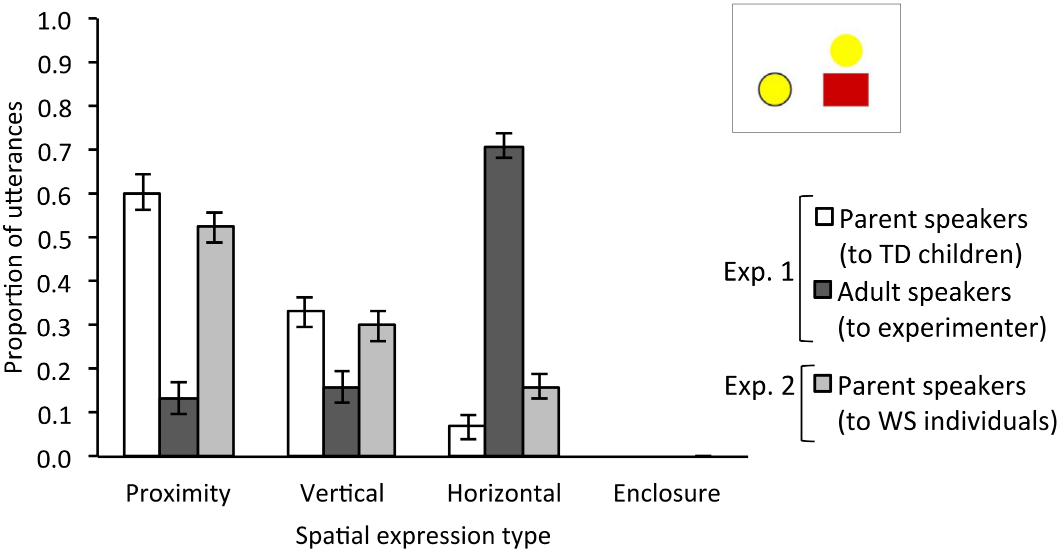

Fig. 6. Proportion of utterances containing spatial word types for Proximity versus Horizontal arrays, which were designed to compare use of terms encoding proximity (e.g., *near/far*) with use of horizontal terms (e.g., *left/right*).

parents ($\beta = 5.17$, $p < .001$) (cf. the two groups did not differ in their usage of proximal terms; $\beta = -1.13$, $p = .13$). (See Supplementary Material for the full multinomial model.)

Post hoc within-group pairwise comparisons revealed that parents of TD children used proximity and vertical terms at rates that did not significantly differ ($p = .13$), but these were both used more than horizontal terms ($p < .001$ for both comparisons). The converse of this pattern is true of adults, who used horizontal terms significantly more than proximity and vertical terms ($p < .001$ for both comparisons), the latter two not differing from one another ($p = .33$).

Finally, Fig. 7 displays the data for Vertical versus Enclosure arrays, which were designed to pit vertical terms (*above/below* the blue line) against enclosure terms (*inside/outside* the square). Parents predominantly employed vertical terms, consistent with the vertical preference observed for the other array types. They also used enclosure terms in 25% of their descriptions. Adult speakers used enclosure terms 50% of the time, followed by vertical terms and then horizontal terms (e.g., "The triangle on the right"). Parents avoided horizontal terms almost entirely (using them in only 1% of their descriptions). A multinomial logistic regression (response types enclosure, horizontal, and vertical) revealed that adults used horizontal terms significantly more than parents ($\beta = 4.22$, $p < .001$), and also used descriptions of enclosure more than parents ($\beta = 2.73$, $p < .001$). (See Supplementary Material for the full multinomial model.)

Post hoc within-group comparisons indicated that parents of TD children used vertical terms more than horizontal terms ($p < .001$), and in turn horizontal terms more than

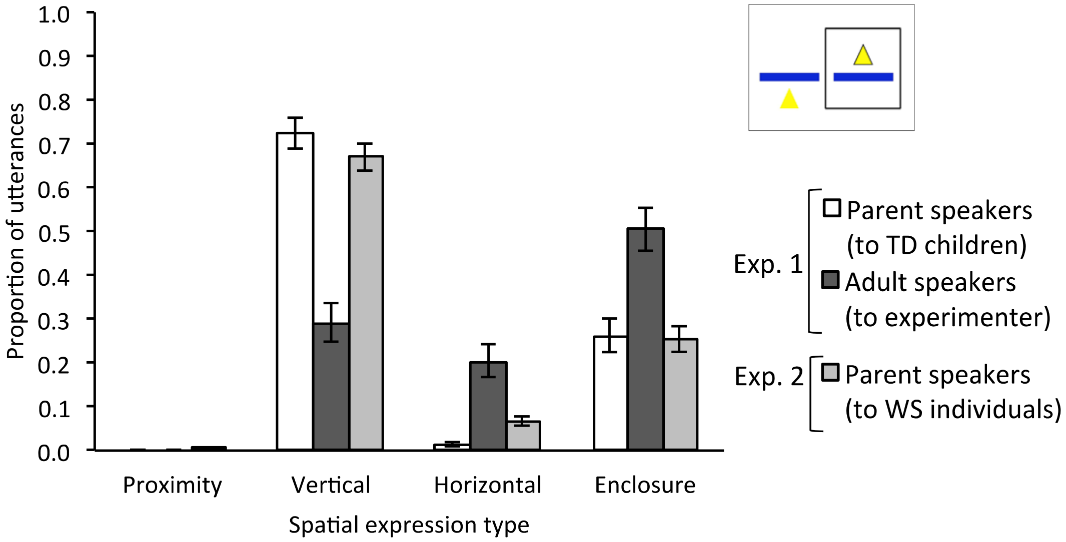

Fig. 7. Proportion of utterances containing spatial word types for Vertical versus Enclosure arrays, which were designed to pit vertical terms (e.g., *above/below*) against enclosure (*inside/outside*).

enclosure terms ($p < .001$). Pairwise comparisons for adults among the horizontal, vertical, and enclosure response types did not reveal any significant differences.

2.3.2. *Part 2 arrays*

While the arrays of Part 1 allowed the target item to be identified by multiple kinds of spatial expressions, the three array types of Part 2 were specifically designed to elicit horizontal terms. Given the avoidance of such terms by parents in Part 1, at least two possible outcomes can be anticipated for Part 2 trials. Parents could resort to horizontal terms, in spite of limited child comprehension, when alternative relations (vertical, proximity, etc.) do not suffice to identify the target item. Or, consistent with a strong embedded listener model, parents could continue to avoid horizontal expressions and find creative ways of identifying targets. In either case, adults speaking to the adult experimenter would be expected to use horizontal terms for these arrays.

As shown in Fig. 8, adults speaking to the adult experimenter did indeed produce horizontal terms nearly 100% of the time. In contrast, parent speakers used horizontal terms in roughly half of their descriptions. Even when horizontal terms were used, they were often supplemented by **external** descriptions that drew upon the spatial locations of other objects in the testing room (e.g., “The one closer to the door”), or the child’s own body (e.g., “The one on the side of the hand that you use to color”). Parents also incorporated **ordinal** descriptions containing numbers (e.g., “Pretend that I’m counting, like 1, 2, 3… I want you to pick the yellow circle that is number 2”). Numbers were always used such that they mapped onto the horizontal axis, with smaller numbers on the left of the array and larger numbers moving rightward. Strikingly, neither of the latter two types of expression was ever used by the adult speakers.

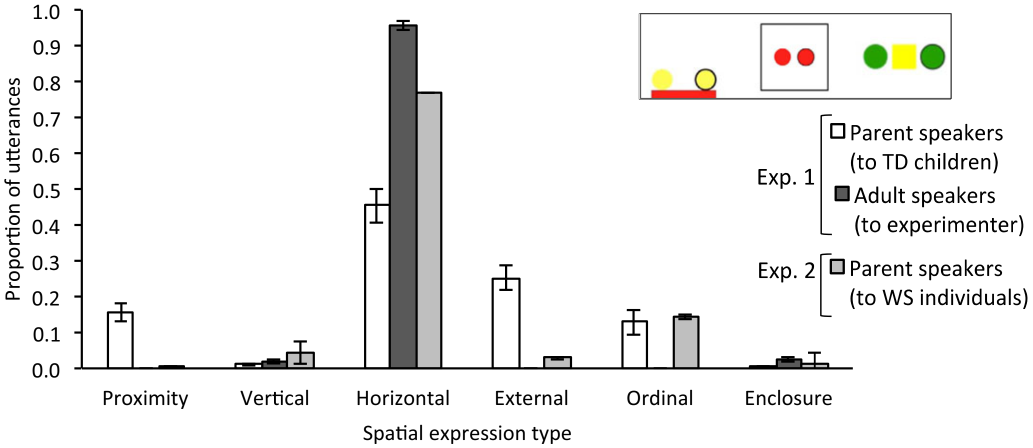

Fig. 8. Proportion of utterances containing spatial word types for Part 2 arrays, which were designed to require that speakers use horizontal axis terms (e.g., *left*/*right*) to accurately locate the target.

A multinomial logistic regression analysis including all relevant spatial expression types (proximity, horizontal, vertical, ordinal, and external) revealed that adults provided significantly fewer ordinal, external, and proximity response types than parents ($\beta = -8.15$, $p < .001$; $\beta = -8.10$, $p < .001$; $\beta = -11.61$, $p < .001$, respectively). Adults were less likely to offer descriptions of proximity or external references when speaking to another adult; these descriptions require more effort and are perhaps less direct than using the straightforward descriptions of *left*/*right*, which the speaker could infer that their adult conversational partner would be able to understand. The rate of horizontal term usage in Part 2 was marginally significantly greater for adults in comparison to parents ($\beta = 1.94$, $p = .076$). (See Supplementary Material for the full multinomial model.)

Post hoc pairwise comparisons of parent speech indicate that parents used horizontal terms more frequently than all other types ($p < .001$ for all comparisons). Counting (ordinal) and external world-related terms were both used less than horizontal terms, but the latter were offered just as frequently as proximity, and more so than vertical terms. Parents also employed descriptions of proximity more than enclosure. In contrast, adults favored horizontal terms over descriptions of enclosure and proximity.

2.4. Discussion

The differences between parent and adult descriptions support the claim that speakers adapt their target descriptions to their listeners. Parents adapted their target descriptions to their child's understanding of spatial terms, especially by privileging spatial terms for locations along the vertical axis (*above*, *below*) and avoiding spatial terms for locations along the horizontal axis (*left*, *right*). The adult experimenter dyads provide a baseline with which these patterns of spatial language to children and associated claims about the embedded listener model can be disentangled from preferences of the speaker herself.

In Part 2, evidence of parents departing from their own preferences to meet the needs of their child listener was most clearly demonstrated by the fact that they used spatial term categories (external and ordinal) that were never used by adults describing the arrays to the fellow adult experimenter. In addition to the different spatial term categories preferred by parents versus adults, the types of spatial terms within a category also provide support for the embedded listener model. There was clearly more variation within expression type for TD parents (see Appendix A) in comparison to adults (see Appendix B), indicating that they strove to describe the spatial relationship in a way that is most accessible to their child (e.g., for a vertical relation a parent used the description "the very tiptop," whereas for an adult a straightforward "top" would suffice). Comparison of A and B appendices highlights the sheer quantity of spatial descriptions given by parents (even with immediate repetitions ignored) that far outweigh those offered by adults. Furthermore, TD parents offered a significantly greater number of different spatial expression types than adults in Part 2, as they strove to provide horizontal descriptions that would be understood by their child. This reveals parents going beyond the ways in which they would speak to another adult, where one or at most two spatial expressions would be deemed sufficient (the most complex utterance given by adults were combinations in the form of “upper left”).

In Experiment 2, we follow-up these findings by probing the conditions and consequences of engaging an embedded listener model. As discussed earlier, the strongest version of the model assumes that speakers always adjust to their listeners. Yet there are individual differences even among adult speakers in the extent to which they adjust to listeners (Schober, 2009), which may be modulated by the demands of the communication task. To test the limits of use, we gathered data from parents of people with Williams syndrome (WS). In this case it may be particularly difficult for parents to evaluate their child’s level of spatial understanding as it applies to the “I spy” game and adapt their spatial descriptions accordingly. Comparing the input data from parents of TD preschoolers in Experiment 1 and parents of people with WS in Experiment 2, we then return to the question of whether the adaptations made by parents in each group conform to the actual level of spatial understanding shown by their own child.

3. Experiment 2

3.1. Method

3.1.1. Participants

Twenty-one individuals with WS (aged 5.58–32.58, 8 males, $M_{\text{age}} = 15.42$) and their parents (6 males) participated in Experiment 2. Fifteen parent–child pairs who lived within a 2.5 h travel range from the Johns Hopkins University participated in the study at our lab. The remaining six were tested at the biennial meeting of the Williams Syndrome Association in Boston, MA. WS participants were recruited with the assistance of the Williams Syndrome Association, and all were diagnosed by a geneticist and had a positive FSH test. The design, stimuli, and coding of Experiment 2 were the same as those described for Experiment 1.

3.2. Results

As was observed for the TD group, most WS individuals were accurate in selecting the target shape based on their parent’s descriptions for Part 1 stimuli and showed more variability for Part 2. On average, they correctly selected the target shape on 85% of the trials in Part 1 (range = 58–100%, *SE* = 3%), which is significantly above chance (33%), $t(20) = 19.54$, $p < .001$. In Part 2, they correctly selected the target shape on 83% of trials (range = 0–100%, *SE* = 6%), which is also significantly above chance rates of performance (33%), $t(20) = 8.45$, $p < .001$.

3.2.1. Part 1 arrays

As was done for the typically developing and adult experimenter groups, we will first consider the spatial expression types used by parents to describe the target shape within the different arrays. Fig. 4 (Experiment 2: Parent speakers to WS individuals) illustrates a strong similarity in the usage patterns of parents of TD children and parents of WS individuals for Vertical versus Horizontal arrays. When presented with an array that offers the option of describing the target shape by either vertical or horizontal terms, vertical terms are largely preferred. Binary logistic regression (horizontal terms vs. vertical) confirmed that WS parents did not use horizontal terms at significantly greater rates than TD parents ($\beta = 1.32$, $p = .14$). Post hoc within-group comparisons showed that parents speaking to WS individuals used significantly more vertical terms than horizontal terms ($p < .001$), just as had been found for the parents of TD children.

Fig. 5 shows data for arrays that were designed to elicit vertical and/or proximal terms (Vertical vs. Proximity). Again, we see the same pattern that was shown by parents of TD children. WS parents did not use proximal terms at significantly greater rates than TD parents ($\beta = -0.31$, $p = .71$). Post hoc pairwise comparisons indicate that proximal terms are significantly preferred by WS parents over vertical terms ($p < .001$), which apply somewhat indirectly in these particular arrays, as discussed above.

Fig. 6 illustrates data for arrays in which either proximal terms or horizontal terms could be used to identify the location of the target (Proximity vs. Horizontal). Parents of individuals with WS again closely resemble parents of TD 4-year-olds in their overwhelming preference for vertical terms. Multinomial logistic regression revealed that WS parents used horizontal terms at significantly greater rates than TD parents ($\beta = 1.96$, $p < .05$; cf. there was no difference between these groups for proximity terms; $\beta = 0.07$, $p = .93$). Post hoc pairwise comparisons of the spatial expression types used by WS parents demonstrated that both proximal and vertical terms were used significantly more than horizontal terms ($p < .001$ for both comparisons).

Lastly, Fig. 7 shows the data for arrays in which either axial terms (vertical or horizontal) or descriptions of enclosure would serve to uniquely describe the target (Vertical vs. Enclosure). Parents of individuals with WS used vertical terms most often, at rates similar to parents of TD children. WS parents, however, did use horizontal terms more frequently than TD parents ($\beta = 1.96$, $p < .05$), as indicated by multinomial logistic regression, although the rates of use are still quite low (<10%). Post hoc pairwise comparisons for the WS group demonstrated that vertical terms were used significantly more often than horizontal terms ($p < .001$), just as had been found for the TD group. Collectively, evidence from the arrays in Part 1 supports the hypothesis that parents of individuals with WS adopt an embedded listener model that closely resembles the model adopted by parents of TD 4-year-olds. For some arrays, however, we did observe a stronger bias toward horizontal terms, which foreshadows the pattern to be discussed for Part 2 arrays.

3.2.2. Part 2 arrays

For trials in which disambiguation of the target shape required reference to one side of the horizontal axis, we see a somewhat different pattern emerge for the WS group (Fig. 8). The overall rate of usage of horizontal terms is higher in this case; 45% of the TD parents' descriptions were horizontal terms, compared to 79% of the WS parents'.

We also do not see as frequent use of the alternative strategies discussed above (e.g., using the left to right arrangement of the number line, drawing upon salient items on either the left or right side of the room, or mapping left/right direction onto the child's egocentric reference frame). Multinomial logistic regression analysis including all relevant spatial expression types (proximity, horizontal, vertical, ordinal, and external) revealed that WS parents used external references ($\beta = -4.47$, $p < .001$) and descriptions of proximity ($\beta = -6.37$, $p < .001$) less frequently than TD parents. Within the WS group, post hoc pairwise comparisons indicated that horizontal terms were used more frequently than all other response types (all p's $< .001$).

The observed differences between the TD and WS groups may simply be due to the fact that WS individuals do not require the same type of adjusted tuning as 4-year-olds. Consideration of the types of expressions used within a spatial category (Appendix C) indicates that parents of WS individuals showed greater variability than adults, but not to the same extent as TD parents. The more frequent usage of horizontal terms by parents in this group may be a direct result of the fact that their children are able to consistently demonstrate accurate knowledge of *left*/*right* terms. Alternatively, it may be the case that parents of individuals with WS have a more difficult time adopting an embedded listener model of their own child's abilities. We next turn to consider the potential link between the spatial terms used by individual parents and how their child performed when tested for comprehension of those same terms.

4. Calibration of parent language to individual child comprehension: Comparison of TD and WS groups

Testing whether a parent possesses an appropriate embedded listener model of her child also requires evaluation of the child's own competence in the use of spatial terms. This evaluation was achieved via a measure of spatial language that was comprised of two subtasks (Production and Comprehension), administered after the main spatial language task. Both subtasks were modified from previous studies (Dessalegn & Landau, 2008; Landau & Hoffman, 2005). The Production task was always administered first so that children's performance would not be affected by terms they heard in the Comprehension task. Our main question was whether parents' use of *left*/*right* in the main task was conditioned by their children's comprehension of *left*/*right*. If so, this would be consistent with our hypothesis that parents were sensitive to their children's level of understanding of these terms, and tailored their language accordingly.

In the Production task, participants were told that they were going to talk about "where things are" with the experimenter. Participants were seated before a laptop computer screen at a distance of 45–60 cm. A 3 × 3-cm square was displayed at the center of the screen, with a smiley face placed next to one of its sides (left, right, top, or bottom). Locations were presented in a randomized order, with four trials for each side, for a total of 16 trials. On each trial, participants were asked, "Where is the smiley face to the square?" If needed, they were prompted by the experimenter saying, "The face is …".

Participants' verbal responses (e.g., "He is on the top of the square") were recorded and transcribed. For the *top* and *bottom* trials, both TD and WS participants produced accurate responses on 100% of the trials. For *left/right* trials, TD children produced those terms on only 12% of the trials (*SE* = 8%), and WS individuals did so on 17% of trials (*SE* = 8%). Far more frequent production responses were *next to* and *on the side of* for trials testing *left* and *right* (88% of trials for TD children, *SE* = 8%; 73% of trials for WS individuals, *SE* = 9%). The relatively rare production of *left/right* in both groups accords with previous findings (Landau & Hoffman, 2005) and suggests that children and people with WS are unlikely to use these terms to describe spatial relationships.

In the Comprehension task, an 8.5 × 11 inch piece of paper with a 3 × 3 cm gray square drawn at the center was placed in front of the participant. The experimenter then asked the participant to "draw a line at the left (or right/top/bottom) of the square." Each term was tested four times in a randomized order, with 16 trials total. For the *top* and *bottom* trials, TD children drew a line at the correct location on 100% of the trials. WS individuals also did so at high rates of accuracy, 98% for *top* (*SE* = 2%), and 95% (*SE* = 3%) for *bottom*, although with some errors from the younger individuals tested. For the *left/right* trials, TD children drew a line at the correct location on 61% of the trials (*SE* = 6%), and WS individuals did so on 69% of the trials (*SE* = 8%).

Were individual parents attuned to their children's degree of *left/right* mastery, as assessed by the Comprehension test? We considered trials on which parents had to provide descriptions that identified one side of the horizontal axis (those in Part 2 of the study). This analysis uses the same six spatial expression types as coded above [vertical, horizontal, proximity, enclosure, external, and ordinal]. On these trials, parents who are attuned to their child's mastery of *left/right* should opt to use these terms in isolation only if their child demonstrates strong comprehension of *left* and *right* on the spatial language test. In contrast, parents of children who do not clearly know the difference between *left* and *right* should demonstrate adjustment to their own child's comprehension level by offering supplemental descriptions. Instead of identifying the target by using exclusively horizontal expression types, these parents may offer descriptions with additional spatial cues, such as "The circle on the left, remember this is on the side of the hand that you use to throw a ball."

A logistic regression model of the experimentally elicited spatial language by parents in both the TD and WS groups allowed us to evaluate whether the child comprehension score for *left/right* was a significant predictor of parent use of *left/right* terms, without additional spatial information, for trials in Part 2. The model revealed a significant interaction between group and the predictor of child *left/right* comprehension score, such that the effect of this predictor was significantly greater for the TD group than the WS group ($B = 1.38$, $SE\ B = 0.53$, $e^B = 10.80$, $z = 3.97$, $p = .008$). At the group level, we observed that parents of TD children (mean = 0.31 of trials, *SD* = 0.38) are less likely to use *left/right* terms than parents of WS individuals (mean = 0.73 of trials, *SD* = 0.39).

To pursue this difference further, we next considered the TD and WS groups separately and used logistic regression models to determine whether individual child compre-

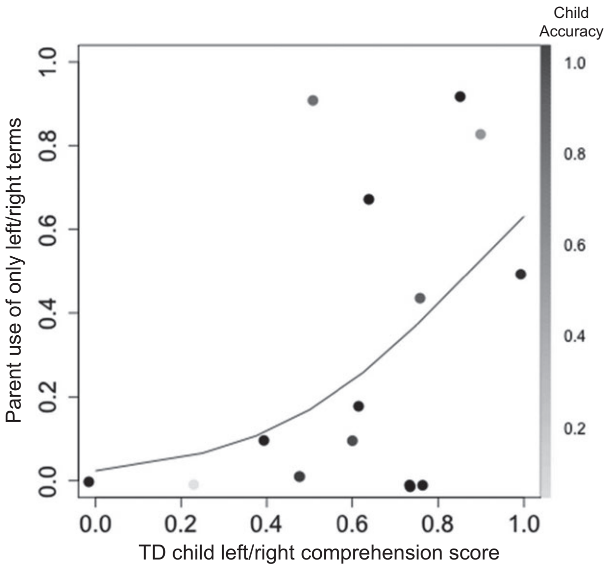

Fig. 9. Relationship between TD childrens' comprehension score for *left*/*right* terms and Part 2 trials on which their parents opted to use only *left*/*right* terms to describe the location of the target shape. Child accuracy in identifying the target shape is indicated by shading, where black represents 100% accuracy, and lightening shades of gray represent decreasing task accuracy.

hension score for *left*/*right* terms was a significant predictor of his/her parent's usage of these terms in isolation. For the TD group, the model revealed a highly significant effect of child comprehension score on parents' probability of using only *left*/*right* terms for trials in Part 2 (where z-scores of comprehension and age were calculated to avoid correlation with the intercept, $B = 1.74$, $SE\ B = 0.68$, $e^B = 5.70$, $z = 2.57$, $p = .01$). Fig. 9 illustrates a scatter plot of the relationship between the two variables of interest, with the best fit line generated from the separate model analysis. As spatial language mastery may greatly improve between the ages of 3.5 and 4.5, we conducted a separate correlation analysis to investigate the possibility of a relationship with age. Child age and *left*/*right* comprehension score were not significantly correlated (Spearman's rank-order correlation, $r_s(14) = 0.14$, $p = .60$). This may not be surprising, given that we tested children in a fairly narrow age range. Furthermore, when child age was entered in the logistic regression model, it did not reach significance ($B = -1.06$, $SE\ B = 0.62$, $e^B = 0.35$, $z = -1.72$, $p = .09$); child comprehension of *left*/*right* terms remained the only significant predictor of parents' use of horizontal terms in isolation ($B = 1.83$, $SE\ B = 0.60$, $e^B = 6.23$, $z = 3.05$, $p = .002$).

The parallel scatter plot for the WS group is shown in Fig. 10. In the logistic regression analysis for the WS group, comprehension score for *left*/*right* did not prove to be a significant predictor of parents' usage of these terms ($B = -0.56$, $SE\ B = 0.61$, $e^B = 0.57$, $z = -0.93$, $p = .35$). But in this case, there was a significant correlation between the age of the WS participants and their comprehension of *left*/*right*

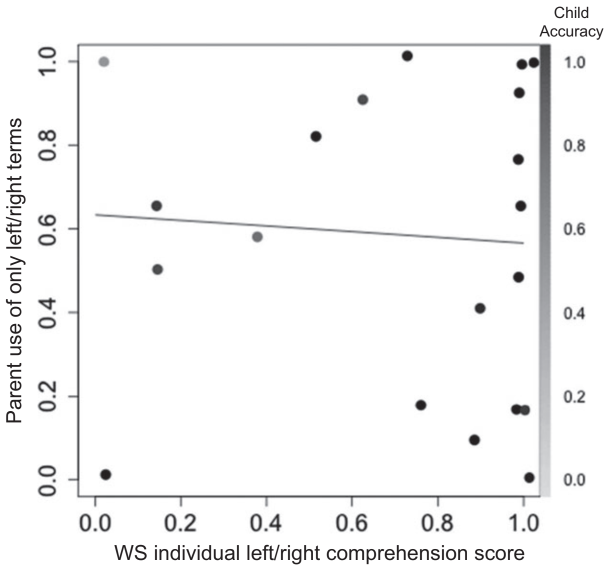

Fig. 10. Relationship between WS individuals' comprehension score for *left*/*right* terms and Part 2 trials on which their parents opted to use only *left*/*right* terms to describe the location of the target shape. WS individuals' accuracy in identifying the target shape is indicated by shading, where black represents 100% accuracy, and lighter shades of gray represent decreasing task accuracy.

terms ($r_s(19) = 0.53$, $p = .01$). Inclusion of WS individuals' age in the model revealed that this factor was not a significant predictor of parents' use of *left*/*right* terms in isolation ($B = 0.06$, $SE\ B = 0.73$, $e^B = 1.06$ $z = 0.08$, $p = .93$), and WS comprehension of *left*/*right* terms remained a non-significant predictor ($B = -0.60$, SE $B = 0.72$, $e^B = 0.55$, $z = -0.83$, $p = .41$).

Returning to the TD data, one may infer a threshold effect for TD parents; if their child has a comprehension score of 0.75 or higher, the parent is far more likely to use only *left*/*right* terms. This indicates that if a child demonstrates (fairly) strong mastery of *left*/*right* terms on the comprehension measure, her parent will likely use solely *left*/*right* to describe the location of the target shape. This input may in turn serve to bolster the child's partial mastery of *left*/*right* terms, providing more exposure and opportunity to practice her developing knowledge.

How accurate were TD children and WS individuals in selecting the target shape when their parents used only *left* or *right* to describe its location on the screen? We evaluated this relationship by dividing the participants into two groups: those who demonstrated strong mastery of *left*/*right* terms (scored 0.75 or higher on the comprehension measure) and those who demonstrated weak or inconsistent knowledge of *left*/*right* terms (scored below 0.75 on the comprehension measure). As is evidenced by the adaptive tuning of TD parents discussed above, TD children's comprehension of *left*/*right* terms and parent usage of these terms in isolation were highly correlated ($r_s(14) = 0.63$, $p = .009$). For the group of TD children who weakly knew their *left* and *right* (scored below 0.75 on the comprehension measure), their parents used only *left*/*right* terms in just 18% of their descriptions in Part 2. On these trials, in which they were given only horizontal descriptions, these children correctly selected the target 69% of the time. For the group of TD children who demonstrated strong knowledge of *left*/*right* terms (scored 0.75 or higher on the comprehension measure), their parents used only *left*/*right* terms in 75% of their descriptions in Part 2. On these trials, this group of children correctly selected the target 78% of the time. Thus, in comparison to those who had variable performance on the comprehension measure, children who demonstrated strong knowledge of *left*/*right* were better able to interpret and act upon instructions from their parents that contained exclusively horizontal terms.

The same relationship did not hold true for the WS group. WS individuals' comprehension of *left*/*right* terms and parent usage of these terms in isolation were not significantly correlated ($r_s(19) = -0.21$, $p = .36$). Further dividing the WS individuals by comprehension score did not reveal the same relationship with accuracy as had been found for the TD children. For the group of WS individuals who weakly knew their *left* and *right*, their parents used only *left*/*right* terms in more than half (67%) of their descriptions in Part 2. On these trials in which they were given only horizontal descriptions, these WS individuals correctly selected the target 60% of the time. It is likely that this accuracy score could have been improved if these individuals had heard more supplemental information, beyond solely *left*/*right* terms. For the group of WS individuals who demonstrated strong knowledge of *left*/*right* terms, their parents used only these terms in 52% of their descriptions in Part 2. Individuals correctly selected the target on 96% of these trials. This high level of accuracy indicates that many of these parents may have underestimated their child's mastery of *left* and *right*. Thus, the impact of parent usage of *left*/*right* terms on the WS participants' task accuracy illustrates cases of parent embedded listener models that appear to be too far tuned in one direction; some parents overestimate their children's spatial term comprehension, whereas others underestimate what descriptions their children will be able to accurately act upon in the context of the guessing game.

5. General discussion

We asked whether speakers adapt their language to the needs of the listener, consistent with an embedded listener model of production. Focusing on the language produced to describe targets in spatial arrays, we asked whether speakers modify their spatial descriptions in accordance with listeners' perceived spatial competence. In Experiment 1, we asked adults to describe targets to a fellow adult, and compared these descriptions to those produced by parents to their TD 3- and 4-year-olds. In Experiment 2, we asked parents of people with severe spatial deficits to describe the same targets to their children. These three speaker groups provide a rich comparative dataset to test the constraints of the embedded listener model, both as it pertains to the nature of linguistic input in young children's spatial cognitive development, as well as within a population with known spatial difficulties. To establish a connection between parent language and child comprehension, an independent measure of children's spatial term understanding was included. Our findings provide evidence in support of an embedded listener model for spatial language. This was despite the fact that speakers as a whole shared certain biases to encode particular spatial relationships over others, in particular, relationships along the vertical axis in preference to those along the horizontal axis. The results also suggest that by and large, parents of TD children create embedded models that accurately reflect their child's spatial competence. Finally, we found that such embedded models are not an inevitable outcome: Parents of people with severe spatial limitations were less able to create an accurate model of their child listener and use it to tailor their language.

As overall support for the embedded listener model, we observed systematic variation in the type of spatial expressions used by speakers across the different interlocutor groups, reflecting differential adjustments of the speaker's language to match the spatial term competency of particular listener types. When given the choice between vertical or horizontal terms, parents of TD children and WS individuals opted to use vertical terms in the majority of their descriptions. Independent evidence from production and comprehension tasks showed that both groups of children were at ceiling in their mastery of these terms, suggesting that this parental preference would be effective in enhancing communicative interaction. In contrast, adults speaking to the adult experimenter also used *left/right* terms, which they could be more certain their listener would be able to accurately interpret.

The same general pattern held for arrays that pitted horizontal terms (*left/right*) against terms encoding proximity (*near/far*). TD and WS children were correct on only roughly half of the left/right trials on the independent production and comprehension tasks. The adult experimenter dyads demonstrated preferential usage of *left/right*, whereas the TD and WS parents avoided *left/right* terms, instead using proximity terms or an indirect application of *above/below* (e.g., target located *above* a reference object on a diagonal). The systematic modulation among the different groups cannot be attributed solely to ease of production on behalf of the speaker—as all were adults, we would have observed similar patterns of spatial language use if speakers' utterances reflected only internal production constraints. Instead, the spatial descriptions offered by adult speakers across the different groups qualitatively differed from one another, and these differences likely reflect adjustments made to maximize the likelihood of comprehension on behalf of their unique listener group.[1] Collectively, these data demonstrate that both adults speaking to a fellow adult experimenter and parents speaking to young children adapt their descriptions to accommodate their listener's understanding of spatial terms.

The data also provide evidence that is consistent with the idea that speakers have biases to encode relationships along the vertical axis over the horizontal axis. When speakers had the option to choose among multiple valid spatial terms to describe the location of the target within an array (Part 1 trials), vertical terms were the overwhelming favorite among all groups whenever applicable. For example, when presented with arrays that pitted vertical terms (*above/below*) against proximity (*near/far*), parents speaking to their TD child or child with WS, as well as adults speaking to the adult experimenter, all opted to use vertical terms to describe the location of the target the majority of the time.

This vertical axis bias is well documented in the literature for a variety of tasks, and it is evidenced in measures of reaction time (e.g., Logan & Sadler, 1996), as well as location memory and linguistic identification among both adults and children (Hayward & Tarr, 1994; Landau & Hoffman, 2005). The use of vertical axis terms when other terms provide an equally valid description of a target's location indicates speaker pressures that may reflect both the ease of encoding vertical relationships, and the higher likelihood that the listener will be able to accurately decode the relationship.

Several of our findings suggest that parents of TD children largely created accurate embedded models of their children's spatial competence and used these in their target descriptions, but that parents of people with WS were less able to do so. First, when parents of TD children were faced with the challenge of providing spatial descriptions that uniquely identified one side of the horizontal axis (Part 2 arrays), many generated spontaneous creative strategies that took advantage of polarity correspondences of familiar actions (e.g., "The one closer to the hand that you throw a ball with"), or the left-to-right progression of the number line (e.g., "Pick the one that is number 3 in the row"). Such expressions were never observed in the descriptions adult speakers gave their fellow adult listener, presumably because the speakers knew that their listener had a firm grasp on the *left/right* mapping to horizontal space. However, they were also not used by parents of people with WS, who did have difficulties comprehending *left/right* terms. This may be because the WS participants themselves were considerably older than the TD children, and these strategies may have seemed inappropriate to parents.

More important, we examined the degree of coupling between parents' spatial descriptions and their children's spatial term competence at the level of individual parent–child dyads, by using a separate measure of spatial term competence. This allowed us to gauge the types of utterances a particular listener would comprehend—would they be able to select the target shape with solely the prompt of *left* or *right*, or would they require supplementary descriptions? We evaluated the listeners' competency in relation to the spatial terms their speakers used to identify the location of an item on one side of the horizontal axis. At the level of individual subjects, we found that TD children's score for spatial term competence was a strong predictor of whether their parent would choose to use *left/right* terms or not. That is, a particular child who performed poorly on the left/right trials of the spatial comprehension task tended to have a parent who appropriately matched her child's comprehension by offering helpful alternative descriptions (e.g., "Pick the one that is closer to the door"). In contrast, a child who scored relatively highly on the spatial comprehension task tended to have a parent who matched this level of competence by offering more descriptions that contained *left/right* terms, which the child was likely to comprehend. Children's age itself did not predict parental usage.

For the WS group, we observed more instances of over- and under-estimation on behalf of the parents. Some used solely *left/right* terms when their child did not demonstrate strong mastery on the comprehension measure, whereas others used elaborative descriptions that may not have been necessary for their child, who demonstrated near perfect mastery of *left/right* terms on the comprehension measure. This indicates a looser degree of coupling between parental spatial language and child comprehension among the members of this group. These parents may find it difficult to judge their child's level of spatial term comprehension, and if so, it might be hard for them to adjust their language to fit their child's spatial term competence. In their attempt to search for appropriate terms that will be helpful to their child, they may provide lengthy over-informative descriptions that are difficult to process, and confuse the listener further. This could be especially problematic for listeners with intellectual disability. There may also be more nuanced embedded listener models that accommodate these outcomes. For example, parents who have adolescent or adult offspring with severe spatial deficits may have to choose between competing models of their children, who are in many ways like TD adolescents or adults, but are in other ways more like TD 4–6 year-olds. These parents might face the problem of having two different embedded listener models that compete with each other; the outcome could be a coarsely tuned model, or it could be one in which the parent switches between multiple models. This possibility suggests additional research that examines the way that people adjudicate between competing embedded listener models and the potential incremental formation of these models (Guhe, 2012) based on prior experiences with their particular listener.

Our research adopts a novel approach to investigating parents' spatial language input that goes beyond counting the raw number of spatial terms and computing correlations with vocabulary growth (e.g., Huttenlocher et al., 2010) and performance on other spatial tasks (e.g., Pruden et al., 2011). By exploring the communicative exchanges between parents and young children in a method traditionally associated with the literature of audience design, we find that parents' spatial descriptions often incorporate an embedded listener model that reflects their child's representation of spatial arrays and spatial terms. These descriptions, however, are not entirely free from the speaker's own internal representational biases, which more often result in descriptions along the vertical axis of space rather than the horizontal (even though *left/right* and *up/down* are both comprehensible by adult listeners), and also favor the vertical axis over descriptions of proximity (even though young children readily comprehend *near/far* as well). In many cases, parents coupled difficult *left/right* terms with supplemental descriptions to scaffold their child's learning of spatial terms (e.g., "Point to the one on the left, remember that is the side that is closer to the door"). These teaching episodes illustrate an avenue that may be further explored to determine how spatial language input may be specifically tuned to a particular child's comprehension level, which can then benefit the child's own cognitive growth. In the case of atypical development, such insight will be informative in developing training techniques to help parents appropriately scale their language input to not only meet the comprehension level of their child, but also aid in the acquisition and mastery of new ways of describing spatial relationships. An additional point of further investigation is the effect of priming, as it is possible that parents who use more *left/right* terms during the communication task may have provided a linguistic model that primed their children to more accurately produce these terms on the subsequent Production task. A final point is specific focus on socioeconomic factors, as previous research suggests a link between the quantity of parent language input and socioeconomic status (SES), both of which predict children's comprehension vocabulary 3 years later (Goldin-Meadow et al., 2014). Further research is needed to elucidate the impact of SES on parent–child communicative interactions, both within TD and special populations.

The central contribution of this study is the demonstration of strong listener-oriented effects in spatial language. Adults radically shift their repertoire of spatial expressions in speech to children, in comparison to speech directed to another adult, though certain populations (WS) may make appropriate shifts more challenging. These results provide clear evidence for an embedded listener model, as the expressions avoided by parents are precisely those known to generally show protracted development in children. We have also provided evidence of speaker adaptation at the level of individual parent-TD child pairs. While listener-oriented effects may be difficult to distinguish from speaker-oriented factors in many settings and the efficacy of many listener-oriented modifications in speech may be unclear, the present findings suggest that spatial language use is tailored to the needs and knowledge of young listeners.

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Note

1. The experimenter as listener might in principle have invited the adult speakers to tailor their language specially, if, for example, they thought the experimenter knew all the answers in advance, or if they thought the experimenter was “playing dumb” on purpose. We doubt that this is the case, since the adult speakers produced patterns that conformed to rational principles (i.e., they primarily used vertical terms when given the option, and horizontal terms when given the option). One way to determine if the experimenter’s role had an effect would be to have adult speakers describe the arrays to naive adult listeners (i.e., use two experimental participants for each dyad).

References

Acredolo, L. P. (1978). The development of spatial orientation in infancy. *Developmental Psychology*, *14*, 224–234.

Acredolo, L. P., & Evans, D. (1980). Developmental changes in the effects of landmarks on infant spatial behavior. *Developmental Psychology*, *16*, 312–318.

Allen, G. L., & Kirasic, K. C. (1988). Young children's spontaneous use of spatial frames of reference in a learning task. *British Journal of Developmental Psychology*, *6*, 125–135.

Bellugi, U., Wang, P. P., & Jernigan, T. L. (1994). Williams syndrome: An unusual neuropsychological profile. In S. Broman & J. Grafman (Eds.), *Atypical cognitive deficits in developmental disorders: Implications for brain function* (pp. 23–56). Hillsdale, NJ: Lawrence Erlbaum Associates.

Bowerman, M. (1989). Learning a semantic system: What role do cognitive predispositions play? In M. Rice & R. Schiefelbusch (Eds.), *The teachability of language* (pp. 133–169). Baltimore, MD: Paul H. Brookes.

Carlson-Radvansky, L. A., & Logan, G. D. (1997). The influence of reference frame selection on spatial template construction. *Journal of Memory and Language*, *37*, 411–437.

Cartmill, E. A., Armstrong, B. F., Gleitman, L. R., Goldin-Meadow, S., Medina, A. N., & Trueswell, J. C. (2013). Quality of early parent input predicts child vocabulary 3 years later. *Proceedings of the National Academy of Sciences USA*, *110*, 11278–11283.

Clark, H. H. (1972). Difficulties people have in answering the question "Where is it?" *Journal of Verbal Learning and Verbal Behavior*, *11*, 265–277.

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

Clark, E. V. (1974). Nonlinguistic strategies and the acquisition of word meanings. *Cognition*, *2*, 161–182.

Clark, E. V. (1991). Acquisitional principles in lexical development. In S. A. Gelman & J. P. Byrnes (Eds.), *Perspectives on thought and language: Interrelations in development* (pp. 31–71). Cambridge, England: Cambridge University Press.

Clark, H. H. (1996). Communities, commonalities, and communication. In J. Gumperz & S. Levinson (Eds.), *Rethinking linguistic relativity* (pp. 324–355). Cambridge, England: Cambridge University Press.

Clark, H. H., & Carlson, T. B. (1982). Critics' beliefs about hearers' beliefs: A rejoinder to Johnson- Laird, Sperber, and Wilks. In N. V. Smith (Ed.), *Mutual knowledge* (pp. 5–259). New York: Academic Press.

Clark, E. V., & Estigarribia, B. (2011). Using speech and gesture to introduce new objects to children. *Gesture*, *11*, 1–23.

Clark, H. H., & Marshall, C. R. (1981). Definite reference and mutual knowledge. In A. K. Joshi, B. Webber, & I. Sag (Eds.), *Elements of discourse understanding* (pp. 10–63). Cambridge, England: Cambridge University Press.

Clark, E. V., & Wong, A. D.-W. (2002). Pragmatic directions about language use: Offers of words and relations. *Language in Society*, *31*, 181–212.

Cook, P., & Stevenson, S. (2009). An unsupervised model for text message normalization. In A. Feldman & B. Lönneker-Rodman (Eds.), *Proceedings of the workshop on computational approaches to linguistic creativity* (pp. 71–78). Boulder, CO: OmniPress.

Craton, L. G., Elicker, J., Plumert, J. M., & Pick, H. L., Jr (1990). Children's use of frames of reference in communication of spatial location. *Child Development*, *61*, 1528–1543.

Cristia, A., & Seidl, A. (2013). The hyperarticulation hypothesis of infant-directed speech. *Journal of Child Language*, *40*, 1–22.

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent-child activity. *Science Education*, *85*, 712–732.

Davies, C., & Katsos, N. (2009). Are interlocutors as sensitive to over-informativeness as they are to under-informativeness? Poster presented at Pre-CogSci 2009, Workshop on the Production of Referring Expressions, Amsterdam.

de Hevia, M. D., & Spelke, E. S. (2009). Spontaneous mapping of number and space in adults and young children. *Cognition*, *110*, 198–207.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and numerical magnitude. *Journal of Experimental Psychology: General*, *122*, 371–396.

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

Dilks, D., Hoffman, J. E., & Landau, B. (2008). Vision for perception and vision for action: Normal and unusual development. *Developmental Science*, *11*, 474–486.

Engelhardt, P. E., Bailey, K. G. D., & Ferreira, F. (2006). Do speakers and listeners observe the Gricean Maxim of Quantity? *Journal of Memory and Language*, *54*, 554–573.

Fernald, A., & Kuhl, P. (1987). Acoustic determinants of infant preference for motherese speech. *Infant Behavior and Development*, *10*, 279–293.

Fernald, A., & Mazzie, C. (1991). Prosody and focus in speech to infants and adults. *Developmental Psychology*, *27*, 209–221.

Ferreira, V. S., & Dell, G. S. (2000). The effect of ambiguity and lexical availability on syntactic and lexical production. *Cognitive Psychology*, *40*, 296–340.

Frank, M. C., & Goodman, N. D. (2012). Predicting pragmatic reasoning in language games. *Science*, *336*, 998.

Fussell, S. R., & Krauss, R. M. (1992). Coordination of knowledge in communication: Effects of speakers' assumptions about what others know. *Journal of Personality and Social Psychology*, *62*, 378–391.

Gahl, S., & Garnsey, S. M. (2004). Knowledge of grammar, knowledge of usage: Syntactic probabilities affect pronunciation variation. *Language*, *80*, 748–775.

Gallaway, C., & Richards, B. J. (Eds.) (1994). *Input and interaction in language acquisition*. Cambridge, England: Cambridge University Press.

Gibson, E. (1998). Linguistic complexity: Locality of syntactic dependencies. *Cognition*, *68*, 1–76.

Goldin-Meadow, S., Levine, S. C., Hedges, L. V., Huttenlocher, J., Raudenbush, S., & Small, S. (2014). New evidence about language and cognitive development based on a longitudinal study: Hypotheses for intervention. *American Psychologist*, *69*, 588–599.

Golland, D., Liang, P., & Klein, D. (2010). A game-theoretic approach to generating spatial descriptions. In H. Li & L. Màrquez (Eds.), *Proceedings of empirical methods on natural language processing* (pp. 410–419). Stroudsburg, PA: Association for Computational Linguistics.

Guhe, M. (2012). Utility-based generation of referring expressions. *Topics in Cognitive Science*, *4*, 306–329.

Hadfield, J. D. (2010). MCMC methods for multi-response generalised linear mixed models: The MCMC glmm R package. *Journal of Statistical Software*, *33*, 1–22.

Hale, J. (2003). The information conveyed by words in sentences. *Journal of Psycholinguistic Research*, *32*, 101–123.

Harris, L. (1972). Discrimination of left and right, and development of the logic relations. *Merrill–Palmer Quarterly*, *18*, 307–320.

Hawkins, J. A. (1994). *A performance theory of order and constituency*. Cambridge, England: Cambridge University Press.

Hayward, W. G., & Tarr, M. J. (1995). Spatial language and spatial representation. *Cognition*, *55*, 39–84.

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*, 343–365.

Isaacs, E. A., & Clark, H. H. (1987). References in conversations between experts and novices. *Journal of Experimental Psychology: General*, *116*, 26–37.

Jaeger, T. F., & Tily, H. (2011). Language processing complexity and communicative efficiency. *WIRE: Cognitive Science*, *2*, 323–335.

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

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

Kruschke, J. (2011). *Doing Bayesian data analysis: A tutorial introduction with R and BUGS*. Burlington, MA: Academic Press/Elsevier.

Kuczaj, S. A., & Maratsos, M. P. (1975). On the acquisition of front, back, and side. *Child Development*, *46*, 202–210.

Landau, B., & Hoffman, J. E. (2005). Parallels between spatial cognition and spatial language: Evidence from Williams syndrome. *Journal of Memory & Language*, *53*, 163–185.

Landau, B., & Hoffman, J. E. (2012). *Spatial representation: From gene to mind*. New York: Oxford University Press.

Landau, B., Hoffman, J., & Kurz, N. (2006). Object recognition with severe spatial deficits in Williams syndrome: Sparing and breakdown. *Cognition*, *100*, 483–510.

Levy, R., & Jaeger, T. (2007). Speakers optimize information density through syntactic reduction. In B. Scholkopf, J. Platt, & T. Hoffman (Eds.), *Advances in neural information processing systems* (vol. 19, pp. 849–856). Cambridge, MA: MIT Press.

Lockridge, C. B., & Brennan, S. E. (2002). Addressees' needs influence speakers' early syntactic choices. *Psychonomic Bulletin & Review*, *9*, 550–557.

Logan, G. D. (1995). Linguistic and conceptual control of visual spatial attention. *Cognitive Psychology*, *28*, 103–174.

Logan, G. D., & Sadler, D. D. (1996). A computational analysis of the apprehension of spatial relations. In P. Bloom, M. A. Peterson, L. Nadel, & M. Garrett (Eds.), *Language and space* (pp. 493–529). Cambridge, MA: MIT Press.

MacDonald, M. C. (2013). How language production shapes language form and comprehension. *Frontiers in Psychology*, *4*, 1–16.

Mandler, J. M., & Day, J. (1975). Memory for orientation of forms as a function of their meaningfulness and complexity. *Journal of Experimental Child Psychology*, *20*, 430–444.

McMurray, B., Kovack-Lesh, K. A., Goodwin, D., & McEchron, W. (2013). Infant directed speech and the development of speech perception: Enhancing development or an unintended consequence? *Cognition*, *129*, 362–378.

Mervis, C. B., & Morris, C. A. (2007). *Williams syndrome*. In M. M. M. Mazzocco & J. L. Ross (Eds.), *Neurogenetic developmental disorders: Variation of manifestation in childhood* (pp. 199–262). Cambridge, MA: MIT Press.

Morris, C. A. (2006). Genotype-phenotype correlations in Williams-Beuren syndrome. In C. A. Morris, H. Lenhoff, & P. Wang (Eds.), *Williams-Beuren syndrome: Research, evaluation, and treatment* (pp. 59–82). Baltimore, MD: Johns Hopkins University Press.

Musolino, J., Chunyo, G., & Landau, B. (2010). Uncovering knowledge of core syntactic and semantic principles in individuals with Williams syndrome. *Language Learning and Development*, *6*, 126–161.

Newcombe, N. S., Huttenlocher, J., Drummey, A. B., & Wiley, J. G. (1998). The development of spatial location coding: Place learning and dead reckoning in the second and third years. *Cognitive Development*, *13*, 185–200.

Newport, E. L., Gleitman, H., & Gleitman, L. (1977). Mother, I'd rather do it myself: Some effects and non-effects of maternal speech style. In C. E. Snow & C. A. Ferguson (Eds.), *Talking to children: Language input and acquisition* (pp. 109–150). Cambridge, England: Cambridge University Press.

Opfer, J. E., Thompson, C. A., & Furlong, E. E. (2010). Early development of spatial-numeric associations: Evidence from spatial and quantitative performance of preschoolers. *Developmental Science*, *13*, 761–771.

Overman, W. H., Pate, B. J., Moore, K., & Peuster, A. (1996). Ontogeny of place learning in children as measured in the radial arm maze, Morris search task, and open field task. *Behavioral Neuroscience*, *110*, 1205–1228.

Palomares, M., Landau, B., & Egeth, H. (2009). Orientation perception in Williams syndrome: Discrimination and integration. *Brain and Cognition*, *70*, 21–30.

Plumert, J. M., Haggerty, K., Mickunas, A., Herzog, L., & Shadrick, C. (2012). Mother-child communication about location: Giving and following directions for finding hidden objects. *Developmental Psychology*, *48*, 956–968.

Pruden, S. M., Levine, S. C., & Huttenlocher, J. (2011). Children's spatial thinking: Does talk about the spatial world matter? *Developmental Science*, *14*, 1417–1430.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York: Oxford University Press.

Rogoff, B. (1998). Cognition as a collaborative process. In W. Damon (Series Ed.), D. Kuhn, & R. S. Siegler (Eds.), *Handbook of child psychology, Vol. 2., Cognition, perception, and language* (pp. 679–744). New York: Wiley.

Schnadt, M. J., & Corley, M. (2006). The influence of lexical, conceptual and planning based factors on disfluency production. In R. Sun & N. Miyake (Eds.), *Proceedings of the Twenty-Eight Meeting of the Cognitive Science Society* (pp. 750–755). Mahwah, NJ: Lawrence Erlbaum Associates.

Schober, M. F. (2009). Spatial dialogue between partners with mismatched abilities. In K. R. Coventry, T. Tenbrink, & J. A. Bateman (Eds.), *Spatial language and dialogue* (pp. 23–39). Oxford, England: Oxford University Press.

Schober, M. F., & Clark, H. H. (1989). Understanding by addressees and overhearers. *Cognitive Psychology*, *21*, 211–232.

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

Sluzenski, J., Newcombe, N. S., & Satlow, E. (2004). Knowing where things are in the second year of life: Implications for hippocampal development. *Journal of Cognitive Neuroscience*, *16*, 1443–1451.

Snow, C. E., & Ferguson, C. A. (Eds.) (1977). *Talking to children*. Cambridge, England: Cambridge University Press.

Tanenhaus, M. K. (2013). All P's or mixed vegetables? *Frontiers in Psychology*, *4*, 1–3.

Viethen, J., & Dale, R. (2008). The use of spatial relations in referring expressions. In M. White, C. Nakatsu & D. McDonald (Eds.), *Proceedings of the 5th international conference on natural language generation* (pp. 59–67). Salt Fork, OH: CUP.

Weisleder, A., & Fernald, A. (2013). Talking to children matters: Early language experience strengthens processing and builds vocabulary. *Psychological Science*, *24*, 2143–2152.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Multinomial analyses of counts of spatial category expressions across three interlocutor groups (Experiment 1 and 2).

Appendix A: Spatial expressions list: TD parents

Inclusive lists of spatial expressions offered by parents of typically developing children that were categorized as belonging to one of the six spatial expression types of the coding scheme, given with number of instances for each.

Vertical: *on top* (80), *on the bottom* (63), *on the top* (42), *above* (32), *underneath* (31), *below* (24), *under* (22), *up* (17), *down* (12), *on the top row* (11), *lower* (11), *at the bottom* (10), *upper* (10), *on the bottom row* (9), *low* (8), *lowest* (8), *at the top* (6), *highest* (6), *the highest one* (5), *up high* (4), *the top* (4), *the bottom one* (4), *up top* (3), *on the top line* (2), *in the top row* (2), *high* (1), *higher* (1), *very bottom* (1), *top* (1), *the very top* (1), *the very tip-top* (1), *over top* (1).

Horizontal: *on the left* (43), *on the right* (35), *on the right side* (17), *on the left side* (8), *right* (7), *left* (6), *your left side* (4), *your left* (3), *right side* (3), *right corner* (3), *on the right hand side* (3), *to the left* (2), *right hand* (1), *left hand* (1)

Proximity: *next to* (31), *closest* (23), *by itself* (22), *closer to* (10), *near* (8), *close to* (6), *far from* (6), *beside* (4), *by* (3), *close* (3), *far* (2), *almost touching* (1)

Enclosure: *inside* (23), *in* (18), *outside* (18).

External: *the door* (26), *her* (referring to the experimenter) (24), *the shelf* (14), *the one driving the car* (9), *Kate* (the experimenter's name) (7), *number 2 on the keyboard* (7), *number 9 on the keyboard* (6), *the one not driving the car* (4), *the bookshelf* (4), *the keyboard* (2), *your thumb-sucking hand* (2), *the hand that you type on the computer with* (2), *the hand that you throw with* (2), *the hand that you throw a ball with* (2), *the hand that you hold a pencil or crayon in* (1), *the boxes* (1), *on the side that you suck your thumb* (1), *on the passenger side of the car* (1).

Ordinal: *the first one* (20), *second one* (18), *first* (3), *one* (1)

Appendix B: Spatial expressions list: Adults

Inclusive lists of spatial expressions offered by adults speaking to another adult were categorized as belonging to one of the six spatial expression types of the coding scheme, given with number of instances for each.

Vertical: *on the bottom* (9), *on the top* (9), *above* (7), *on top* (5), *under* (5), *to the bottom* (5), *below* (4), *to the top* (4), *lower* (3), *upper* (3), *on your bottom* (2), *on your top* (1), *your top* (1), *top* (1).

Horizontal: *to the left* (20), *to the right* (19), *on the left side* (9), *on the right side* (7), *right* (5), *right corner* (5), *right hand corner* (3), *to the right side* (3), *on the left* (2), *left corner* (2), *left side* (1), *right side* (1), *left* (1).

Proximity: *next to* (3), *closer to* (1), *farther* (1).

Enclosure: *inside* (10), *outside* (9), *in* (8), *within* (8).

External: none.

Ordinal: none.

Appendix C: Spatial expressions list: WS parents

Inclusive lists of spatial expressions offered by parents of individuals with WS that were categorized as belonging to one of the six spatial expression types of the coding scheme, given with number of instances for each.

Vertical: *on top* (69), *below* (63), *above* (48), *on the bottom* (26), *under* (22), *underneath* (20), *on the top* (20), *over* (18), *bottom* (13), *on the bottom* (13), *highest* (10), *top* (10), *at the top* (9), *lowest* (9), *top row* (7), *bottom row* (6), *at the bottom* (6), *up* (6), *down* (6), *up top* (5), *lower* (5), *upper* (1), *low* (1), *on the very bottom* (1), *toward the top* (1), *the very top* (1).

Horizontal: *on the right* (42), *on the left* (41), *on the right side* (28), *left* (20), *right hand side* (19), *left hand side* (18), *on your left* (15), *right* (12), *on the left side* (10), *on your right* (8), *to the left* (7), *right hand corner* (5), *left hand corner* (3), *right hand* (3), *my right hand* (3), *on your right side* (2), *to the right* (1), *to the left* (1), *left hand* (1), *on your left side* (1), *to your left* (1), *the left eye* (1), *your right hand side* (1), *your left hand* (1).

Proximity: *next to* (35), *all by itself* (5), *beside* (3), *near* (3), *by* (2), *by itself* (1), *all alone* (1), *closer to the side of* (1), *closest* (1), *far away* (1), *has a neighbor* (1), *on its own* (1).

Enclosure: *inside* (36), *outside* (10), *within* (3), *in* (3), *has a box around it* (1).

External: *the keyboard* (1), *a face* (1), *the hand that is the hand your write with* (3), *opposite the side you write with* (3), *your hands* (1).

Ordinal: *second* (17), *first* (14), *first one* (10), *number one* (4), *third* (3), *number three* (2), *number two* (2), *first thing* (2), *second row* (2).