Developmental Changes in Spatial Semantic Categories in English

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1. Introduction

The natural partitions theory (Gentner & Boroditsky 2009) predicts that children find it easier to acquire referential concepts, such as concrete nouns (e.g., BALL, HAND) compared to relational concepts, such as verbs and prepositions (e.g., HOLD, KICK, ABOVE). According to Gentner & Boroditsky (2009), the learning advantage for referential concepts arises because of the “greater perceptual learnability of [noun] referents in children’s early experience” (Gentner & Boroditsky, 2009: p. 5). That is, concrete nouns denote particular entities that can be individuated from a set of objects in the world. Relational concepts denote relationships between or amongst entities and are not “out there” in the world to point to. Several studies from different languages demonstrate support for this hypothesis (Gentner, 1982; Tardif, Gelman, & Xu, 1999; Au et al., 1994; Caselli et al. 1995) although the salience and frequency of verbs in the input language also play a role in influencing children’s preference for nouns versus verbs (e.g. Tardif, 1996; Gopnik & Choi, 1990).

Here we ask: what is the role of the referential-relational asymmetry in later semantic development? Does children’s early difficulty in inferring relational meaning extend to later lexical development, as children learn to extend newly learned words to the appropriate category of referents? If children initially have a tenuous grasp of multifaceted verb meaning, they might find it difficult to identify, or appropriately weight, the semantic features that condition verb extension patterns in adult language. Prior research suggests that children’s verb categories show little convergence with adult categories (Saji et al., 2011) whereas children’s noun categories converge with those of adults to a relatively greater degree (Ameel et al., 2008). The study by Ameel et al. of Dutch nouns for containers reveals a modest correlation between naming patterns in children and adults for bottles (r=.56 for 5-year-olds; r=.68 for 8-year-olds) with a higher correlation for dishes (r=.72 for 5-year-olds; r=.82 for 6-year-olds; r=.8 for 8-year-olds)

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Although differences in the types of stimuli used in the studies preclude direct comparisons between them, children’s verb categorization patterns appear to converge with adult patterns even more gradually than nouns. Thus, in comparison with the correlations reported for nouns (Ameel et al., 2008), a study of ‘carrying and holding’ verbs in Mandarin-speaking children reveals relatively lower correlations between naming patterns in children versus adults ($r = .43$ for 5-year-olds; $r = .58$ for 7-year-olds) and also exhibits considerable individual variation (Saji et al., 2011; see also Pye, Loeb, & Pao, 1996).

Spatial prepositions (e.g., *in*, *on*, *above*, etc.) differ from verbs in being closed class items with high input frequency. They also encode core spatial concepts such as containment, tight-fit, and support to which children exhibit sensitivity at an early age (Bowerman & Choi 2003; Hespos & Spelke 2004; Casasola & Cohen, 2002). However, early preposition use does not entail adult-like meanings and extensions. Prepositions are highly polysemous, which may cause children difficulties in identifying the appropriate extensions for even the concrete meanings. For instance, children take longer to master the uses of prepositions for atypical spatial relationships versus typical ones (Meints et al. 2002). Prepositions such as *on*, that encode different subtypes of support, pose a more complex learning challenge for children than prepositions such as *in*, whose internal structure is relatively homogenous (Landau et al., 2016). Further, prepositional categories that do not conform to typologically prevalent systems—e.g., the Dutch prepositions of contact and support (*op*, *aan*, and *om*)—may be acquired relatively late (Gentner & Bowerman, 2009). Although the literature on spatial semantics is rich and extensive, we do not know how the extensions of different spatial prepositions develop as interconnected network. For instance, how are the categories of prepositions encoding containment and support restructured over time? How do they develop in tandem with prepositions encoding notions such as proximity (e.g., *next to*), superadjacency (e.g., *above*), encirclement (*around*), and subjacency (e.g., *under*)? This paper explores the developmental trajectory of children’s use of high frequency spatial prepositions and seeks to determine how early those spatial preposition categories converge with those of adults.

2. Methods

2.1. Participants

A total of 76 participants took part in the study, and were divided into three age groups: ‘4-year-olds’ ($n = 24$, mean age $= 4.6$; range: 3;2-5;4 ), ‘7-year-olds’ ($n = 28$, mean age $= 7;11$; range: 6;3-9;11 ), and adults ($n = 24$). The children were monolingual speakers of English and the adults were primarily monolingual with little exposure to other languages. The children were recruited in the city of Boulder and surrounding areas in Colorado, and the adults consisted of undergraduate students recruited from the University of Colorado Boulder.
2.2. Stimuli and procedure

Participants were instructed to tell a near-blind mouse character “Mousie” where objects were in relation to other objects. They were shown a total of 71 scenes depicting spatial relations (Figures 1a. APPLE IN BOWL, 1b. CUP ON TABLE) from the Topological Relations Picture Series (Bowerman & Pederson, 1992). To ensure that participants understood the task, they were given three warm-up scenes. The 71 scenes were split into 10 blocks and after each block, they were rewarded with stickers. They were first presented with the ground element (“Here’s a Y”) followed by the figure element (“Here’s a X”) and then asked, “where is the X-figure?” to elicit the “basic locative construction” “X is PREP Y” (Levinson & Wilkins, 2006).

![apple in bowl](image1)
![cup on table](image2)

Figure 1: a. APPLE IN BOWL; b. CUP ON TABLE

All the participants were audio- and video-recorded and their responses were transcribed using ELAN (Sloetjes & Wittenburg, 2008). Each preposition was coded as its own category; however, semantically similar categories were collapsed (e.g. on the top of was categorized as ON TOP OF). Preposition use for each scene was tabulated across all participants and across age groups. The procedure outlined in Ameel et al. (2008) was followed in order to compare children and adults’ naming patterns of the 71 scenes. Scene-by-preposition matrices were constructed for each age group and correlations were calculated for row vector pairs, reflecting pairwise similarity of spatial relations based on labeling patterns. Second-order correlations were calculated between the first-order correlation matrices, representing naming similarities between groups. In addition, the difference between age groups was analyzed with Analysis of Similarity (ANOSIM) using the anosim function of the vegan package in R (version 3.3.2). In order to obtain visual representations of how the 71 scenes were grouped by participants of different ages, dissimilarity matrices were constructed based on the scene-by-preposition matrices constructed for each age group. We then used the cmdscale function in R (version 3.3.2) to obtain MDS (multidimensional scaling) solutions from the dissimilarity matrices, and the ggplot function in the ggrepel package to generate plots showing the pattern of proximities for each age group.

3. Results

The correlational analyses showed a high level of convergence between the categorization patterns of children and adults (4-year-olds and adults: r=0.85; 7-year-olds and adults: r=0.91) and between the two child age groups (r=0.96). Despite these high levels of convergence across groups, the ANOSIM (analysis
of similarity) test revealed significant differences between the age groups. Adults differed significantly from both the 7-year-olds (R = 0.03, P < 0.05, 999 permutations) as well as the 4-year-olds (R = 0.03, P < 0.01, 999 permutations). The two child age groups also differed from each other in their categorization patterns (R = 0.07, P < 0.01, 999 permutations). The relatively low R values in the ANOSIM analyses suggest that the age differences are modest, supporting the high naming correlations we found between the age groups.

In order to explore the pattern of similarities as well as differences across age groups we conducted qualitative analyses of patterns of preposition use based on visual inspection of the MDS plots for each age group (see Figures 2, 4, and 8). In the MDS plots, scenes that are close to each other in space are enclosed using a dashed line. The labels next to each grouping of scenes represent the most frequent preposition(s) used to label those scenes. We identified the most frequent preposition used for a scene by assigning a ranking from most frequent to least frequent (lowest rank). A frequency ranking obscures the fact that the highest ranked preposition may differ from the second-highest preposition by a single use in some cases, or by a much higher magnitude in other cases. However, a simple ranking system enables us to identify overall patterns in the data that a more fine-grained system might obscure. In some cases, a particular preposition may be associated with more than one cluster. For instance, in the plot for each age group, there is a small number of scenes labeled in, on that occur at an intermediate location between the clusters of scenes most frequently labeled with in (top right part of the plots) and on (upper-left part of the plots). These in, on clusters occupy an intermediate position, in part because they consist of scenes that are (a) labeled equally frequently with in and with on, or (b) labeled most frequently with one of the two prepositions, but also described quite frequently with the other preposition. Conversely, a particular cluster of spatially contiguous scenes on the plot may be associated with more than one preposition. For instance, scenes most frequently labeled by behind, next to, and in front of occur within the same cluster for all three age groups.

Children and adults differ little in the number of preposition types they use: 4-year-olds and adults produced 26 different types of prepositions, while 7-year-olds produced 27 types. However, the scenes to which the prepositions are most frequently applied changes over time. Figure 2 shows the preposition patterns for the ‘four-year-olds.’ Along the x-axis in the plot, we see a large cluster of scenes, most frequently labeled by the preposition on, that is spatially separated from the remaining scenes. Along the y-axis, scenes most frequently labeled with in are maximally separated from subadjacency scenes labeled most frequently with the preposition under, as well as scenes encoding contiguity and projective notions labeled with behind, next to, and in front of. Scenes depicting superadjacency such as (47) ‘LAMP ABOVE TABLE’ (fig. 3b) and (23) ‘CLOUD ABOVE MOUNTAIN’; (fig. 3c) are most frequently labeled by on top of (and less frequently with prepositions such as on and over). Scenes encoding contact with gravitational support ‘HOSE ON TOP OF STUMP’ (Scene 43) (fig. 3a) are also labeled by the (complex) preposition on top of, but the preferred preposition is on.
Figure 2: Preposition labeling of scenes for the 4-year-olds

Figure 3:  a. HOSE ON TOP OF STUMP; b. LAMP ABOVE TABLE; c. CLOUD ABOVE MOUNTAIN

Figure 4 shows the preposition patterns for the 7-year-olds. Children at this age have nearly the same main groupings of scenes as the 4-year-olds, however these scenes are more tightly organized into distinct clusters. Scenes encoding containment, support, and subadjacency are more consistently encoded with high frequency prepositions such as in, on, and under in this age group. For example, (see Fig. 5a-b) the scenes (63) ‘SPOON UNDER CLOTH’ and (36) ‘GUM UNDER TABLE’ were more consistently labeled with the preposition under and moved towards the under cluster compared to the 4-year-olds. Certain scenes (fig. 5c-d), such as (41) ‘HOSE AROUND STUMP’ and (32) ‘FENCE AROUND HOUSE,’ were most frequently labeled with around by 4-year-olds, but they also used on or in. The seven-year-olds more consistently labeled these scenes using around.
There are also shifts in relative preference in choice of labels in the 7-year-olds. For instance, there is an increased preference for *in* versus *on* for some scenes (see Fig. 6a-d). Scenes (13) ‘Boat On Water’ and (25) ‘Cork In Bottle,’ which used to be labeled most frequently with *on* (and less frequently with *on top of*) in the 4-year-old age group are now beginning to be labeled more frequently with *in* as seen in their movement in the direction of the intermediate *in, on* cluster. Scene (35) ‘Foot In Shoe’ and (6) ‘Arrow Through Apple’, which 4-year-olds labeled with *on* as well as *in*, are beginning to be labeled more often with *in*; so they have moved closer to the cluster of scenes most frequently labeled by *in*. 
Other shifts in preference involve an increase in the use of prepositions such as *above*, *through*, and *inside*. Whereas 4-year-olds most frequently labeled (47) ‘LAMP ABOVE TABLE’ (Fig. 7a) and (23) ‘CLOUD ABOVE MOUNTAIN’ (Fig. 7b) using *on top of*, 7-year-olds more frequently labeled these superadjacency scenes with *above*. Additionally, although the core set of scenes most frequently labeled by *in* does not change from 4 years to 7 years, we see an increased preference for other prepositions in the 7-year-olds. Scene (6) ‘ARROW THROUGH APPLE’ (Fig. 7c) is labeled more often using *through* (as well as *in*), and scenes (29) ‘DOG INSIDE KENNEL’ (Fig. 7d) and (69) ‘TREE INSIDE FENCE’ (Fig. 7e) are more frequently labeled using *inside*.

Figure 7: a. LAMP ABOVE TABLE; b. CLOUD ABOVE MOUNTAIN; c. ARROW THROUGH APPLE; d. DOG INSIDE KENNEL; e. TREE INSIDE FENCE

Figure 8 shows the adults’ categories. The adult clusters resemble those of the children in having three main clusters labeled most frequently by *in*, *on*, and *under*, as well as smaller clusters corresponding to scenes labeled most frequently by prepositions such as *behind*, *in front of*, *above*, *around*, *next to*, and *outside*. We also see, in the adult plot, the pattern of migration of scenes from the *on* cluster in the direction of the *in* cluster that we noticed in the 7-year-olds: scenes (31) ‘EARRING IN EAR’ (Fig. 9a) and (5) ‘APPLES IN TREE,’ (Fig. 9b) which used to be labeled most frequently with *on* by 4-year-olds and 7-year-old are now beginning to be labeled more often with *in* (and *through* for Scene 31).
However, in contrast to the greater consolidation of scenes seen in the 7-year-olds, the adult categories reveal relatively greater fractionation into a number of smaller clusters. This picture appears to be similar to the plot for the 4-year-olds, but the resemblance is superficial as the internal organization of the categories in adults differs from that of the 4-year-olds in a number of ways. Several scenes that belonged to the on cluster in the child age groups are now labeled most frequently by other prepositions including:

- **on top of** scenes (27) ‘CUP ON TOP OF TABLE,’ (fig. 10a) (43) ‘HOSE ON TOP OF STUMP,’ (66) ‘TABLECLOTH ON TOP OF TABLE,’ (71) ‘TREE ON TOP OF MOUNTAIN’ (fig. 10b);
- **against** scene 45 ‘LADDER AGAINST WALL’ (fig. 10c);
• **around**: scenes (10) ‘BANDANNA AROUND HEAD,’ (12) ‘BELT AROUND WOMAN,’ (fig. 10d) (52) ‘NECKLACE AROUND NECK,’ (60) ‘RIBBON AROUND CANDLE’ (fig. 10e).

Two scenes have broken off from the *in* cluster: scene (6) ‘ARROW THROUGH APPLE’ is labeled most frequently using *through* and scene (69) ‘TREE INSIDE FENCE’ (fig. 10f) is labeled most frequently using *inside*. Although it is not a high-frequency pattern, it is interesting to note that adults use more verbs than either age group, either in isolation or in conjunction with prepositions such as *to* or *from* (cf. Landau et al., 2016). Verbs used in isolation include *surrounding* for scene (15) ‘FENCE AROUND HOUSE,’ (fig. 10g) and *piercing* for scene (30) ‘ARROW THROUGH APPLE’ (fig. 10h) Verb-preposition usages include *hanging on* or *hanging from* for scenes such as (63) ‘LAMP ON CEILING,’ (45) ‘APPLES ON TREE,’ (45) ‘APPLE ON TWIG,’ (fig. 10i) etc. and *tied to* and *tied around* for scene (20) ‘BALLOON ON STICK’ (fig. 10j).

![Figure 10: a. CUP ON TOP OF TABLE; b. TREE ON TOP OF MOUNTAIN; c. LADDER AGAINST WALL; d. BELT AROUND WOMAN; e. RIBBON AROUND CANDLE; f. TREE INSIDE FENCE; g. FENCE AROUND HOUSE; h. ARROW THROUGH APPLE; i. APPLE ON TWIG; j. BALLOON ON STICK](image)

In summary, all three age groups are similar in having distinct *in*, *on*, and *under* clusters, as well as a number of smaller clusters of scenes depicting spatial notions such as superadjacency, subadjacency, contiguity, encirclement, and projective relations. The main change from 4 years to 7 years involves consolidation of isolated (sets of) scenes into more tightly organized clusters that are more consistently labeled by individual prepositions or involve overlapping uses by multiple prepositions. There is also movement of scenes out of the *on* cluster into the *in* cluster and an increasing preference for prepositions other than *in* within the cluster of scenes most frequently labeled by *in*. From the age of 7 years to adults, we again see a shift in preference from *on* to *in* for some scenes. A number of new clusters have formed by breaking off from the *on* cluster as well as the *in* cluster, giving rise to a more differentiated partitioning of semantic space. These new clusters include scenes that previously involved overlapping uses or two or more prepositions in 7-year-olds (e.g., *on* and *on top of; in* and *through*); by adulthood, one of these prepositions has ‘won’ the competition and become the preferred label for a particular scene.
4. Discussion and conclusions

Children’s preposition categories converge with adult-like categories at an early age. There could be a number of reasons for this precocious achievement. Children show early sensitivity to concepts of containment, support, tight-fit, etc., that are central to the spatial meanings of a number of prepositions. Children are also highly attuned to the frequency of preposition use across situations. In our data, the scenes to which the prepositions are most frequently applied tend to be similar across age groups. Static spatial relationships between objects persist over time; they can be pointed to and labeled (unlike dynamic actions typically labeled using verbs). Thus any early difficulties that children experience in inferring relational meaning does not appear to extend to the later semantic development of relational words. Children’s networks of spatial semantic meanings are similar to those of adults, as gauged by the extension patterns of spatial prepositions.

But children’s preposition use is not identical to that of adults—we also find evidence of semantic reorganization in children’s spatial meanings. In general, the on category is most likely to be overextended by children. Over time there is increasing competition between on and more specific prepositions for some scenes, e.g., around, on top of, against. This competition typically gets resolved in favor of the more specific preposition. A similar pattern is also seen for the in category, although to a lesser degree. For certain scenes, there is also competition between in and on, which is eventually resolved in favor of in. Over time, we also see some reorganization of scenes encoding contiguity, projective notions, superadjacency, and encirclement. In contrast, membership of subadjacency scenes in the under category appears to be relatively stable across the age groups.

The developmental changes we have observed in our data could arise due to a number of different reasons. First, children and adults may differ in which aspects of a scene they find salient, e.g. children may select in versus through for ‘ARROW THROUGH STICK’ since the containment of the arrow within the apple captures their attention, whereas adults attend more to the extension of the stick from either side of the apple. Adults are also more likely to use lexical verbs than children, e.g., hanging (from) for scene (46) ‘LAMP ON CEILING’, to highlight aspects of the scene such as the attachment of figure to ground (see also Landau et al., 2016). Second, frequent or conventional ways of describing certain spatial relationships may lead to more figure-ground reversals in children than in adults (e.g., describing ‘FOOT IN SHOE’ as shoe on foot). Third, adults may seek to provide explicit spatial contrasts using specific prepositions for pragmatic reasons (cf. see footnote 6 in Gentner & Bowerman, 2009; see also Levinson et al., 2003). Fourth, children may be less familiar with a preposition that adults are likely to use (e.g., against to describe ‘LADDER AGAINST WALL’) or might not yet have acquired the (relative weighting of) the semantic features that influence adult use of prepositions (e.g., on top of is typically used by adults for scenes involving contact, whereas 4-year-olds use on top of for scenes involving superadjacency without contact, e.g., ‘CLOUD ABOVE MOUNTAIN’). If factors such as perceptual salience and selective attention, frequency, or pragmatics influence extension
patterns, one might argue that children already have adult-like sensitivity to the relevant dimensions of spatial meaning at an early age; what develops over time is sensitivity to additional factors that influence preposition use in adult language. To the extent that one is able to separate meaning from the processing or communicative factors that also influence children’s extension patterns, this point is valid. However these factors are closely intertwined and not easily disentangled. Developmental changes in selective attention, greater exposure to frequent patterns in the input over time, and increasing sensitivity to pragmatic factors may themselves serve to trigger a reweighting of the semantic features of a word with concomitant changes in its extensional patterns. Our study has provided a first glimpse of the shifting patterns of change in an interconnected network of spatial meanings in children who have already been using spatial prepositions for several years. Further research with children at different ages and with a greater range of stimuli may shed more light on the causes of the developmental patterns reported here.

References


