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The importance of lexical verbs in the acquisition of spatial prepositions: The case of *in* and *on*

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ABSTRACT

The prepositions *in* and *on* appear early in children's descriptions of simple containment and support relations, such as "apple in the bowl" and "cup on the table". However, mature use of these basic terms extends across a very broad range of object configurations, raising the question of whether children and adults share the same underlying semantic space, and if so, how children's use of *in* and *on* comes to match that of adults. With a new battery containing diverse object configurations, we asked how 4 and 6 year-olds and adults distribute basic spatial expressions (*isin, is on*) and lexical verbs (*hang, attach,* etc.) across subtypes of containment and support. Our results reveal probabilistic distributions of *in* and *on* in both adult and child language, with similar distributions among adults and children for *in* but different patterns for *on*. Moreover, we find substantial differences in the use of lexical verbs across the two spatial domains and across ages. We propose that children and adults share a structured semantic space for both containment and support relations, but larger portions of this space are described by *in* and *on* early in development because alternative descriptions employing lexical verbs are inhibited. Using computational modeling along with experimental data, we link developmental changes in the scope of basic spatial expressions to increasing use of lexical verbs in parts of the space that reflect less central relations of containment or support. This result supports a nuanced view of spatial language acquisition that shifts the focus from how children learn basic expressions to how they learn to distribute expressions of varying content and complexity across the semantic space.

1. Introduction

It has often been noted that all languages encode objects and their spatial relationships. Many languages have a limited set of closed-class terms dedicated to expressing these relationships (Landau & Jackendoff, 1993; Levinson & Wilkins, 2006; Talmy, 1985); in English, these include prepositions such as *in*, *on*, *above*, *under*, etc. Terms *in* and *on* appear in children's vocabulary quite early in development and have traditionally been assumed to map onto pre-linguistic concepts of containment and support (Clark, 1973, 1975; Johnston & Slobin, 1979). More recently, however, cross-linguistic studies have pointed to significant variability in the range of relations that are encoded by *in*/*on* and their counterparts in other languages (Bowerman & Pederson, 1992; Pederson et al., 1998), leading some to suggest that there may be no 'core' concepts underlying these terms (Levinson & Wilkins, 2006; Levinson, 2003). Moreover, developmental studies have shown that acquisition of these terms is far from complete by age 3 (Gentner & Bowerman, 2009), reinforcing the idea that the underlying semantic space may be far more complex than previously thought and suggesting that this space is organized by the meaning of language-specific lexical items rather than by pre-linguistic distinctions.

In this paper, we present a new approach to understanding the representation and acquisition of *in* and *on*. Departing from previous approaches, we track children's and adults' use of these and other terms across a quite broad range of object configurations. The relative frequencies of basic spatial expressions and lexical verbs across the configurations are shown to have systematic patterns across the age groups, a finding that is consistent with a structured and developmentally stable conceptual space. What might appear to be a conceptual reorganization can instead be attributed to the increasing accessibility of lexical verbs, which gradually supplant the basic spatial prepositions when the latter fail to express important semantic distinctions. The result is a novel approach to the development of spatial language, in which the probabilistic distribution of prepositions and lexical verbs reflects both a core conceptual organization for spatial configurations

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and growth of the lexicon available to describe such configurations.

2. Background

The acquisition of the terms *in* and *on* has long been of interest to researchers because of their acknowledged centrality to the representation of objects and their spatial relationships. As noted earlier, much of the literature has assumed that early acquisition of these terms is rooted in pre-linguistic understanding of the concepts 'containment' and 'support' (Bowerman, 1996; Casasola, 2005, 2008; Clark, 1973; Johnston & Slobin, 1979; *inter alia*). On this view, these concepts would support the ability to map the words *in* and *on* to configurations where physical containment and support are readily understood—e.g., apples in bowls and cups on tables (Hespos & Baillargeon, 2001; Hespos & Spelke, 2004, 2007; Needham & Baillargeon, 1993).

Despite the putative centrality of these configurations, however, *in* and *on* cover a surprisingly broad semantic terrain: *in* can be used to encode the relationship "apple in a bowl" or "marbles in a box", but also "hole in a sock" and "plug in a socket"—instances that do not obviously instantiate the core sense of 'containment'. Similarly, *on* can be used to encode the relationship of "cup on a table" or "book on a desk" but can also be used to express the relationship of "stamp on envelope" and "pendant on neck"—again, not obviously central embodiments of 'support'. Many scholars have noted such breadth of usage, which has made it notoriously difficult to define the meanings of prepositions considered in isolation (e.g., Bennett, 1975; Feist, 2000; Herskovits, 1986; Regier, 1995).

These broad usage patterns present two significant questions. The first concerns the conceptual and semantic terrain occupied by *in* and *on*. Are there any 'core' distinctions underlying children's and adults' use of these prepositions? Although classical theories of spatial term acquisition assume this, cross-linguistic studies of spatial language have emphasized that there is considerable variation in the mapping between basic spatial terms and sets of spatial configurations, leading some to question whether such universal cores exist at all (Bowerman & Choi, 2001, 2003; Khetarpal, Majid, & Regier, 2009; Levinson & Wilkins, 2006). However, it is entirely possible that spatial cores exist within broad classes of spatial relationships (e.g. containment, support), and that the variation observed across languages pertain largely to non-core relationships within those classes. It is also possible that the degree of variation observed for non-core relationships varies over different classes of relationships.

The most pertinent study comes from Gentner and Bowerman (2009), who tested 2–6 year-olds learning English or Dutch on their mastery of terms encoding containment and support. Children in both language groups mastered *in* rather early, extending it to eight different containment scenes (e.g., "cookie in bowl", "candle in bottle"). This suggests that there may be a core notion of containment underlying uses of English *in* and its equivalent in Dutch. The class of support relationships appeared to show more variability. Children learning English also applied *on* across a broad range of support types including support from below (e.g., cookie on plate), hanging (e.g., clothes on a line), and encirclement (e.g., necklace on a neck). Children learning Dutch also mastered cases of support from below quite early (encoded by *op* in Dutch) but lagged behind for other terms encoding different kinds of support (e.g., *aan* for "clothes on a line", *om* for encirclement). This finding suggests that there may also be a core for support (support from below, mastered early by both groups) but also that the non-core relationships (other than support from below) may interact with the available lexicon differently across languages.

The second question concerns the mapping between this conceptual/semantic space and linguistic expressions other than basic prepositions. If there are core instances within each domain, contrasted with more marginal configurations, it could be that this structure is reflected in the distribution of lexical verbs that encode aspects of containment and support. Although the basic locative expression—the closed class spatial term used alone or with a light verb, the copula (e.g., *be in/on* for English, Gentner & Bowerman, 2009; Levinson & Wilkins, 2006)—may be used primarily for central configurations, a large, open class of lexical verbs exists to block the use of *X is in/on Y* for other configurations. For example, if shown a coat on a hook, speakers might describe the configuration with *on*, but it is also possible that they could block the preposition with a different, richer expression, e.g., "the coat is hanging on a hook".

To date, studies of *in* and *on* and their equivalents in other languages have typically reported the use of the basic locative expression. These studies have reported either proportions of use of these expressions across spatial relation scenes, or modal adult use of the basic locative expression (Levinson & Wilkins, 2006), limiting the degree to which we can assess and generalize the relative roles of spatial prepositions and lexical verbs in describing these scenes. In particular, such analyses limit our ability to determine whether there is a core set of configurations that closely maps to the basic use of *in* and *on* (i.e., *is in/on* in English, following Levinson & Wilkins, 2006) and whether for configurations lying further from the *in/on* core, lexical verbs are used. In the current studies, we move beyond modal basic expression use to examine fine-grained use of both basic preposition-based expressions as well as lexical verb expressions. Our approach builds on typological observations from a number of semantic domains (see Bresnan, Dingare, & Manning, 2001; Coventry, Griffiths, & Hamilton, 2014; Givón, 1979) in which a categorical distinction in one language "is mirrored by a frequency-based distinction in other languages" (Bresnan & Aissen, 2002, p.88). In this way, we propose that meaningful conceptual distinctions among spatial relations are reflected in the relatively frequency with which adults and children use different expressions to encode them.

Our approach addresses these questions by a using a novel battery of items for containment and support and analyzing adults' and children's use of basic spatial prepositions and lexical verbs as they describe where things are. Following previous work on spatial language development (Gentner & Bowerman, 2009; Johannes, Wilson, & Landau, 2012; Landau, Johannes, Skordos, & Papafragou, 2016), we chose to measure spatial descriptions from 4- and 6-year-old children. Children in these age groups make for interesting comparisons to adult language: they are able to felicitously describe a large sample of spatial scenes, but their descriptions do not always align with those of adult speakers. Our battery was structured after one developed for cross-linguistic studies of spatial language in English and Greek (Landau et al., 2016). We provide an overview here, with details in the Methods section. The logic of the battery was to provide participants with a wide range of object configurations that ranged from those that are intuitively the most central to the category to those that are considerably more marginal. For example, the containment battery included configurations showing an apple in a bowl and a hole in a sock; the support battery included configurations showing a cup on a table and a necklace on a neck. The range of configurations was structured as a set of subtypes suggested by existing batteries (e.g., Bowerman & Pederson, 1992) as well as the larger literature, which has suggested distinctions such as tight/loose fit within containment (e.g., Bowerman & Choi, 2003). Each of the subtypes was based on contrasts noted in pre-linguistic and cross-linguistic work on spatial categorization as well as theoretical accounts of spatial meaning. For containment, we hypothesized four core subtypes, each representing rather conventional types of containment. We contrasted degree of containment (full vs. partial), and degree of fit (loose-fitting vs. tight-fitting), yielding full, loose containment of one object by another (e.g., an apple in a bowl), followed by partial, loose containment, full, tight containment, and partial, tight containment. Finally, we included two non-conventional subtypes, which contrasted with the core cases due to either the exceptional nature of the 'figure objects' (e.g., holes, cracks, and rips), or the functional nature of the object relationship (e.g., plugs in electrical outlets; light bulbs in sockets). For support, the hypothesized core subtype was support from below, e.g., "a cup on a table" (as in Gentner & Bowerman, 2009) and the remaining subtypes varied the precise mechanism of support, including adhesion, hanging, attachment at a single point, or embedding within a surface (following Bowerman & Pederson, 1992).

Using this battery of 11 subtypes (each with multiple examples), we aimed to examine how children and adults distribute the basic locative expression (*is in/on*) across the wide range of instances of containment and support, and how specific lexical verbs block use the basic terms for some configurations but not others. We therefore address both the representation and mapping problems by expanding the spatial language inventory beyond prepositions to include a small class of lexical verb expressions (e.g., *insert, hang from, connect to, stick on*) that encode mechanical and relational information about object configurations that are naturally encoded by English *in* and *on*. We propose that, far from complicating the space-language mapping, examining a language inventory that packages spatial information in both preposition-based and verb-based expressions lends key insights into the organization of the conceptual space underlying spatial language use. Moreover, considering the role of lexical verb expressions in the development of spatial language, rather than obscuring the learning problem, sheds light on the fine-grained developmental trajectory of early acquired prepositions like *in* and *on*. We argue that over the course of development, increasing the use of lexical verbs for specific spatial relations gradually shapes the usage profiles for preposition-based expressions (e.g., *is in/on*) into those of adults.

3. Experiment 1

3.1. Participants

Twelve adults ages 18–22 years (mean age 19.8 years) and 12 typically developing 4-year-olds (mean = 4;5, range = 4;2–4;10) participated in the study. Adults were undergraduate students at Johns Hopkins University participating for course credit; children were recruited from the Baltimore community. Two additional 4-year-olds did not complete the experiment due to failure to follow task instructions.

3.2. Materials and design

The battery consisted of 33 static images of spatial scenes showing one object (designated by an arrow as the figure object), in some spatial configuration with another object (designated as the ground object circled in white; see Fig. 1 for example and Table A1 for descriptions of all 33 items). Each participant described all 33 items, which were presented in a different random order for each adult and child participant, with the constraint that consecutive items did not belong to the same subtype.

3.3. Spatial battery

There was one battery for containment relations and one for support, each divided into several subtypes; there were three distinct items for each subtype. The subtypes and their items represented a collection sampled from theoretical and experimental studies of spatial language that have been studied in the context of both the acquisition of English and other languages (Bowerman & Choi, 2001; Bowerman & Pederson, 1992; Feist, 2000; Herskovits, 1986; Landau & Jackendoff, 1993; Levinson, Meira, et al., 2003; Vandeloise, 2010; *inter alia*).

Fig. 1. Sample battery item presented to participants. The red arrow indicates the figure object in the scene, and the white line outlines the ground object. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The containment battery consisted of 6 subtypes, each represented by three different items (Fig. 2a). The first subtype represented Full, Loose containment of one object by another (e.g., an apple in a bowl). Three additional subtypes included Partial Loose, Full Tight, and Full Loose containment, which collectively were hypothesized to be part of a 'core' or central type of the containment category. The last two subtypes represented non-core containment relations: Interlocking relations, which featured a figure object in a specific functional relationship with the ground object (e.g., a light bulb screwed into a socket), and Embedded containment relations, in which the figure 'object' was a negative space such as a hole or crack. Our analyses compared each of the first four subtypes to each other, and the entire group of 'core' subtypes to the remaining two.

The support battery consisted of 5 subtypes, each represented by three items (Fig. 2b). The first subtype represented Gravitational support (i.e., support from below) and was hypothesized to be the 'core' subtype for the support category. The other four subtypes represented support by other mechanical means, including one object Embedded on another (e.g., a tattoo on a hand), supported via Adhesion (e.g., a sticker stuck to a book), Hanging (e.g., a mug hanging on a stand), and Point-attachment (e.g., a flag attached to a pole). Our analyses compared the first Gravitational subtype to all others, and each of the other four to one another. For both batteries, our question was how the relative frequencies of the preposition *in* or *on* in its basic locative form (i.e., *is in/on*), and of alternative expressions involving lexical verbs, would vary across the subtypes.

3.4. Procedure

Participants were given 3 practice trials followed by 33 self-paced spatial description trials, presented to adults on a computer

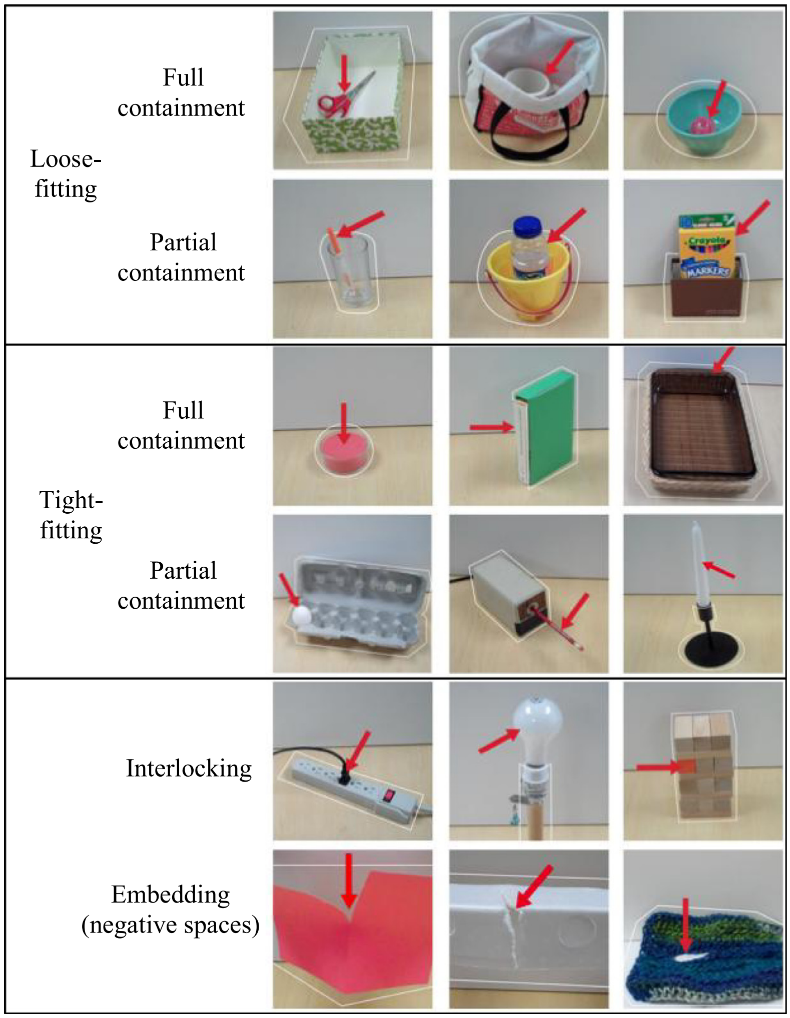

Fig. 2a. Containment battery with six subtypes and items.

and to children by an experimenter who progressed through the trials as children responded. Adults were asked to type into the computer a complete sentence answer to the question "Where is the (object pointed to by the arrow)?" in space provided below the image. Children were asked to label the figure and ground objects in the scene, to ensure that they knew which objects were intended to serve in the two roles. Children's object labels were largely consistent with those provided by adults. Once they labeled each object, children were asked the question "Where is the [figure object]?" using the label they provided for the figure object in the scene. Children received a small sticker after each completed trial and their responses were video recorded for later transcription.

3.5. Coding

Descriptions were coded to identify references to the Figure and Ground objects and the presence of prepositions and verbs, as in examples (1) and (2). Agreement between two independent coders on one-quarter of the adult descriptions was 100%, and 96% for one-quarter of the child corpus. Prepositions and lexical verbs served as the main data for subsequent analysis.

(1) [The scissors]$_{\text{Figure}}$ [are]$_{\text{Verb}}$ [in]$_{\text{Prep}}$ [the box]$_{\text{Ground}}$
(2) [The paper]$_{\text{Figure}}$ [is stuck]$_{\text{Verb}}$ [to]$_{\text{Prep}}$ [the book]$_{\text{Ground}}$

Most descriptions took one of two forms. Preposition-based expressions, illustrated in (1), were composed of a copular verb, which contributes little or no spatial content, and one of the spatial prepositions *in* (for descriptions of containment relations) or *on* (for descriptions of support relations). Lexical verb expressions, as in (2), were composed of a lexical verb, which encoded configurational (e.g., *sit*) or mechanical information (e.g., *stick, hang*), and a preposition, which varied according to the argument structure and subcategorization properties of the verb.

3.6. Results

We analyzed the numbers of basic spatial expressions (*is in/on)* and then the numbers of lexical verbs and their prepositional complements. These two types of expression accounted for 71.3% of the corpus for children (69.4% basic expressions) and 88.9% (51.3% basic expressions) for adults. Children's remaining descriptions included compositional prepositions such as "X is in the middle of Y" (21%), where the child effectively redefined the reference object as a region within the intended ground object, and use of other prepositions encoding proximity or relative axial position (e.g., *near/beside/above/under*; 4.1%) or relations other than that intended (for example by reversing figure and ground object roles in encoding; 3.6%). Adults' remaining descriptions also included compositional prepositions (7.3%), encoding of proximity or axial

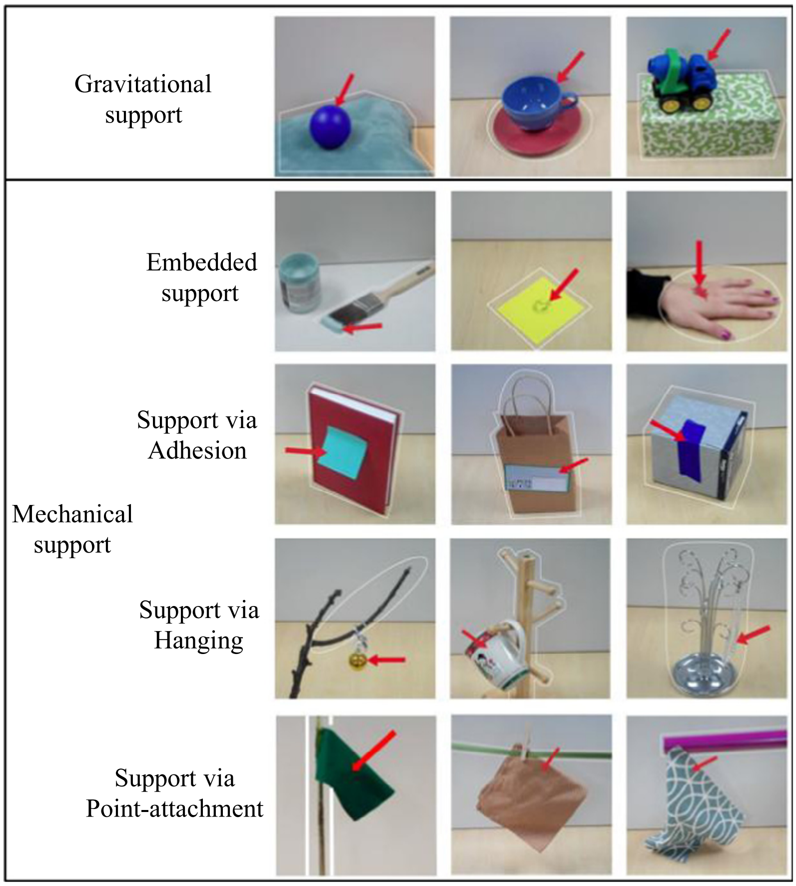

Fig. 2b. Support battery with five subtypes and items.

position (2.5%), and encoding of non-intended relations (1.3%). Figs. A1 and A2 show the distribution of these remaining expression types across subtypes of containment and support, respectively.

Critically, we did not analyze prepositions independently of the verb they accompanied. This is because our focus is on the prepositions in the basic (copular) frame (*is in/on*) compared to uses of lexical verbs, many of which select for a narrow set of prepositional complements. The complete list of lexical verbs and their frequency across subtypes is provided in Appendix A.

For each analysis, spatial descriptions were binary coded for whether or not they contained a designated expression (e.g., *is in/on* for containment and support, respectively). We entered these data into separate mixed-effects logistic regression models for the containment and support items (Jaeger, 2008). Models were fit using the MCMCglmm package for R (Hadfield, 2010) and had the following fixed and random structures: Subtype of spatial relation and Age were treated as fixed effects; the models included random intercepts for Subject and Item, and random Subtype effect slopes for Subjects.

Starting with a minimal model containing an intercept only, nested model comparisons determined which fixed factors were significant predictors (e.g., Quené & van den Bergh, 2008). Coefficients reported below correspond to log-odds ratio of the outcome, given the values of the fixed-effect predictors.

3.7. Containment

Adults and 4 year-olds showed systematic variability in their use of *is in* across the containment subtypes, suggesting linguistic sensitivity to conceptual differences across these spatial relations (see Fig. 3a and b for proportions of use). Both groups used *is in* most frequently for Loose-fitting Full- and Partial-containment, followed by Tight-fitting Full and Partial containment relations. For Interlocking and Embedded relations, *is in* was used to describe fewer than half of the items by either adults or 4-year-olds.

Subtype fixed effects were determined by a set of orthogonal contrasts mapped to our hypothesized distinctions between core and non-core types.[1] One contrast compared Full- and Partial-containment (including both Loose and Tight fit) with Interlocking and Embedding. Another set of contrasts compared Full- vs. Partial-containment, Loose- vs. Tight-fit containment, and Interlocking vs. Embedding relations.

The model that best predicted patterns of *is in* usage included Subtype as a fixed effect, suggesting that use of this expression was responsive to the hypothesized differences among subtypes. Adults and children used *is in* at greater rates for Full and Partial containment relations (Loose/Tight fit) compared to Interlocking and Embedding relations ($\beta = 7.41$, 95% CI = [5.01, 9.73], $p < 0.001$) and, within Full and Partial containment, more for Loose-fitting than Tight-fitting relations ($\beta = 3.79$, 95% CI = [1.63, 6.36], $p < 0.01$). All other contrasts failed to reach significance. Age was not a significant predictor of *is in* use, nor was the interaction between Age and Subtype, indicating that adults and 4-year-olds did not differ in the production of this expression across the subtypes, which reliably reflected many of the hypothesized distinctions embodied in the design of the battery.

[1] Defining and interpreting the fixed effect coefficients using a set of orthogonal contrast weights did not change the overall fit of the model.

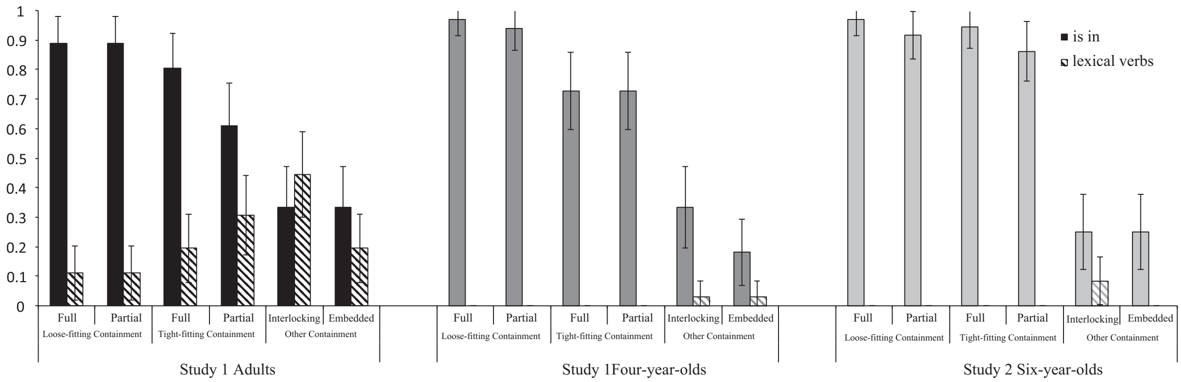

Fig. 3. Proportion of use of *is in* and lexical verb expressions across containment subtypes by (a) Adults (Experiment 1), (b) 4-year-olds (Experiment 1), and (c) 6-year-olds (Experiment 2).

Analysis of the lexical verbs revealed a complementary pattern for adults. After *is in,* lexical verbs were the most frequent type of expression produced by adults (23% of containment item descriptions) but were rarely used by 4-year-olds (4% of item descriptions). Adults' proportions of lexical verb expressions, and the specific verbs they chose, varied systematically across subtypes of containment relations (Tables A2 and A3). Posture verbs like *sit, stand,* and *lie* express information about the configuration of the figure object and were appeared exclusively in descriptions of Full- and Partial-containment relations. Spatio-temporal verbs such as *run* and *extend* were used most often to describe Embedding relations. De-nominal verbs like *plug* and *screw* described the spatial relationship between the figure and ground objects, primarily for Interlocking relations.

Lexical verb use was analyzed with the same statistical procedure above (with the binary dependent variable now coding the presence of a non-copular verb rather than of *is in*). Lexical verbs more appeared more often in descriptions of Interlocking and Embedding relations than of Full and Partial containment relations ($\beta = 7.83$, 95% CI = [5.17, 11.28], $p < 0.001$) and, within Full and Partial containment, they were used more for Tight-fitting than for Loose-fitting relations ($\beta = 6.54$, 95% CI = [4.62, 10.23], $p < 0.001$). Thus adults appear to distribute lexical verbs across subtypes in a complementary manner to their distribution of the basic locative expression *be in*. The distributions of both types of expression indicate that the Full and Partial containment subtypes have a different conceptual status from Embedding or Interlocking relations. Four-year-olds' data were not analyzed due to extremely infrequent use of lexical verbs.

3.8. Support

Adults and 4-year-olds displayed different patterns of *is on* use in their descriptions of the five subtypes of support (Fig. 4). In both groups, the rate of *is on* was highest for the Gravitational subtype. Adults showed reliable variation across the remaining subtypes with *is on* used most for Embedded support, followed by support via Adhesion, and least often for Hanging and Point-attachment. Four-year-olds, by contrast, used *is on* at high and approximately equal rates (69.75% of descriptions) for all four subtypes of Mechanical support.

The distribution of *is on* was analyzed with the same statistical method as for expressions of containment. The Subtype fixed effect was coded by a set of orthogonal contrasts mapped to our hypothesized distinctions between core and non-core types. Gravitational support (i.e., support from below) was first contrasted with all four Mechanical support subtypes. We then compared Embedded and Adhesion to Hanging and Point-attachment, and finally compared Embedded vs. Adhesion and Hanging vs. Point-attachment.

The best model included Subtype and Age, along with their interaction. Adults and 4-year-olds, together, used *is on* more often for Gravitational support compared to the other four subtypes ($\beta = 5.92$, 95% CI = [3.13, 8.45], $p < 0.001$). They also used *is on* more for Embedded and Adhesion compared to Hanging and Point-attachment ($\beta = 3.35$, 95% CI = [0.84, 6.08], $p < 0.01$). However, this effect was modulated by an interaction with Age: Adults showed the distinction between Embedded/Adhesion and Hanging/Point Attachment, but 4-year-olds' did not ($\beta = 3.38$, 95% CI = [1.79, 5.29], $p < 0.01$). Adults also further distinguished Embedded support from Adhesion, while 4-year-olds did not ($\beta = 1.14$, 95% CI = [0.01, 2.08], $p < 0.05$). Four-year-olds used *is on* at higher rates, overall, compared to adults ($\beta = -2.41$, 95% CI = [−4.05, −0.91], $p < 0.01$). Thus, adult descriptions revealed a highly articulated space of subtypes, while descriptions by 4-year-olds distinguished between Gravitational and other subtypes without further articulation.

Lexical verbs were produced frequently by adults (56% of support descriptions; Table A2), but again rarely by 4-year-olds (4%). Adults used lexical verbs encoding the posture or configuration of the figure object (*lie, sit, stand*) for Gravitational support only, and used verbs encoding a mechanical relation (*attach, hang*, *pin*, *stic*k, etc.) for the other subtypes. We analyzed the adult lexical verb data as we had for containment. Adults' use of lexical verbs over subtypes complemented their pattern for *is on*: Lexical verbs were used more for Mechanical support relations compared to Gravitational support ($\beta = -8.71$, 95% CI = [−13.70, −3.79], $p < 0.001$) and, within Mechanical support, were used more for Hanging and Point-attachment compared to Embedded and Adhesion ($\beta = -8.99$, 95% CI = [−13.69, −4.48], $p < 0.001$). All other contrasts failed to reach significance. Data from 4-year-olds were not analyzed due to infrequent use of lexical verbs.

3.9. Discussion

For both containment and support relations, production of the basic expressions *is in*/*on* varied systematically along our hypothesized lines of distinction between core and non-core subtypes. For containment, adults and children used *is in* more frequently for Full- and Partial-containment than for Interlocking and Embedding. They also chose it more for Full than Partial containment, and more for Interlocking than Embedding. Where *is in* was least frequent, lexical verbs appeared instead (principally by adults). For example, adults produced de-nominal verbs like *plug* and *screw* to encode Interlocking relations, and verbs like *rip, tear,* and *make* to encode Embedding relations. For support, adults and children

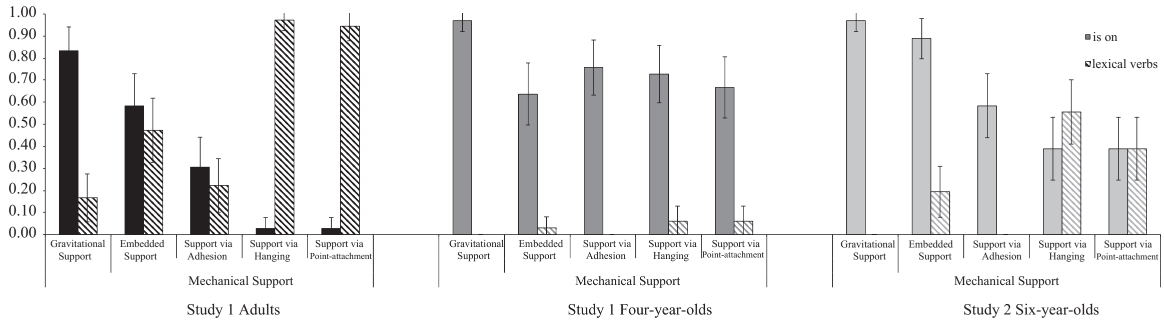

Fig. 4. Proportions of use of *is on* and lexical verb expressions across support subtypes by (a) Adults (Experiment 1), (b) 4-year-olds (Experiment 1), and (c) 6-year-olds (Experiment 2).

used *is on* most frequently for Gravitational cases (support from below). Adults further showed differential use of *is on* across the mechanical subtypes, but children did not. The adults' articulation of the underlying space was again revealed by their use and choice of lexical verbs: Where uses of *is on* declined, adults increasingly used lexical verbs that specified the mechanism of support (e.g., hanging, attaching, sticking, etc.). These verbs encode mechanical-relational information that differentiates among subtypes of Mechanical support relation (Embedded support, Adhesion, Hanging, and Point-attachment), rather than merely specifying the configuration of one object (e.g., *sit*, *stand*). The absence of these verbs in child spatial descriptions leads to striking developmental differences in the uses of the basic expression (*is on*) for support, but less so for containment (*is in*).[2]

The results suggest several important points. First, the distribution of basic spatial expressions *is in/on* appears to reflect an underlying semantic/ conceptual space in which certain subtypes of containment and support may be represented as more central examples of the category. Other examples may elicit the basic expression but do so in a more limited fashion, and importantly, are supplanted in some cases by lexical verbs when the basic locative expression is not as felicitous. Second, adults' and children's distributions of spatial expressions reflect similar sets of distinctions for containment, but this similarity diminishes for support, where children are willing to use *is on* quite broadly across subtypes and instances. This is reminiscent of Gentner and Bowerman's (2009) finding that children learning English use *on* for a broad set of configurations ranging from support from below ("cookie on plate") to encirclement ("necklace on neck"). It also mirrors findings from Landau et al. (2016), with a very similar battery. We explore possible reasons for these developmental differences below.

3.10. Further results

There are a number of possible reasons for the large differences between adults and 4-year-olds in their use of spatial expressions across subtypes, especially for support. A first possibility is that young children have assigned different meanings to the relevant expressions; e.g., children may have a much broader meaning for *is on* than adults, enabling them to use it across extremely diverse instances. This seems unlikely in light of the fact that the statistical analyses above found that both age groups used *is in* in a quite similar manner across subtypes, and they also used is *on* most often for gravitational support instances. A second possibility is that the 4-year-olds do not command the lexical verbs that adults used in their descriptions, and that it is this—and not a different underlying conceptual space—that drives use of the basic expression. As a first step, we addressed these possibilities by providing a separate group of 12 4-year-olds (mean age 4 year, 5 months, range 4;1–4;10) with felicitous lexical descriptions, via a forced-choice task, for the items in Experiment 1. For each item, we asked children to choose which of two expressions was "better" as a description of the location of an object in the scene. The critical forced-choice contrast was between descriptions with the appropriate basic locative expression (*is in/on* for containment and support, respectively) or an expression using a felicitous lexical verb, produced for that item by the adults in Experiment 1 (e.g., *is on* vs. *is stuck to*). We included three additional contrasts to ensure that children were not simply choosing the longer or more complex expression without regard to the felicity of the description. These control contrasts are outlined below along with children's choices across all trials:

(1) Contrast between *is in/on* and an infelicitous lexical verb (e.g., "The scissors are plugged into the box" for the scene in Fig. 1), for which children chose *is in/on* on 98% of trials.
(2) Contrast between felicitous and infelicitous lexical verbs, for which children chose the felicitous verb on 100% of trials.
(3) Contrast between *is in* and *is on* to establish that all children considered *is in* the basic locative expression for containment relations, and *is on* the basic locative expression for support. Children were also at ceiling for these pairs, choosing *is in* on 96% of containment items and *is on* for 98% of support items.

For the critical contrast between (felicitous) lexical verbs and the basic locative expression, children's choices of lexical verbs (vs. *is in/on*) for each of the 33 items varied across item and subtype (see Table A2 for mean proportions of lexical verb choice) and positively correlated with adults' use of lexical verbs in their descriptions of the same items ($r\ (31) = 0.60$, $p < 0.001$). Our analysis revealed an even stronger correlation for support items ($r\ (13) = 0.82$, $p < 0.001$), where adults used many lexical verbs, suggesting that the lack of lexical verbs in the 4-year-olds' descriptions was not due to meaning differences relative to adults or complete absence of the verbs in their vocabularies.

Another possibility, consistent with the preceding production findings and these additional forced-choice results, is that children have not developed the ability to block the use of *is in/on* when a lexical verb would be more appropriate. This would suggest that the growing acquisition and use of lexical verbs plays a role in shaping the profile of dedicated spatial expression (*is in/on*) use, with the two form classes developing in tandem. Importantly, this scenario would not indicate a change over development in the conceptual structure of spatial relations, or even the mapping from

[2] It is worth noting that adults and children also differ in their tendency to describe items using other preposition-based expressions (e.g., *is under, is in the middle of*, etc.), which leads to similar distributions for containment but not for support.

that structure to expression meaning; rather, it would involve only a change in the processes by which more frequent and default expressions are blocked by those that are dedicated to non-core spatial relations. In the remaining experiments, we test this hypothesis as follows. In Experiment 2, we ask whether the pattern of use of *is in/on* becomes more adult-like by age 6, given the assumed growth of and increased access to the lexical verb vocabulary. In Experiment 3, we carry out formal modeling to see what the underlying semantic space of an adult would look if they (like 4-year-olds) could not use lexical verbs. We also test the predictions of the model by carrying out an experiment with adults who are instructed not to use lexical verbs.

4. Experiment 2

4.1. Method

4.1.1. Participants

Twelve typically developing 6-year-olds ranging from 6 years, 1 month to 6 years, 8 months (mean age 6 years, 5 months; 6 females) participated in the study.

4.1.2. Design, materials, and procedure

The design, materials and procedure were identical to Experiment 1.

4.2. Results

Six-year-olds' production of *is in/on* and lexical verb expressions were analyzed separately for containment and support, as before, and compared to the adult and 4-year-old data from Experiment 1. These two construction types, together, accounted for 79.3% (67.9% *is in/on* expressions) of 6-year-olds' descriptions. We employed the same mixed-effect logistic regression analysis method outlined in Experiment 1, starting with *is in/on* for each category and moving to lexical verb expressions. Each model featured Age (Experiment 1 adults, Experiment 1 4-year-olds, and Experiment 2 6-year-olds), Subtype, and an Age $*$ Subtype interaction term, as possible fixed effect predictors and Subject and Item as random effects. As in Experiment 1, Subtype factors were coded in each model as a set of *a priori* contrasts, based on hypothesized distinctions among subtypes of relations in each category.

4.2.1. Containment

Like adults (Fig. 3a) and 4-year-olds (Fig. 3b), 6-year-olds (Fig. 3c) used *is in* to describe the greatest proportion of Loose-fitting Full-containment scenes, followed by Loose-fitting Partial containment, and Tight-fitting Full-, and then Partial-containment scenes; they used *is in* to describe fewer than half of the Interlocking and Embedding scenes.

The model that best predicted usage patterns of *is in* featured Subtype and the interaction between Age and Subtype as fixed effects. Age, on its own, was not a significant predictor of *is in* usage: adults, 4-year-olds, and 6-year-olds did not differ in overall rates of *is in* expressions. All three age groups, together, produced *is in* at greater rates for Full and Partial containment relations compared to Interlocking and Embedding relations ($\beta = 10.65$, 95% CI = [7.82, 13.52], $p < 0.001$) and, within Full- and Partial- containment, *is in* appeared more for Loose-fitting compared to Tight-fitting relations ($\beta = 6.40$, 95% CI = [3.59, 9.65], $p < 0.001$). The model revealed one interaction between Age and Subtype: compared to 4-year-olds, 6-year-olds' *is in* use showed a greater difference between Full and Partial containment relations compared to Interlocking and Embedding relations ($\beta = -2.45$, 95% CI = [−4.74, −0.29], $p < 0.05$). There were no other significant predictors or interactions.

Six-year-olds' production of *is in* reliably differentiated among subtypes of containment relations, with a profile that was similar to the adults and 4-year-olds in Experiment 1. Like 4-year-olds, our sample of 6-year-olds used lexical verbs very infrequently (1.4% of containment item descriptions, compared to 22.7% of adult containment item descriptions), and thus we did not carry out a separate analysis of these expressions for containment relations.

4.2.2. Support

Adults (Fig. 4a), 4-year-olds (Fig. 4b), and 6-year-olds (Fig. 4c) used *is on* at greatest proportions to describe Gravitational support scenes, relative to other subtypes. Adults and 6-year-olds both used *is on* at lowest rates for via Hanging and via Point-attachment scenes (5%, 39%, respectively). Embedded support and support via Adhesion were numerically in-between for both groups.

The model that best predicted use of *is on* included Age and Subtype and their interaction as predictors. Overall, 6-year-olds used *is on* at greater rates than adults ($\beta = -4.51$, 95% CI = [−6.99, −2.08], $p < 0.001$), but at rates not reliably different from 4-year-olds. Adults, 4-year-olds, and 6-year-olds, together, used *is on* more for Gravitational support relations than for Mechanical support relations ($\beta = 10.84$, 95% CI = [6.73, 16.19], $p < 0.001$) and within Mechanical support relations, they used *is on* more for Embedded support and Adhesion than for Hanging and Point Attachment ($\beta = 3.59$, 95% CI = [1.09, 6.42], $p < 0.01$). Interactions between Age and Subtype revealed a greater difference between Gravitational and Mechanical support relations for 6-year-olds compared to 4-year-olds ($\beta = -6.25$, 95% CI = [−11.33, −2.15], $p < 0.001$). Six-year-olds' *is on* use showed a difference between Embedding and Adhesion vs. Hanging and Point attachment that was larger than the difference for 4-year-olds ($\beta = -3.53$, 95% CI = [−5.33, −1.61], $p < 0.001$) but smaller than adults ($\beta = 3.52$, 95% CI = [1.26, 6.36], $p < 0.001$). Thus, 6-year-olds reliably differentiated between different subtypes of support relations, showing a pattern of *is on* use that was more well-articulated than the 4-year-old pattern, but less sharp than the pattern of adults.

Six-year-olds used lexical verb expressions for 23% of their support descriptions, compared to 56% for adults (Fig. 4, Table A2). They primarily used lexical verbs for descriptions of Hanging and Point-attachment relations, similar to adults' almost exclusive use of lexical verbs for encoding these two subtypes. The model that best predicted use of lexical verbs included Age and Subtype, as well as their interaction, as predictors. Overall, adults produced a greater proportion of lexical verb expressions than 6-year-olds ($\beta = 5.57$, 95% CI = [3.11, 8.55], $p < 0.001$). Adults and 6-year-olds, together, used a greater proportion of lexical verb expressions for Mechanical compared to Gravitational support relations ($\beta = -5.12$, 95% CI = [−10.86, −1.31], $p < 0.001$) and within Mechanical support, both groups used lexical verbs more for Hanging and Point-attachment relations compared to Embedded support and Adhesion ($\beta = -12.69$, 95% CI = [−16.37, −9.11], $p < 0.001$). Finally, for both age groups, a greater proportion of lexical verbs appeared for Adhesion relations compared to Embedded support ($\beta = -6.17$, 95% CI = [−10.48, −2.52], $p < 0.001$), however this difference was mediated by an interaction between Age and Subtype: adults showed a reliable difference in their lexical verb use for Adhesion vs. Embedded support, while 6-year-olds did not ($\beta = 4.82$, 95% CI = [1.30, 8.33], $p < 0.001$).

Taken with the findings of Experiment 1, the results of Experiment 2 support the hypothesis that development of lexical verb expressions is an important force in shaping the use of the basic locative expressions, but that this varies substantially over content domain. In containment, where 4-year-olds, 6-year-olds and adults showed similar patterns of *is in* use, adults used lexical verbs about 23% of the time (largely for Interlocking and Embedding subtypes), whereas 4- and 6-year-olds produced them rarely. For support, where the profile of *is on* was quite different between 4- and 6-year-olds and adults, the use of lexical verbs varied as well. Four year-olds' distribution of *is on* showed only one of the distinctions made by adults (Gravitational vs. Mechanical), 6-year-olds' use showed two of the distinctions made by adults (Gravitational vs. Mechanical, and Embedded/ Adhesion vs. Hanging/Point attachment). Both 6-year-olds and adults showed similar patterns of use for lexical verbs, whereas 4-year-olds produced these verbs rarely. The changing shape for use of *is on* between 4, 6, and adulthood appears to be linked to the increasing use of lexical verbs.

In Experiment 3, we formulate and test the hypothesis stated above about the role of lexical verbs in the changing usage pattern for the basic locative expression *is in/on*. We hypothesized that over development, lexical verbs increasingly come to be used by speakers to complement the basic locative expression, but that this change in the use of different expressions does not reflect changes in the underlying semantic space, which represents differences across subtypes of containment and support. If both of these are true, then adults who are prevented from using lexical verbs should show a distribution of *is in/on* that is the same across subtypes as 4 year-olds, who do not use these verbs. We test this hypothesis using both computational modeling and experimentation.

5. Experiment 3

Our hypothesis can be formalized as a probabilistic model in which child and adult spatial systems are identical except for the overall rate at which lexical verbs are produced. Differences between child and adult language patterns stem, according to the model, entirely from higher rates of *is in/on*; they do not reflect differences in conceptual structure or in the semantics of spatial expressions. Unlike the preceding statistical analyses of Experiments 1 and 2, the model presented here preserves fine-gained distinctions among individual lexical items. That is, different lexical verb expression such as *hang from* and *stick to*, which were collapsed under the binary coding of lexical verb in the logistic regression analyses, are treated as distinct by the model.

In the model, adult data from Experiment 1 provide a 'baseline' estimate of the probability of each spatial expression for each item in the battery. An alternative, child-specific model is identical to the baseline except for a single fit parameter that lowers the probabilities of all expressions containing lexical verbs. This same parameter commensurately raises the probabilities of copular expressions, in a way that matches their relative frequencies in adult speech. For example, adults described an item from the support via hanging subtype with the lexical verb expressions *attach to, hang from*, respectively, for 16.7% and 66.7% of descriptions, and used the copular verb expressions *is on* and *is under* for 8.3% and 8.3% of descriptions, respectively. Using this pattern as a baseline, if we impose a penalty on lexical verb expressions *attach to* and *hang from* for children, then we predict greater probability (higher rates) of use of *is on* and *is under* in the child-specific model. A penalty that decreased the probability of lexical verbs by 50% would yield a commensurate increase of the probability of each of *is on* and *is under* to 0.291 (predicting that these expressions would each be used at a rate of 29.1%).

We chose to use adult language as a baseline based on the assumption that mature language has a stable semantic basis. In our model, we modify only the frequency of specific (lexical verb) expressions in the adult corpus and find improved fit to patterns of child language use. Under this assumption about the stability of adult spatial concepts, improvements in predicting child spatial language support developing expression use, and not developing underlying concepts, as the locus of spatial language change.

In what follows, we set out the baseline and child-specific models in computational detail and compare their performance on predicting child usage patterns. We ask whether a single penalty on lexical verbs is sufficient to provide a coherent account of adult and child spatial language. We then ask whether this penalty is greater for younger children (4-year-olds, compared to 6-year-olds) and seek further experimental support, from adults, for a lexical verb-based account of age differences in this aspect of spatial language.

5.1. Baseline model

The relative frequencies of spatial expressions in the adult data of Experiment 1 served as the baseline model. For each item of the battery separately, we calculated how often each spatial expression (*is in/on* or particular lexical verb) was produced across all of the adult participants. The raw frequencies were then smoothed by adding a small positive constant (0.5), and then converted to relative frequencies by dividing by the total smoothed count for each item. The purpose of the baseline model is to assess how well these fine-grained adult relative frequencies can predict child spatial language in the same experiment. On the basis of the statistical analyses reported earlier, we expected the baseline model to perform poorly and therefore modified it minimally to create a child-specific model.

5.2. Child-specific model

If developmental differences in spatial language are the result of children's failure to use lexical verb expressions, then a child-specific model that penalizes lexical verb expressions in adult spatial language patterns, should closely resemble the observed patterns of expression use produced by 4- and 6-year-old children. Our child-specific model should, therefore, predict child patterns with greater accuracy than the baseline model estimated solely from adult language. The model allows us to further examine the *strength* of the penalty for lexical verbs across ages. The 4-year-olds in Experiment 1 rarely used lexical verb expressions in their spatial descriptions and, as such, we expect the penalty on lexical verbs in our child-specific model to be high for 4-year-olds. Specifically, we predict a higher penalty in the best-fitting models of 4-year-olds' spatial expression use compared to models of 6-year-olds' or adults' expression use.

In the child-specific model, the probability that an expression y_i would be used to describe a particular item was determined as follows (Fig. 5). The relative frequencies of the baseline model (i.e., the relative frequencies calculated from the smoothed adult counts) were first transformed to log values, denoted for each expression by x_i. Each expression was then associated with a binary feature f_i indicating whether it contained a lexical verb. If this feature was 'on', the log baseline value of the expression was multiplied by a child-specific lexical verb penalty, denoted by α_j; otherwise, the log value from the baseline model was unchanged. Equivalently, the baseline value was multiplied by α_j raised to the power f_i (recall that $\alpha_j^1 = \alpha_j$ while $\alpha_j^0 = 1$, for any real value α_j). Finally, the exponential of the resulting values were renormalized to sum to one, giving a multinomial distribution over spatial expressions for the appropriate battery item.

Note that when $\alpha_j = 1$, the resulting predicted probabilities are identical to those in the baseline model. For values of α_j less than 1, the probabilities of lexical verb expressions will lower and that of *is in/on* will raise commensurately. Note further that the single child-specific penalty parameter affects all lexical verb expressions

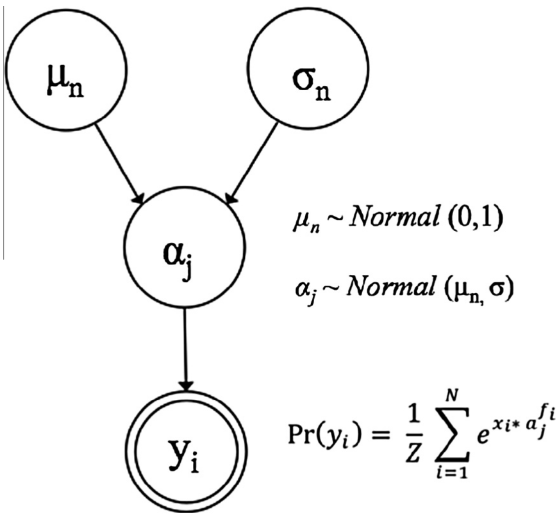

Fig. 5. Graphical summary of the child-specific model, applied separately to containment and support items.

equally (i.e., regardless of whether the verb expresses spatio-temporal, mechanical, or other information).

We used Bayesian inference, instantiated through a Gibbs sampling algorithm in RJAGS (Gelman, Carlin, Stern, & Rubin, 2004; Kruschke, 2014; Plummer, 2013) to estimate the lexical verb penalty parameter, α_j, for each subject j. In this inference process, the posterior probability of α_j, given each subjects' pattern of spatial expression use, is a product of two factors: the likelihood of the observed pattern of item-expression pairs, given the value of α_j, and the prior probability of the penalty α_j. Fig. 5 gives a graphical summary of the model. The prior probability distribution for the verb penalty parameter α_j, in this case, was defined to include a hierarchical relationship between α_j, estimated individually for each subject j, and an age group prior distribution, a Normal distribution with mean μ_n—specific to the age group n—and standard deviation σ, from which α_j is drawn for each subject in the age group.

5.3. Results

Compared to the baseline model, the child-specific model, with its lexical verb penalty parameter, was a better fit to child production data for both 4-year-olds and 6-year-olds. That is, changing only the probability of lexical verb expressions in the adult corpus led to more accurate predictions of child spatial language at the level of individual scene-expression pairs, compared to the baseline model with no lexical verb penalty.

We quantified this improvement in fit by computing the log-odds likelihood of producing the precise patterns of child and adult language use for the 18 containment and 15 support items, using the baseline and child-specific models. We compared the likelihood of the data for each age group under both models using a likelihood-ratio test (Quené & van den Bergh, 2008). For child spatial language, the best-fitting verb-modified models produced significantly more accurate predictions than baseline models of both 4-year-olds' ($\chi^2(1) = 7.56$, $p < 0.01$ for containment; $\chi^2(1) = 10.37$, $p < 0.01$ for support) and 6-year-olds' ($\chi^2(1) = 7.03$, $p < 0.01$ for containment; $\chi^2(1) = 12.45$, $p < 0.01$ for support) spatial language use. By including a single parameter that modulates the preference (or dis-preference) for lexical verb expressions in the spatial description corpus, the adult profile of spatial language use can be made to approximate and more accurately predict child spatial language for both young children and older children.

In addition to evaluating the predictive accuracy of our verb-modified spatial language models, we calculated and compared the distribution of values for the verb-modification parameter across ages. Specifically, we compared the estimates for the age-group prior distributions focusing on μ_n for each age-group distribution—the mean of the distribution from which verb-modification parameter α_j values were drawn for each subject in age group n—and report the 95% High Density Interval (HDI) for estimates—the range of the distribution that encompassed 95% of the estimates for μ_n values. Values of μ_n closer to 1 indicate a lesser degree of verb modification, and decreasing values of μ_n reflect a greater decrease in the probability of lexical verbs in the models.

For 4-year-olds, the probability of lexical verbs in the model was heavily penalized and decreased to almost 0 for both containment ($\mu_4 = 0.001$; 95% HDI = 0.0008–0.009) and support relations ($\mu_4 = 0.001$; 95% HDI = 0.0001–0.23). This statistical result suggests that, in terms of spatial language use, 4-year-olds are like adults without any lexical verbs. We experimentally validated this statistical prediction by testing a behavioral version of our verb penalty parameter, which we describe below.

By contrast, the models for 6-year-old children decreased the probability of lexical verbs to different degrees for containment vs. support relations. For containment relations, 6-year-olds, like 4-year-olds, are like adults without lexical verbs ($\mu_6 = 0.004$; 95% HDI = 0.001–0.41). For support relations, however, the model imposed only a moderate decrease in the probability of lexical verb expressions ($\mu_6 = 0.48$; 95% HDI = 0.01–0.98). We did not experimentally implement the lexical verb penalty parameter values for 6-year-old models, as we were unclear about how to consistently and unambiguously manipulate subjects' use of lexical verb expressions to an intermediate degree.

The model makes a number of fine-grained predictions about lexical verb use that are not dependent on particular penalty values as estimated above, and which were evaluated by comparing the adult and 6-year-old data (as the 4-year-olds rarely used verbs at all). First, because the model applies the same penalty to all lexical verbs regardless of semantic content, it predicts (for any penalty $0 < \alpha < 1$) that the probability of each verb will by higher in spatial descriptions offered by adults than in those given by children. The elicited frequencies are in accord with this prediction: 89% (32/36) of the lexical verb types present all of the data were used more often by adults; the only cases running counter to prediction are *connect* (used four times by the children but never by the adults), as well as *hold*, *tie*, and *touch* (each appearing once in the child data). Second, the model makes a similar prediction at the level of individual battery items: for each item, the probability of using lexical verbs in general should be higher for adults than for children. This is borne out by the frequency distributions for 100% (32/32) of the items in the battery.

Finally, the most granular set of model predictions hold for individual lexical verbs used to describe particular items. While the available data on this point is somewhat sparse, we are encouraged to find that 88% (67/76) of the lexical verb-item pairs that occurred in the data were more frequent in the adult descriptions. Furthermore, nearly all of the cases going against prediction involved a frequency difference of one (e.g., children used the verb *stick* to describe 'sticker on a bag' three times, while adults did so only twice). To summarize, when children employed lexical verbs, they did so in a way that closely tracked adult usage at the level of lexical items, experimental items, and combinations of those two. This supports the claim that avoidance of lexical verb use is a general property of child language use, rather than an indicator of immature semantic or conceptual knowledge.

5.4. Experimental model validation

The model described above predicts that if adults are prohibited from using lexical verbs, they should deploy other spatial expressions, like *is in* and *is on*, in a manner that resembles the spatial language of young children. In order to directly test this prediction, we collected an additional set of experimental data from adults using instructions designed to mimic the lexical verb penalty from the child-specific models above. We asked 12 new adult participants to provide descriptions for each of the 33 scenes in the spatial battery, as in Experiment 1, with one change in procedure. Participants were instructed to *avoid* using lexical verbs in their descriptions through the following addition to the experiment instructions:

> "*...It is very important that you avoid using certain words in your description. Specifically, we would like you to* avoid *using verbs like sit, hang and attach and only use the verbs is and are (and no others) in your descriptions.*"

These new "verbless" adults produced a corpus of descriptions that differed from the descriptions produced by adults in Experiment 1, but did not reliably differ from those produced by 4-year-olds in Experiment 1 (Fig. 6, containment; Fig. 7, support). This was confirmed by two mixed effect logistic regression models, one for containment and another for support, with Experimental Group (Experiment 1 4-year-olds, Experiment 3 verbless adults), Subtype of relation, and Group*Subtype as fixed-effects and Scene and Subject as random effect. Both the Group and the Group*Subtype interaction fixed effects failed to reach significance. The similarity in expression use was especially striking for support relations, for which Experiment 1 adults and 4-year-olds produced reliably different patterns in their use of both *is on* and lexical verbs, and for which our best-fitting child-specific statistical models required the greatest decrease in lexical verb probabilities.[3]

In sum, we successfully modeled the 4- and 6- year-old patterns of expression use across containment and support with a minimal modification of the adult pattern. We employed the adult expression frequencies as a baseline and imposed a child-specific lexical verb penalty, meant to represent a lowered probability of using lexical verbs across all items. This model was also empirically tested by eliciting descriptions from adults who were instructed not to use lexical verbs. Given that these adults showed the same distribution of *is in/on* as 4 year-olds for both containment and support, we conclude that the underlying shape of the semantic space for both domains is remarkably similar between age 4 and adulthood, but that the increasing use of lexical verbs reshapes the usage of the basic locative expression.

6. General discussion

The acquisition of the spatial terms *in* and *on* has long been viewed as a prime testing ground for understanding how children come to map spatial language onto pre-linguistic concepts. Yet, as we discussed in the introduction, uses of these terms extend far beyond simple physical configurations in which one object is fully contained or supported from below by another; moreover, languages vary in how these configurations are linguistically grouped by the basic spatial terms. These facts raise two related questions. First, is there a well-organized semantic/conceptual space underlying the use of *in* and *on,* and can this be observed among children and adults? Second, how does the distribution of terms *in* and *on* reflect this space, and if it is an uneven distribution, then what fills the gaps, and can this latter distribution also shed light on the underlying space?

[3] The experimental manipulation was designed to make adults' expression use approximate that of 4-year-olds, but not 6-year-olds, as there was no simple way to experimentally impose the moderate penalty on lexical verbs suggested by the model.

In the present studies, we provide a novel perspective on these issues by examining the distributions of uses of terms *in/on* in their so-called basic locative construction (*is in/on,* Levinson & Wilkins, 2006) across a broad set of spatial configurations in the domains of containment and support. Importantly, we also examined the distributions of lexical verbs that people used to describe the configurations when they do not use *is in/on*. The configurations themselves formed a structured battery that included full physical containment and support from below, as well as less central exemplars that can nevertheless be described in English with the terms *in* and *on*. We found three main results.

First, for the domain of containment, 4- and 6- year-old children and adults showed highly similar usage patterns of *is in* across the six subtypes we tested. In all groups, Full- and Partial- containment relations were differentiated in their use of *is in* from Interlocking and Embedding relations; in addition, Tight-fitting Full and Partial relations were differentiated from Loose-fitting relations and Interlocking was distinguished from Embedding. These common patterns suggest a similar underlying semantic/conceptual space across all age groups, reflected by similar distributions of uses of the basic locative expression. Lexical verbs were used predominantly by adults and were differentiated across specific subtypes, with posture verbs used for the Full and Partial containment types, but verbs corresponding to specific mechanisms (e.g., plug, screw) corresponding to Interlocking and Embedding. The lexical verbs were used most often for those subtypes (Interlocking, Embedding) that were least frequently described using *is in* by adults. These findings for containment are quite similar to those reported by Landau et al. (2016).

Second, the domain of support showed clear developmental change across the five subtypes. Four-year-olds' uses of *is on* was much less differentiated across subtypes than that of adults, with 6-year-olds in between. All groups showed reliably greater use of *be on* for Gravitational support compared to Mechanical support relations, but 4-year-olds did not show differentiation among the other subtypes within Mechanical support. Six-year-olds and adults differentiated Hanging and Point attachment from Embedded support and Adhesion; adults also made a further distinction between Embedded and Adhesion relations. Importantly, as distributional patterns of *is on* use became more differentiated from age 4 to adult, lexical verb use increased, showing usage patterns that were reciprocal to *is on*.

Third, we found a link between the changing use of *is on* and the increase in lexical verbs. We modeled adults' production with a numerical penalty for using lexical verbs, and experimentally penalized adults for using lexical verbs. In both cases, we found that adult use of *be on* when they did not use lexical verbs mirrored that of 4 year-olds. We therefore conclude that the underlying semantic spaces for both containment and support are quite similar in 4 and 6 year-olds and adults. What changes is the tendency to use lexical verbs to specify how particular subtypes deviate from more central ones. Although we saw little of this change for the domain of containment, the findings from adults in this domain suggests that they also elect to use lexical verbs over the basic locative expression in just those cases where the subtypes are farthest from the more central ones. As a whole, our findings suggest that the changing uses of *in* and *on* across development reflect much more than simple mapping of the terms to a small set of configurations. Rather, developmental changes reflect a relatively stable underlying semantic-conceptual space, together with changes in the linguistic resources used to describe the wide range of configurations that could in principle be described with the expressions *is in/on*.

The results of our studies shed light on several aspects of the acquisition of spatial prepositions *in/ on*. First, our results show that, although children use the expressions *is in* and *is on* quite

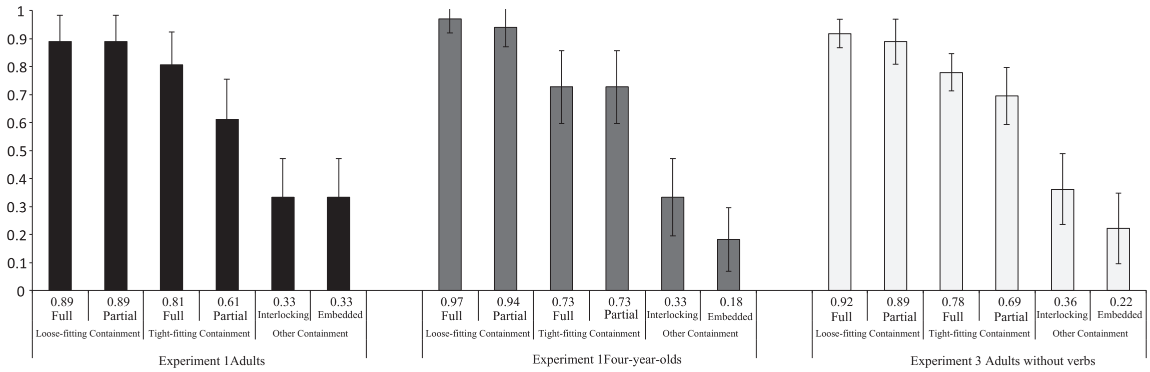

Fig. 6. Proportion of *is in* use across Containment relations by (a) Adults (Experiment 1), (b) 4-year-olds (Experiment 1), and (c) Adults without lexical verbs (Experiment 3).

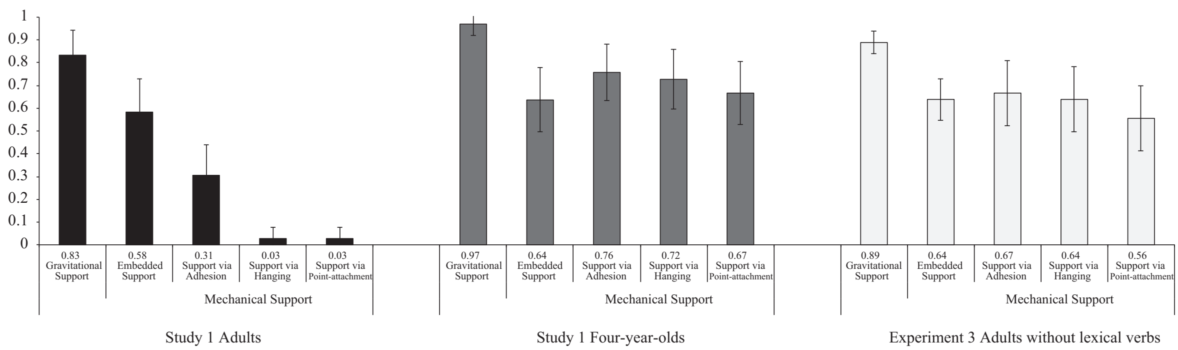

Fig. 7. Proportion of *is on* use across Support relations by (a) Adults (Experiment 1), (b) 4-year-olds (Experiment 1), and (c) Adults without lexical verbs (Experiment 3).

early in development (and equivalent expressions in other languages, see Johnston & Slobin, 1979), children's fine-grained distribution of these expressions at age 4, and even at age 6 is not yet adult-like. This finding is consistent with Gentner and Bowerman's (2009) work, which describes a lengthy trajectory for the development of uses for *on* in Dutch-speaking children.

Second, our results emphasize that part of this development interacts significantly with the acquisition and availability of other expressions, most significantly, lexical verbs, which share the burden of spatial encoding along with the spatial prepositions. This fact is especially important in view of a recent debate about what have been thought to be enduring cross-linguistic differences in categorization. Choi and Bowerman (1991) uncovered significant differences in the way that Korean- and English-speaking adults and children encode joining and separating events: Korean-speaking adults and children consistently used verbs that encode degree of fit, using *kkita* for tight-fitting events, and *nhota* for loose-fitting events; English-speakers, on the other hand, only encoded differences between joining and separating events—via their use of prepositions like *in/on/together* (for joining) and *out/off/apart* (for separating). In our view, these differences arguably stem from focusing on different classes of spatial expressions in each language. For Korean speakers, only verbs were analyzed as the carriers of spatial information (see Kawachi, 2007, for precisely what that spatial information is), but for English speakers, only prepositions were considered.

In keeping with the importance of considering the roles of both lexical verbs and prepositions, Gürcanlı and Landau (2008; see also Norbury, Waxman, & Song, 2008) demonstrated that English speakers tend to use a range of different lexical verbs such as *connect, disconnect,* and *fit* to express tight-fit joining and separating events, even though some have argued that English lacks dedicated verbs for expressing the tight-loose contrast. In the domain of joining and separating events, English prepositions and verbs share the burden of encoding complex object relations: lexical verbs are used to express conceptual information related to degree of fit that is not encoded by prepositions like *in* and *out*. The same may be true of Korean, although we know of no analyses that consider both spatial verbs and adpositions as carriers of spatial information in such contexts.

Our findings also suggest a previously undocumented asymmetry between the domains of containment and support, with respect to the distribution of basic locative expressions, *is in/on* and the complementary use of lexical verbs. For containment, child and adult distributions of *is in* did not reliably differ and children did not develop more articulated profiles of *is in* as a function of lexical verb growth: adults showed a constant 20% increase, compared to children, in their rate of lexical verb use across containment subtypes. For the domain of support, by contrast, children's and adults' distributions of *is on* varied substantially over development, and the increase lexical verb use on the part of adults was linked specifically to the increasingly restricted use of the basic expression. One possible explanation for this asymmetry between containment and support is our choice of subtypes and items in each category. Specifically, our containment subtypes may have included a greater proportion of central instances, which featured a number of variations on degree of containment (Full vs. Partial) and fit (Tight vs. Loose). The remaining two subtypes, Interlocking (e.g., plug in socket) and Embedding (crack in table), were clearly less 'containment-like', and these constituted one-third of the battery. Our support subtypes, on the other hand, consisted of a single central type of support (Gravitational) plus four other variations that embodied different mechanics of support (e.g., support via Adhesion, Embedding, Hanging, Point attachment). Thus, the set of containment subtypes in our studies may have shown less of an effect of lexical verb growth simply by virtue of the range of items we tested.

This is possible, but we do not think that it is the whole story. Although we may have under-represented unusual means of containment in our battery, we also believe that the two domains reflect qualitatively different kinds of learning problems, and that full understanding of the support domain in particular may be a late development relative to containment. Consistent with this possibility, infants appear to understand containment relationships earlier than support (Casasola, 2005; Casasola, Cohen, & Chiarello, 2003; Casasola & Cohen, 2002); moreover, *in* is understood before *on* (Johnston & Slobin, 1979). In our results, a close look at the lexical verbs used by adults suggests that there may be differences in what aspects of containment and support need to be learned. In particular, we found that adults used two different classes of lexical verbs for encoding containment and support relations. They used posture verbs like *sit, stand,* and *lie* to encode the configuration of the figure object for Full- and Partial- containment subtypes as well as Gravitational support subtypes, but not Interlocking or Embedding relations or any of the Mechanical support relations. These verbs are frequent in general adult and child language but, in the context of encoding spatial relations, they provide little to no information about the mechanics of the relationship between figure and ground objects.

By contrast, adults used lexical verbs reflecting the mechanics of spatial relations between objects for the other subtypes, including verbs that encode how an object is contained (by e.g., by inserting, connecting, fitting, etc.) or supported (by e.g., by means of sticking, hanging, magnetic force, etc.) by another object. Adults used a wide range of these verbs to express the configurations of containment and support that were unlikely to be encoded using *be in/on*. Six-year-olds also used this type of verb to encode a subset of Mechanical support relations, namely Hanging and Point-attachment relations. The lexical verbs that 6-year-olds recruited in their spatial descriptions were not predicted by overall frequency in adult, child-produced or child-directed speech (Balota et al., 2007; MacWhinney, 2000). However, the relations for which children used these lexical verb expressions—Hanging and Point-attachment—corresponded to the cases in which adults were most likely to use lexical verbs (and used the same verbs as children) in their descriptions. The mechanical information encoded by lexical verbs like *hang* and *attach* was salient for both adults and 6-year-olds, despite the general relative infrequency of these verbs. Mechanisms of support are essentially endless—humans have created a wide range of means by which we can ensure that one object is supported by another, and these mechanisms have not yet been systematically explored in pre-linguistic populations.[4] In addition to knowing how support mechanisms work and to which objects they can apply, children must learn how and when they are linguistically encoded by expressions beyond prepositions. Mechanisms of containment may, by contrast, be relatively limited in scope, affording easy mastery of the domain.

A final unanswered question concerns why our youngest children didn't use lexical verbs in their spatial descriptions. We are not sure, but can rule out several possibilities. One is that children may simply not know these verbs or may not understand the conditions under which they can be used felicitously. This is unlikely on a number of grounds. First, the verbs produced by adults are attested before age 4 in child corpus data from CHILDES (MacWhinney, 2000). Second, our own results from the forced-choice comprehension tasks described in the Experiment 1 discussion demonstrate that, when provided with lexical verb response options, children choose as "better" the adult-generated lexical verbs as opposed to their own production of *is in/on*. A second possibility is that children's low rates of lexical verb use (and high rates of *is in/on* use) reflect a kind of self-priming during the spatial description task: 4-year-olds, on this view, are reinforcing their tendency to use *is in/on* and are, therefore, increasingly likely to use *is in/on* as the experiment progresses. Over the course of development, children's tendency to prime their own responses across trials may decrease. This is unlikely to be a full explanation of children's tendency to avoid lexical verbs because when adults are instructed to avoid using lexical verbs, they use *is in/on* at the same rate as 4-year-olds but are not assumed to self-prime to the degree that children do. Moreover, while children's failure to use lexical verbs is prominent in the support domain, neither they nor adults produced many lexical verbs in the containment domain.

We believe that the children's failure to use lexical verbs is probably a combination of several factors. One is simply difficulty generating or accessing these expressions in our task. To generate a lexical verb that is both grammatical and semantically appropriate for the configuration, children minimally need to decide on a verb, choose the appropriate tense marking—in this case the progressive—and choose the appropriate prepositional complement, which is constrained by the verb itself. It is possible that children have difficulty with any one of these parts of the production process. A related possibility is that the expressions *is in/on* are ones that adults use quite frequently when describing spatial relationships to their children. These expressions would need to compete with less frequent lexical verb expressions during the elicited production task, and the latter might therefore show reduced likelihood of being produced.

Crucially, when children do start reliably using lexical verbs in their descriptions, it is for the items that adults almost exclusively encode with lexical verbs expressions, e.g., *hanging, sticking*. This suggests that a child's likelihood of using lexical verbs is not based on the overall frequency of a particular lexical verb in everyday language, but rather the frequency with which that verb is used to encode a particular spatial relation. For some relations, then, the balance between spatial information encoded by prepositions and verbs is shifted to place greater burden on lexical verbs.

In sum, our studies have revealed that both children and adults share underlying semantic/conceptual spaces that support the mapping of the basic locative expression *is in/on* in English. However, the distribution of uses of these expressions changes over development; crucially, these changes reflect the growing interaction of spatial prepositions with lexical verbs. Together, the two form classes share the burden of describing where things are.

[4] Specifically, work on infants' understanding of support relations has probed early concepts of contact (Needham & Baillargeon, 1993), the type or direction of contact—e.g., on top of a platform vs. against a side wall (Hespos & Baillargeon, 2008), and the amount of contact between two surface (e.g., 15% vs. 100% of a surface in contact with a supporting object; Hespos & Baillargeon, 2008). However, to our knowledge, there has been no systematic examination of infants' understanding of the mechanisms responsible for support in relations that do not have large amounts of contact and support from below (e.g., hanging relations).

Appendix A

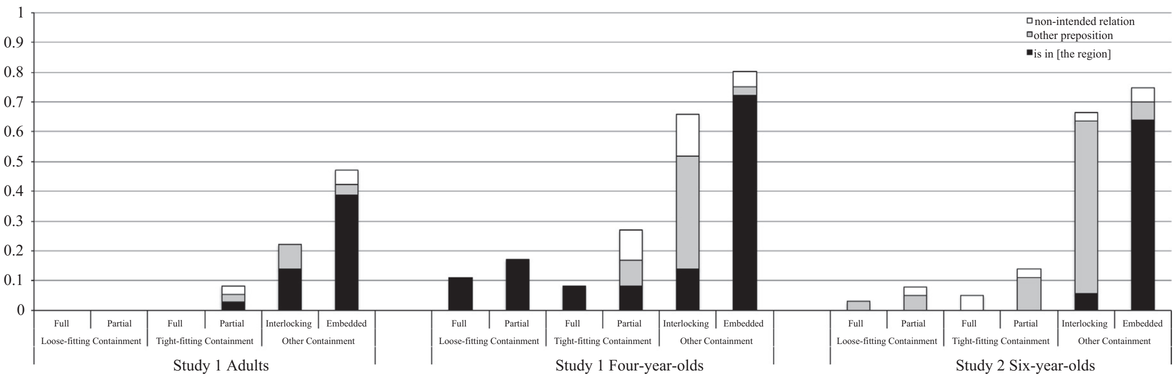

Fig. A1. Distribution of remaining expression types—*in [the region] of* (e.g., *in the middle of*), other prepositions (e.g., *is between*), and the felicitous encoding of non-intended relations (e.g., reversal of figure and ground objects) across subtypes of containment.

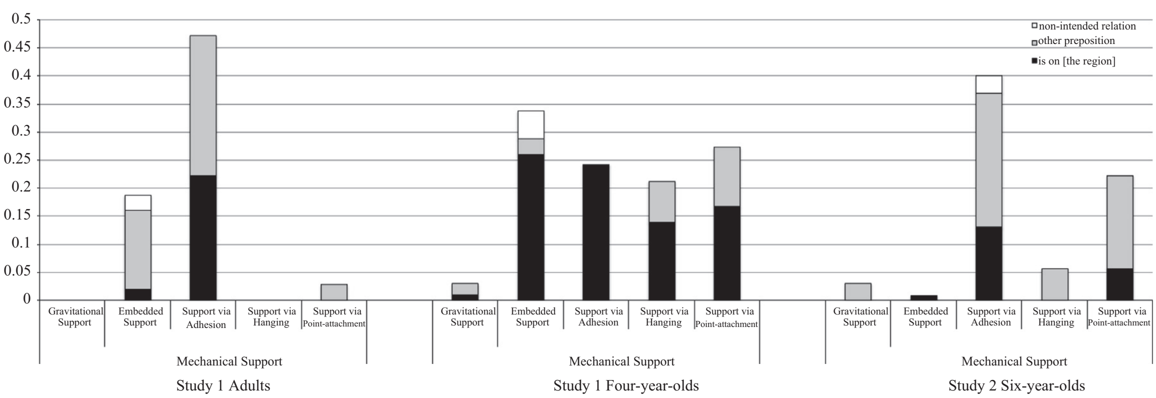

Fig. A2. Distribution of remaining expression types—*on [the region] of* (e.g., *on the side of*), other prepositions (e.g., *is under*), and the felicitous encoding of non-intended relations (e.g., reversal of figure and ground objects) across subtypes of support.

Table A1
Descriptions of the 33 items (18 containment, 15 support) in the spatial batteries.

Containment		Support	
Subtype	Item	Subtype	Item
Loose-fitting	*Scissors in box*	Gravitational support	*Ball on pillow*
Full	*Mug in bag*		*Cup on plate*
Containment	*Ball in bowl*		*Truck on box*
Loose-fitting	*Marker in glass*	Embedded support	*Paint on brush*
Partial	*Bottle in bucket*		*Stamp on paper*
Containment	*Markers in box*		*Tattoo on hand*
Tight-fitting	*Dish in basket*	Support via Adhesion	*Post-it note on book*
Full	*Book in sleeve*		*Sticker on bag*
Containment	*Dish in basket*		*Tape on box*
Tight-fitting	*Egg in carton*	Support via Hanging	*Ornament on branch*
Partial	*Pencil in sharpener*		*Mug on hook*
Containment	*Candle in holder*		*Necklace on stand*
Interlocking	*Plug in outlet*	Support via Point attachment	*Flag on pole*
	Bulb in socket		*Cloth on ribbon*
	Block in tower		*Fabric on pole*
Embedding	*Rip in paper*		
	Crack in foam		
	Hole in knitting		

Table A2
Mean proportions (with standard errors) of lexical verb expression use or choice for containment (top) and support (bottom) by adults (Experiment 1), 4 year-olds (Experiment 1), 4 year-olds forced-choice responses (Experiment 1, Further Results), and 6-year-olds (Experiment 2).

Containment	Full-loose	Partial-loose	Full-tight	Partial-tight	Interlocking	Embedding
Adults Exp. 1	0.11 *(0.09)*	0.11 *(0.09)*	0.19 *(0.11)*	0.31 *(0.09)*	0.44 *(0.14)*	0.18 *(0.11)*
4-year-olds Exp. 1	–	–	–	–	0.03 *(0.05)*	0.03 *(0.05)*
4-year-olds Forced-choice	0.55 *(0.15)*	0.52 *(0.15)*	0.21 *(0.12)*	0.40 *(0.14)*	0.83*(0.11)*	0.45 *(0.15)*
6-year-olds Exp. 2	–	–	–	–	0.08 *(0.08)*	–

Support	Gravitational support	Embedded support	Support via Adhesion	Support via Hanging	Support via Point Attachment
Adults Exp. 1	0.17 *(0.11)*	0.22 *(0.12)*	0.47 *(0.15)*	0.97 *(0.05)*	0.94 *(0.07)*
4-year-olds Exp. 1	–	0.08 *(0.05)*	0.08 *(0.05)*	0.06 *(0.07)*	0.06 *(0.07)*
4-year-olds Forced-choice	0.47 *(0.15)*	0.69 *(0.13)*	0.83 *(0.11)*	0.98 *(0.05)*	0.91 *(0.09)*
6-year-olds Exp. 2	–	0.19 *(0.11)*	0.19 *(0.11)*	0.55 *(0.15)*	0.39 *(0.14)*

Table A3
Lexical verb frequencies in the corpus with in/on or other preposition complements.

	With in/on	With other prep	Total
Adhere	0	1	1
Attach	0	9	9
Clip	0	2	2
Connect	0	4	4
Contain	0	2	2
Dangle	0	2	2
Dry	1	0	1
Fit	0	1	1
Hang	29	50	79
Hold	1	0	1
Implant	1	0	1
Imprint	3	1	4
Insert	0	2	2
Lie	3	4	7
Lodge	1	0	1
Make	1	2	3
Miss	0	1	1
Perch	0	1	1
Pin	0	4	4
Place	2	0	2
Plug	0	5	5
Present	0	1	1
Push	0	1	1
Rest	6	1	7
Rip	1	2	3
Screw	3	4	7
Sit	7	1	8
Situate	0	1	1
Stamp	1	0	1
Stand	1	1	1
Stick	5	23	28
Support	0	1	1
Surround	0	2	2
Tape	0	1	1
Tear	0	1	1
Tie	1	0	1
Touch	0	1	1
Wave	0	1	1
Total	67	133	200

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.08.022.

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