COGNITIVE SCIENCE
A Multidisciplinary Journal

Cognitive Science (2016) 1–32

ISSN: 0364-0213 print / 1551-6709 online
DOI: 10.1111/cogs.12389

Containment and Support: Core and Complexity in Spatial Language Learning

Barbara Landau,[a] Kristen Johannes,[a] Dimitrios Skordos,[b] Anna Papafragou[b]

[a]*Department of Cognitive Science, Johns Hopkins University*
[b]*Department of Psychological & Brain Sciences, University of Delaware*

Received 6 August 2014; received in revised form 22 February 2016; accepted 7 March 2016

Abstract

Containment and support have traditionally been assumed to represent universal conceptual foundations for spatial terms. This assumption can be challenged, however: English *in* and *on* are applied across a surprisingly broad range of exemplars, and comparable terms in other languages show significant variation in their application. We propose that the broad domains of both containment and support have internal structure that reflects different subtypes, that this structure is reflected in basic spatial term usage across languages, and that it constrains children's spatial term learning. Using a newly developed battery, we asked how adults and 4-year-old children speaking English or Greek distribute basic spatial terms across subtypes of containment and support. We found that containment showed similar distributions of basic terms across subtypes among all groups while support showed such similarity only among adults, with striking differences between children learning English versus Greek. We conclude that the two domains differ considerably in the learning problems they present, and that learning *in* and *on* is remarkably complex. Together, our results point to the need for a more nuanced view of spatial term learning.

Keywords: Spatial language; Cross-linguistic; Language learning; Containment; Support; Spatial relations

1. Introduction

Traditional theories of cognitive and linguistic development assume that human spatial concepts are largely universal and that language maps rather directly onto pre-existing, shared conceptual categories (E. V. Clark, 1973; H.H. Clark, 1973; Johnston & Slobin, 1978; Mandler, 2004). Chief candidates among such spatial concepts are containment and support, which are represented by infants prior to language (Casasola, 2008; Casasola,

Correspondence should be sent to Barbara Landau, Department of Cognitive Science, Johns Hopkins University, Baltimore, MD 21218. E-mail: landau@jhu.edu

Cohen, & Chiarello, 2003; Hespos & Baillargeon, 2001a; Mandler, 2004; Needham & Baillargeon, 1993) and are among the earliest relationships expressed linguistically by toddlers (Bloom, 1973; Bowerman, 1996; Brown, 1973). These theories fit comfortably within a larger view of spatial language which posits a small set of universal pre-linguistic spatial concepts that serve as the foundation of young children's early acquisition of spatial terms (E.V. Clark, 1973; Landau & Jackendoff, 1993; Regier, 1996; Talmy, 1983). The learning problem can then be viewed as a simple one—children learn to map spatial words such as *in* and *on* onto previously available spatial concepts.

This simple view of learning to talk about space has been challenged on two fronts. A first challenge lies in the substantial breadth that is observed in the range of spatial configurations that can be encoded by basic spatial terms such as *in* and *on*. For example, the English term *in* seems ideally suited to expressing physical relationships in which one object clearly contains another (e.g., "The apple is in the bowl"), but it is also used for situations that do not as easily fit this scheme. An apple that is perched atop a dozen other apples can still be said to be *in the bowl*, even though all of its edges lie far above the edges of the container. We can also express partial containment, as in "The straw is *in* the glass" (even if most of the straw is sticking out of the glass), embedding, as in "There is a crack *in* the table" (where the crack is a negative space embedded in the table), and partial but tight insertion, as in "The plug is *in* the socket." Even leaving aside highly abstract uses such as "bird *in* the hand," the uses of *in* appear to span wide conceptual territory. The same is true for *on,* which expresses support relationships. One can express concrete physical support of one object by another directly below it, as in "The book is *on* the table," but also other kinds of support, including adhesion, as in "The stamp is *on* the envelope," hanging, as in "The picture is *on* the wall," and so forth. The wide range of cases that invite the use of *in* and *on* in English has been used to argue that basic spatial terms are not purely geometric, and must involve significant functional information, making their representation quite complex (e.g., Coventry, Carmichael, & Garrod, 1994; Herskovits, 1986). When it comes to learning, however, theorists have paid relatively little attention to the broader applications of these terms, focusing on relatively simple spatial configurations in which one object is either inserted in or supported by another (Bowerman & Choi, 2003; Casasola et al., 2003; Hespos & Spelke, 2004). Limiting studies of acquisition to such simple cases may seriously underestimate both the complexity of the learning problem, and the richness of children's representations of spatial configurations and their encoding in language.

A second, more substantive challenge to the simple view of learning is posed by evidence from cross-linguistic studies. These have pointed to significant cross-linguistic differences in the encoding of what would appear to be basic spatial relationships (Bowerman, 1996; Gentner & Bowerman, 2009; Levinson et al., 2003). They have also pointed to the fact that at least some of these differences are learned quite early, that is by the age of about 2. For example, Bowerman (1996; Bowerman & Choi, 2003) first reported that 2-year olds learning English use "put in" or "put on" to describe a diverse set of spatial actions in which two objects are joined in tight or loose configurations, whereas 2-year olds learning Korean differentiate the same set of actions using a range of more specific verbs.[1] These findings are especially interesting, in our view, as they suggest that both prepositions and postpositions (commonly grouped together as "adpositions") and lexical verbs may play an important part in encoding spatial relationships, a point to which we return throughout the paper. More broadly, theoretical views of cross-linguistic variation in the spatial domain have led some to question the idea of universal pre-linguistic primitives supporting the acquisition of basic spatial terms. For example, after examining the encoding of spatial relationships across a wide range of languages, Levinson et al. (2003) conclude:

> The differences between the languages turn out to be so significant as to be incompatible with the stronger versions of the universal conceptual categories hypothesis. Rather, the language-specific spatial adposition meanings seem to emerge as compact subsets of an underlying semantic space, with certain areas being statistical attractors or foci. (p. 485)

At present, both the extent and the nature of cross-linguistic variation remain ripe for further exploration. Notice that cross-linguistic differences need not be incompatible with the idea of universal conceptual categories. Indeed, the idea of "foci" has long organized the domain of color terms, where it is assumed that some universal aspects of color perception organize the mapping of linguistic terms across languages (Berlin & Kay, 1969; Regier, Kay, & Khetarpal, 2007). These foci may be a specific example of "cognitive reference points," which have been argued to organize many domains (Rosch, 1975). Similarly, Levinson et al.'s idea of statistical attractors is based on the idea that certain spatial properties (or dimensions) can result in a configuration being a central exemplar of the containment or support category, and these central exemplars could constitute universal areas of conceptual space that invite the use of basic spatial terms. For example, they argue that features such as "contained figure," "canonical 3-D figure," and "close contact" lend themselves to encoding with the basic spatial terms whereas "contained ground," "negative space (or hole)," and "separation," do not. Configurations such as a cup on a table or an apple in a bowl turn out to have high values on the preferred features, and thus are likely candidates for application of the basic spatial terms (e.g., *in* and *on*). In this way, the attractor space represents a multi-dimensional space in which combinations of features determine whether a configuration is more or less likely to elicit basic spatial terms. This featural representation view assumes that humans organize spatial categories around certain configurations that exemplify the "core"—that which captures the essence of the category—and that this organization invites people to linguistically encode these configurations with basic spatial terms. This hypothesis is completely compatible with the idea that there are universal constraints on the kinds of spatial relationships that will be encoded by the basic spatial prepositions, argued by many other writers (e.g., Clark, 1973b; Landau & Jackendoff, 1993).

Surprisingly, despite the size of the literature on the nature and acquisition of locative vocabulary (Carlson & van der Zee, 2005; Clark, 1973a; Choi & Bowerman, 1991; Corrigan, Halpern, Aviezer, & Goldblatt, 1981; Dromi, 1979; Emmorey, 1996; Herskovits, 1986; Jackendoff, 1996; Johnston & Slobin, 1978; Leikin, 1998; Newcombe & Huttenlocher, 2003; Talmy, 1983; Vandeloise, 2010; among many others), empirical tests of this hypothesis across a broad range of spatial exemplars and among children and adults are limited. One exception is the study reported by Levinson et al. (2003; cf. Levinson & Wilkins, 2006). This study relied on a battery of 71 line-drawings developed by Bowerman and colleagues to represent a range of the so-called topological relationships (e.g., relationships that would be encoded in English by *in, on, under, over, near* and *against*; Bowerman & Pederson, 1992; Bowerman & Choi, 2003). Levinson et al. (2003) used this battery to test adult speakers of nine languages, asking for each picture "Where is the (figure object)?". Ten informants were queried, and the data were summarized in terms of the basic spatial adpositions that were used by the majority of the informants in each language, for each picture. Levinson et al. (2003) reported substantial cross-linguistic variation in the pattern of encoding across pictures, and concluded: "there is no cross-linguistic agreement on large IN, ON, or other categories" (p. 496). In their examples, scenes that seem to be clear instances of containment (apple in bowl) were grouped together with a fish in a bowl in one language, but not another; a scene that seems a clear example of support (apple on table) was grouped together with a boat on water and a dog on mat in one language, but not another.

Such variation is hard to evaluate, however. First, the picture battery had little theoretical structure; the 71 items spanned a wide variety of spatial relations that might or might not be conceptualized as belonging to the containment/support domain, thus limiting the inferences that can be made based on individual language groupings and data from small numbers of informants (sometimes as few as 2). Second, the idea that particular configurations are more likely to be encoded by the basic spatial terms suggests that there is a probabilistic relationship between the two. Basic spatial terms need not apply always and only to certain configurations to support the notion that there are universal preferences, but evaluating this idea requires going beyond the modal use of a term by individuals in a language group, and eliciting larger amounts of data from groups of informants, considering their patterns of use across a wide range of exemplars.

Gentner and Bowerman (2009) sought to discover organizing principles between spatial categories and their linguistic encoding in children by using a portion of the same battery. They focused on containment and support relationships, testing the idea that there are universal constraints on which configurations children would most readily map to their basic spatial terms. Children ages 2–6 who were learning either Dutch or English were shown eight containment scenes (e.g., cookie in bowl, candle in bottle) and 24 support scenes which were divided evenly among three different subtypes of support that vary in their cross-linguistic frequency. English encodes all of their subtypes with the single adposition *on*, but Dutch encodes them using distinct terms—*op* for solid support from below (e.g., cookie on plate), *aan* for "tenuous support" (e.g., clothes on line), and *om* for encirclement or surrounding (e.g., a necklace on a neck). Gentner and Bowerman found that children learning both Dutch and English mastered usage of terms for the containment scenes by age 3, suggesting a developmental priority for configurations representing containment. By contrast, children's mastery of the support terms varied over language group: All subtypes were mastered early by English-speaking children, who simply used a single term (*on)* for all, but much later by Dutch-speaking children, who mastered *op* early, but struggled with *aan* and *om*, first over-generalizing *op* and only later mastering them.

Gentner and Bowerman's findings of special priority of terms for containment over support, as well as the relative difficulty of learning specific terms for support, suggest that there are important constraints on learners' hypotheses about the potential meanings and uses of the basic terms in these domains. They also suggest that there are commonalities across learners that reveal themselves in both the ease of acquisition of certain subtypes (e.g., containment, support from below) and the difficulty for others (e.g., support by encirclement). Such constraints constitute important evidence for universal concepts or categories underlying the acquisition of basic spatial terms. To our knowledge, this study remains the only one to use a theoretically-structured battery to examine possible cross-linguistic commonalities in how children structure the domains of containment and support for the purposes of spatial language.

1.1. Current study

The goal of the current study is to contribute to our understanding of the mature representation of spatial language and its acquisition by children, focusing on containment and support. Our study began with the fairly classical assumption that there are significant commonalities in the way that both children and adults (even if they speak different languages) structure the two domains for the purposes of expressing spatial relationships. Unlike several classic accounts, however, our study went beyond the simple "word to concept" mapping by assuming that the semantic space of containment and support is both principled and complex, and thus one would have to look at detailed semantic profiles within each of these relations to capture the intricacies of spatial language and its acquisition. More specifically, we hypothesized that adults and children structure each of the broad semantic categories of containment and support internally as a set of semantic subtypes, including types that are represented as more central or "core" to each semantic domain. Such core subtypes are not simply more frequent, but also more canonical, in some deep sense, within the semantic domain (see below for details). We tested this hypothesis by probing in detail the nature of underlying structure in the domains of containment and support in 4-year-old children and adult speakers of two typologically distinct languages, English and Greek. Adults clearly represent the mature state for use of spatial expressions, providing us with a picture of the end-state across two different languages. Four-year olds are informative in another way: They represent a group who has learned to produce and understand at least some uses of the basic spatial terms we investigate, but have not fully acquired all uses (e.g., Gentner & Bowerman, 2009). Thus, they provide us with a vehicle to test whether certain core subtypes might be easier to acquire than others.

To accomplish our goals, we created a detailed spatial battery with realistic stimuli (photographs) depicting containment and support scenes. Within each of these two spatial domains, we defined several subtypes of interest inspired by theoretical studies of spatial terms (Landau & Jackendoff, 1993; Talmy, 1983), empirical studies showing cross-linguistic distinctions in the domains of containment (e.g., Bowerman & Choi, 2003; Narasimhan & Brown, 2009) and support (e.g., Gentner & Bowerman, 2009; Levinson & Wilkins, 2006), and infant studies documenting basic distinctions at the heart of early spatial event categories (Baillargeon et al., 2012). Crucially, our subtypes emphasized both physical/geometrical, but also functional and mechanical aspects of spatial configurations (Coventry et al., 1994; Vandeloise, 2005, 2010). Even though some of these subtypes have so far only been documented in languages outside our sample, we believe that a closer look at spatial encoding patterns in English and Greek might reveal sensitivity to some of these distinctions in ways that would otherwise be hard to detect (see also Gürcanli & Landau, 2008; Johanson & Papafragou, 2014, for support of this broad point).

Specifically, within Containment, we identified two cross-cutting dimensions, Full versus Partial Containment (apple in bowl vs. carton in bowl) and Loose versus Tight Fit (bunny in bag vs. ice cube in tray). All of these capture what we normally think of as straightforward cases of containment, albeit with some variation that has been discussed as important in a number of languages (for Full vs. Partial Containment, see the spatial systems of Hindi, Narasimhan & Brown, 2009; and Tiriyo, Levinson et al., 2003; for Loose versus Tight Fit, see Korean, Bowerman & Choi, 2003; cf. Gürcanli & Landau, 2008). Together, we hypothesized that these four subtypes represent core types of containment, with the combination of Full Containment/Loose Fit (as in the scene of an apple in a bowl) perhaps being the most central of all (see Gentner & Bowerman, 2009). This hypothesis is consistent with evidence that sensitivity to Full/Partial Containment (whether tight or loose) is an early hallmark of physical reasoning: Infants have formed a category of containment and realize that physically contained objects move with their container by about 2.5–3 months of age (Hespos & Baillargeon, 2001a), with further features of containment related to tightness of fit and degree of containment emerging shortly afterward (e.g., the relevance of the width of a container appears by 4 months; Wang, Baillargeon, & Brueckner, 2004; the role of the relative height of a container for the visibility of the contained object emerges by 7.5 months; Hespos & Baillargeon, 2001b, 2006). The Containment set also included Interlocking Containment (e.g., plug in outlet) and Embedded Containment (e.g., a hole in the socks) scenes. Interlocking and Embedding relationships seem quite different from the type of containment typical of the first four subtypes and have been linked to less stable uses of basic containment expressions compared to more canonical containment scenes across languages (see Levinson & Wilkins, 2006).

Within Support, we distinguished between "Gravitational" Support (solid supporting surface below, as in book on table), versus Embedded Support (e.g., flower on cup), Support via Adhesion (e.g., stamp on envelope), Support via Hanging (e.g., coat on hook), and Support via Point-attachment (e.g., leaf on stem). Gravitational Support was hypothesized to be the "core" feature of support relations. This hypothesis was motivated by the observation that Gravitational Support seems to be important for spatial encoding cross-linguistically (Levinson & Wilkins, 2006; Terzi & Tsakali, 2009). This hypothesis was also based in part on the finding that children learning Dutch failed to learn the specific term for Point-attachment until quite a bit later than the more general term for Gravitational Support (*on*; Gentner & Bowerman, 2009). The core role of Gravitational Support is also consistent with the fact that this category emerges early in development: infants around 4 or 5 months know that, when an object is placed on top of a supporting surface, the surface blocks the fall of the object (Baillargeon et al., 2012). The other types of support were generated as options for mechanisms that did not involve support from below (and were considered more peripheral). These options are lexicalized in several languages that possess support expressions but to more variable degrees (Bowerman & Choi, 2003; Levinson & Wilkins, 2006).

For each subtype and exemplar, we asked English- and Greek-speaking children and adults to answer the question "Where is X?," focusing our analyses on the "basic locative construction" (Levinson & Wilkins, 2006), for example, in English, BE *in/on*. This assumes that languages typically have a dedicated set of closed class items that are used to encode spatial relationships. Specifically, it assumes that spatial adpositions (either pre- or postpositions) are key terms used to encode location (Landau & Jackendoff, 1993; Talmy, 1983). We hypothesized that speakers of each language would distribute their use of the basic construction differentially across subtypes within each broad domain, with core subtypes eliciting the highest proportion of basic constructions. We also examined what children and adults said when they did *not* use basic spatial constructions. We reasoned that spatial verbs (e.g., *hang, attach, stick*, etc.) might also be used to describe certain kinds of spatial relationships and in some cases may even be more felicitous. We hypothesized that such spatial verbs, which can more adequately encode the force-dynamic mechanism by which the figure can be located, are more likely to be recruited for subtypes that represent less central kinds of containment or support. Therefore, where pertinent, we also analyzed participants' use of lexical verbs (as distinct from the basic locative expressions, which use tensed forms of the main verb BE, for example, *is*, plus a preposition).

Beyond these broad hypotheses, we asked whether the distributions of basic locative constructions within each domain were similar among young 4-year-old children and adults of each language, suggesting a similar starting point for children learning each language, or alternatively, whether the child and adult encodings would reveal more difference than similarity. One could imagine that children might be more limited in their application of the dedicated terms than adults, confining their use of basic adposition constructions only to core exemplars or subtypes. Alternatively, it is possible that children might apply these dedicated terms to a much wider range of types than adults, essentially over-generalizing use of the terms. Finally, it is possible that different patterns could hold for the two categories of containment and support. Notice that, even though locative expressions such as *in* and *on* are known to appear around age two in English and across languages (Bowerman, 1996; Johnston & Slobin, 1978), we know virtually nothing about how children's meanings for these terms are structured and whether or how they are applied to a broader, adult-like range of spatial referent scenes. Moreover, we know that other aspects of the acquisition of spatial language continue through the age of 5 and beyond cross-linguistically (e.g., Johanson & Papafragou, 2014; Munnich & Landau, 2010; Papafragou, Massey, & Gleitman, 2002).

Finally, we looked for similarities and differences in how native speakers of English and Greek used their basic construction across the subtypes that we defined within each domain. Both languages belong to the Indo-European family and convey static containment and support through prepositions—*in* and *on* in English and *mesa* and *pano* in Greek (the latter typically appear within the complex prepositions *mesa se* and *pano se* when combining with a noun phrase referring to the reference object; Terzi, 2010; Terzi & Tsakali, 2009). However, it remains unknown whether the use of these prepositions is sensitive to the same semantic distinctions (subtypes) in the two languages. Furthermore, the overall spatial systems of the two languages vary in ways that might affect the use of the basic spatial construction to describe containment and support (at least in adults). First, Greek has been characterized as a verb-framed language (Papafragou et al., 2002; after Talmy, 1985), in which verbs of motion incorporate the path but not the manner (which may then be encoded as a participle or other modifier). Several spatial subtypes in our battery that rely on mechanical or force-dynamic properties (especially mechanisms of support such as hanging, attaching, sticking, etc.) could be considered a kind of manner; we might thus expect lower rates of lexical verb production for those subtypes in Greek compared to English speakers, and correspondingly higher rates of basic spatial constructions. Second, Greek tends to be a language where pragmatic inferences in the spatial domain are rich and differ somewhat from English. For example, unlike English, Greek has an all-purpose locative preposition *se* ("at") that can be interpreted as involving a variety of spatial relationships, including containment and support, depending on the context (see Holton, Mackridge, Filippaki-Warburton, & Spyropoulos, 2012). Thus, a configuration showing an apple in a bowl could be expressed grammatically by "to milo ine sto bol" (lit. "the apple is at the bowl"), where the two objects are named, and the specific relationship is inferred (see also Papafragou, Massey, & Gleitman, 2006, for related evidence that manner of motion is specified in Greek when it cannot be inferred). It is possible that Greek speakers might be less likely than English speakers to specify non-core aspects of containment and support (e.g., various specific mechanisms of non-gravitational support) in their linguistic descriptions and might instead relegate these relations to pragmatic inference.

In sum, we defined several semantic subtypes within the domains of Containment and Support and used them to guide hypothesis-testing about the nature and acquisition of spatial language. We asked, among other things, (a) whether there would be internal structure to the categories—more specifically, whether the core subtypes for containment and support (i.e., Full and Partial Containment; Gravitational Support) would elicit different linguistic marking from the other subtypes, and (b) whether these patterns would be respected across languages (English vs. Greek) and ages (4-year olds vs. adults). Our three main analytic questions were whether participants used the basic spatial construction differentially across the subtypes of the containment and support batteries within each language, whether child patterns in each language were similar to those of adults in that language, and whether adult–adult and child–child patterns were similar across the two languages.

2. Participants

We tested 16 adult native speakers of English or Greek, 16 4-year-old children learning English and 14 learning Greek (M = 4;4, range = 4;1–4;6). English-speaking adults were recruited from the undergraduate population at Johns Hopkins University and tested on campus; they were given course credit for participation. Greek-speaking adults were recruited and tested in Ioannina, Greece. They were either undergraduate students or recent college graduates. Children learning English were recruited from preschools and through advertisements and were tested at JHU. Children learning Greek were recruited in Ioannina, Greece, and tested at their preschools.

3. Design, stimuli, procedure

We created a novel battery of photographs depicting containment and support spatial scenes. Our battery included 24 scenes representing containment organized in terms of six subtypes (Full and Partial Containment, each crossed by Loose and Tight Fit; Interlocking; and Embedded Containment) and 20 scenes representing support, organized in terms of five subtypes (Gravitational Support; Embedded Support; Support by Adhesion; Support by Hanging; and Support by Point-attachment). Within each relation, each subtype was represented by four exemplars (see Fig. 1 for one exemplar per subtype; the full battery is shown in Appendix S1).

Each of the 44 scenes included two objects, one of which was designated the figure object (shown by an arrow in the scene), and the other as ground object (surrounded by a thin white outline, illustrated in Fig. 2). In addition to the 44 test scenes, 36 filler scenes were included. The fillers displayed other spatial relationships such as piercing and encirclement, which are known to elicit less frequent use of basic locative constructions (Levinson & Wilkins, 2006) and indeed, rarely elicited these expressions. We do not analyze these filler items.[2]

Adults were tested using a Powerpoint program that displayed the following instructions:

> We are interested in how different languages encode spatial relationships between objects. You are going to view some slides in which an object is in some spatial relationship with another object. Your task will be to look at each slide, and then answer the question "Where is (the object pointed to by the red arrow) with respect to (the circled/outlined object)?"

Adult participants were shown a practice item, with a sample sentence, for example, "The shoe is next to the box." They then viewed each scene and typed their response into a spreadsheet. Because we hypothesized that some of the scenes might be more acceptable instances for using the basic spatial construction, participants were also told, "If the

Containment sub-type	Example scene	Support sub-type	Example scene
Full containment, Loose-fit	 *Apple in bowl*	Gravitational support	 *Cup on plate*
Full containment, Tight-fit	 *Paper in box*	Embedded	 *Picture on mug*
Partial containment, Loose-fit	 *Book in box*	Adhesion	 *Stamp on envelope*
Partial containment, Tight-fit	 *Cup in sleeve*	Hanging	 *Coat on hook*
Interlocking	 *Plug in outlet*	Point-attachment	 *Clothes on line*
Embedded	 *Crack in mug*		

Fig. 1. Subtypes of containment and support relations, with exemplars. Each subtype included four exemplars; all are listed in Appendix S1.

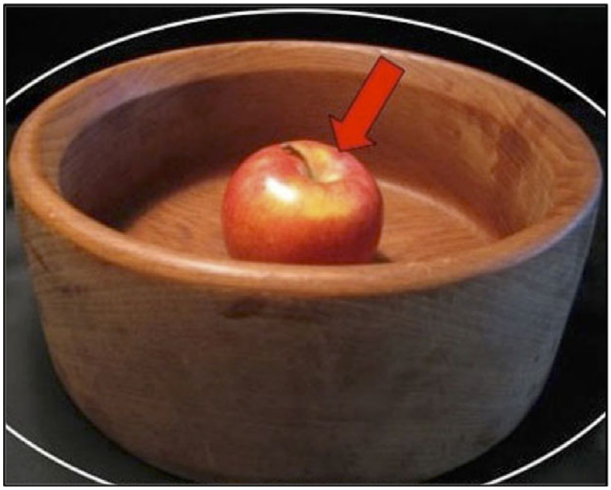

Fig. 2. Example of experimental scene. Figure object is designated by an arrow and Ground object is outlined in white.

expression you provided feels even a bit unnatural, please indicate this (in the space provided)." Participants placed a check in the space if they felt their description was unnatural and these data were used as a supplement to the basic analyses.

Children were shown a practice scene and asked, "What's the arrow pointing to?" After they answered with the name of the figure object, they were asked the name of the ground object. When they produced that, the experimenter asked, "Where's the (figure)?" using the term produced by the child. If there were gross errors of kind in the practice set, children were corrected. If children failed to answer with the name of the figure object or the ground object, the experimenter provided the names and then asked the children, "Where's the (figure)?" If children did not provide an answer at all, the experimenter would attempt to elicit a response with the following prompt: "The (figure) is (mmm)... the (ground)." Children's responses were videotaped/audiotaped for later transcription. Children were given two practice trials before the test sequence. All participants saw test stimuli in one of several randomized orders.

Participants' full responses were transferred to coding sheets that listed the noun for the figure object and ground object, the adposition, and any verb, including BE (or the Greek equivalent INE[3]). Native speakers of English and Greek transferred the data from participants in their own language group.

4. Results

We considered the basic spatial constructions in English to include BE plus the adposition *in* (for containment scenes) or *on* (for support). A limited number of BE *inside* uses were also coded as BE *in*. The corresponding terms in Greek included INE *mesa/mesa se* (containment) or INE *pano/pano se* (support). We also included a handful of interpretable but incorrect occurrences of the basic containment expression in the Greek child data (INE *mesa apo*). For simplicity, we henceforth refer to the basic spatial constructions in Greek as INE *mesa* (containment) and INE *pano* (support).

We analyzed the use of the basic spatial construction for the containment and support batteries separately, first examining patterns for children and adults within each language, then comparing children to adults within each language, and finally comparing adults across the two languages and children across the two languages. Our principal analyses examined the proportions of the basic spatial constructions compared to all other constructions. The raw data were codes of 1/0 (a binary distinction) for each item within each subtype, indicating each participant's use or non-use of the basic construction. We entered these data into mixed-model logistic regression analyses, using the MCMCglmm package for R (Hadfield, 2010). These analyses are well suited for accurately modeling the type of binary categorical outcome that we were interested in, that is, use or non-use of the basic construction (see Baayen, 2008 for the details of this model, as well as Jaeger, 2008 for comparisons to standard ANOVA). In each analysis, the Subtype was treated as a fixed-effect factor, and Subject and Scene (item) were treated as random-effect factors. The random-effects structure for each of the models included Subject and Scene random effects on model intercepts as well as Subject random effects on the slope of the model specified by the fixed effect of the Subtype.[4] Age was treated as an additional fixed-effect factor in a second analysis that compared children to adults within each language and Language was an additional fixed-effect factor in the third analysis comparing each age group across the two languages.

4.1. Containment

The proportions of use of BE *in*/INE *mesa* are shown in Fig. 3a for English-speaking adults and children and in Fig. 3b for Greek adults and children.[5] The most obvious pattern is that, as we had hypothesized, across all ages and both language groups, scenes showing Full and Partial Containment, both Loose and Tight, elicited the highest proportion of basic spatial expressions, with drops in usage for Interlocking and Embedding relations, especially the latter.

To examine the patterns statistically, we report four separate mixed-model logistic regression models, first looking separately at English adults, then 4-year olds, and then doing the same for Greek. In all four analyses, we included Subtype as the fixed effect, and Scene and Subject as random effects, with the random-effects structure described above; the best fitting models predicting the use of the basic expression (BE *in*/INE *mesa*) included these effects. To examine the details of the Subtype effect, we set regression coefficient weights to reflect a set of orthogonal contrasts among different Subtypes of containment relations,[6] determined *a priori* and reflecting hypothesized differences among containment relations in the Spatial Battery. Specifically, we had hypothesized that the "core" would include four subtypes of Full- and Partial- Containment (both Loose and Tight), with Full Containment/Loose perhaps most central of all. We therefore

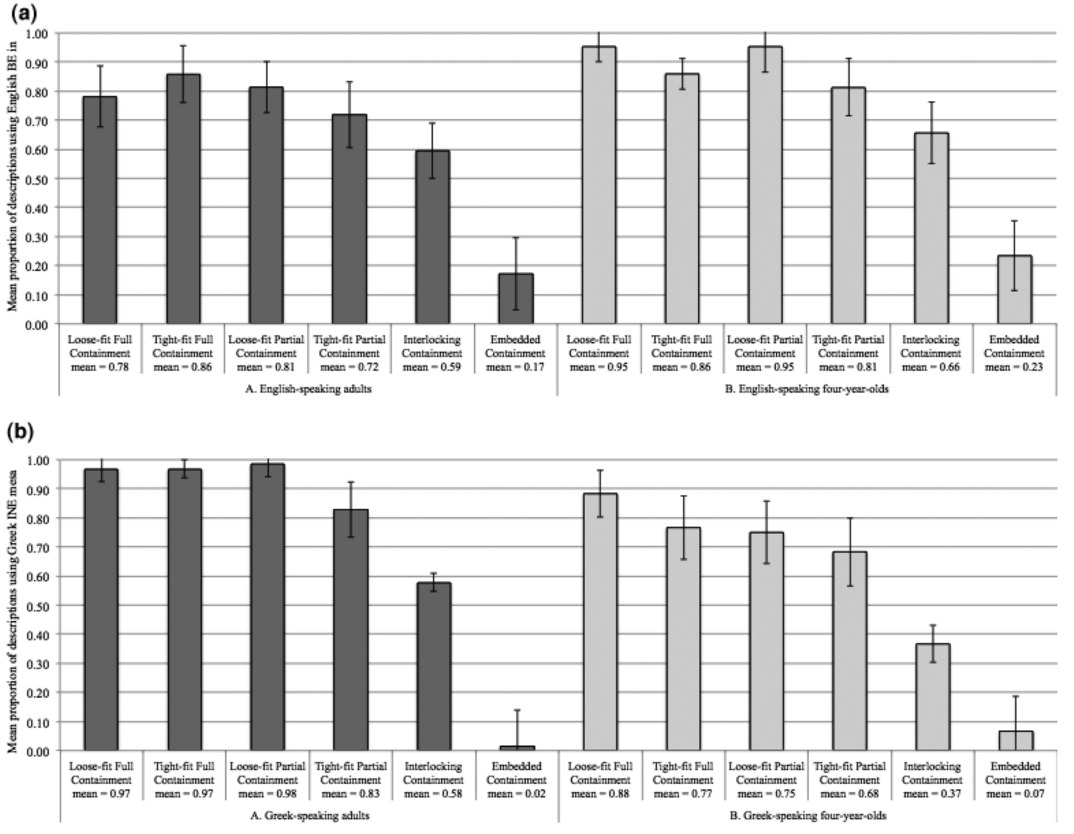

Fig. 3. (a) Mean proportions of English-speaking adults' and children's use of BE *in* across Containment subtypes. (b) Mean proportions of Greek-speaking adults' and children's use of INE *mesa* across Containment subtypes.

first compared Full versus Partial Containment and Loose versus Tight Containment, then all four postulated core subtypes to the more marginal subtypes of Interlocking and Embedded Containment, and then Interlocking to Embedded relations. Finally, we compared Full Containment/Loose to each of the other subtypes, to determine whether it had special priority.

4.1.1. English-speaking adults and children

Adults made several spatial distinctions in their uses of BE *in*. First, as we hypothesized, they used this expression more often for the "core" Containment relations (Full and Partial) than non-core Interlocking and Embedded relations ($\beta = 5.17$, 95% CI = 3.51–6.57, $p < .001$); they did not distinguish between the features organizing the four core subtypes (Full vs. Partial, Loose vs. Tight). Second, adults used BE *in* more for Interlocking than Embedded relations ($\beta = 1.75$, 95% CI = 0.72–2.91, $p < .01$). Third, they showed special priority for Full Containment/Loose, which we had hypothesized to be the most central of all subtypes: They used BE *in* more often for Full Containment/Loose compared to Partial Containment- Tight (β = 1.42, 95% CI = 0.64–1.94, $p < .05$), Interlocking (β = 1.86, 95% CI = 0.19–2.93, $p < .05$), and Embedded relationships (β = 4.51, 95% CI = 3.07–6.24, $p < .001$).[7] Adults also used BE *in* less often for Full Containment/Loose than Full Containment/Tight (β = −1.79, 95% CI = −3.40 to −0.35, $p < .05$); there were no differences between Full/Loose versus Partial/Loose.

The degree to which people used BE *in* was inversely correlated with whether they found their own description natural or not: As mean uses of BE *in* declined, people tended to more often mark their own descriptions as "unnatural" (Spearman rank-sum correlation, ρ = −0.49, $t(22) = -2.22$, $p < .05$). For example, describing a key as being "*in* a lock" was judged to be more unnatural than describing a teddy bear as being "*in* a bag."

When adults did not use BE *in*, they primarily used lexical verbs and these varied over subtypes, with greatest uses for Partial Containment/Tight, Interlocking, and Embedded. The percentages of lexical verb classes used are shown in Table 1.[8] Full and Partial Loose Containment elicited only posture verbs (12.5%, 18.8%, respectively, e.g., *sit, stand*); Partial Containment/Tight largely elicited verbs of manner of insertion (20.3%, e.g., *fit, insert*), Interlocking also elicited manner of insertion (34.4%), and Embedded elicited spatio-temporal verbs (26.6%, e.g., *extend, go*).

Children made similar distinctions to the adults in their use of BE *in.* They used this expression more often to describe the four core subtypes Full and Partial Containment (both Loose and Tight) than Interlocking or Embedded (β = 6.35, 95% CI = 4.67–8.25, $p < .001$), and more to describe Interlocking relations than Embedded relations (β = 1.66, 95% CI = 0.65–2.60, $p < .01$). In addition, the children showed special priority for Full Containment/Loose, using BE i*n* more often for this relation compared to Partial Containment/Tight (β = 1.78, 95% CI = 0.78–2.52, $p < .05$), Interlocking (β = 2.13, 95% CI = 0.77–3.64, $p < .001$), and Embedded subtypes (β = 5.49, 95% CI = 3.93–7.34, $p < .001$). The children made one additional distinction that adults did not: they used BE *in* more often for Loose-fitting than Tight-fitting Containment (β = 2.32, 95% CI = 0.23–4.72, $p < .05$).

Table 1
English-speaking adults' and children's responses across Containment Subtypes. The three entries correspond to BE *in*, lexical verb with adposition, or other, which largely included BE with other adpositions

	Adults (%)			Children (%)		
Containment	BE *in*	LexV	Other	BE *in*	LexV	Other
Loose-fit Full	78.13	12.50	9.38	95.31	0.00	4.69
Tight-fit Full	85.94	7.81	6.25	85.94	0.00	14.06
Loose-fit Partial	81.25	18.75	0.00	95.31	1.56	3.13
Tight-fit Partial	71.88	20.31	7.81	81.25	1.56	17.19
Interlocking	59.38	34.38	6.25	65.63	1.56	32.81
Embedded	17.19	26.56	56.25	23.44	3.13	73.44

Children also used the copula BE with a range of other adpositions that reflected different encodings of the spatial relationships (or errors in term use, e.g., *above, under, on top of*) as well as complex adpositional phrases such as *in the middle of* and *on the side of* (see Table 1). They used lexical verbs at very low rates (Mean = 1.3% over all subtypes).

These results suggest that the patterns for adults and children are quite similar. This was confirmed by adding Age (adult, 4-year old) as a second fixed effect. The analysis revealed that BE *in* was used more frequently for the hypothesized core subtypes, Full and Partial Containment, than for Interlocking or Embedded; and more for Interlocking than Embedded. BE *in* was used more for Loose-fitting than Tight-fitting Containment (β = 0.95, 95% CI = −0.039–1.86, $p < .05$), but this was modulated by the only significant interaction in the model, between Age and Tight versus Loose Containment subtypes (β = −0.94, 95% CI = −1.91–0.07, $p < .05$). Four-year olds produced BE *in* more often for Loose than Tight containment, while adults did not differentiate between the two types.

4.1.2. Greek-speaking adults and children

The Greek-speaking adults showed distinctions that were quite similar to those of their English counterparts. They used the basic spatial expression INE *mesa* more often when describing the four core subtypes, Full and Partial Containment, than they did for Interlocking and Embedded Containment relations (β = 14.24, 95% CI = 8.82–21.10, $p < .001$), and they used INE *mesa* more for describing Interlocking relations compared to Embedded relations (β = 4.89, 95% CI = 2.31–7.93, $p < .001$). These adults also showed special priority for Full Containment/Loose, using INE *mesa* at reliably greater rates than for Partial Containment/Tight (β = 1.46, 95% CI = 0.53–2.10, $p < .05$), Interlocking (β = 2.86, 95% CI = 0.80–5.81, $p < .05$), and Embedded subtypes (β = 10.85, 95% CI = 7.25–14.31, $p < .001$). Greek speakers tended to mark as "unnatural" those scenes which elicited lower uses of INE *mesa* (ρ = −0.68, $t(22) = -4.37$, $p < .01$).

Greek adults rarely used lexical verbs instead of INE *mesa*; the subtype with the most frequent use of lexical verbs was Interlocking, with the most dominant verb class manner of insertion (6.2%, see Table 2). This low rate of lexical verb use differed substantially from the pattern shown by English adult speakers, who used lexical verbs fairly frequently for Interlocking and Embedded. However, the relative proportions were similar, with Partial Containment/Tight and Interlocking eliciting the largest proportions of lexical verbs in both groups.

Like the other groups, Greek-speaking children used INE *mesa* more frequently for the hypothesized core subtypes, Full and Partial Containment, than for Interlocking and Embedded (β = 6.77, 95% CI = 5.07–8.63, $p < .001$), and they used it more for Interlocking relations than Embedded relations (β = 1.54, 95% CI = 0.24–2.89, $p < .05$). They showed some priority for Full Containment/Loose, using INE *mesa* more often for that subtype compared to Interlocking (β = 1.23, 95% CI = 0.11–2.31, $p < .05$) and Embedded relations (β = 2.29, 95% CI = 0.95–3.59, $p < .01$). Interestingly, these children also distinguished between Loose and Tight-fitting Containment, using INE *mesa* more for the former (β = 1.28, 95% CI = −0.18–2.84, $p < .05$); this effect was similar to

Table 2
Greek-speaking adults' and children's responses across Containment subtypes. The three entries correspond to INE *mesa* ("BE *in*"), lexical verb, or other expression, which included *se* (all-purpose locative), other adposition, or no adposition (i.e., omission)

	Adults (%)			Children (%)		
Containment	INE *mesa*	LexV	Other	INE *mesa*	LexV	Other
Loose-fit Full	97.00	0.00	3.00	88.30	0.00	11.70
Tight-fit Full	96.80	0.00	3.20	76.70	0.00	23.30
Loose-fit Partial	98.40	0.00	1.60	75.00	0.00	25.00
Tight-fit Partial	82.80	1.60	15.60	68.30	6.70	25.00
Interlocking	57.80	6.20	36.00	36.70	8.30	55.00
Embedded	1.60	0.00	98.40	6.70	21.70	71.60

English-speaking children, but it was not observed among adult speakers of either English or Greek. The children used lexical verbs to describe 5.7% of Containment scenes, somewhat more than the English-speaking children; but like both adult groups, these uses clustered in the subtypes of Partial Containment/Tight, Interlocking, and Embedded.

Greek-speaking children were overall quite similar to their adult counterparts. Adding Age as a second fixed effect revealed that Greek adults produced a greater proportion of INE *mesa* expressions than Greek 4-year olds ($\beta = 0.49$, 95% CI = 0.06–1.01, $p < .05$). However, both groups used INE *mesa* for the core subtypes Full and Partial Containment than for Interlocking or Embedded; and more for Interlocking than Embedded. The only reliable interaction between Age and Subtype reflected that adults showed a greater difference in INE *mesa* use than children did when comparing the core Full and Partial Containment relations versus Interlocking and Embedded ($\beta = 1.08$, 95% CI = 0.09–2.07, $p < .05$).

4.1.3. Cross-linguistic comparisons

The patterns across the two languages were quite similar. Adding Language as a fixed effect to the model for the Greek and English-speaking adults resulted in no main effect of Language, but one interaction: There was a larger difference between Full/Partial Containment compared to the other two subtypes among Greek speakers, relative to English speakers ($\beta = -1.73$, 95% CI = −2.76–0.80, $p < .01$). This was due to higher proportions of the basic construction INE *mesa* usage among Greek speakers for Full and Partial Containment. The same analysis for Greek and English-speaking children showed lower use of the basic construction overall among Greek-speaking children ($\beta = 0.54$, 95% CI = 0.038–1.09, $p < .05$), but no interactions between Subtype and Language.

4.1.4. Summary for containment

Adults and children of both language communities showed similar differentiation across Containment subtypes in their use of the basic locative expression. As expected, both English and Greek-speaking adults made a broad distinction between Full and Partial Containment (both Tight and Loose Fit), which elicited more frequent uses than either

Interlocking or Embedded subtypes. In addition, Interlocking elicited more uses of the basic construction than Embedded. Both English and Greek-speaking 4-year olds made the same distinctions, and added Loose versus Tight Fit, with the former eliciting more of the basic construction than the latter. Thus, the broad distinction between our four "core" subtypes and the other two appear in all groups. The distinction between Loose and Tight-fit is made by both English- and Greek-speaking 4-year-old children, but disappears among adults, leaving only Partial Containment/Tight cases to show diminished use of the basic construction, at least compared to Full Containment/Loose. Lexical verbs then appear more prominently in adult descriptions for Partial Containment/Tight cases.

4.2. Support

The proportions of use of BE *on*/INE *pano* are shown in Fig. 4a for English and Fig. 4b for Greek. As we had hypothesized, the patterns for support across subtypes

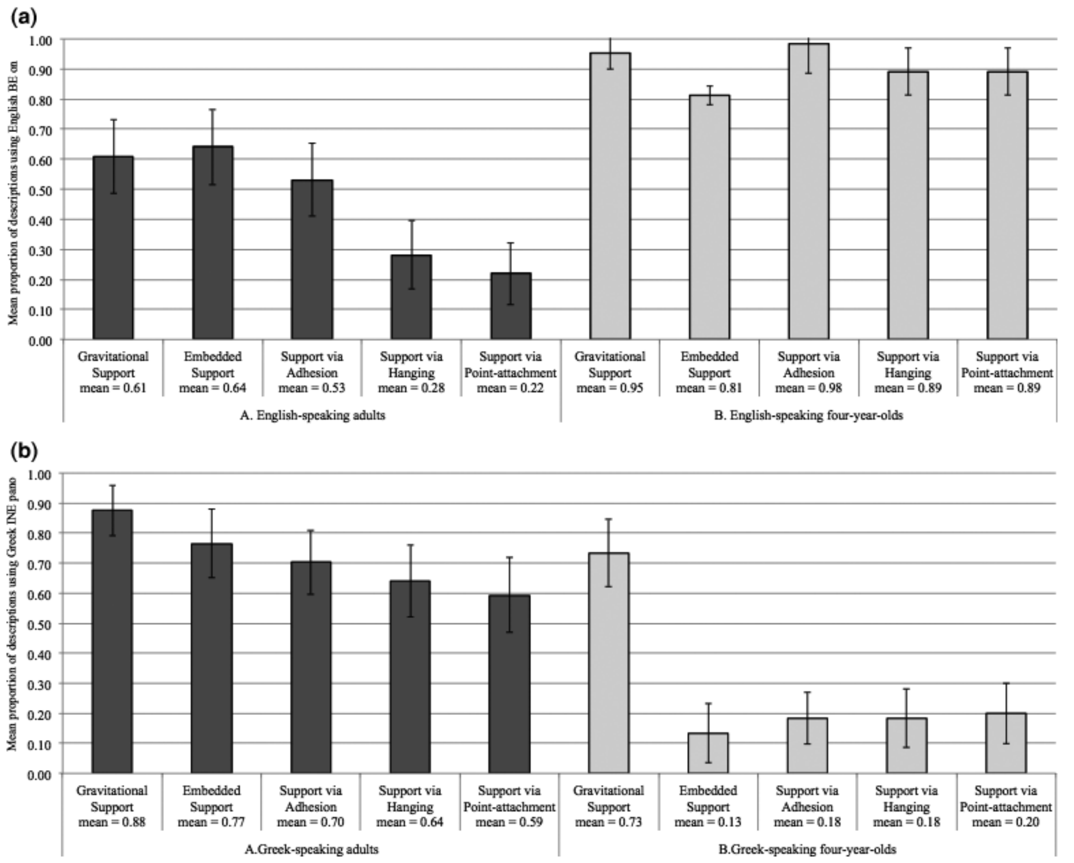

Fig. 4. (a) Mean proportions of English-speaking adults' and children's use of BE *on* across Support Subtypes. (b) Mean proportions of Greek-speaking adults' and children's use of INE *pano* across Support Subtypes.

generally exhibited high levels of the basic construction for the Gravitational (support from below) subtype. Other subtypes showed varying levels of use depending on language and age.

We again report four separate mixed model logistic regression models, first looking at English adults and 4-year olds, and then doing the same for Greek. We again included Subtype as the fixed effect, and Scene and Subject as random effects; the best-fitting models predicting BE *on*/INE *pano* use included all of these effects. Our *a priori* hypothesis was that the Gravitational Support subtype is the core, and therefore would elicit the most robust use of BE *on*/INE *pano*, with other subtypes, reflecting a variety of mechanical support mechanisms, eliciting less usage. We therefore defined a first contrast to test for differences between Gravitational Support (i.e., support from below) and the group of four different types of mechanical support—Embedded Support, Support via Adhesion, Hanging, and Point-attachment. We then defined three additional orthogonal contrasts to test for differences among the mechanical support relations, with comparisons of Embedded and Adhesion versus Hanging and Point-attachment relations, Adhesion versus Embedded, and Hanging versus Point-attachment.

4.2.1. English-speaking adults and children

As Fig. 4a shows, English-speaking adults used BE *on* most frequently for Gravitational Support, Embedded and Adhesion, with lower uses for Hanging and Point-attachment. Our *a priori* hypothesis that Gravitational Support would elicit more uses of BE *on* than the other relations was tested using the logistic regression model, which confirmed higher usage of BE *on* for Gravitational Support than for the group of four other Subtypes of support ($\beta = 1.32$, 95% CI = 0.25–2.43, $p < .05$). We also found that within the other four subtypes, adults used BE *on* more for Embedded and Adhesion compared to Hanging and Point-attachment ($\beta = 3.64$, 95% CI = 2.17–5.16, $p < .001$). No other comparisons reached significance.

As the data in Fig. 4a indicate, the reliable difference between Gravitational Support and the other subtypes was probably driven by low BE *on* use for Hanging and Point-attachment, since Embedded and Adhesion looked quite similar to Gravitational Support. We therefore conducted an additional set of *post hoc* pair-wise comparisons, using a separate mixed logistic regression model, which compared BE *on* use for Gravitational Support to each of the other four subtypes. English-speaking adults used BE *on* at a greater rate for Gravitational Support compared to Hanging ($\beta = -2.79$, 95% CI = −4.29 to −1.31, $p < .001$) and Point-attachment relations ($\beta = -4.12$, 95% CI = −6.79 to −1.97, $p < .001$), but did not differ, statistically, from Embedded or Adhesion. Marking an expression as “unnatural” for a given scene was not reliably correlated with lower uses of BE *on* ($\rho = 0.11$, $t(18) = 0.49$, ns.).

When adults did not use BE *on*, they used lexical verbs that varied over subtypes (see Table 3). Gravitational Support elicited only posture verbs, as had Full and Partial Containment; these posture verbs did not appear for any other subtypes. Embedded elicited verbs describing how the embedded figure was created (e.g., *paint, draw*), and both

Table 3
English-speaking adults' and children's responses across Support Subtypes. The three entries correspond to BE *on*, lexical verb with adposition, or other, which largely included BE with other adpositions

	Adults (%)			Children (%)		
Support	BE *on*	LexV	Other ad	BE *on*	LexV	Other ad
Gravitational	60.94	20.31	18.75	95.31	0.00	4.69
Embedded	64.06	15.63	20.31	81.25	0.00	18.75
Adhesion	53.13	15.63	31.25	98.44	0.00	1.56
Hanging	28.13	59.38	12.50	89.06	3.13	7.81
Point-attachment	21.88	78.13	0.00	89.06	4.69	6.25

Adhesion and Hanging as well as Point-attachment elicited spatio-mechanical verbs (e.g., *attach, connect, stick* and *hang, hold, tie*, respectively).

Unlike the adults, 4-year olds did not show systematic variation in their use of BE *on* across different subtypes. The comparison between Gravitational and the set of other subtypes did not show a reliable effect ($\beta = 2.57$, 95% CI = −0.66–5.72, $p = 0.14$). In a set of *post hoc* pair-wise comparisons like those conducted for adults, only one statistically significant distinction emerged, reflecting greater BE *on* production for Gravitational Support compared to Hanging ($\beta = -3.09$, 95% CI = −7.15 to −0.16, $p < .05$). The children occasionally used the copula BE with other adpositions (*in, between, under*), including complex phrases such as *in the middle of*. They used lexical verbs very rarely (Mean = 1.5% over all subtypes).

Clearly, English-speaking adults and 4-year olds showed very different patterns of BE *on* in their description of Support relations. Adding the fixed effect of Age to the previous model, we found that English 4-year-old children used BE *on* more frequently across the entire set of support relations than adults ($\beta = -1.41$, 95% CI = −2.04 to −0.74, $p < .001$). Results for the effect of Subtype were similar to the findings for adults alone: BE *on* was used reliably more often for Gravitational Support relations compared to the other support relations ($\beta = 0.89$, 95% CI = 0.22–1.78, $p < .05$), and it was used more often for Embedded and Adhesion compared to Hanging and Point-attachment ($\beta = 1.66$, 95% CI = 0.81–2.53, $p < .001$). However, this finding was clearly due to the robust pattern among adults, since the children showed no detailed pattern across subtypes. Consistent with this, age interacted with subtype: Adults used BE *on* more for Embedded and Adhesion than for Hanging and Point-attachment relations, but 4-year olds did not ($\beta = 1.10$, 95% CI = 0.12–1.85, $p < .05$). In addition, Adhesion elicited more BE *on* use than Embedded for 4-year olds, but the adults showed the opposite pattern ($\beta = 0.79$, 95% CI = 0.07–1.46, $p < .05$).

4.2.2. Greek-speaking adults and children

Greek-speaking adults' use of INE *pano* was similar to English-speaking adults' use of BE *on* (Fig. 4b). A logistic regression model showed that the adults used INE *pano* more often for the hypothesized central subtype, Gravitational Support, compared to all other subtypes, though this difference only approached traditional significance (β = 2.09, 95% CI = 0.67–4.54, $p < .06$). All other comparisons failed to reach significance. As with the English adult data, we supplemented these analyses with a *post hoc* model of pair-wise comparisons between Gravitational Support and each of the other subtypes. These comparisons showed that Greek-speaking adults used INE *pano* more often for Gravitational Support compared to Hanging (β = −2.42, 95% CI = −5.30–0.12, $p < .06$) and Point-attachment (β = −2.73, 95% CI = −5.46–0.07, $p < .05$), though the first difference was marginally reliable. Greek adults tended to mark as "unnatural" those scenes which elicited lower uses of INE *pano* (ρ = −0.64, $t(18) = -3.50$, $p < .01$).

Although they had rarely used lexical verbs for the Containment subtypes, Greek adults did use lexical verbs about 15–20% of the time for subtypes other than Gravitational Support (see Table 4), again showing distribution that complemented use of INE *pano* across subtypes. The dominant verbs they used for each of the subtypes were the same as those used by English-speaking adults, even though their rates of use were lower.

Like the Greek-speaking adults, Greek-speaking 4-year olds used INE *pano* more frequently for the hypothesized central subtype, Gravitational Support, compared to the other subtypes as a whole (β = 4.05, 95% CI = 2.52–5.88, $p < .001$; Fig. 4b). The children did not show any other reliable differences in use of INE *pano* among the other subtypes. An additional *post hoc* model of pair-wise comparisons showed that INE *pano* was used more frequently for Gravitational Support than for each of the other subtypes (Embedded: β = −5.23, 95% CI = −7.65 to −2.67; Adhesion: β = −4.67, 95% CI = −7.16 to −2.43; Hanging: β = −4.58, 95% CI = −6.89 to −2.24; Point-attachment: β = −4.37, 95% CI = −6.91 to −2.25, all reliable at $p < .001$). Children used lexical verbs approximately 22% of the time overall, and their uses across subtypes paralleled that of the adults (Table 4).

Given the similar profile of adults and children (with highest uses of INE *pano* for Gravitational support), adding Age as a fixed effect revealed that overall use of INE *pano* was more frequent for Gravitational Support than for the group of other subtypes (β = 1.87, 95% CI = 0.78–2.95, $p < .05$). In addition, adults used INE *pano* overall more frequently than children (β = 1.08, 95% CI = 0.41–1.81, $p < .01$). Children showed a

Table 4
Greek-speaking adults' and children's responses across Support Subtypes. The three entries correspond to INE *pano* ("BE on"), lexical verb, or "other," which combined uses of *se* (all-purpose locative), other adposition, and no adposition

	Adults (%)			Children (%)		
Support	INE *pano*	LexV	Other	INE *pano*	LexV	Other
Gravitational	87.50	3.10	9.40	55.00	0.00	45.00
Embedded	76.60	17.10	6.30	13.30	23.30	63.40
Adhesion	73.40	18.80	7.80	18.30	23.30	58.40
Hanging	64.10	18.60	17.30	18.30	33.30	48.40
Point-attachment	59.40	20.30	20.30	18.30	30.00	51.70

greater difference, compared to adults, in their use of INE *pano* for Gravitational Support compared to the group of other support relations (β = −0.82, 95% CI = −1.53 to −0.01, $p < .05$). Thus, children made a sharper distinction between Gravitational Support and other subtypes than adults.

4.2.3. Cross-linguistic comparisons

Fig. 4a and b suggest a few differences between Greek and English-speaking adults in their use of their basic expression over subtypes, but massive differences between the two child groups. Indeed, adding Language as a fixed effect to the basic model for adults showed just one interaction between Language and Subtype indicating a smaller difference between Embedded/Adhesion versus Hanging/Point-attachment for Greek speakers than English speakers (β = 1.24, 95% CI = 0.33–2.10, $p < .01$).

Adding Language to the model for children showed greater overall use of the basic expression by English-speaking children (β = 1.81, 95% CI = 1.01–2.52, $p < .001$), not surprising given that these children used BE *on* at very high levels, and with little discrimination over subtypes. By contrast, the Greek-speaking children showed a sharp distinction between Gravitational Support and other subtypes. The difference in patterns across the child groups was confirmed by an interaction of Language with Gravitational Support versus other subtypes (β = −1.19, 95% CI = −2.05 to −0.37, $p < .01$).

4.2.4. Summary for support

English- and Greek-speaking adults showed quite significant structure across support subtypes as reflected in their use of BE *on* and INE *pano*. As hypothesized, Gravitational Support in both groups elicited more frequent uses of these basic expressions than at least two of the other subtypes, Hanging or Point-attachment.

By contrast to the adult patterns, the two groups of child speakers varied sharply in their use of their language's basic expression across support relationships. Greek-speaking children showed a sharp distinction between Gravitational Support and all other means of support, while English-speaking children showed no distinction across any of the support relationships; these children used BE *on* indiscriminately across all subtypes. Notably, this meant that the children in both language groups showed a *less* structured pattern of distinctions across all subtypes than adults speaking their language. In particular, the secondary distinctions that adults had shown among Non-Gravitational Support relations (Embedded and Adhesion vs. Hanging and Point-attachment) did not appear in either group of 4-year olds.

5. General discussion

In this paper, we focused on the mapping between basic spatial terms and spatial relationships within the domains of containment and support—arguably two of the most basic categories that learners might bring to language acquisition. Our experimental investigation re-examined the traditional, simple view of spatial term learning, according to which learning spatial terms is a straightforward mapping from input onto preexisting spatial concepts, in the context of two challenges. First, uses of *in* and *on* (and their equivalents in other languages) often go beyond simple physical configurations in which one object is contained or supported by another. Second, cross-linguistic data and analyses have suggested to some that the cross-linguistic differences in the encoding of containment and support are significant enough that they suggest no simple pre-linguistic universals that can serve as the elements onto which basic spatial terms are mapped.

Our goal was to see whether a suitably expanded version of the traditional view could address both the richness of meanings encoded in terms such as *in* and *on* within a language and the variation in the encoding of containment and support across languages. Specifically, we tested the hypothesis that there are significant commonalities in the way that both adults and children learning different languages (here, English vs. Greek) structure the broad domains of containment and support for the purposes of language. Using a newly designed battery that included a range of spatio-mechanical relations for Containment and Support, we tested the hypothesis that the basic spatial adpositions in their most neutral construction (e.g., English BE *in/on* and Greek INE *mesa/pano*) would be distributed systematically and unevenly across distinct subtypes for each domain. In particular, we predicted the greatest use of these expressions for "core" subtypes within the domains of containment and support, specifically, Full and Partial (both Loose and Tight) Containment and Gravitational Support, and declining use for other subtypes such as Embedding and Interlocking (for Containment) or Adhesion, Embedding, Hanging, and Point-attachment (for Support). Even though, individually, the spatial features embodied in the battery have been examined by others in various studies (e.g., Bowerman & Pederson, 1992; Choi & Bowerman, 1991; Levinson et al., 2003), our study was the first to examine these subtypes comparatively and systematically, by querying both children and adults on multiple exemplars across each category and subtype.

We found several striking results. First, there were clear effects of internal subtype structure within each of the broader categories of Containment and Support. For Containment, Full and Partial containment configurations elicited more basic constructions than Interlocking or Embedded; for Support, Gravitational configurations elicited more basic constructions than Hanging or Point Attachment. Second, the two domains showed distinctly different subtype profiles across age and language. Containment elicited quite similar patterns across adults and children of both language groups in the profile of basic expressions across subtypes. Support, by contrast, showed similar patterns across adults of both language groups, but striking differences among the children. For both Containment and Support, child results did not pattern exactly with their same-language adult models, with small differences for Containment and very large differences for Support. Importantly, the children's data also suggest substantial complexity in how the language across the two domains is learned. As we discussed in the introduction, children's uses might have been very restrictive, with little generalization across the subtypes, or they might have been highly general, with lack of differentiation across the subtypes. Our results suggest that both of these patterns occurred, but for different domains, pointing to the need for more nuanced hypotheses about learning spatial language. Accordingly, we first discuss the profiles revealed within each category, and then return to the issue of how acquiring the mapping between adpositions and the two broad categories of containment and support might reflect somewhat different learning problems for the child.[9]

5.1. Core structure within containment and support

Containment elicited similar patterns across adults and children of both language groups in the use of the basic locative expression for their languages. All groups showed a first cut distinction between Full and Partial Containment (whether Tight or Loose fit) versus the subtypes of Interlocking and Embedding. Full and Partial Containment elicited the highest levels of basic expression, while Interlocking and Embedding elicited much lower levels. Although we had noted that Full Containment/Loose might be the most central of the four "core" subtypes, we did not find special priority for this subtype over each of the others. Not surprisingly, this subtype was differentiated from Interlocking and Embedded; more surprising, it was also differentiated from Partial Containment/Tight. This is of special interest as previous studies have used instances of Partial Containment/Tight fit to make the argument that English does not distinguish between tight and loose fit (e.g., Bowerman & Choi, 2003).

Full and Partial Containment (perhaps leaving aside Partial/Tight) thus represent those subtypes that could be considered core, eliciting the highest uses of the basic expression. In addition to this first broad cut among the subtypes, children made distinctions that were not respected by the adults. Children of both language groups made a distinction between Loose and Tight-fit relationships within Full and Partial Containment, with the Loose-fit relationships eliciting more frequent use of the basic expressions. These distinctions did not appear in the adult uses of BE *in* or INE *mesa,* and thus reflect *reduction* of these secondary distinctions in the adult usage patterns.

Note that we are not claiming that these distinctions are completely erased in the language of adults. In fact, we saw that Partial Containment/Tight fit was the outlier within the group of four core subtypes. Instead, we believe it is likely that, at least for English, these distinctions grow to be more often encoded by lexical verbs that reflect degree of fit and/or other aspects of meaning. Indeed, one of the salient facts about the English adult use of BE *in* for the four core Containment subtypes is that it did not reach ceiling, but hovered around 70–80% of the total expressions, compared to Greek adult rates of INE *mesa* which were closer to 100%. The lowest proportions of BE *in*/INE *mesa* was for Partial Containment/Tight (e.g., a pencil in a pencil sharpener). For this subtype, English-speaking adults used lexical verbs of manner of insertion (e.g., *insert, fit*). Greek adults did not use lexical verbs for any of the Containment subtypes, a point to which we return later.

In sum, the organization of the Containment subtypes was tight and quite similar across development and over two languages, supporting the idea that there is similar organization of the containment domain (at least, across our subtypes), with certain subtypes representing more central, or core kinds of configurations for child and adults speakers of different languages. The fact that Loose/Tight fit was respected by children but not by adults suggests that this property may be more widespread in languages of the world than one might suspect. Additional evidence shows that this property is respected by pre-linguistic infants (Hespos & Spelke, 2004) and by English-speaking adults in their language (Gürcanli, Wilson, & Landau, 2014; Norbury, Waxman, & Song, 2008).

Quite a different picture emerged for the category of Support. Adult speakers of English and Greek showed similar patterns, differentiating Gravitational Support from either Hanging or Point-attachment. Greek speakers used their basic expression, INE *pano*, more frequently than English speakers used BE *on,* but their distribution of uses across the subtypes was quite similar. Moreover, use of lexical verbs across the two adult groups was virtually identical, with posture verbs used exclusively for Gravitational Support, and other verbs also pegged to particular subtypes (e.g., *hang* for Hanging scenes, *draw, paint* for Embedding scenes).

By contrast, the children's uses of the basic expressions were strikingly different—both from each other and from their adult language-mates. English-speaking children showed an undifferentiated pattern of use for BE *on,* using it across the five subtypes with virtually no distinction. They used almost no lexical verbs. Greek-speaking children showed a highly differentiated pattern of use for INE *pano*, using it robustly for Gravitational Support, but negligibly for the remaining four subtypes. They used lexical verbs at low and constant rates across the non-gravitational subtypes, and these verbs were quite similar to those used by the adults, and at roughly the same levels.

5.2. Learning to talk about containment and support

The results for containment are consistent with our hypothesis that the internal structure of a spatial domain is robustly reflected by the distribution of uses of spatial adpositions in their most basic form—with a neutral verb, that is, one that does not add any additional spatial information. The patterns of usage for both English and Greek adult speakers, and for children learning these languages, were overwhelmingly similar. There were few lexical verbs used by any group except the English-speaking adults, who used lexical verbs that were specific to subtype. They confined their uses to posture verbs for Full and Partial Containment, and brought in verbs that described manner of insertion for Interlocking, and spatio-temporal verbs (*extend, go*) to describe Embedded relationships of negative parts (such as cracks, holes) relative to their ground object. Although it may be true that, in English, one can use the expression "plug in the socket" for interlocking relationships, or "crack in the table" for embedding ones, these expressions may not be felicitous answers to the question "Where is X?" Our adult English speakers produced lexical verbs for those instances where "X is in the Y" was not natural. For example, they often used "plugged" or "inserted" for cases of interlocking, "went" for cases of cracks (e.g., "the crack went across the table"), and sometimes change-of-state predicates to describe negative spaces (e.g., "the sock tore," rather than *"the hole is in the sock"). Our adult Greek speakers appeared to be more willing, overall, to use the basic expression INE *mesa*, most likely because Greek tends to allow much more spatial information to remain as part of pragmatic inference than does English (see also below).

The results for support also suggested internal structure to the category, reflected by use of the basic expression BE *on*/INE *pano*. But they also suggested complex interactions between the subtypes, the linguistic resources available to reflect these, and the age of the speaker. For adults, the patterns across English and Greek were quite similar: Gravitational Support elicited the basic construction more frequently than either Hanging or Point-attachment and lexical verbs that encoded the mechanism of support tended to be produced more frequently when the basic construction was not used. In addition, English-speaking adults produced fewer basic constructions overall than their Greek counterparts, and, reciprocally, more lexical verbs to reflect the specific mechanism of support. But the distribution of lexical verbs and their meanings suggest similar mechanisms of "filling in" important information about the different spatial configurations.

Thus, the adult data suggest that Gravitational Support is a core subtype for support but Hanging and Point-attachment are not. Adhesion and Embedded were not predicted to be core subtypes, but their levels of basic construction were no different from Gravitational Support for English or Greek speakers. Note, however, that the lexical verbs used for these two categories encoded specific mechanisms of support (like for Hanging and Point-attachment), while the lexical verbs used for Gravitational Support were only posture verbs—the same ones occasionally used for Containment relations. Posture verbs encode the orientation of the figure object, whereas the verbs used for the other subtypes encode the manner of support. We therefore tentatively conclude that Adhesion and Embedded do not form an equivalence class with Gravitational Support, but exactly how these differ from each other will require further study.

Finally, there were striking differences observed among children in their patterns of use for the support battery. Greek-speaking children produced a highly articulated pattern of use of the basic expression across subtypes. This echoed the adult patterns in showing high use for Gravitational Support and low use for Hanging and Point-attachment, but differed from either group of adults in also showing low use for Adhesion and Embedded. These children used lexical verbs at low rates, but principally among the four subtypes other than Gravitational Support, again demonstrating the centrality of that category for the basic construction. By contrast, the English-speaking children produced high levels of basic construction across all subtypes, reflecting little to no internal structure across the subtypes.

We believe that the striking contrast between the English and Greek-speaking children may be explained by the interactions among the subtypes, and the linguistic resources available to children, including the basic spatial adposition constructions and lexical verbs. In order to approximate the adult pattern, Greek and English-speaking children may face somewhat different learning problems. In Greek, as noted already, adults tend to use the basic construction more often for support than English-speaking adults, with few lexical verbs being brought in to describe the specific mechanism of support. This may reflect two broader facts about the language mentioned in the Introduction. Recall that Greek has been characterized as a verb-framed language (Papafragou et al., 2002; after Talmy, 1985), in which verbs of motion incorporate the path but not the manner (which may then be encoded as a participle or other modifier). If we consider the mechanism of support to be a kind of manner (e.g., hang, attach, stick, etc.), this could partially explain the Greek adult speakers' low rates of lexical verb production for those support subtypes that elicited many such verbs in English adult speakers. Relatedly, recall that Greek tends to be a language where pragmatic inferences in the spatial domain are rich, and omissions are therefore permissible and prominent (Papafragou et al., 2006). Thus, the mechanism of support in static spatial configurations need not be specified in the linguistic description produced, but it can simply be inferred. Given these tendencies, Greek learners are well on their way to acquiring the adult system, since they already show evidence of acquiring lexical verbs and using them at similar rates and for the same subtypes as the Greek adults. Nevertheless, the Greek children have not yet learned that Adhesion and Embedded belong to those subtypes that can be readily expressed by the basic expression INE *pano*.

Children learning English face a somewhat different problem. We know that English is a language rich in manner verbs (see Talmy, 1985) and that adult English speakers freely produce such verbs in answer to the question "Where is X" for certain subtypes. English-speaking 4-year-old children, however, show an undifferentiated pattern across subtypes and so have not yet learned to use more lexical verbs for certain subtypes, which would lead to a more articulated profile for the basic construction. Why do they fail to use lexical verbs at age four and how do they come to increase their usage for key subtypes? Recent evidence suggests that children and adults share more than is apparent in their representation of the subtypes, and that the learning problem centers on coming to know which verbs are optimal descriptors of different support subtypes. Johannes, Wilson, and Landau (2013, unpublished data) found that adults could be instructed in such a way as to induce the 4-year-old pattern, and vice versa. Specifically, when adults were instructed to refrain from using any lexical verbs in their descriptions of the same support scenes, their basic adposition construction distribution over subtypes was indistinguishable from that of 4-year olds, suggesting that it is indeed the introduction of lexical verbs that becomes crucial to an adult-like way of carving up the subtype space. Moreover, in the same study, when 4-year olds were given a forced-choice task, offering them a description using the basic construction (i.e., "X is on Y") versus a lexical verb that adults had produced in the original experiment (e.g., "X is hanging from Y"; "X is stuck on Y"), children preferred the adult-produced constructions (i.e., those with lexical verbs specifying mechanism of support). These results suggest that the child's job is to learn that these verbs are more felicitous answers to the question than the basic locative construction. Johannes et al. (unpublished data) find that this happens between ages 4 and 6—by which time, the children's distribution of BE *on* and their use of lexical verbs appear quite similar to that of adult speakers.

One remaining puzzle for the Support category is the adult use of subtypes of Embedded and Adhesion; these show usage patterns that appear to be somewhere in between Gravitational subtype and the Hanging/Point-attachment subtypes. One possibility is that the "core" category for Support should be broadened to include the concept of relationships highly resistant to separation of figure and ground. If the figure object is either embedded in or adheres to its ground, then support should be more robust than if it is either hanging or attached by a small point. If this is correct, then adults would show high use of the basic construction for these configurations as well as Gravitational subtypes, and children would hear these uses, learning them. A second possibility is that the uses of BE *on* for Embedded and Adhesion come into the language as a consequence of processes such as the process of semantic chaining, that is, extension of a word to conceptually similar entities, and thereon to other items (Malt, Sloman, Gennari, Shi, & Wang, 1999).

6. Conclusion

We have argued that both containment and support are core categories that are each internally structured into subtypes, with certain subtypes playing a more central role than others in the way that humans represent location via language. The subtype structure plays a crucial role in the mapping of basic spatial adpositions to instances in the two domains, and this structure guides both adults and children. These results point to the importance of universal ways of understanding spatial relationships of containment and support, and the importance of these categories and their internal structure in children's learning of spatial language.

The two categories we have focused on are heavily imbued with force-dynamic properties—indeed, some have argued that containment and support are primarily force-dynamic and only marginally based on geometric properties such as enclosure, contact, or proximity (Coventry et al., 1994; Vandeloise, 2005, 2010). We believe that this fact explains the powerful role played by lexical verbs in the carving up of the subtypes: Although the best answer to "Where is X" might recruit the basic adpositional construction for the most central subtypes, subtypes that represent less central kinds of containment or support are more likely to recruit lexical verbs that can more adequately encode the force-dynamic mechanism by which the figure can be located.

The fact that there were large differences between the containment and support batteries in the extent to which lexical verbs were recruited may indicate that the two domains are fundamentally different: Mechanisms of containment primarily embody relations between two volumes, one of which exerts control over the other (Coventry et al., 1994; Herskovits, 1986). Mechanisms of support, by contrast, vary enormously: One object can be supported by the other via gluing, taping, hanging, inserting, painting, and so forth—the range of verbs that capture the vast number of support mechanisms is large, simply because the mechanisms themselves vary so much. This view predicts that it should be difficult if not impossible to create containment scenes that engage the same range of lexical verbs as we found for support. It is possible, of course, that the two domains are more equivalent than we propose, but empirical literature does suggest that containment may be more primary in development than support. For instance, when infants are given an equally intensive learning experience, they make containment distinctions more readily than support distinctions (Casasola & Cohen, 2002; cf. Casasola et al., 2003).

The subtypes we have examined were developed using insights gleaned from the theoretical and empirical literature, and although they may not be perfect, we believe they have brought us back to a point, where we can confidently assert that there is a strong degree of organization within these two domains within the much broader arena of space, that both child and adult speakers of at least two languages show interesting commonalities in the ways that they organize the domains, and that these commonalities may indeed serve both as a starting point and even as an end point for mapping the basic language of space, when we ask “Where is it?”.

Acknowledgments

We acknowledge partial support from NIH grant #4R01HD055498 to Anna Papafragou, awarded by the Eunice Kennedy Shriver National Institute of Child Health and Human Development. We thank Taraneh Mojaverian for help in constructing the stimuli, and Joshua Viau for help with data collection. Kristen Johannes is now at WestEd of Oakland, CA, and Dimitrios Skordos is now at the University of California, San Diego.

Notes

1. Bowerman and Choi did not report use of postpositions (similar to prepositions in English) by Korean children or adults, so we do not know whether these terms were also used.
2. One might be concerned that children might have difficulty interpreting the scenes from two-dimensional pictures or might not produce enough relational language (compared to, for instance, situations where they would have to handle actual objects). We did not see evidence for such interpretive difficulties in our data.
3. We use the third-person singular of the copula in referring to the basic spatial construction in Greek.
4. The models were fit in MCMCglmm, using Markov chain Monte Carlo algorithms, with weak Bayesian priors on random effects and with the gelman prior covariance matrix, based on a scaled Cauchy distribution, applied to the Subtype fixed effect (see Gelman, Jakulin, Grazia Pittau, & Su, 2008). Coefficients reported for each model express log-odds ratio of the outcome, given the fixed-effect predictor.
5. Note that, while we show proportions in plots of basic spatial construction use, our analyses were based on binary data measuring the presence or absence of a given spatial construction by individual subjects on each trial.
6. Defining and interpreting the fixed effect coefficients, using a set of orthogonal contrast weights does not change the overall fit of the model. The coefficients can be interpreted as log-odds of using BE *in* weighted by the contrast values appropriate for the scene (i.e., based on the Subtype of Containment relation for that scene).

7. The Embedding relationship elicited the fewest expressions of BE *in* among English-speaking adults as well as English-speaking children, and Greek-speaking adults and children. The single most frequent adposition used for this category was "on" in English and its equivalent in Greek. This suggests that Embedding may be on the boundary of the two categories, Containment and Support.
8. We did not code the adpositions accompanying lexical verb use. In the English data*, in* and *on* adpositions co-occurred with these lexical verbs rarely, about 7% of the time across age groups. In the Greek data, the corresponding occurrence of *mesa* and *pano* was 2%.
9. Our project aimed at looking at how speakers actually *use or combine* the spatial lexical resources of their language to make inferences about semantic subtypes of containment and support. We recognize that one can infer linguistic meaning from usage only indirectly: Usage in a particular context is determined by many factors, for example, whether a term is available, whether it is familiar and/or frequent enough, whether there are alternative responses and whether participants have the requisite meta-communicative awareness to realize what is required of them in the task. Thus, a truth value judgment task might lead to somewhat different patterns. Nevertheless, we take it that simply examining whether the conventional meanings of spatial forms do or do not apply to specific scenes might obscure deeper patterns that govern their use by speakers.

References

Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge, UK: Cambridge University Press.

Baillargeon, R., Stavans, M., Wu, D., Gertner, Y., Setoh, P., Kittredge, A. K., & Bernard, A. (2012). Object individuation and physical reasoning in infancy: An integrative account. *Language Learning and Development*, *8*(1), 4–46.

Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution*. Berkeley and Los Angeles: University of California Press.

Bloom, L. (1973). *One word at a time*. The Hague, the Netherlands: Mouton.

Bowerman, M. (1996). Learning how to structure space for language: A crosslinguistic perspective. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 385–436). Cambridge, MA: MIT Press.

Bowerman, M., & Choi, S. (2003). Space under construction: Language-specific spatial categorization in first language acquisition. In D. Gentner & S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 387–428). Cambridge, MA: MIT Press.

Bowerman, M., & Pederson, E. (1992). Topological relations picture series. In S. C. Levinson (Ed.), *Space stimuli kit 1(2), November 1992, 51*. Nijmegen: Max Planck Institute for Psycholinguistics.

Brown, R. (1973). *A first language*. Cambridge, MA: Harvard University Press.

Carlson, L. A., & van der Zee, E. (2005). *Functional features in language and space: Insights from perception, categorization and development*. Oxford, UK: Oxford University Press.

Casasola, M. (2008). The development of infants' spatial categories. *Current Directions in Psychological Science*, *17*, 21–25.

Casasola, M., & Cohen, L. B. (2002). Infant categorization of containment, support and tight-fit spatial relationships. *Developmental Science*, *5*, 247–264.

Casasola, M., Cohen, L. B., & Chiarello, E. (2003). Six-month-olds infants' categorization of containment spatial relations. *Child Development*, *74*, 679–693.

Choi, S., & Bowerman, M. (1991). Learning to express motion events in English and Korean: The influence of language-specific lexicalization patterns. *Cognition*, *41*, 83–121.

Clark, E. V. (1973). Non-linguistic strategies and the acquisition of word meanings. *Cognition*, *2*, 161–182.

Clark, H. H. (1973). Space, time, semantics, and the child. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 28–64). New York: Academic Press.

Corrigan, R., Halpern, E., Aviezer, O., & Goldblatt, A. (1981). The development of three spatial concepts: In, on, under. *International Journal of Behavioral Development*, *4*, 403–419.

Coventry, K. R., Carmichael, R., & Garrod, S. C. (1994). Spatial prepositions, object-specific function, and task requirements. *Journal of Semantics*, *11*(4), 289–311.

Dromi, E. (1979). More on the acquisition of locative prepositions: An analysis of Hebrew data. *Journal of Child Language*, *6*, 547–62.

Emmorey, K. (1996). The confluence of space and language in signed languages. In P. Bloom, M. Peterson, L. Nadel, & M. Garrett (Eds.), *Language and space* (pp. 171–210). Cambridge, MA: MIT Press.

Gelman, A., Jakulin, A., Grazia Pittau, M., & Su, J.-S. (2008). A weakly informative default prior distribution for logistic and other regression models. *Annals of Applied Statistics*, *2*(4), 1360–1383.

Gentner, D., & Bowerman, M. (2009). Why some spatial semantic categories are harder to learn than others: The typological prevalence hypothesis. In J. Guo, E. Lieven, S. Ervin-Tripp, N. Budwig, S. Ozkaliskan, & K. Nakamura (Eds.), *Crosslinguistic approaches to the psychology of language: Research in the tradition of Dan Isaac Slobin* (pp. 465–480). New York, NY: Lawrence Erlbaum Associates.

Gürcanli, Ö., & Landau, B. (2008). Putting things together: How children and adults distribute spatial information across the clause. Paper presented at the 33rd annual Boston University Conference on Language Development, Boston, MA.

Gürcanli, Ö., Wilson, C., & Landau, B. (2014) Putting things together: Encoding tight-fit in English. Unpublished manuscript, Johns Hopkins University.

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

Herskovits, A. (1986). *Language and spatial cognition: An interdisciplinary study of the prepositions in English*. Cambridge, UK: Cambridge University Press.

Hespos, S. J., & Baillargeon, R. (2001a). Reasoning about containment events in very young infants. *Cognition*, *78*(3), 207–245.

Hespos, S., & Baillargeon, R. (2001b). Infants' knowledge about occlusion and containment events: A surprising discrepancy. *Psychological Science*, *12*(2), 141–147.

Hespos, S., & Baillargeon, R. (2006). Décalage in infants' knowledge about occlusion and containment events: Converging evidence from action tasks. *Cognition*, *99*, B31–B41.

Hespos, S. J., & Spelke, E. (2004). Conceptual precursors to language. *Nature*, *430*, 453–456.

Holton, D., Mackridge, P., Filippaki-Warburton, I., & Spyropoulos, V. (2012). *Greek: A comprehensive grammar of the modern language*. London & New York: Routledge.

Jackendoff, R. (1996). The architecture of the linguistic-spatial interface. In P. Bloom, M. Peterson, L. Nadel, & M. Garrett (Eds.), *Language and space* (pp. 1–30). Cambridge, MA: MIT Press.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAS (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, *59*, 434–446.

Johannes, K., Wilson, C., & Landau, B. (2013). Modeling spatial language acquisition as lexical verb development. Poster session presented at the Annual Meeting of the Cognitive Science Society, Humboldt University, Berlin.

Johanson, M., & Papafragou, A. (2014). What does children's spatial language reveal about spatial concepts? Evidence from the use of containment expressions. *Cognitive Science*, *38*, 1–30.

Johnston, J. R., & Slobin, D. I. (1978). The development of locative expressions in English, Italian, Serbo-Croation, and Turkish. *Child Language*, *6*(3), 529–545.

Landau, B., & Jackendoff, R. (1993). "What" and "where" in spatial language and spatial cognition. *Behavioral and Brain Sciences*, *16*, 217–238.

Leikin, M. (1998). Acquisition of locative prepositions in Russian. *Journal of Psycholinguistic Research*, *27* (1), 91–108.

Levinson, S. C., & Meira, S., and The Language and Cognition Group (2003). "Natural concepts" in the spatial topological domain—adpositional meanings in crosslinguistic perspective: An exercise in semantic typology. *Language*, *79*, 485–516.

Levinson, S. C., & Wilkins, D. (Eds.) (2006). *Grammars of space*. Cambridge: Cambridge University Press.

Malt, B. C., Sloman, S. A., Gennari, S. P., Shi, M., & Wang, Y. (1999). Knowing versus naming: Similarity and the linguistic categorization of artifacts. *Journal of Memory and Language*, *40*, 230–262.

Mandler, J. (2004). *The foundations of mind: Origins of conceptual thought*. Oxford, UK: Oxford University Press.

Munnich, E., & Landau, B. (2010). Developmental decline in the acquisition of spatial language. *Language Learning and Development*, *6*(1), 32–59.

Narasimhan, B., & Brown, P. (2009). Getting the INSIDE story: Learning to express containment in Tzeltal and Hindi. In V. Gathercole (Ed.), *Routes to language: Studies in honor of Melissa Bowerman* (pp. 97–132). New York & Hove: Psychology Press.

Needham, A., & Baillargeon, R. (1993). Intuitions about support in 4.5 month-old infants. *Cognition*, *47*(2), 121–148.

Newcombe, N., & Huttenlocher, J. (2003). *Making space: The development of spatial representation and reasoning*. Cambridge, MA: MIT Press.

Norbury, H. M., Waxman, S. R., & Song, H.-J. (2008). *Tight* and *loose* are not created equal: An asymmetry underlying the representation of *fit* in English and Korean speakers. *Cognition*, *109*(3), 316–325.

Papafragou, A., Massey, C., & Gleitman, L. (2002). *Shake, rattle, "n" roll:* The representation of motion in language and cognition. *Cognition*, *84*, 189–219.

Papafragou, A., Massey, C., & Gleitman, L. (2006). When English proposes what Greek presupposes: The cross-linguistic encoding of motion events. *Cognition*, *98*, B75–87.

Regier, T. (1996). *The human semantic potential: Spatial language and constrained connectionism*. Cambridge, MA: MIT Press.

Regier, T., Kay, P., & Khetarpal, N. (2007). Color naming reflects optimal partitions of color space. *Proceedings of the National Academy of Sciences*, *104*, 1436–1441.

Rosch, E. H. (1975). Cognitive reference points. *Cognitive Psychology*, *7*(4), 532–47.

Talmy, L. (1983). How language structures space. In H. Pick & L. Acredolo (Eds.), *Spatial orientation: Theory, research and application* (pp. 225–282). New York: Plenum.

Talmy, L. (1985). Lexicalization patterns: Semantic structure in lexical form. In T. Shopen (Ed.), *Language typology and syntactic description* (Vol. 3, pp. 36–149). Cambridge, UK: Cambridge University Press.

Terzi, A. (2010). Locative prepositions and place. In G. Cinque & L. Rizzi (Eds.), *Mapping spatial PPs* (pp. 196–224). Oxford, UK: Oxford University Press.

Terzi, A., & Tsakali, V. (2009). On vs. above: Lexical semantics and syntactic factors affecting spatial acquisition. In J. Chandlee, M. Franchini, S. Lord, & G.-M. Rheiner (Eds.), *Proceedings of the 33rd Annual Boston University Conference on language development* (pp. 540–551). Somerville, MA: Cascadilla Press.

Vandeloise, C. (2005). Force and function in the acquisition of the preposition in. In L. Carlson & E. van der Zee (Eds.), *Functional features in language and space* (pp. 219–231). New York: Oxford University Press.

Vandeloise, C. (2010). Genesis of spatial terms. In V. Evans & P. Chilton (Eds.), *Language, cognition, and space: The state of the art and new directions* (pp. 171–192). London: Equinox.

Wang, S., Baillargeon, R., & Brueckner, L. (2004). Young infants' reasoning about hidden objects: Evidence from violation-of-expectation tasks with test trials only. *Cognition*, *93*(3), 167–198.

Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Appendix S1. Full stimulus set.