Systematic feature variation underlies adults' and children's use of *in* and *on*

Kristen Johannes (kjohann@WestEd.org)
WestEd, 300 Lakeside Dr., 25th floor, Oakland, CA 94609, USA

Colin Wilson (wilson@cogsci.jhu.edu)
Department of Cognitive Science, Johns Hopkins University, Krieger Hall
3400 N Charles St., Baltimore, MD 21218, USA

Barbara Landau (landau@cogsci.jhu.edu)
Department of Cognitive Science, Johns Hopkins University, Krieger Hall
3400 N Charles St., Baltimore, MD 21218, USA

Abstract

The spatial prepositions *in* and *on* apply to a wide range of containment and support relations, making exhaustive definitions difficult. Theories differ in whether they endorse geometric or functional properties and how these properties are related to meaning and use. This study directly examines the roles of geometric and functional information in adults' and children's use of *in* and *on* by developing a large sample of relations situated within a small gradable geometric and functional feature space. We propose that variation in features across items is systematically related to the use of *in* and *on* and demonstrate that feature-language relationships change across development: adults' expression use is sensitive to both geometric and functional features, while children's use varies only according to geometric features.

Keywords: Spatial language; spatial cognition; acquisition; language use

Background

All natural languages have a limited system of terms dedicated to the expression of spatial relationships between objects (Talmy, 1985). In the current study, we focus on the English prepositions *in* and *on*, considered the primary vehicles for expressing containment and support relations, respectively (Bowerman, 1996; Landau & Jackendoff, 1993; Talmy, 1985; Gentner & Bowerman, 2009; Herskovits, 1986, *inter alia*). Within these broad relationships, terms *in* and *on* cover a wide range of object configurations: from *apples in bowls* and *books on tables,* to *pieces in a puzzle* and *fish on a line*. The mapping between these expressions and object configurations must abstract over many fine-grained properties of individual objects, and capturing the critical properties has been challenging, especially given the early acquisition of these terms by children. Some theories endorse coarse-grained geometric properties of object representations, such as volumes, surfaces, and axes (Landau & Jackendoff, 1993), while others propose various functional properties of containment and support as relations between any objects (e.g., Garrod et al., 2009).

In this paper, we directly examine the role of geometric and functional information in English speakers' spatial uses of *in* and *on* and develop two hypotheses to address the following two questions: 1) How are geometric and functional information jointly engaged in the use of *in* and *on*? And 2) How does the relationship between functional and geometric knowledge and language develop over the course of acquisition?

Although *in* and *on* are are among the earliest words acquired by children (Johnston & Slobin, 1979), they have broad and sometimes nuanced uses in adult language, making the meanings of these terms notoriously resistant to formal definition (Herskovits, 1986; Garrod et al., 1999, *i.a.*) and their trajectory of acquisition poorly understood.

The Current Study

We selected a limited set of geometric and functional properties (hereafter 'features') of spatial relations believed to be relevant to language-independent notions of containment and support and the spatial meanings of the English terms *in* and *on*. Using a rating task, we situated a sample of 128 natural scenes within this feature space. The scenes featured object configurations that reflected a wide range of containment and support relations that varied parametrically across the geometric features and in an uncontrolled way across a functional feature. We used this feature space to test two hypotheses about the relationship between feature variation across our items and speakers' use of *in* and *on* to describe those items:

Hypothesis 1: Variation in gradable geometric and functional features is systematically related to differences in adults' probabilistic use of *in* and *on*.

Hypothesis 2: Children's probabilistic use of *in* and *on* will show early sensitivity to geometric features, evidenced pre-linguistically, but not to functional features.

Three key elements differentiate our proposal from previous accounts of *in* and *on*: 1) We developed a set of language-independent geometric features, motivated by pre-linguistic and cross-linguistic evidence, and a functional feature based on psycholinguistic findings, discussed below; 2) We selected a large and highly diverse sample of containment and support relations; and 3) We focused on mappings between our continuous feature space and probabilistic language use.

Why (not) geometry?

Geometric notions (see Landau & Jackendoff, 1993; Talmy, 1985) have served as a cornerstone for theories of the meanings of individual spatial prepositions, and the earliest accounts of prepositions are based solely on geometry. As one example, Bennett (1975) defines the preposition *in* using the highly geometric notion of an interior and a general location function, so that the expression *A is in B* for objects A and B in (1) simply means that A is located at the interior of B. Similarly, Bennett defines the preposition *on* via the location function applied to an object's surface, in (2) (Bennett, 1975, p. 71).

(1) A is *in* B: A [locative [interior of B]]
(2) A is *on* B: A [locative [surface of B]]

These strictly geometric definitions work for stereotypical cases, such as the scenes in Figure 1-A. However, relying solely on notions like interior and surface as constraints on the meanings of *in* and *on* fail to account for many of the regular (i.e., non-idiomatic) uses of the terms, such as for Figure 1-B (Herskovits, 1986; Feist, 2000, Garrod et al., 1999, Coventry et al., 1994, *i.a.*) and predicts unattested uses, such as Figure 1-C.
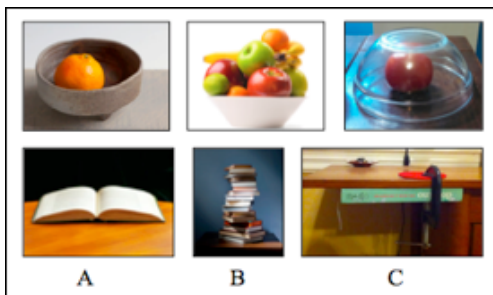

Figure 1. Purely geometric accounts predict that "The orange is *in* the bowl" and "The book is *on* the desk" felicitously describe the respective top and bottom cases for A, but not B (orange/books on top of other fruit/books), and incorrectly predicts that the expressions describe the cases in C (orange/book under bowl/desk).

These are just a few of many counterexamples that have been levied against purely geometric accounts of *in* and *on*. However, we propose that there are a number of connected reasons why an account like Bennett's might fail to capture the full range of meanings and typical uses of *in* and *on*. First, these accounts may simply choose the wrong type of geometric information by building a theory of meaning based on narrow, conventional cases of containment and support (*oranges in bowls* and *books on tables*) while ignoring less central spatial cases for which *in* and *on* can be used, such as *arrows in targets* or *clothes on a line*.

Second, previous geometric accounts may fail as a consequence of the mapping between geometric information and spatial term meaning and *use*. Many proposals, including that of Bennett (1975), state or implicitly assume a deterministic all-or-none relationship between the

presence of a feature, geometric or otherwise, and the use of a spatial term: if the feature applies to the relation, then the spatial term can be used to describe it, if the feature doesn't apply, then the term cannot be used. On these accounts, features are assumed to be binary[1] — either applying perfectly to a particular object configuration or not at all — and spatial language use is assumed to be uniform — all configurations to which, for example, the term *in* applies are "equally good" instances of the features specified in the meaning of *in*.

In this paper, we argue against such a deterministic mapping and propose a probabilistic relationship between conceptual features and speaker's use of spatial language (specifically, *in* and *on*). We suggest that the geometric features relevant to containment and support relations are not binary but are instead *gradable* so that different configurations can instantiate features to varying degrees. Following this, we observe that some object configurations are intuitively "better" and more frequent instances of *in* or *on* than others (e.g., example, *on* is used more frequently for *books on a table* than *fish on a line*), and propose a probabilistic mapping between spatial relations and terms.

Support for this proposal comes from previous work by Johannes and colleagues (Johannes, Wilson, Landau, 2013, under review; Johannes et al., 2015) who have uncovered distinctions among hypothesized sub-types of containment and support relations on the basis of differences in speakers' rates of use of individual expressions. For example, across multiple languages, speakers' spatial term use reliably distinguishes cases of loose-fitting containment (e.g., *apples in bowls*) from interlocking cases (e.g., *puzzle pieces in a puzzle*), and cases of support from below (e.g., *books on a table*) from support by hanging (e.g., *fish on a line*).

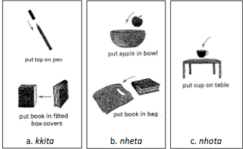## Geometric features of containment and support

We consulted a history of work on pre-linguistic and cross-linguistic spatial categorization to identify pairs of candidate features for containment and support relations. These features are likely to be language-independent in the sense of being salient pre-linguistically, suggesting that these features should not be specific to the spatial meanings of English alone (Gentner & Bowerman, 2009, Hespos & Spelke, 2004), and should be attested in the lexicons of culturally and typologically diverse languages.

Results from studies of pre-linguistic and cross-linguistic spatial concepts converge on a small set of geometric features — two for containment and two for support relations — around which, we hypothesize, the spatial meanings of *in* and *on* can be organized. These four geometric features are outlined in Table 1, along with supporting pre-linguistic and cross-linguistic evidence.

---

[1] On some accounts, features are not binary by design, but feature values are subject to thresholding to make binary distinctions.
[2] Children completed the rating task on an iPad alongside an

Table 1. Geometric features for containment and support items are listed with the pre-linguistic and cross-linguistic evidence used to select each feature for use in the study.

Feature	Feature Description	Pre-linguistic Evidence	Cross-linguistic Evidence
Containment Enclosure	*The extent to which one (containing) object encloses or surrounds another (contained) object*	When reasoning about containment, 3.5 month-olds are sensitive to both the solidity of a container as well as whether it has an open top (Hespos & Baillargeon, 2001).	Speakers of Jaminjung (Australia) use enclosure-sensitive coverbs *walthub* and *walyag* to encode the configurations below (Levinson & Wilkins, 2006).
Containment Volume Match	*The amount of empty space between containing and contained objects (alternatively, the tightness of fit between a containing and contained object)*	At 5 months, infants expect objects to move separately when there is a lot of empty space between them and to move together when there is little empty space (Hespos & Spelke, 2004).	Korean speakers use contrastive verbs to encode fit: A. *kkita* for interlocking ('tight-fit') cases; B. *nheta*, used for 'loose-fit' containment; C. *nhota*, used objects put on horizontal surfaces. (Bowerman & Choi, 2001).
Support Vertical Position	*The vertical position of one (supported) object relative to the other (supporting) object*	At 5.5 months, infants expect an object to remain supported after being placed on the top surface of an object but not after being placed against the side surface (Hespos & Baillargeon, 2008).	Dutch speakers use three prepositions to distinguish cases of support: *op* is reserved for support from below/ permanent contact; *aan* is used for hanging and attachment; *om* is used for encirclement (Gentner & Bowerman, 2007).
Support Surface Contact	*The proportion of one (supported) object's surface that is in contact with the surface of the other (supporting) object*	6.5 month-olds reach more for an object placed with 100% of its surface in contact with a supporting object, compared to events with 15% surface contact, reasoning that objects in the latter case were permanently attached (Hespos & Baillargeon, 2008).	Speakers of *Yêlî Dnye* (Papua New Guinea), use the term *yedê* (roughly glossed as *on a surface*) to express surface contact independent of the (vertical) position of the figure and ground objects (Levinson & Wilkins, 2006).

Functional feature: Location control for *in* and *on*

A growing number of proposals based on psycholinguistic data have considered functional information to be at the core of prepositional meanings and usage, including abstract means of *in* and *on* (Jamrozik & Gentner, 2015). Garrod and colleagues (Garrod, Ferrier, & Campbell, 1999) propose hybrid accounts of the meanings of *in* and *on* that combine geometric and functional properties. Specifically, speakers' use of *in* and *on* reflect different kinds of *locational control* between figure and ground objects, in combination with geometric properties. Successful use of *in* reflects regional enclosure with locational control, so that one object (the figure) is likely to be *in* another object (the ground) if the ground encloses the figure, and the ground (and not some other object) controls the location of the figure. Locational control differentiates cases like Figure 2-a and 2-b (taken from Garrod et al., 1999), where the pear (shaded grey object) is judged to by *in* the bowl in case (a) but not (b), despite having the same objective degree of enclosure in both cases.
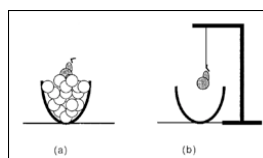

Figure 2. The pear in (a) is judged to be *in the bowl*, while the pear in (b) is not, despite the same degree of enclosure in both cases. (Figure adapted from Garrod et al., 1999)

In experiments testing speakers' confidence about *in/on* descriptions across relations that varied in the geometric properties and locational control, Garrod et al. (1999) found that for cases where regional enclosure and regional contact were high (i.e., prototypical *in* and prototypical *on* cases), judgments of locational control did not predict or influence speakers' confidence about *in* and *on*, respectively. Locational control is predicted to apply equally across cases and is only "blocked" (or reduced in importance) when geometric properties are very salient, suggesting a complex interplay between the two types of information. We examine the interplay of geometry and function in the following experiments by adding a gradable functional feature: *locational control*, operationalized as the likelihood that the figure object of a configuration will move together with the ground object.

Experiment

We developed two large item sets of internet-sourced images of objects in containment and support relations, respectively. We used a simple feature-rating task to situate containment and support items in their own 3-dimensional feature space (two geometric features and one functional feature) and then elicited simple spatial descriptions from a new group of adults to examine relationships between containment and support feature variation and rate of *in* and *on* use, respectively. Adults' patterns of use of *in* and *on* are well-captured by combinations of gradable geometric and functional features.

Methods

Design. One group of adult participants and one group of child participants completed a feature-rating task for each sets of items (containment or support). A separate group of participants from each age group completed a spatial description task with the same items.

Participants One hundred adults (mean age = 19.2 years) participated in the experiment through a self-paced online interface in return for course credit. Fifty participants provided feature ratings for a set of containment (N=25, 14 males) or support items (N=25, 12 males). The other 50 participants provided descriptions for the same containment (N=25, 13 males) or support items (N=25, 11 males). All participants were native English speakers. Twenty 6-year-olds (mean age = 6;5, 11 males) participated in a modified version of the rating task[2], and 24 6-year-olds (mean age = 6;6, 14 males) provided spatial descriptions for containment and support items.

Materials Stimuli consisted of 64 containment items (Figure 3) and 64 support items (Figure 4). The items were chosen, by hypothesis, to parametrically vary along two geometric dimensions: Enclosure and Volume Match for containment items, and Vertical Position and Surface Contact for support items. Locational Control was not manipulated in item selection but was hypothesized to vary randomly across items.

Procedure. Participants in the feature-rating task were familiarized with the set of geometric and functional features then shown either containment or support items, one at a time in random order. For each item, participants were instructed to consider the two salient labeled objects (e.g. "Object A: a sandwich", "Object B: a plate") and provide ratings on a 4-point scale for each of the features. Features, rating prompts, and the response scale endpoints provided to subjects are given below in Table 2.
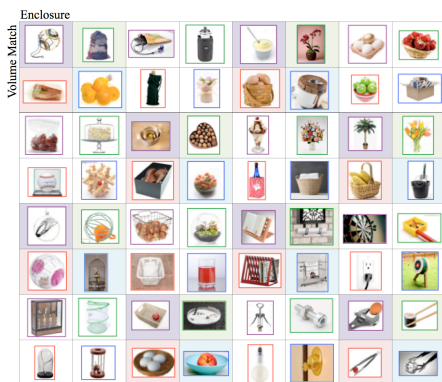

Figure 3. The 64 containment items organized hypothesized Enclosure and Volume Match feature values.

---

[2] Children completed the rating task on an iPad alongside an experimenter, who labeled each object and read the prompts aloud.

Figure 4. The 64 support items organized by hypothesized Vertical Position and Surface Contact feature values.

Table 2. Prompts and scale endpoints for the adult and child versions of the feature-rating task.

Containment feature rating task: Prompts and scale endpoints			
	Enclosure	Volume Match	Locational Control
Adult prompts	How much of object A is enclosed by object B?	How much empty space is present between object A and object B?	If object B is moved, how likely is it that object A will move with it?
Adult endpoints	{All/hardly any} of A is enclosed by B	There is {a lot/ hardly any} empty space between A and B	A is {very likely/ unlikely} to move where B moves
Child prompts	Is [object B]...	Is there...	If I move [object B] do you think [object A] will...
Child endpoints	{All around/ not really around} [object A]	{Lots of/ no} empty space	{Definitely/ probably won't} move with it
Support feature rating task: Prompts and scale endpoints			
	Vertical position	Surface Contact	Locational Control
Adult prompts	How much of object A is higher than object B?	How much of object A's surface is in contact with object B?	
Adult endpoints	{All/ none} of A is higher than B	{All/ hardly any} of A is in contact with B	(same as above)
Child prompts	How much of [object A] is higher than [object B]?	How much of [object A] is touching [object B]?	
Child endpoints	{All, no part} is higher	{All, almost no part} of A is touching B	

Adult participants in the spatial description task typed in a brief description into the space provided in the online interface by answering the question "Where is [Object A] in relation to [Object B]?" for the labeled objects in the image. Child participants gave verbal descriptions that were later transcribed.

Results

Feature rating task Adults and children were both reliable in their geometric feature ratings (Adults: r=0.92, p<.01; Children: r=0.89, p<.01) and their mean ratings supported our hypothesized item variation across the geometric features in both containment and support item sets. Adults, but not children, were also reliable in their ratings of Locational Control. Adults' ratings of two geometric features, Enclosure for containment and Vertical Position for support, were correlated with their ratings of Locational Control (Enclosure: r=0.485, p<.01; Vertical Position: r=0.548, p<.01). Items rated highest in Enclosure or Vertical Position were also rated highest in Locational Control, suggesting that Enclosure and Vertical Position may be geometry-based mechanisms by which one object can exert control over another object.

Spatial description task Each participant provided a single description for each scene in the form: "Object A [spatial expression] Object B", where the spatial expression included one or more verbs, a preposition, and an optional modifier. Descriptions were coded for the presence of the copular verb BE combined with the prepositions *in* (for containment items), or *on* (for support items) — for example "The sandwich *is in* the bag" and "The pillow *is on* the stool". This coding was designed to exclude descriptions with lexical verbs (e.g., "The sandwich *is sealed in* the bag", "The pillow *is sitting on* the stool"), which encode additional spatial, configurational, or mechanical information (see Johannes, Wilson, & Landau, under review), as well as descriptions with prepositions other than *in* or *on*, both of which were the focus of other analyses, not reported here (54% of adult descriptions and 36% of child descriptions). This coding was used to assign a binary value to each description: a description was coded as 1 if it included *in* (for containment) or *on* (for support), and was coded as 0 otherwise.

Adults and children showed similar patterns of usage of *in* and *on* across containment and support items and adult and child uses of *in* and *on* were reliably correlated (Pearson's R_{in}= 0.67, *p<.01*; R_{on}= 0.77, *p<.01)*. Some items were described exclusively with *in* or *on*, while others were rarely described this way.

We computed four mixed-effects logistic regression models to examine the relationship between mean geometric and functional feature ratings and the distribution of adult and child speakers' use of *in* and *on* across containment and support scenes. Models included item and subject as random effects and each of the features was coded as a fixed-effect predictor[3].

Adults' use of both *in* and *on* was related to a combination of geometric and functional features (as rated by the separate group of adults). Table 3 gives examples of

---

[3] Covariance between pairs of features was controlled by using the residuals of preliminary linear models predicting one feature from another.

---

the containment and support items that were predicted by the models to have high and low rates of *in* and *on* use. For containment, items rated high in Enclosure and in Locational Control were most likely to be described with *in* (see Table 3 for the standardized model coefficients, β, for each feature predictor). This pattern suggests that, for containment, the geometric property of Enclosure is a means by which one object can contain another object and by which it can control the location or movement of another object. For support, items rated highly on Vertical Position and Surface Contact features, but *low* in Locational Control were most likely to be described using *on* (standardized model coefficients in Table 3). This seemingly non-intuitive pattern suggests that Locational Control is a salient means of support only when the Vertical Position and Surface Contact between objects are not. For both containment and support, the model-fitted probabilities of *in* and *on* use for each item were highly correlated with the adults' observed frequency and distribution of use.

Table 3. Results of feature-language models: items predicted to elicit high and low *in/on* use for adults and children; model standardized coefficents (β) for each predictor; and correlations between model-fitted probability of *in/on* use and observed relative frequency of *in/on* use.

Containment	Adult Results	Child Results
Item with high predicted *in* use	oranges in a bag	hamster in a ball
Item with low predicted *in* use	sushi in chopsticks	(top) book in a box
Enclosure β	**0.47, *p<.01***	**0.18, *p<.01***
Volume Match β	-0.05, *(ns)*	0.07, *(ns)*
Location Control β	**0.48, *p<.01***	-0.08, *(ns)*
Correlations: predicted and attested use	*R= 0.67, p<.05*	*R= 0.61, p<.01*
Support	**Adult Results**	**Child Results**
Item with high predicted *on* use	sandwich on a plate	plate on a stick
Item with low predicted *on* use	ornament on a branch	
Vertical Position β	**0.33, *p<.01***	**0.26, *p<.01***
Surface Contact β	**0.52, *p<.01***	0.11, *(ns)*
Location Control β	**-0.29, *p<.05***	-0.04, *(ns)*
Correlations: predicted and attested use	*R= 0.81, p<.01*	*R= 0.69, p<.01*

In contrast to adults, children's use of *in* and *on* was related to single geometric features of containment (Enclosure) and support (Vertical Position) and not by children's functional

ratings, which were noisy and unreliable, or by adults' functional ratings. Table 3 shows examples of items with predicted high and low *in* and *on* use and the standardized model coefficients for each feature predictor. We hypothesized that children's reliance on geometric over functional information stems from their robust geometric knowledge, acquired before the onset of language, along with still-developing knowledge of control relationships, which may require extremely rich knowledge about object functions and force-dynamic relationships between objects.

Discussion

In the current study, we developed a large structured sample of containment and support items to test the relationship between geometric and functional feature variation and spatial language use at two points in development. Our feature rating results confirm that a wide range of containment and support relations are organized around several geometric features, while also varying on the functional feature of location control.

Confirming our first hypothesis, geometric and functional feature variation in our sample of containment and support items was reliably related to adults' probability of using *in* and *on* to describe the items. Specifically, geometric and functional features combined to predict differences in adults' use of *in* and *on* across items.

We further examined whether the relationships between feature variation and language shown for adults also held for children's spatial language, specifically evaluating the hypothesis that children's early use of *in* and *on* is sensitive to pre-linguistically available geometric information but is not sensitive to functional feature variation among containment and support relations. Our results demonstrate that children's probabilistic use of *in* and *on* shows early adult-like sensitivity to geometric variation across relations but not to functional feature variation, suggesting that robust pre-linguistic geometric knowledge, but not functional knowledge, constrains children's early uses of *in* and *on*.

We designed our feature sets with features that were *relational*: they encode information about both the figure and the ground objects in each item. We tested our features against an alternative set of plausible, *non-relational* features: the degree of curvature of either the figure or ground object, for containment items, and horizontal orientation of either the figure or ground object, for support items. Variation in these non-relational features failed to reliably predict the use of *in* and *on* across the items in our study and ratings for these features did not correlate with ratings of the relational features in our study. Arguably, speakers' use of spatial terms like *in* and *on* is most sensitive to relational information – and not merely to properties of individual objects – in object configurations.

Conclusion

We have demonstrated that variation in combinations of geometric and functional features is related to variation in speakers' expression use across a large and diverse sample of containment and support relations. Our proposal that gradable features are related to speakers' probabilistic use of *in* and *on* reconciles the fact that, while we can use the same spatial term for a wide range of cases, some cases are better instances of *in* and *on* than others. Put another way, while relations with (any degree of) certain geometric or functional properties license a given spatial term, having those properties to a greater or lesser degree is related to how "good" a relation is as the extension of a term.

References

Bennett, D.C. (1975). *Spatial and Temporal Uses of English Prepositions.* London: Longman.

Feist, M. I., & Gentner, D. (1998). On plates, bowls, and dishes: Factors in the use of English IN and ON. *Proceedings of the 20th Annual Meeting of the Cognitive Science Society,* 345-349.

Garrod, S., Ferrier, G., & Campbell, S. (1999). In and on: investigating the functional geometry of spatial prepositions. *Cognition, 72,* 167-189.

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

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

Hespos, S.J., & Baillargeon, R. (2008). Young infants' action reveal their developing knowledge of support variables: Converging evidence for violation-of-expectation findings. *Cognition, 107(1),* 304-316.

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

Johannes, K., Wang, J., Papafragou, A., & Landau, B. (2015). Systematicity and variation in the distribution of spatial expressions in three distinct languages. *Proceedings of the 37th Annual Meeting of the Cognitive Science Society,* 997-1002.

Jamrozik, A., & Gentner, D. (2015). Well-hidden regularities: Abstract Uses of *in* and *on* retain an aspect of their spatial meaning. *Cognitive Science*, *39,* 1881-1911.

Johannes, K., Wilson, C., & Landau, B. (under review). The importance of lexical verbs in the acquisition of spatial language: The case of *in* and *on*.

Johnston, J.R., & Slobin, D.I. (1979). The development of locative expressions in English, Italian, Serbo-Croatian and Turkish. *Journal of Child Language, 6(3),* 529-545.

Landau, B. & Jackendoff, R. (1993). 'What' and 'where' in spatial language and spatial cognition. *Behavioural and Brain Sciences, 16(2),* 217-265.

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

Talmy, L. (1985). Lexicalization patterns: Semantic structure in lexical forms. In Timothy Shopen (ed.), *Language typology and syntactic description* (pp. 57-149). Cambridge: Cambridge University Press.