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The development of spatial category representations from four to seven years

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Abstract

Representation of spatial categories was assessed in four to seven year-olds. Across nine spatial categories (In, On, Under, In Front, Behind, Above, Below, Left and Right), children were asked to pick the odd-one-out from four images, three of which displayed the same spatial relationship between two objects, and one which showed a different spatial relationship. Results support our proposed model of spatial category representation. Children progressed through three levels of understanding: from rigid (level 1), to abstract (level 2) to broad (including non-prototypical category exemplars) (level 3) understanding of spatial category membership. This developmental pattern was common to all spatial categories, and the ages at which children reached each level varied across categories, in line with the order in which category representations emerge in infancy.

Keywords: space, spatial categories, spatial language

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Introduction

Space has both categorical (above, in) and continual (metric distances and directions) properties. As a result spatial categories include both prototypical and non-prototypical members. That is, we accept that a pen in the centre of the table (the prototypical location), or a pen protruding over the edge of the table, are both *on* the table (Feist & Gentner, 2007). Similarly, for more complex categories such as *above*, we accept prototypical examples that are directly above the referent, as well as weaker examples that are far above, or diagonally above to the left or right (Landau & Hoffman, 2005). Relatedly, spatial category members are rated as more typical, the more proximal they are to the category prototype (i.e. the most central example of a category) (Meints, Plunkett, Harris & Dimmock, 2002). This study explores how this flexible representation of spatial categories develops.

The emergence of spatial category representations

The ability to recognise categories of spatial relationships emerges in the first two years (Bowerman, 1996). Preferential looking has shown that 6-month-olds begin to understand categories for containment (*in*) and *above* and *below*, and other spatial representations follow, such as *between* at 10 months, and support (*on*) at 14 months (Casasola, 2008). Furthermore, infants move from a rigid understanding to a more flexible understanding of spatial categories; spatial categories are initially tied to specific or familiar objects and as the infant begins to notice the equivalence of spatial relations across different sets of objects, spatial categories become more abstract (Casasola, 2008). For example, a 3 month old infant can discriminate between *above* and *below* for familiar, but abstract categorical understanding does not come on-line until 6 months objects (Quinn, Cummins, Kase, Martin & Weissman, 1996).

The development of a prototype framework

Meints et al. (2002) used preferential looking to show that 15-month-olds are able to differentiate between the words *on* and *under* for prototypical examples, but that by 24 months the effect is observed for both prototypical (e.g. a cat *on* the centre of a table) and non-prototypical examples (e.g. a cat *on* the edge of a table). This points to some use of a prototype framework from two years.

Erreich and Valian (1979) explored 4- and 6-year-old's understanding of *in*, *above*, *below* and *beside*. When asked to draw the best example of a category children and adults drew prototypical representations at above chance levels (except for *beside* which does not adhere to a strong prototype). In a matching task, adults were largely accurate. In contrast, children confused non-prototypical examples that were off the vertical and horizontal axes, with a non-category member. Similarly Landau and Hoffman (2005) demonstrated that children (3-6 years) applied the words *above, below*, *left* and *right* more readily to objects that were directly on-axis, than objects that were slightly off-axis. Thus, young children are beginning to apply a prototype framework, but do not have adult-like representations.

Insights from spatial language production

With the exception of the studies above, little is known about the development of spatial category representations between infancy and adulthood. Studies of school-age children demonstrate that production of spatial language is not adultlike, but have not investigated why this might be. An obvious candidate is category membership as discussed above. Clark (1973) showed that 3-year-olds use the terms *above* and *below* interchangeably and only later determine the associated directional information for each. Durkin (1980) reports difficulties in comprehending *in front of, behind, above* and *below* persisting through the first years of school, and demonstrated a number of developmental changes in the production of spatial terms from 3;10 to 7;10 years. First, the proportion of prepositions employed compared to overall vocabulary increases with age. Second, failures in the ability to describe spatial relationships decrease with age. Third, general prepositions (e.g. *near*) are initially favoured, with more complex terms (e.g. *above*) increasing in use with age. This provides evidence that, although spatial category terms are produced, they are not as stable as in adulthood. The aim of this study is to determine why this might be by exploring children’s understanding of category membership. In line with Erreich and Valian (1979), we will work with children from 4 to 7 years due to the continued refinement of spatial language use until at least 7 years (Durkin, 1980).

The Spatial Category Representation Model

We deliberately designed a measure of spatial category representation that involved perceptual comparison. This by no means precludes linguistic input given that spatial category representations are so intertwined with their corresponding verbal labels, but it enables one to determine the range of perceptual representations that children accept as category members, thus providing insight into the development of spatial category representations.

Drawing on Casasola (2008) and Meints et al. (2002) we propose the spatial category representation model, which comprises three levels of representation of spatial categories. Level 1 is akin to the rigid understanding of spatial categories reported in infancy and relies on recognition of common spatial relations as well as common objects across examples (Casasola, 2008). Level 2 is the formation of abstract categories, based on that described in infancy (Casasola, 2008) and relies on common spatial relations across examples. Although the transition from an understanding of rigid to flexible understanding of spatial categories, as measured by levels 1 and 2, has been documented for early acquired terms such as *in*, we do not know whether this developmental pattern holds across other spatial categories, or the respective ages at which this transition might occur. Level 3 involves the use of a prototype framework (Erreich & Valian, 1979; Meints et al., 2002). Where levels 1 and 2 refer to prototypical spatial category exemplars, level 3 includes both prototypical and non-prototypical examples and relies on children having developed broad category membership.

We measured development across our three proposed levels for nine spatial categories, using an odd-one-out task. Children were shown four images, each of which displayed two objects. Three of the images showed the same spatial relationship between the objects, and one image was the ‘odd-one-out’. Levels 1, 2 and 3 of the task corresponded to levels 1, 2 and 3 of the model respectively. Level 1 (rigid understanding) required children to compare across examples of spatial relations that involved identical pairs of objects. We expected this level to be the easiest. In Level 2 (abstract understanding), each image depicted a different pair of objects, with three of the pairs displaying a common spatial relation. Success was dependent on children determining this common spatial relation, despite the difference in object identities. Level 3 (broad understanding), predicted to be the most difficult level, provides a measure of the ages in which a prototype framework is available in childhood across nine spatial categories. Children who perceive prototypical and non-prototypical category members as belonging to the same spatial category will succeed on level 3.

We hypothesised that spatial category representations become increasingly flexible and stable with development. Children will pass each successive level with increasing age, thus indicating development through the three levels of our spatial category representation model. We also predicted that, because prototypical items appear to be used as a starting point for the development of spatial categories, the order in which children progress through the model will resemble the order in which the nine spatial categories are acquired: *In, On, Under, In Front* and *Behind, Above* and *Below*, *Left* and *Right*. Because spatial category representations and spatial language are so intertwined we also predicted a relationship between the level of representation reached in the odd-one-out task and spatial language scores.

Method

Participants

Twenty four-year-olds, 18 five-year-olds, 18 six-year-olds and 19 seven-year-olds took part. Participants were recruited from UK primary schools. Participant details are shown in Table 1. Verbal mental age (British Picture Vocabulary Scale 2nd Edition; BPVS-II, Dunn, Dunn, Whetton & Burley, 1997) was age-appropriate.

Table 1

Design and Procedure

Participants completed the odd-one-out task (our measure of spatial category representations), BPVS-II (Dunn et al., 1997), spatial language comprehension and production tasks and one other task not reported here (Raven’s Coloured Progressive Matrices; Raven, 1993).

The odd-one-out task was split into two equivalent blocks. The order of administration of the two blocks was counterbalanced across participants, and interleaved with the BPVS and RCPM (also counterbalanced for order). The spatial language comprehension and production task were always administered at the end of the session with the production task preceding the comprehension task to ensure that participants had not been exposed to the correct terms prior to the production task. Testing was completed across two sessions, totalling forty-five minutes.

Odd-one-out task

Nine spatial categories were employed: *In, On, Under, In Front, Behind, Above*, *Below, Left* and *Right*. Participants were shown a display of four images in a two-by-two array on a 15-inch laptop and asked to click (with a mouse) on the image that was different from the other images, i.e. the odd-one-out (Figures 1a,b). Each of the four images displayed two objects; three of the images represented the same spatial relation between the two objects, while one displayed a different relation, the ‘odd-one-out’. The correct answer featured in each quadrant of the display equally frequently.

The located and reference objects were equivalent in terms of imageability rating (mean: 6.4/ 7; range: 5.6 to 6.9) and familiarity rating (mean: 4.1/ 5; range: 2.73 to 4.77), and all had an age-of-acquisition of under four years (mean: 23.8 months; range 22.1 to 38.5 months) (Morrison, Chappell & Ellis, 1997). Thematic relations between objects were reduced to encourage children to categorise by spatial relation as opposed to another common feature, such as colour. Reference objects were symmetrical objects whose function would not influence prototypical spatial relations (Coventry et al., 2010), e.g. a table.

There were three difficulty levels (Figure 1a), each measuring a different level of our model. Levels 1 and 2 displayed prototypical examples of all spatial relationships (e.g. a cup *on* the centre of a table). Meints et al. (2002) used similar images to represent prototypical relationships; adults rated them as the most typical example of the category. In Level 1 trials the located (e.g. book) and reference (e.g. box) objects were the same across the four images; three images were identical and the fourth, the odd-one-out, showed the opposite spatial relationship (e.g. Figure 1a, Level 1: cake *on* box vs. cake off box, the odd-one-out). In Level 2 trials four different located objects were paired with the same reference object, across the four images (e.g. Figure 1a, Level 2: book, apple, key or flower paired with a box); three images showed the same spatial relationship between a located object and the reference object, and the fourth, the odd-one-out, showed the opposite spatial relationship (e.g. Figure 1a: object on box vs. object off box). Level 3 images also used 4 different located objects paired with the same reference object, but the relationship between located and reference objects for all four images represented prototypical and non-prototypical exemplars. Three images showed the same spatial relationship (one prototypical, two non-prototypical), and the fourth showed the opposite spatial relationship in a prototypical format (e.g. Figure 1a, Level 3: plane *on* box [prototypical]; brush *on* box [non-prototypical]; teacup *on* box [non-prototypical]; cat off box [odd-one-out]).

In level 3, the extent to which the two images that showed non-prototypical spatial relations was controlled as follows. For *in*, *on* and *under* trials, just over 50% of the located object remained *in*, *on* or *under* the reference object, with displacement to the left and right of centre for the two non-prototypical images respectively

(Figures 1a, b). This is similar to Meints et al. (2002) who presented located objects at the edge of a table; adults rated these as atypical examples of the category.

A*bove, below, left* and *right* categories are based on an axial reference system in adults, with the most typical examples falling on horizontal (left and right) and vertical (above and below) axes (Hayward & Tarr, 1995). Thus, for *in front, behind, above, below, left* and *right,* the located object was placed off the prototypical axis by just under ±45 degrees such that whilst being off-axis, the closest axis was still correct for that category (for the two non-prototypical examples in each trial, one was off-axis in a positive direction, the other was off axis in a negative direction).

Participants first completed six practice trials; two images, each showing a teddy and a box in the same (3 trials) or different (3 trials) prototypical spatial relations, were presented. The experimenter asked: “Can you tell me whether these pictures are the same or different?”. All participants achieved 100% accuracy on the practice trials; this ensured that participants were able to compare images, and so would understand the concept of an odd-one-out.

In the experimental trials, on presentation of each trial the experimenter asked the child to: “Click on the picture that is different from the other pictures”, i.e. the odd-one-out. For each of the three difficulty levels, each spatial category type was presented 4 times, each time represented by different image pairs. A total of 108 trials was split into two equivalent blocks of 54-trial blocks (2 blocks x 9 relations x 3 levels x 2 trials). Trials in each block were presented in a random order such that all spatial relations and levels were interspersed. Each block included five motivational screens (e.g. “Well Done!”).

The task was validated with ten adult participants, mean (s.d.) chronological age: 33;03 (11;08) years; months. The majority of adults achieved >95% accuracy.

Two participants scored lower, at 94% and 88%. Participants showed no systematic pattern of errors. The adult group’s ability to locate the odd-one-out with ease validates the shared category membership across the other three images, for all levels and categories.

Figures 1a,b

Spatial language tasks

Comprehension and production tasks provided a background measure of linguistic category development and so only prototypical examples were used. Participants were shown a teddy bear and a clear plastic box. To test production, the procedure followed Landau and Hoffman (2005). The experimenter said: “I’m going to put the teddy in different places and when I do, I want you to look very carefully at the teddy and the box and then tell me where the teddy is. I’m going to move the teddy and the box around and then I want you to describe where the teddy is. Where is the teddy? The teddy is ____ the box.” All children understood the task instructions. This procedure was repeated for each of the nine spatial relationships. Infrequently, children produced an ambiguous description (e.g., “he is *next to* the box”) and were asked once if they could be more specific.

In the comprehension task, participants were asked to demonstrate each of the nine spatial relationships. The experimenter said: “Now I’m going to tell you where to put the teddy. You’re going to move the teddy to different places just like I did.” followed by, for example: “Put the teddy *in* the box.”

Results

Odd-one-out task

Comparison across first and second blocks of the odd-one-out task showed no evidence of learning or fatigue. ANOVA with a between-participant factor of Age (4 levels: 4-, 5-, 6-, and 7-year-olds) and within-participant factors of Spatial Category (9 levels: In, On, Under, In Front, Behind, Above, Below, Left and Right) and Level (3 levels) showed a significant main effect of Age, F (3, 71) = 32.341, p < .001, η_p^2 =.577, due to increased accuracy with age, with a plateau at 6 years (Tukey comparisons: p<.05 for all comparisons except for between 6 and 7 year olds, p = .299). There was a significant effect of Spatial Category, F (8, 568) = 78.988, p < .001, η_p^2 =.527. With the terms entered in the documented order of acquisition in infancy (in, on, under, in front and behind, above and below, left and right) the effect was best described as linear (linear contrast: F (1, 71)= 300.460, p<.001, η_p^2 =.809) (Figure 2). Bonferroni corrected pairwise comparisons confirmed this pattern, and further demonstrated no difference between equivalent pairs (in front vs. behind, above vs. below, left vs. right, p>.05 for each pair). The effect of Level was also significant, F (2, 142) = 126.403, p < .001, η_p^2 =.640, due to decreased accuracy with increasing difficulty (linear contrast, F (1, 71) = 193.622, p < .001, η_p^2 =.732).

All interactions were significant: Spatial Category by Age, F(24, 568)=1.554, p=.046, η_p^2 =.062; Level by Age, F(6, 142)=5.733, p<.001, η_p^2 =.195; Spatial Category by Level, F(16, 1136)=11.057, p<.001, η_p^2 =.135; Spatial Category by Level by Age, F(48, 1136)=3.341, p<.001, η_p^2 =.124. To best explore the data, a separate ANOVA was carried out for each Spatial Category, each with a between-participant factor of Age and a within-participant factor of Level. There was a consistent main effect of Level and main effect of Age for every Spatial Category (p < .05 for all). Differences emerged across the interactions between Level and Age (Figure 3). These are described for each Spatial Category in turn below.

For *In* Level and Age interacted due to a main effect of Level for the 4- and 5-year-olds, but not at 6 and 7 years. For *On* Level and Age interacted due to a main effect of Level for all ages, with the exception of the 7 year olds. For *Under*, all groups behaved consistently, with Level 1 easier than Levels 2 and 3. For *In Front*, there was an interaction between Level and Age; this was because the main effect of Level was present at 4 years only, due to 4-year-olds passing Level 1 only, and showing chance performance for Levels 2 and 3. From 5 years, children passed all Levels, with no differentiation in difficulty across Levels. For *Behind*, the main effect of Level was linear and did not interact with Age. For *Above*, Level and Age interacted. This was due to the 4-year-olds performing equally poorly across all three Levels, with performance classed as at chance for Level 3, whilst the 5- and 6-year-olds found Level 3 harder than the Levels 1 and 2 (although the difference between Levels 1 and 3 was not significant at 5 years), and the 7-year-olds performed well across Levels. For *Below*, all groups behaved consistently (no Level by Age interaction), due to Levels 1 and 2 being easier than Level 3. For *Left* and *Right*, Level and Age interacted; the 4-year-olds were at chance for Levels 2 and 3 for both *Left* and *Right*. At 4 years, for Left there was some linear progression for *Right* (p=.005), but not *Left (*p=.051*)*. At 5 years, Level 1 was stronger than Levels 2 and 3 for *Left*, and Level 2 was stronger than Level 3 (Level 1 was above Level 3, but not significantly so) for *Right*. For 6- and 7-year-olds, Levels 1 and 2 were at a similarly strong level and significantly above Level 3 for both *Left* and *Right*. All age groups showed chance performance at Level 3 for both *Left* and *Right*.

To complement Figure 3, Table 2 illustrates the highest level that was achieved for each age group, for each spatial category. A score of 1, 2 or 3 was given according to the levels passed. A pass was classified as correctly identifying the odd-one-out on two or more of the four trials for that level, provided that they had passed any preceding level(s). One-sample t-tests of participant scores to a score of 1, 2 and 3 indicated the overall levels achieved for each group and category. We recognise that passing a level does not indicate mastery, but Table 2 provides a simple documentation of developmental progression through the levels of our model.

To determine whether the stability of spatial category understanding is yoked to children's understanding of the corresponding spatial language terms, the ANOVA of the odd-one-out task data was repeated with spatial language production score (maximum = 9) as a covariate. This variable was chosen over spatial language comprehension score because it was significantly associated with overall spatial category understanding ability ($F(1, 70)=6.787$, $p=.011$, $\eta_p^2 =.088$), where comprehension was not, due to low variability in comprehension scores ($F<1$). All main effects and interactions remained, with the exception of non-significant interactions between Spatial Category and Level, $F(16, 1120)=1.473$, $p=.102$, $\eta_p^2 =.021$, and Spatial Category and Age, $F(24, 560)=1.175$, $p=.258$, $\eta_p^2 =.048$. This suggests that variation in children's fragility of their spatial representations across spatial categories is yoked to their ability to produce spatial language terms.

Figures 2,3,Table 2

Comprehension and Production Tasks

Table 3 shows the spatial terms listed in order of acquisition as documented in the literature. Comparing across the terms, in line with the literature, the data demonstrates a decrease in the percentage of children showing comprehension and production of each term, as the difficulty of the categories increases.

Participants were awarded a score out of nine for the number of terms that they could comprehend and for the number of terms that they could produce. Correlational analysis demonstrated a significant relationship between comprehension and production scores, $r=.501$, $p<.001$. Analysis of Variance (ANOVA) with Age (4 levels: 4- 5- 6-, and 7-year-olds) as a between-participant factor and Task (comprehension, production) as a within-participant factor demonstrated a main effect of Age, $F(3, 71)=7.512$, $p<.001$, $\eta_p^2 =.241$, due to a general progression with increasing age (Tukey comparisons: 4 years < 6 and 7 years; 5 years < 7 years; $p<.05$ for all; all other comparisons, $p>.05$). Comprehension was stronger than Production ($F(1, 71)=149.002$, $p<.001$, $\eta_p^2 =.677$) across all age groups (Task by Age: $F(3, 71)=2.466$, $p=.069$, $\eta_p^2 =.094$).

Table 3

Discussion

The data support our spatial category representation model, that for each spatial category, children progress through three levels of understanding. Children initially represent categories as fixed relationships between the same pair of objects (level 1). They then progress to an abstract understanding that the spatial relationship can apply to any objects (level 2). This mirrors the specific to abstract pattern reported in infancy (Casasola, 2008). Finally, they move to accepting that both prototypical and non-prototypical examples of spatial relations belong to the same category, as shown in adults (level 3; Feist & Gentner, 2007). This is consistent with Meints et al. (2002) who documented the beginning of this transition for *on* and *under*. We have also demonstrated that the age at which children progress from one level to the next differs according to the spatial category, and the order in which these transitions occur follows the same order in which spatial category representations emerge. Thus, once a category has been formed, children’s representations of that category progress through three levels of representation to become more adultlike with cumulated exposure to examples of that category.

Casasola (2008) suggests that the move from specific to abstract spatial categories in infants reflects a move from attending more to the spatial relations than to the objects. It is interesting that, despite infants showing some abstract category representations from as young as 6 months (Quinn et al., 1996), our data echo this specific to abstract pattern even at school-age. This supports the notion that the pattern is robust, whilst also demonstrating that representations of spatial categories have a long developmental trajectory. At fourteen months, infants are able to demonstrate abstract category understanding when familiarised to two object pairs, but do not show categorical understanding when six object pairs are employed (Casasola, 2005). In the current study children were shown four object pairs; perhaps this limited children’s ability to focus on the spatial relation.

Our data extends the range of spatial categories in which a specific to abstract transition has been documented. If our results were purely a visual phenomenon in which level 1 odd-one-out images are more likely to show pop-out than level 2 odd-one-out images, then the transition from level 1 to level 2 would occur concurrently across spatial relationship categories, as the executive functions required to disengage from the array and focus on the spatial relationships develop. Whilst we cannot rule this out as a contributing factor, the difference in the age at which level 2 understanding becomes proficient is evidence for a predominant influence of spatial category development. Nonetheless, future research could include a condition in which images use the same object pairs to display non-prototypical examples (a combination of levels 1 and 3) to reduce the executive function load; comparison across this condition and the current condition 3 would differentiate between these potential contributors to performance. Observation of Figure 2 also demonstrates that for many categories, the differentiation between performance at level 1 versus level 2, reduces with increasing age, and eventually disappears at which point we suggest that level 2 (abstract) category understanding has become stable. This progression suggests that the transition from specific to abstract category understanding is gradual with categories becoming more stable with experience. In our data, this is only observed for the earlier acquired categories, but had we tested a wider age range, this pattern might have also been evident for later acquired categories.

Beyond the transition from specific to abstract representations of categories, children begin to extend the range of exemplars that they are willing to accept as category members, i.e. they start to adopt a prototype framework. To our knowledge, this is the first time that this progression has been documented developmentally in school-age children. Meints et al. (2002) demonstrated the beginnings of the use of a prototype framework from as early as two years for *On* and *Under*. However, this was only present when the spatial relationship between an animate object and a referent was used, suggestive of restricted application of a prototype framework at this age. The current study, with the exception of a dog and a cat, used inanimate objects. Above chance performance at passing level 3 was not evident until 5 years for *Under* and at 6 years for *On*, which supports Meints et al.'s (2002) notion that the use of a prototype framework is not yet stable in toddlers.

The transition to using a prototype framework is also related to increased experience, indicated by stronger level 3 understanding with increasing age, as well as stronger level 3 understanding for earlier than later acquired categories. The data here showed level 3 understanding of *In* and *Under* at 5 years, *On, In Front, Below* and *Behind* at 6 years, *Above* at 7 years. *Left* and *Right* had not reached level 3 understanding by 7 years, and thus further research is required to determine when this understanding of *Left* and *Right* develops. We must be cautious, however, in classing accuracy on two or more trials out of four as entirely stable.

Whilst in this study we explored flexible categorical understanding by including prototypical and non-prototypical members of categories, other examples of broad category membership were not explored. We used loose fit support examples for *on*. Other examples include tight fit support such as a ring *on* a finger (Casasola & Bhagwot, 2007). Also, for categories in which the prototype is axial, we represented broader category membership by presenting off-axis members, rather than extending the distance between the object and referent. Erreich and Valian (1979) and Landau and Hoffman (2005) demonstrated that children up to six years do not accept off-axes examples as category members for *Above*, *Below*, *Left, Right*, *In* and *Beside*, but do accept both near and far on-axis examples as category members. First, this is consistent with our findings for off-axes examples. Second, this suggests that flexibility in accepting different variations as category members have different developmental trajectories; a topic for future research.

Future research could also extend the age range. It remains unclear how spatial category representations develop between toddlerhood and four years. We were also unable to determine the age at which an adultlike representation is reached for all of the nine categories investigated. Furthermore, the non-prototypical stimuli were systematically designed to be equivalent with respect to ‘non-prototypicality’; whilst our adult data validates category membership, an additional study would be required to confirm equivalency across spatial categories.

Performance on the odd-one-out task was related to children’s ability to produce spatial language terms. We did not aim to speak to the direction of influence between perceptual representation and linguistic labelling of spatial categories, but this indicated that the two are yoked. Indeed, when spatial language production score was added as a covariate, differences in the level reached on the odd-one-out task across the spatial categories, and differences in spatial category representations with age, were no longer apparent. This suggests that children’s ability to produce spatial language terms confidently is related to category membership, i.e. the more terms a child can produce, the more level 3 representations are observed across spatial categories. Similarly, increases in spatial language production with age are associated with increased spatial category understanding with age. Our findings also suggest that the difficulties with producing spatial terms in school-age children (Durkin, 1980) relates to category membership. Given that in the real world, many category members are non-prototypical, when a child has not reached a level 3 representation of that category, this likely restricts the range of exemplars in which they are confident to apply spatial categorical labels to. This might explain why general descriptors such as ‘next to’ are commonly used in children, rather than specific terms like ‘left’. Of course, we cannot rule out the opposing argument that it is a restricted set of verbal category labels that limits the development of perceptual category membership.

Spontaneous verbal coding is typically not available to the age groups investigated here (Hitch et al., 1988). Nevertheless, if children were using verbal labelling, this could have had a facilitatory effect; studies that have used explicit verbal labelling have shown a positive influence on young children’s performance on spatial tasks (e.g. Dessalegn & Landau, 2008; 2013; Loewenstein & Gentner, 2005). However, recent evidence from adults has demonstrated that whilst the ability to discriminate stimuli with reference to category membership is stronger for easier-to-name than harder-to-name categories, this advantage is not influenced by verbal interference or by verbal training (Kranjec, Lupyan & Chatterjee, 2014). This suggests that in this kind of category discrimination task adult's perceptual categories coincide with linguistic categories, but are not facilitated by verbal labelling. This suggests that spatial language experience, i.e. the knowledge that verbal labels can be used to group and discriminate objects, has an impact on our attention to and categorisation of those objects. Further research is required to determine whether the same is true developmentally, for example by using verbal interference and through cross-cultural data (cf. McDonough, Choi & Mandler, 2003).

In summary, adults include prototypical and non-prototypical category members within their representation of spatial categories (Feist & Gentner, 2007). We demonstrated that children proceed through three levels of spatial category understanding to reach a flexible level of understanding, with each category showing a similar developmental pattern, over different, but overlapping, developmental timespans.

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Table 1: Participant details

Group	N (males: female)	Chronological age		BPVS verbal mental age	
		years; months			
		Mean	S.D.	Mean	S.D.
Four-year-olds	20 (11:9)	4;08	0;02	5;02	1;01
Five-year-olds	18 (10:8)	5;07	0;03	5;11	1;00
Six-year-olds	18 (8:10)	6;05	0;04	7;03	1;02
Seven-year-olds	19 (11:8)	7;06	0;04	8;05	1;04

Table 2
Level of perceptual spatial representation reached (above chance performance) for each spatial category from 4 to 7 years.

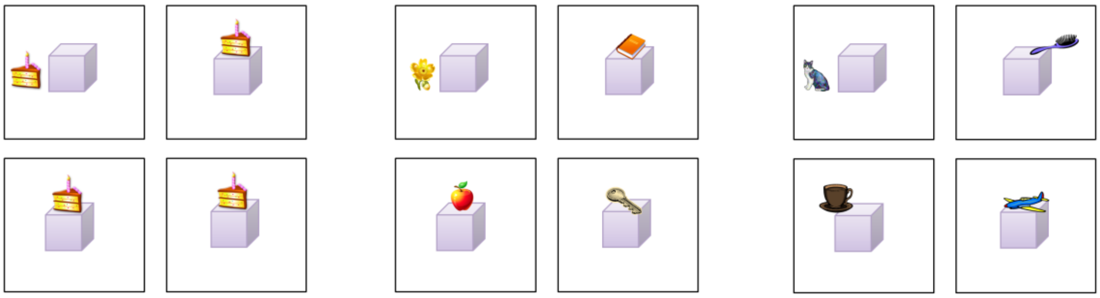
Age	Spatial Category								
	In	On	Under	In front	Behind	Above	Below	Left	Right
4 years	2	2	2	2	1	1	1	<1	1
5 years	3	2	3	2	2	2	2	1	1
6 years	3	3	3	3	3	2	3	2	2
7 years	3	3	3	3	3	3	3	2	2

Key
1: Rigid spatial representation
2: Abstract spatial representation
3: Prototype framework representation

Table 3
Percentage of participants able to comprehend and produce each spatial language term.

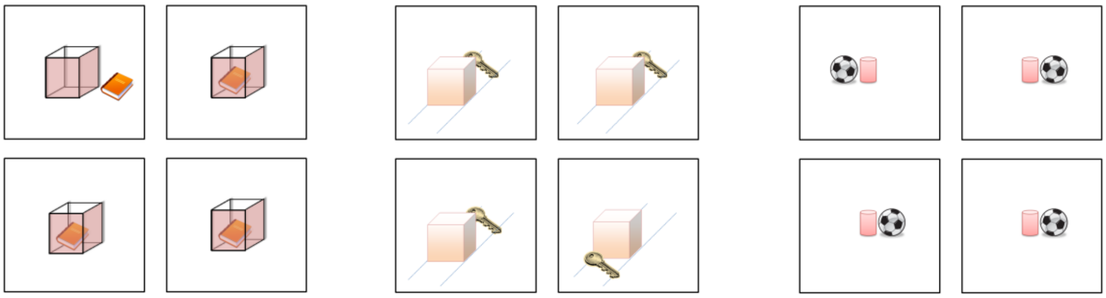
Spatial term	Age	4 years	5 years	6 years	7 years
In	Comprehension	100	100	100	100
	Production	100	100	100	100
On	Comprehension	100	100	100	100
	Production	90.00	94.40	100	100
Under	Comprehension	100	100	100	100
	Production	75.00	61.10	83.30	89.50
In front	Comprehension	100	100	100	100
	Production	75.00	88.90	83.30	94.70
Behind	Comprehension	100	100	100	100
	Production	50.00	77.80	88.90	94.70
Above	Comprehension	80.00	94.40	100	100
	Production	10.00	22.20	22.20	63.20
Below	Comprehension	55.00	77.80	100	100
	Production	0.00	5.60	16.70	15.80
Left	Comprehension	55.00	66.70	83.30	78.90
	Production	40.00	44.40	61.10	78.90
Right	Comprehension	55.00	66.70	83.30	78.90
	Production	40.00	50.00	61.10	78.90

Figure 1a: Example of odd-one-out task stimuli; Levels 1, 2 and 3 for *On*

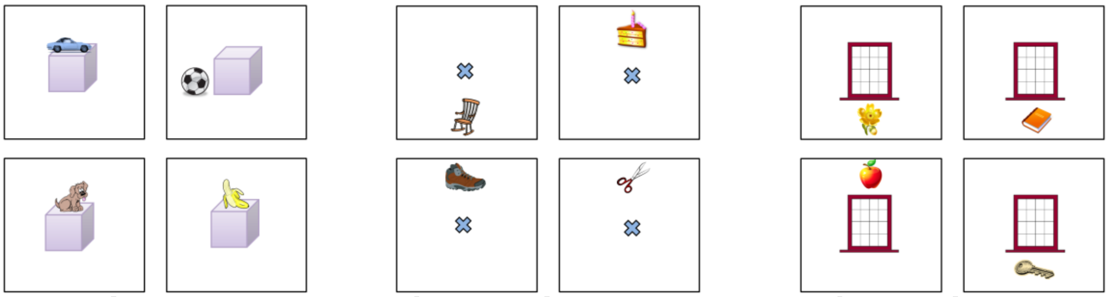


On Level 1 *On* Level 2 *On* Level 3

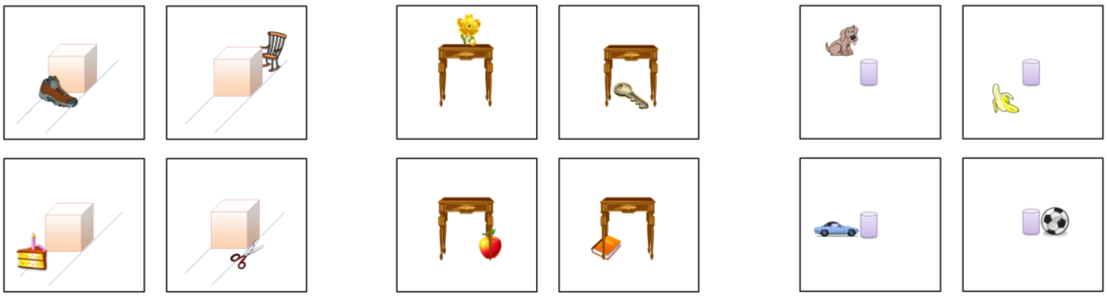
Figure 1b: Examples of odd-one-out task stimuli; *In*, *On*, *Under*, *In Front*, *Behind*, *Above*, *Below*, *Left* and *Right* exemplars across all Levels.



In Level 1 *Behind* Level 1 *Right* Level 1



On Level 2 *Above* Level 2 *Below* Level 2



In front Level 3 *Under* Level 3 *Left* Level 3

Figure 2: The development of spatial category understanding on the odd-one-out task across age groups

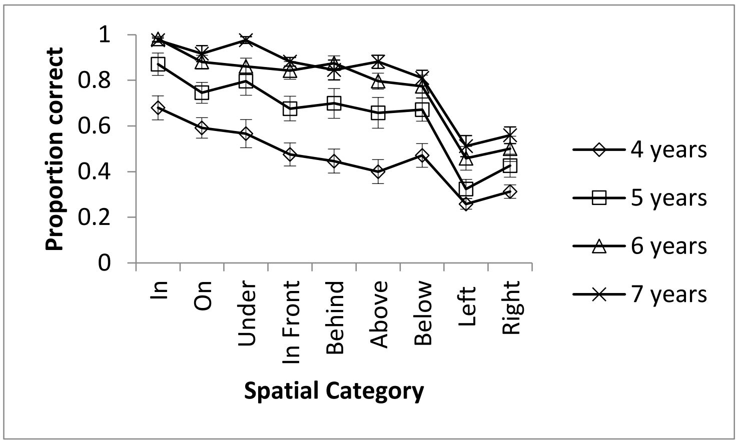


Figure 3: Odd-one-out task performance across nine spatial categories