Published in final edited form as:

J Exp Child Psychol. 2014 March ; 119: 101–111. doi:10.1016/j.jecp.2013.10.011.

The Construction of Visual-spatial Situation Models in Children's Reading and Their Relation to Reading Comprehension

Marcia A. Barnes^{1,2}, Kimberly P. Raghubar³, Heather Faulkner⁴, and Carolyn A. Denton¹

¹Children's Learning Institute, University of Texas Health Science Center-Houston

² Department of Special Education, University of Texas at Austin

³ Psychology Department, University of Houston

⁴Halifax, Nova Scotia

Abstract

Readers construct mental models of situations described by text to comprehend what they read, updating these situation models based on explicitly described and inferred information about causal, temporal, and spatial relations. Fluent adult readers update their situation models while reading narrative text based in part on spatial location information that is consistent with the perspective of the protagonist. The current study investigates whether children update spatial situation models in a similar way, whether there are age-related changes in children's formation of spatial situation models during reading, and whether measures of the ability to construct and update spatial situation models are predictive of reading comprehension. Typically-developing children from ages 9 through 16 years ($n=81$) were familiarized with a physical model of a marketplace. Then the model was covered, and children read stories that described the movement of a protagonist through the marketplace and were administered items requiring memory for both explicitly stated and inferred information about the character's movements. Accuracy of responses and response times were evaluated. Results indicated that: (a) location and object information during reading appeared to be activated and updated not simply from explicit text-based information but from a mental model of the real world situation described by the text; (b) this pattern showed no age-related differences; and (c) the ability to update the situation model of the text based on inferred information, but not explicitly stated information, was uniquely predictive of reading comprehension after accounting for word decoding.

Keywords

Situation models; reading comprehension; inference; spatial perspective-taking

© 2013 Elsevier Inc. All rights reserved.

Correspondence to: Marcia A. Barnes Special Education University of Texas at Austin Sanchez Building STOP D5300 Austin, TX, 78712.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Readers construct representations of the situation described by text that includes, but also goes beyond, the propositional information provided by the text (Kintsch, 1988). These situation models anchor the text in the real world and, as such, contain information about character's motivations and goals, their spatial locations, the temporal nature of events, and physical causal relations (Zwaan, Langston, & Graesser, 1995). Recent studies suggest that comprehension involves mental simulations of the referential situation described by text or discourse (reviewed in Fischer & Zwaan, 2008). These simulations are constrained by linguistic and pictorial information, the reader's processing capacity, and the reader's knowledge about and experiences with their physical and social worlds (Glenberg & Kaschak, 2002; Zwaan, 1999).

Children's developing knowledge of spatial, causal and temporal relations, and of psychological and motivational factors influences the types of situation models they are able to construct. Because of this connection to real world knowledge and experience, the developmental parameters of situation model construction map onto cognitive development more generally. For example, tracking a character's mental perspective during narrative comprehension shows development between 3 and 5 years of age (Fecica & O'Neill, 2010; O'Neill & Shultis, 2007) consistent with children's growth in perspective-taking ability across this same time frame. In contrast, the ability to construct temporal situation models from text shows change into middle childhood and early adolescence, likely related to capacity-based difficulties of younger children in revising situation models to accommodate events that are presented out of sequence (Pyykkönen & Järvikivi, 2012). Individual differences in the construction of situation models have also been reported. For example, children who have deficits in coordinate spatial perception associated with neurodevelopmental disorder can construct visual-spatial situation models at the single sentence level, but have difficulty updating these models from ongoing text (Barnes, Huber, Johnston, & Dennis, 2007).

The current study investigates the formation and updating of visual-spatial situation models during comprehension in typically developing school-age children. In young children, spatial situation models have been tested using paradigms where evidence of the listener's perspective is inferred based on children's errors in recall or by the ways in which they interpret ambiguous referents. For example, young children have better verbatim recall for deictic verbs (e.g., come versus go; give versus take) that are consistent with the protagonist's perspective than for verbs that are inconsistent with his/her perspective (Rall & Harris, 2000; Ziegler, Mitchell, & Currie, 2005). By about 5 years of age children tend to update their mental representations of what is happening in the text based on the perspective of the protagonist. For example, when listening to a brief story accompanied by two different 3-dimensional models of the locations described in the story (e.g., a field and a barn), children were asked "Can you point to the cow"? This is an ambiguous question because there are two cows – one in the barn and one in the field. Children pointed more often to the cow that the protagonist was thinking about feeding than to the cow in the protagonist's current location (O'Neill & Shultis, 2007). These findings suggest that older preschoolers adopt the mental perspective of a protagonist while listening to a story.

Despite the above examples of seemingly adult-like visual-spatial mental models in preschoolers, there is reason to believe that there may be age-related changes in spatial situation model construction in school-age children, particularly when they must read texts. For example, young readers inconsistently map printed words and phrases to their real world referents because they sometimes approach reading as a decoding exercise rather than an as opportunity for understanding (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004). Indeed, brief interventions that teach typically developing beginning readers and less skilled comprehenders to engage in referential mapping by physically and mentally manipulating objects and events during reading result in improved comprehension (Glenberg et al., 2004; Glenberg, Willford, Gibson, Goldberg, & Zhu, 2012; van der Schoot, Horsley, & van Lieshout, 2010). Age-related differences in situation model construction during reading could also emerge as a function of increased cognitive load involved in *updating* or *revising* the spatial situation model. The need to update the situation model may come into play with longer texts (e.g., Barnes et al., 2007) and the need to revise the situation model occurs when newly read information conflicts with the reader's prior interpretation of an event. In the case of revision of situation models, for example, 12-year-old children do not perform at adult levels when the text requires them to revise an already constructed situation model of the temporal order of events (Pyykkönen & Järvikivi, 2012). Findings such as these suggest that there may be age-related changes in school-age children's ability to construct spatial situation models during reading of texts.

Several important questions about children's construction of spatial situation models remain unanswered. These include: 1) as discussed above, whether there are age-related changes in children's ability to update spatial situation models as they are *reading* texts; 2) whether the visual and/or spatial information young readers access includes information that is not only from explicitly mentioned locations in a text, but also from locations that are not explicitly mentioned in a text, such as those that may be inferred based on a character's actions; and 3) although situation model construction is considered to be important for discourse and text comprehension (van Dijk & Kintsch, 1983), we do not know whether variability in children's ability to construct spatial situation models predicts their general reading comprehension abilities.

In order to investigate these questions we designed an experiment based on studies of spatial situation models in adults (e.g., Morrow, Bower, & Greenspan, 1989). These experiments familiarized readers with spatial layouts of the context in which a story would unfold (e.g., the rooms in a house and objects in those rooms) and tested whether the reader's mental representation of the story included spatial location information based on the perspective of the protagonist. The reader's representations for spatial information activated during reading were assessed, not through comprehension questions or recall of text, but through an implicit memory task in which reading was periodically interrupted to ask whether two objects (words) were from the same or different locations in the house. The objects were never mentioned in the story, but were presumed to be part of the reader's knowledge about the house. When the objects were from the same location, they were either in the explicitly mentioned room from which the protagonist started out (Source – for example, chair and shelves in the bedroom), from the explicitly mentioned room in which the protagonist ended

up (Goal – for example, clock and vase in the kitchen), from the pathway that the protagonist must have traversed to get from the source to the goal, even when the pathway was not mentioned in the story (Path – for example, lamp and radio in the living room), or from a room that the protagonist never visited (Other – for example, glasses and painting in the dining room). In a series of landmark studies (Morrow, Greenspan, & Bower, 1987; Morrow et al., 1989) readers were found to update their situation models as the protagonist moved from one place to another, activating spatial and object-based information in mentioned locations and from unmentioned pathways. In the implicit memory task (Are the two objects from the same or different locations?), locations where the protagonist had been (Source, Path, Goal) were more readily accessible than locations where the protagonist had not been (Other). For example, participants were faster at deciding that a clock and a vase (from the Goal location, the kitchen) were from the same location than they were at deciding that glasses and painting (from the dining room which was neither mentioned nor traversed) were from the same location. There was also an accessibility gradient such that decisions about objects at the Goal and Path locations where the protagonist had most recently been or was going tended to be faster than those for the Source and Other locations.

Faster decisions for objects in the Path suggest that readers inferred and updated the location of the protagonist and activated object-based information from that location even though the location was not mentioned in the story. In typically developing children, the ability to construct a locally and globally coherent representation of the text is critical for comprehension and this is achieved through a variety of higher level referential processes including inference-making and the connecting of text with the reader's prior knowledge (Rapp, van den Broek, McMaster, Kendeou, & Espin, 2007). Inference-making skills show some development across the elementary school years (Barnes, Dennis, & Haefele Kalvaitis, 1996; Casteel, 1993; Pike, Barnes, & Barron, 2010), they are strongly related to reading comprehension in typically developing readers (review in Oakhill & Cain, 2007), and difficulties in inference-making characterize children with specific reading comprehension problems (review in Cain & Oakhill, 2007). To the extent that higher resolution situation models contain information that is inferred from rich domain knowledge (Zwaan, 1999), the ability to make spatial inferences during reading may also be related to comprehension. In adults, reading comprehension scores predicted spatial inference times (Haenggi, Kintsch, & Gernsbacher, 1995). To our knowledge, whether children who are better at accessing unmentioned (i.e., inferred) object- and location-based information during reading are also better comprehenders has not been explored and warrants further study.

In this study we created a child-appropriate version of the situation model experiments described above. We predicted that 1) typically developing readers would construct visual-spatial situation models during reading in ways that suggest they update their situation models as they are reading similar to the pattern seen in adult readers such that objects from goal and path locations would be most accessible; 2) there might be some improvement in this ability with age (in accuracy and/or response times); and 3) that measures of situation model construction, particularly the ability to infer spatial location by activating object-based information from that location, would be related to reading comprehension, but not to word reading ability.

Methods

Participants

Participants included 81 typically developing native English-speakers from ages 9 to 16 years. They comprised 6 age groups (9, 10, 11, 12, 13, and 14-16 years) with roughly equal numbers of children in each group. Numbers of children in each age group, and the age range for each group are in Table 1. Children were recruited from schools in predominantly middle class neighborhoods in southern Ontario or as part of a comparison group for a study of reading in children with neurodevelopmental disorder. Participants from the two sources were combined as there were no differences in reading achievement or performance on the experimental measures between these groups. Children with learning and behavior disorders, or congenital or acquired central nervous system disorders were excluded as were children born prior to 37 weeks gestation or who were small for gestational age. All children had word reading skill commensurate with their grade placement (at or above the 25th percentile for grade). Participants and their parents gave informed consent and/or assent to participate in compliance with the research ethics board at the Toronto Hospital for Sick Children.

Measures

Letter Word Identification—(Woodcock-Johnson Reading Mastery Test-Revised or WJRTM-R, Woodcock & Johnson, 1989) This is an un-timed measure of word reading ability.

Word Attack—This is an untimed measure of the ability to decode pronounceable non-words using knowledge of English phonology and orthography from the WJRTM-R.

Passage Comprehension—This subtest from the WJRTM-R uses a cloze procedure in which participants silently read sentences and paragraphs and show their understanding by filling in the missing word in the passage.

Marketplace task—Children were exposed to and memorized a model of a marketplace containing 7 shops with 3 objects outside of each shop. To avoid pre-experimental associations between shops and objects, objects had only weak semantic associations with the shops outside of which they were located. Figure 1 shows a diagram of the 3-D model studied by the participants, which was created using Playmobil figurines and objects. After studying the market children were given a set of 2-dimensional picture puzzle pieces to reconstruct the market from memory. All children were exposed to the market twice even if 100 percent accuracy was obtained on the first learning/memory trial.

After learning the marketplace layout and objects within the marketplace, children read 6 story episodes presented on the computer. Memory for the layout of the marketplace and the objects was also assessed after the last episode had been read. Each episode was 20 – 25 sentences long and described the protagonist moving through the marketplace. Each episode began by introducing the protagonist and describing his or her goal. Next, the protagonist moved through the marketplace in order to accomplish the goal (e.g., purchasing items from

a list supplied by mother). Sentences described complete motion events where the protagonist moves from one shop (Source) to another shop (Goal) by passing through a third, unmentioned shop (Path). The Appendix contains an example of one episode and the memory probes for that episode as described below.

To determine what information is activated in memory, reading was interrupted periodically, and pairs of words representing objects from the market were presented on the computer screen. Children pressed one key if the two objects were from the same shop and another key if they were from different shops. Referring to the example in the Appendix and Figure 1, in the *same* shop probes, the objects were located either in the mentioned shop from which the character started (Source – for example, Gumballs and Mailbox at the Flower Stand), the mentioned shop that the protagonist was headed towards (Goal – for example, Mirror and Suitcase at the Jewelry Stand), the unmentioned shop that the protagonist would have passed through on the way to the Goal (Path- for example, Milk and Trees at the Fruit and Vegetable Stand), or another shop (Other - for example, Scale and Basket at the Fish Stand), which was neither mentioned in the text at that point nor passed through by the protagonist (i.e., a shop other than the Source, Goal or Path shops). The *different* shop probes contained objects either from the Goal shop and another shop, the Path shop and another shop, or the Source shop and another shop. Each episode contained the described probes above, totaling 7 probes per episode. Objects appeared an approximately equal number of times in each probe condition across the six episodes of the story.

Procedures

Participants were tested in one to two sessions (depending on whether they came from the school-based sample or the comparison group for the study of reading in neurodevelopmental disorders), totaling about 2 hours; however, the marketplace task was conducted in one uninterrupted session. At the beginning of the task, children studied the market layout and were exposed to it for an unrestricted period of time until they thought they knew the layout (trial 1 study time varied between 5-10 minutes). After children indicated that they had studied all aspects of the model, it was covered up, and they filled in a blank layout of the market with pictures of the shops and the objects. Accuracy of recall was recorded, after which children were given a second opportunity to study the model. Then they filled in a second blank layout of the market.

The reading and object memory components of the marketplace task were run on an IBM compatible computer using a program written in Micro Experimental Laboratory that presented the stimuli and recorded responses. A practice story with the memory probes was presented before the 6 experimental episodes. Participants read episodes presented one sentence at a time. Presentation was self-paced; children pressed the space bar to advance from one sentence to the next. Children knew that after some sentences a probe would appear (two words) and that they would need to decide whether the two objects came from the Same shop or a Different shop by pressing one of two labeled keys on the computer keyboard. Participants were instructed to press the button to advance to the next sentence once they had read and understood the previous sentence and periodically, to judge whether two objects came from the same or different market stall; there was no instruction to

imagine the marketplace layout during story reading. Probes appeared after the children pressed the space bar removing the previous sentence. The computer timed from the presentation of the probe words to the responding of participants (pressing the same or different key). Participants were told to make their decisions as quickly and as accurately as possible.

After all story episodes had been read the participants again placed the pictures of the market stalls and their objects on the blank layout to measure memory for the location of the market stalls and their associated objects.

Results

On average, participants performed close to the population mean on Letter-Word Identification, Word Attack, and Passage Comprehension. These findings are in Table 1. There was a main effect of age group for Letter-Word Identification, $F(5, 75) = 2.76, p < .05, \eta^2 = .16$; however, none of the pair-wise contrasts were significant (14-16 vs. 12 year-olds, $p < .06$).

Learning and Remembering the Marketplace Layout and Objects

A 3 time (performance on learning trials 1 and 2 and post-test performance) by 6 age-group (9, 10, 11, 12, 13, 14-16) mixed ANOVA was conducted to examine the effect of age on learning and memory for the layout of the marketplace and the objects. There was a main effect of time, $F(2, 150) = 144.28, p < .001, \eta^2 = .66$, with performance on learning trial 1 being lower than performance on learning trial 2 ($p < .001$) and post-test performance ($p < .001$); learning trial 2 and post-test performance did not significantly differ. No other effects were significant. These findings are in Table 2.

Performance on Memory Probes

Six age group (9, 10, 11, 12, 13, 14-16) by 4 location (Path, Goal, Source, Other) mixed ANOVAs with repeated measures on the second factor were conducted on accuracy and response time for correct responses on the *Same* and *Different* trials. Mean accuracy and response time data are in Tables 2 and 3, respectively. For accuracy on *Same* trials, there was a main effect of location, $F(3, 225) = 7.77, p < .001, \eta^2 = .09$. A priori contrasts (based on findings in Morrow et al., 1989) revealed that children were more accurate on Path probes compared to Goal ($p < .05$), Source ($p < .001$), and Other ($p < .001$) and on Goal probes compared to Other probes ($p < .05$). No other effects were significant.

Response latencies greater than 3 standard deviations above or below the mean for each participant were eliminated and a mean latency for each condition was calculated. For response times on *Same* trials, the effect for location was significant, $F(3, 225) = 9.10, p < .001, \eta^2 = .11$. A priori contrasts revealed that children were slower to respond to Other probes compared to Path, Goal, and Source probes (all p -values $< .001$). No other effects were significant.

Like the findings of Morrow et al. (1989) and those for the *Same* location probes above, results for *Different* trials revealed that accuracy was greatest when one of the objects came

from a more relevant situational location (i.e., path or goal versus source): the main effect of location was significant, $F(2,150) = 246.05$, $p < .001$, $\eta^2 = .77$, and children were more accurate on Path-Other and Goal-Other probes compared to Source-Other probes (all p -values $< .001$). There was no main effect of age and no interaction. For response times on *Different* trials, there was a main effect of location, $F(2, 150) = 4.47$, $p < .05$, $\eta^2 = .06$, such that response times were faster for Source-Other probes compared to Path-Other ($p = .001$) and Goal-Other probes ($p < .05$), which suggests that there may have been a speed-accuracy trade-off for the Source-Other condition. The correlation of accuracy and response time for the source-other condition was .24 ($p < .05$). The effect for age and the interaction were not significant.

Predictors of Passage Comprehension

Bivariate correlations revealed expected relations between all three standardized reading measures from the WJRT-R (all p -values $< .001$ with r s between .46-.65). A regression model examined whether memory probe scores (accuracy on path, goal, and source) predicted performance on Letter-Word Identification. The overall model was not significant $F(3,77) = 1.49$, $p = .23$. A hierarchical regression tested whether memory probe scores predicted performance on Passage Comprehension, controlling for Letter-Word Identification. Letter-Word Identification standard scores were entered in the first block, and accuracy on the Path, Goal, and Source probes were entered in the second block. Letter-Word Identification significantly predicted performance on Passage Comprehension, $F(1,79) = 57.72$, $p < .001$; $R^2 = .42$, and the marketplace scores accounted for additional unique variance, $F(3,76) = 3.85$, $p < .05$; R^2 change = .08, with a significant contribution from Path probes, $t = 3.40$, $p = .001$.

Discussion

This study tested whether typically developing readers between the ages of 9 and 16 years construct and update spatial situation models during reading in ways that are similar to the pattern seen in adult readers, and whether measures of situation model construction, particularly the ability to infer spatial location, are related to reading comprehension.

When children had spatial domain knowledge, in this case, the layout of a marketplace and the location of objects within the market, they accessed that information during the course of reading a story in a way that is consistent with the idea that they adopted the mental perspective of the protagonist. Specifically, objects in locations passed through by the protagonist (source, path, goal) were activated in the reader's memory to a greater extent than objects in locations not traversed by the protagonist, whether the locations were explicitly mentioned in the text or traversed but not mentioned (Morrow et al., 1989). Furthermore, similar to the response time findings obtained with adults (Morrow et al., 1989), the child accuracy data provided evidence for greater activation of spatial location information of most relevance to the current perspective of the protagonist; namely path and goal locations. These findings are consistent with the idea that as the mental model is updated, prior location information (source) becomes less accessible. As is often true for

studies with children, several of the findings were discernable not only in response time, but also in accuracy.

Because objects in unmentioned but relevant locations from the protagonist's point of view (path) were more easily accessible than those in explicitly mentioned, but less relevant locations (source) the effects are not merely due to priming of objects based on reading the name of a particular market stall. Thus, for children, spatial information during reading appears to be activated and updated not simply from explicit text-based information but from a mental model of the real world situation described by the text.

This study differed from those with adults in that we also tested memory for the marketplace and objects after the entire story had been read. Children learned more about the market place locations and their objects after the second study session, and they retained this knowledge over time. Whether reading the story served to reinforce memory for the marketplace cannot be determined, but the findings do suggest that the marketplace information was available to readers for the duration of the experiment.

The level and *pattern* of performance did not differ across the relatively broad grade range of children in this study, which suggests some age-invariance in spatial situation model construction during reading, at least amongst typical readers and once basic word decoding skills are in place. This fits well with studies of much younger pre-readers who also appear to adopt the perspective of the main character when listening to brief descriptions of what characters are doing (e.g., Rall & Harris, 2000; O'Neill & Shultis, 2007). In this case, recently learned spatial information was incorporated into the reader's mental model of the situation being described by ongoing text showing that children not only take the perspective of the protagonist, they are also adept at updating the spatial mental model as a story unfolds over time. These findings suggest that updating spatial location information in the formation of situation models may not be as resource-intensive as some other types of situation model construction such as those involving revision to the temporal order of events for which age-related changes have been reported (Pyykkönen & Järvikivi, 2012).

A novel finding is the specificity of the relation between spatial situation model measures and reading comprehension. Situation model measures predicted reading comprehension, but not reading decoding. Furthermore, it was performance on the Path probes that uniquely predicted reading comprehension after accounting for word decoding. This implies that the ability to update the situation model of the text based on *inferred* information might be particularly important for reading comprehension. It is worth noting that the texts used in the current study, along with pre-teaching of the marketplace, likely resulted in greater use of visual-spatial strategies during situation model construction than might occur with other types of text. Nevertheless, the findings suggest that the ability to include implicit spatial location and object information from the protagonist's perspective in one's mental representation of the text is what is uniquely related to general reading comprehension skill.

The findings add, in a general way, to the literature on the importance of inference-making for reading comprehension (reviewed in Oakhill & Cain, 2007). More specifically, the findings raise questions about the nature of the relationship between situation model

inferences and reading comprehension. Some inferences are necessary for comprehension because they maintain textual coherence and the causal structure of the text representation (Kintsch, 1988). Such inferences have a relatively transparent relation to comprehension. In contrast, the Path information that readers inferred in the current study was not necessary for story comprehension, and so the relation of this type of inference to comprehension is less obvious. Some models of reading comprehension (e.g., Schmalhofer, McDaniel, & Keefe, 2002) make less of a distinction between inferences that are necessary versus those that are not necessary to maintain textual coherence and, instead, focus on the factors that contribute to the persistence of situation model inferences such as those tapped by the Path items in the current study. Because reading is a dynamic process, inferred situational information might be important for comprehension shortly after it has been activated depending on the text that follows, at some later point in the text, or not at all (Schmalhofer et al., 2002). Activating situational information during reading, even when it is not immediately relevant for maintaining narrative coherence, likely increases the probability that this information can later be retrieved from memory should it become important for comprehension. It follows that readers who are better able to activate situational information during reading would have an overall comprehension advantage as texts unfold over time.

Despite the new information provided by this study there are also several limitations. The sample size for each age group is small and the oldest children had to be combined in one group to yield roughly equally sized age groups. It is possible that age effects in the speed with which spatial situation models are constructed are obscured by small group sizes with considerable variability in response times. This study lacks an adult comparison group, which would have been useful for determining whether there are developmental differences in spatial situation model construction beyond adolescence (e.g., Pyykkönen & Järvikivi, 2012). The use of only one measure of reading comprehension limits the generalizability of the findings relating spatial situation model construction to comprehension. Furthermore, an assessment of comprehension for the story might have provided additional information about whether and how situation model construction is related to comprehension of specific texts. Finally, the interpretation that the findings reflect the updating of visual-spatial mental models needs to be tempered by the fact that the same/different location judgments were made to word pairs rather than to objects themselves.

In sum, the findings from the current study make several contributions to the literature on situation models in children. They suggest considerable ability of children, across the broad age range studied, to update their spatial mental models of situations described in text. Furthermore, the finding that children activate object-based information from locations traversed by the protagonist, but not mentioned in the text, suggests that they take the mental perspective of a protagonist in constructing situation models during reading, which is consistent with embodied cognition principles applied to text comprehension (reviewed in Fischer & Zwaan, 2008). Finally, the fact that it is children's ability to update their spatial situation models with inferred information that is most strongly related to reading comprehension, underlines the potential importance of inferential processes for comprehension.

Acknowledgements

We thank Margaret Wilkinson for her assistance with data collection, and the children and staff of the Hamilton Catholic District School Board for their participation. This work was funded by grants from the Institute of Education Sciences (R305F100013) and from NIH (P01 HD3596).

Appendix: Sample episode and accompanying probes

On Saturday Jimmy went to the market at lunch time for his mother. He liked to go to the market because there were always fun things going on there, and he usually saw some of his friends. Today, Jimmy had to buy a couple of things so his mother gave him a list. First, he went to the fruit and vegetable stand. After buying some bananas and some carrots Jimmy walked over to the hot dog vendor.

Scale Basket (Same-Other)

Jimmy was hungry so he got two hot dogs and a bottle of coke. He put ketchup and pickles on the hot dogs and they were very messy. Just the way he liked them. Next he left the hot dog vendor's and went to the flower stand.

Umbrella Blackboard (Different- Goal, Other)

He picked out some pretty pink flowers to take home. Jimmy waved to his friend Mike who was playing basketball. Jimmy hoped that he could come back and shoot some hoops with Mike when he finished all of the shopping. The fish stand was next on Jimmy's list and he went there right after the flower stand.

Gumball Machine Mailbox (Same-Source)

Jimmy picked out some trout and then he looked at his shopping list. He had gotten almost everything on the list. He only had one more stop to make at the market. Jimmy left the fish shop and went to his favorite stand, the pet shop.

Milk Trees (Same -Path)

He quacked at the ducks and oinked at the pig. He checked on the price of rabbits for his mother.

When Jimmy left the pet shop he walked to the basketball court so that he could check to see if his friend was still there.

Fire Hydrant Bucket (Different- Source, Other)

Mike was still playing basketball, but it would be a lot more fun if there were two people so they could play one on one. Jimmy told Mike that he would come back and play a couple of games if his mother said it was OK. Jimmy said good-bye to Mike, left the basketball court, and headed for the jewelry stand.

Mirror Suitcase (Same-Goal)

Jimmy said hello to his cousin who worked at the jewelry stand and then he left to go home. He headed out of the market by the fruit and vegetable stand.

Stop Sign Purse (Different- Path, Other)

References

- Barnes MA, Dennis M, Haefele Kalvaitis J. The effects of knowledge availability and knowledge accessibility on coherence and elaborative inferencing in children from six to fifteen years of age. *Journal of Experimental Child Psychology*. 1996; 61:216–241. [PubMed: 8636665]
- Barnes MA, Huber J, Johnston A, Dennis M. A model of comprehension in spina bifida myelomeningocele: Meaning activation, construction, and revision. *Journal of the International Neuropsychological Society*. 2007; 13:854–864. [PubMed: 17697417]
- Cain, K.; Oakhill, J. Reading comprehension difficulties: Correlates, causes, and consequences.. In: Cain, K.; Oakhill, J., editors. *Children's comprehension problems in oral and written language: A cognitive perspective*. Guilford Press; New York: 2007. p. 41-74.
- Casteel MA. Effects of inference necessity and reading goal on children's inferential generation. *Developmental Psychology*. 1993; 29:346–357.
- Fecica AM, O'Neill DK. A step at a time: Preliterate children's simulation of narrative movement during story comprehension. *Cognition*. 2010; 116:368–381. [PubMed: 20605018]
- Fischer MH, Zwaan RA. Embodied language: A review of the role of motor system in language comprehension. *The Quarterly Journal of Experimental Psychology*. 2008; 61:825–850. [PubMed: 18470815]
- Glenberg AM, Gutierrez T, Levin JR, Japuntich S, Kaschak MP. Activity and imagined activity can enhance young children's reading comprehension. *Journal of Educational Psychology*. 2004; 96:424–436.
- Glenberg AM, Kaschak MP. Grounding language in action. *Psychonomic Bulletin and Review*. 2002; 9:558–565. [PubMed: 12412897]
- Glenberg AM, Willford J, Gibson B, Goldberg A, Zhu X. Improving reading to improve math. *Scientific Studies of Reading*. 2012; 16:316–340.
- Haenggi D, Kintsch W, Gernsbacher MA. Spatial situation models and text comprehension. *Discourse Processes*. 1995; 19:173–199. [PubMed: 25520531]
- Kintsch W. The role of knowledge in discourse comprehension: A construction-integration model. *Psychological Review*. 1988; 95:163–182. [PubMed: 3375398]
- Morrow DG, Bower GH, Greenspan SL. Accessibility and situation models in narrative comprehension. *Journal of Memory and Language*. 1987; 26:165–187.
- Morrow DG, Bower GH, Greenspan SL. Updating situation models during comprehension. *Journal of Memory and Language*. 1989; 13:441–469.
- Oakhill, J.; Cain, K. Introduction to comprehension development.. In: Cain, K.; Oakhill, J., editors. *Children's comprehension problems in oral and written language*. Guilford; New York: 2007.
- O'Neill DK, Shultis R. The emergence of the ability to track a character's mental perspective in narrative. *Developmental Psychology*. 2007; 43:1032–1037. [PubMed: 17605533]
- Pike MM, Barnes MA, Barron RW. The role of illustrations in children's inferential comprehension. *Journal of Experimental Child Psychology*. 2010; 105:243–255. [PubMed: 19954799]
- Pyykkönen P, Järviö J. Children and situation models of multiple events. *Developmental Psychology*. 2012; 48:521–529. [PubMed: 21967560]
- Rall J, Harris PL. In Cinderella's slippers? Story comprehension from the protagonist's point of view. *Developmental Psychology*. 2000; 36:202–208. [PubMed: 10749077]
- Rapp DN, Van den Broek P, McMaster KL, Kendeou P, Espin CA. Higher-order comprehension processes in struggling readers: A perspective for research and intervention. *Scientific Studies of Reading*. 2007; 11:289–312.
- Schmalhofer F, McDaniel MA, Keefe D. A unified model for predictive and bridging inferences. *Discourse Processes*. 2002; 33(2):105–132.

- van Dijk, TA.; Kintsch, W. *Strategies of Discourse Comprehension*. Academic Press; New York: 1983.
- van der Schoot M, Horsley TM, van Lieshout ECDM. The effects of instruction on situation model construction: An eye fixation study on text comprehension in primary school children. *Educational Psychology: An International Journal of Experimental Educational Psychology*. 2010; 30:817–835.
- Woodcock, RW.; Johnson, MB. *Woodcock-Johnson Psycho-Educational Battery-Revised*. Riverside Publishing; Chicago: 1989.
- Ziegler F, Mitchell P, Currie G. How does narrative cue children's perspective taking? *Developmental Psychology*. 2005; 41:115–123. [PubMed: 15656742]
- Zwaan RA. Embodied cognition, perceptual symbols, and situation models. *Discourse Processes*. 1999; 28:81–88.
- Zwaan RA, Langston MC, Graesser AC. The construction of situation models in narrative comprehension: An event-indexing model . *Psychological Science*. 1995; 6:292–297.

- Spatial situation model construction during reading was tested in children.
- Relations of spatial inference to reading decoding and comprehension were assessed.
- Spatial information relevant to the protagonist's perspective was most accessible.
- Reading comprehension was uniquely predicted by inferred spatial location information.

Figure 1.
Diagram of the marketplace, including stalls and objects

Table 1

Performance on Standardized Reading Measures

	9 (<i>n</i> = 14)	10 (<i>n</i> = 17)	11 (<i>n</i> = 13)	12 (<i>n</i> = 12)	13 (<i>n</i> = 10)	14+ (<i>n</i> = 15)
Age Range	9.00 – 9.92	10.10 – 10.92	11.00 – 11.90	12.10 – 12.70	13.08 – 13.92	14.00 – 16.92
<i>Measures</i>						
Letter-Word Identification	108.21 (9.01)	101.00 (8.55)	103.08 (8.92)	99.25 (5.74)	104.30 (15.69)	110.47 (9.49)
Word Attack	106.00 (8.88)	104.76 (8.25)	104.38 (8.12)	104.00 (6.84)	103.30 (14.30)	112.40 (15.41)
Passage Comprehension	106.43 (9.35)	100.59 (10.22)	98.85 (8.12)	101.42 (6.82)	99.50 (14.92)	109.73 (14.18)

Note. Standard deviations are presented in parentheses.

Table 2

Learning and Accuracy Scores by Age on the Market Learning and Story Task

	9 (<i>n</i> = 14)	10 (<i>n</i> = 17)	11 (<i>n</i> = 13)	12 (<i>n</i> = 12)	13 (<i>n</i> = 10)	14+ (<i>n</i> = 15)	All Ages (<i>N</i> = 81)
Learning Trial 1	82.65 (11.11)	83.19 (13.11)	80.22 (10.17)	77.98 (14.99)	79.29 (14.46)	90.95 (11.04)	82.80 (12.82)
Learning Trial 2	96.68 (5.68)	98.74 (3.78)	98.08 (4.28)	100.00 (0.00)	97.86 (3.84)	99.29 (2.77)	98.46 (3.87)
Post-Test Scores	98.98 (2.59)	99.58 (1.73)	98.90 (3.96)	100.00 (0.00)	98.93 (2.41)	99.76 (0.92)	99.38 (2.24)
Same Probes							
Path	71.30 (28.72)	80.78 (28.72)	67.77 (31.82)	85.17 (14.19)	82.70 (22.30)	78.39 (22.23)	77.50 (25.65)
Goal	67.41 (16.55)	64.92 (23.02)	76.16 (12.70)	69.33 (19.83)	72.69 (24.99)	70.18 (10.09)	69.74 (18.18)
Source	62.62 (23.49)	60.39 (28.44)	58.03 (30.37)	81.67 (16.67)	55.33 (31.24)	72.20 (14.60)	65.11 (25.52)
Other	59.12 (19.66)	59.97 (17.99)	56.25 (21.70)	74.83 (18.07)	71.33 (14.46)	68.10 (11.73)	64.34 (18.31)
Different Probes							
Path	92.71 (8.73)	90.70 (12.26)	84.12 (16.80)	92.92 (8.75)	83.64 (15.22)	89.52 (10.05)	89.23 (12.32)
Goal	89.72 (11.73)	83.56 (15.70)	89.14 (15.19)	95.83 (10.31)	84.11 (15.10)	85.71 (15.27)	87.81 (14.29)
Other	57.89 (9.25)	55.92 (14.46)	53.57 (7.68)	56.00 (7.27)	58.07 (8.75)	58.75 (12.26)	56.69 (10.48)

Note. Values are percentages; Standard deviations are presented in parentheses.

Table 3

Response Time by Age on the Market Learning and Story Task

	9 (<i>n</i> = 14)	10 (<i>n</i> = 17)	11 (<i>n</i> = 13)	12 (<i>n</i> = 12)	13 (<i>n</i> = 10)	14+ (<i>n</i> = 15)	All Ages (<i>N</i> = 81)
Same Probes							
Path	5120 (1274)	4172 (1566)	4891 (2147)	4003 (1027)	3995 (810)	3832 (933)	4341 (1435)
Goal	4685 (2019)	4185 (1474)	4279 (800)	4153 (1319)	3678 (1133)	3924 (1479)	4171 (1432)
Source	5485 (1449)	4223 (1535)	4090 (1198)	4226 (1478)	4361 (960)	3975 (1804)	4391 (1506)
Other	5945 (1714)	4743 1765	4807 (1680)	4390 (1159)	5254 (1988)	4930 (1592)	5007 (1685)
Different Probes							
Path	4874 (1285)	4601 (1785)	4044 (714)	4118 (904)	4322 (414)	3890 (1411)	4321 (1259)
Goal	5281 (2189)	4674 (2070)	4070 (1559)	4273 (1790)	3874 (1057)	3913 (1189)	4383 (1751)
Source	4157 (819)	3997 (991)	4078 (1139)	3652 (792)	3687 (598)	3720 (1244)	3897 (968)

Note. Standard deviations are presented in parentheses.