

Children's semantic and world knowledge overrides fictional information during anticipatory linguistic processing

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Abstract

Using real-time eye-movement measures, we asked how a fantastical discourse context competes with stored representations of semantic and world knowledge to influence children's and adults' moment-by-moment interpretation of a story. Seven-year-olds were less effective at bypassing stored semantic and world knowledge during real-time interpretation than adults. Nevertheless, an effect of discourse context on comprehension was still apparent.

Keywords: discourse; children; sentence comprehension; eye-tracking; semantics; cognition; fantastical fiction

Real-time interpretation of fantastic fiction

Linguistic processing requires listeners to identify relevant thematic relationships between the entities and events evoked in a sentence. Studies of visually-situated language processing have shown that comprehenders use such relations to predict upcoming linguistic input, and in turn direct their attention to compatible referents in the visual world (e.g., Altmann & Kamide, 1999; Kamide, Altmann, & Haywood, 2003). For example, when hearing the sentence 'The boy eats the big cake' while looking at a scene containing a cake and a bird, adults and children as young as 2 years of age look to the cake while 'eats' is unfolding (Mani & Huettig, 2012). Children as young as 3 years of age can also use their prior knowledge of the relationships between actions and agents to generate more sophisticated predictions, e.g. anticipating 'bone' upon hearing "The dog hides" (Borovsky, Elman, & Fernald, 2012).

In adults, comprehension is also rapidly influenced by higher-order meaning created by physical, functional and situational relations between entities and events (Chambers & San Juan, 2008; Sedivy, 2003; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Situation-specific factors, including a fictional context, can in fact override lexical and semantic relationships based on stored knowledge (Cook & O'Brien, 2014; Filik, 2008; Nieuwland & Van Berkum, 2006). However, prior research with grade school children has shown that they tend to privilege lexical

information over situation-specific knowledge (Snedeker & Trueswell, 2004; Trueswell, Sekerina, Hill, & Logrip, 1999). Children may therefore find it difficult to rely on a fictional context to inform real-time language processing, particularly in fantastical fiction where described events (e.g., a person flying) strongly depend on information in the narrative, and are at odds with the nature of the real world. Conversely, it is possible that the incongruent actions and salient contrast between the real and narrative worlds involved in a fantastical narrative may strengthen children's mental simulation of story information, and thus support their ability to rely upon contextual information to anticipate upcoming language input. Preschool children are already becoming competent comprehenders of discourse; they become sensitive to its causal structure (Lynch et al., 2008) and begin to make inferences connecting the events evoked in narrative with world knowledge (Barnes, Dennis, & Haeefele-Kalvaitis, 1996). Preschool children also understand that events in fiction can contradict their knowledge of the real world, and involve systematic rules governing what can and cannot happen within the context of that world (Sharon & Woolley, 2004; Van de Vondervoort & Friedman, 2014).

Thus, it is not clear how effectively young children can use fantastical facts introduced in a narrative to interpret the story as it unfolds. Notably little work has investigated the real-time processes and underlying mechanisms involved in children's interpretation of fictional discourse. Most investigations of children's narrative comprehension have instead relied on offline measures, such as the verbal production of story elements (e.g. Paris & Paris, 2003). By using implicit measures such as eye movements we can gain additional insights into children's moment-by-moment and automatic consideration of possible referents as language unfolds in real time.

In the current study, we investigate children's real-time language processing in discourse contexts that present fantastical protagonists and improbable events, using a spoken language eye tracking methodology. The goal of the study is to compare children's and adults' use of fictional

information that contradicts lexical and world knowledge to constrain predictions about upcoming language input. Can young children rely upon fantastical facts introduced in the prior discourse to predict upcoming referents, and what is the time course of this process? In other words, how does a fantastical discourse context compete with information in children's stored representations of semantic and world knowledge to constrain their understanding of the situations being described? The competition between semantic and real-world knowledge and discourse information that violates that knowledge can be explored by presenting children with a discourse-final sentence in which the protagonist acts on an object in an unusual way (e.g., wearing boxes on her feet). By examining eye movements in the window of time between the onset of a verb that semantically constrains the referent (e.g., 'putting on') and the onset of the following noun, we can gain insights into children's interpretation of the unfolding sentence. If children rely upon the fantastical discourse to interpret the sentence, we would expect them to demonstrate more anticipatory eye movement to objects that are congruent with the discourse than to objects that are congruent with stored event semantics and world knowledge, but incongruent with the discourse.

We also explore the relationship of predictive language processing in fantastical contexts with other mental functions. Anticipation of events consistent with a fantastical fictional world is likely to require the suppression of stored knowledge based on the stable semantic relationships of the real world. We might therefore expect it to be positively predicted by inhibitory control and negatively predicted by receptive vocabulary and semantic fluency, which reflect strong, well-defined networks of semantic relationships. Constraints on working memory may also limit children's performance by limiting the ability to maintain concurrent interpretations. Studies measuring event-related potentials (ERPs) have shown working memory to predict adults' ability to use rich contextual information to build a message-level representation of linguistic input (Huettig & Janse, 2016; Wlotko & Federmeier, 2012), perhaps because it binds knowledge to linguistic and semantic knowledge in space and time.

Method

Participants

Sixty-four 7-year-old children (range: 7;0-7;11, Mage: 7;4) and 68 adults (range: 18-35 years; Mage: 25) participated in the current experiment. Seven-year-olds were chosen because they are highly experienced with narratives; because younger (3-5-year-old) children are more often willing to attribute unconventional behaviour to humans (Boerger, 2011); and because pilot testing revealed that they could attend through 16 consecutive eye-tracking trials, and complete the full one-hour procedure without signs of fatigue. Inclusionary criteria were normal or corrected-to-normal vision and no history of diagnosis or treatment of

cognitive, speech, language, hearing, or attentional issues. Children heard English spoken at home more than 75% of the time. Adults were native speakers of English. Data from 27 additional participants were collected, but not used due to: unsuccessful calibration (3 adults, 1 child), no trials that captured eye movements more than 50% of the time (7 adults, 5 children), failed pre-test (3 children), lack of attention (2 adults, 3 children), and misunderstanding the task (1 adult, 2 children).

Materials

Cartoon images were taken from open-source resources, and the displays accompanying each narrative depicted agents and objects against a white background. Sentences were pre-recorded by a female, native Canadian-English speaker.

Norming of stimuli

Offline tasks with a separate group of 4- and 5-year-old participants were conducted to establish that even younger children could recognize the objects and used the verbs to identify referents in the expected manner. Children were tested at the Ontario Science Centre. The experimenter showed the child a four-object display, provided a label, and asked her to identify the relevant object. 100% of children recognized all the images presented during the critical sentences ($N = 8$ per target image). Children were then introduced to pictures of agents (e.g. 'This is Chloe the fairy'), following which they were presented with a four-object display, and asked (e.g.) 'What will Chloe eat?' Four- and 5-year-olds selected the only referent that was semantically plausible following the verb over 90% of the time across trials ($N = 16$ per target image).



Figure 1. Example of stimuli used for the sentence comprehension task.

Procedure

Sentence comprehension task Participants sat in a stationary chair in front of a computer with a 1920x1200 LCD display. Eye movements were recorded using a Tobii X120 eye-tracker. A nine-point calibration procedure was used to set up tracking of both eyes. In the description phase of the experimental condition ($N=32$ 7-year-olds and $N=34$

adults), participants saw a centrally presented picture of a fantastical agent (e.g., a superhero or monster), and simultaneously heard a story. Story sentences contained referents that were semantically congruent with a preceding verb, and referents that were unusual patients of the preceding verb. For instance: 'Chloe the fairy doesn't have cake for her snack. She has snow for her snack! And Chloe doesn't wear shoes on her feet. She wears boxes on her feet! What is Chloe going to do?' Participants then saw a central fixation cross. In a subsequent test phase, participants saw a display comprising the four mentioned items (e.g. cake, snow, shoes, and box), one placed in each corner of the screen, and heard the critical sentence. In 4 of the 8 experimental trials, the verb in the critical sentence was semantically constraining (e.g., 'Chloe is eating up the snow'). Thus, the verb narrowed to 1 the number of referents in the display that were coherent with children's stored semantic knowledge (henceforth, semantically congruent referent, or SCR: e.g., cake) as well as the number of referents that were coherent with the story information (discourse-congruent referent, or DCR: e.g., snow). In the other 4 experimental trials, the verb did not constrain the referent: e.g. 'Chloe is looking at the snow'. Half of the participants heard a critical sentence based on the first part of the story (e.g., Chloe eating up the snow), and half heard a story based on the second part of the story (e.g., Chloe putting on the box). In 8 filler trials, participants heard that agents 'sometimes' performed expected actions and 'sometimes' performed actions that violated world knowledge, breaking up the pattern in the content and outcomes of the stories and reducing the risk of strategic adjustments. Counterbalancing was in place for the portion of the story that was referenced during the critical sentence, the order in which typical and atypical verb patients were mentioned, the pairing of stories with constraining and neutral verbs, and the location of the DCR on the screen. The location of other objects was randomized.

To confirm that children could recall simple discourse of the type used in the experiment, the sentence comprehension task was preceded by two offline pre-trials in which children were asked a comprehension question in place of the critical sentence. For instance, children heard 'Gordon the gnome doesn't bang on a drum. He bangs on a pillow! And Gordon doesn't dig with a shovel. He digs with a toothbrush!' Once the array of possible referents was displayed, children were asked 'What does Gordon bang on?' Only three children failed to identify the target during one or both of the two comprehension trials, and were excluded from the analysis.

A separate set of 32 7-year-olds and 34 adults participated in a *control condition* in which no story discourse preceded the critical sentence. In this condition, during the description phrase participants saw the picture of the agent, but in place of the story they only heard (e.g.) 'This is Chloe the fairy', followed by the critical sentence.

Following the sentence comprehension task participants completed several individual difference measures. These were drawn largely from the National Institutes of Health

Toolbox (NIH TB) Cognition Battery (McDonald, 2014), which is administered in a computerized adaptive format. Each of the tasks in the Toolbox has been normed and validated for ages 3-85.

Inhibitory control The inhibitory control measure was the NIH TB Flanker Inhibitory Control and Attention Test. The test requires participants to focus on a specific stimulus while inhibiting attention to other stimuli flanking it. Sometimes the middle stimulus is congruent (pointing in the same direction as the flankers) and sometimes incongruent (pointing in the opposite direction). Scores reflect both accuracy and reaction time.

Working memory Working memory was measured using the NIH TB List Sorting Working Memory Test, which involves both storage and manipulation of items in memory. Images of animals and foods are displayed with accompanying audio and written text (e.g., "horse"). The participant is asked to repeat back the items in size order from smallest to largest, within a single dimension (either animals or foods: 1-List) and then on 2 dimensions (foods, then animals: 2-List). The score is equal to the number of items that are both recalled and sequenced correctly.

Receptive vocabulary The receptive vocabulary measure was the NIH TB Picture Vocabulary Test. Participants hear a word and simultaneously see four photographic images on the computer screen. Participants were asked to point to the picture that most closely matches the meaning of the word.

Semantic fluency Semantic fluency was measured using two components of the NEPSY word generation task (Korkman, Kirk, & Kemp, 2007). Participants were given one minute to produce as many members of a semantic category as they were able. Categories were 'animals' and 'foods and drinks'. Participants received one point for every correct item. Incorrect words and repetitions were excluded.

Data scoring and analysis

The proportion of time that participants spent looking to each referent was calculated separately for three time-windows corresponding to different speech landmarks, namely the pre-naming window (1000 ms prior to verb onset to verb onset), verb window (1280 ms prior to noun onset to noun onset) and noun window (233 ms after noun onset to 2000 ms after noun onset). Average looking time within these windows was calculated separately for constraining and neutral verb trials, based on gaze position measures assessed every 50 ms.

Raw scores for receptive vocabulary, inhibitory control and attention, and working memory were downloaded from the NIH Toolbox Assessment Center. Two coders viewed video recordings of the semantic fluency (word generation) task. There was excellent agreement between coders' judgments, $r(126) = 1$, $p < .001$. Disagreements were resolved by a third coder.

Looking time data failed to fit a normal distribution following log and empirical logit transformations (Barr, 2008.) Therefore, all analyses were bootstrapped in SPSS 21, using 1000 case resamples with replacement from the original dataset and a 95% percentile confidence interval.

Results

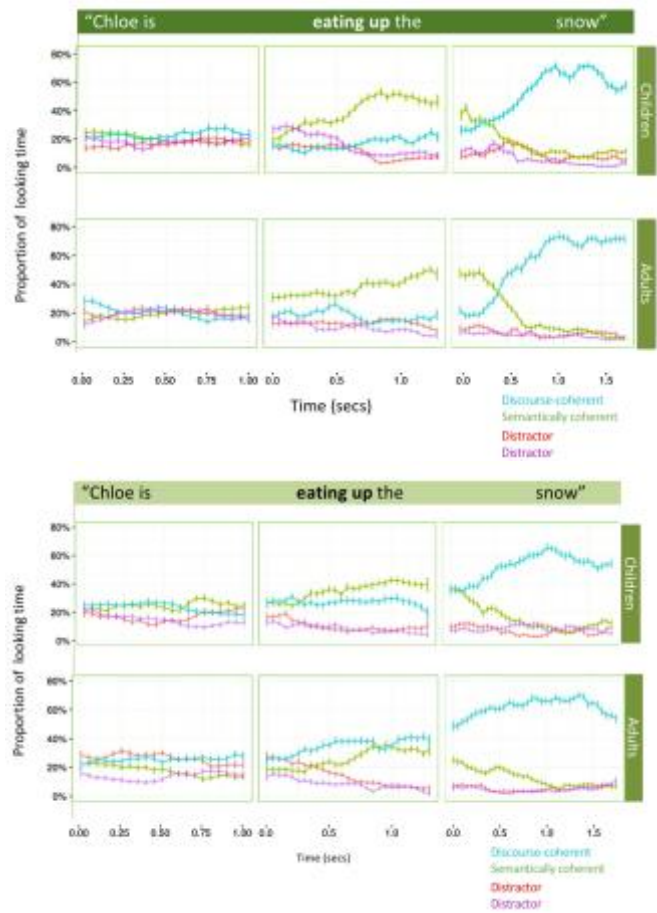
Control condition In the control condition with no story, both children and adults looked at chance to the DCR ($p > .05$), and above chance to the SCR (children: $t(27) = 5.61, p = .001$, adults: $t(29) = 4.64, p = .001$), as expected (Figure 2).

Constraining verb trials Recall that the displays contained two distractor objects in addition to the DCR and SCR. We first ascertained whether participants looked preferentially to the DCR and SCR. Both adults and children did so at a rate significantly above chance (children: $t(31) = 8.1, p = .001$; adults: $t(33) = 7.82, p = .001$). A one-way ANOVA demonstrated that adults' and children's looking behaviour was similar ($F(1,65) = .00, p > .05$.) Thus, both children and adults discounted distractors from their interpretation of the unfolding sentence following verb onset, as seen in Figure 3.

In order to discover how hearing a constraining verb influenced children's and adults' anticipatory processing, we then examined the proportion of time that participants spent looking to the DCR and SCR before and after verb onset. Since constraining and neutral verb trials were identically structured prior to verb onset, we collapsed looking time in the pre-verb window across trial types (constraining and neutral) for this analysis. Paired t-tests demonstrated that upon hearing a constraining verb, the proportion of both children's and adults' looking time to the semantically congruent referent rose relative to its pre-verb baseline (children: $t(31) = -3.54, p = .005$; adults: $t(32) = -2.16, p = .04$). The proportion of adults' looking time to the discourse-congruent referent also rose following the onset of the constraining verb ($t(32) = -3.32, p = .002$); the proportion of children's looking time did not ($p > .05$). Thus, hearing a constraining verb caused adults, but not children, to increase their consideration of the discourse-congruent referent.

We then examined fixation patterns within the verb window separately for the DCR and SCR to determine whether children's and adults' proportions of looking time to these referents differed. They did not significantly differ for either referent (both $p > .05$), nor did proportion of looking time to the SCR differ between children and adults in the no-story control condition ($p > .05$). Next, we examined children's and adults' rates of looking against chance, calculated at .2 to account for looks to blank space on the screen, to establish whether both semantic coherence and discourse context influenced participants' interpretations of the sentence prior to hearing the noun. Both children and adults looked to the DCR at a rate above chance during the verb window, suggesting that both age groups relied to some extent on the discourse context to

interpret an unfolding sentence (children: $t(31) = 2.59, p = .024$; adults: $t(33) = 3.81, p = .002$). Children, but not adults, also looked to the SCR at a rate above chance ($t(31) = 4.75, p = .001$). Thus, taking the verb window as a whole, both children and adults anticipated the DCR as the patient of the constraining verb, while only children anticipated the SCR.



Figures 2&3. Time-course plots of proportion of looking time to potential referents on experimental trials containing constraining verbs (Figure 2), and on control trials with no discourse context containing constraining verbs (Figure 3).

Neutral verb trials

Recall that neutral verb trials did not contain semantically congruent objects because the verb (e.g., "look at" was by definition compatible with all display objects. They instead contained two "discourse-congruent" objects in the sense that each story presented the character carrying out two unusual actions. For neutral verb trials, we therefore collapsed the proportion of looking time to both DCRs. As predicted, neither children nor adults made anticipatory looks to the DCRs during the verb window of the critical sentence. Adults and children looked similarly to the DCRs, and neither adults nor children looked to the DCRs at a rate above chance (all $p > .05$). This confirmed that patterns in the constraining verb conditions were not simply due to

attentional capture or interest in the images used as the SCR and DCR.

Individual differences

Pearson correlations between individual difference measures and proportion of looking time to the DCR and SCR in the verb window were examined separately for adults and children. On control trials containing no story, none of the correlations were significant for children or adults (all $p > .05$). On experimental trials, none were significant for adults on constraining or neutral verb trials, nor for children on neutral verb trials (all $p > .05$). Children's looking time on constraining verb trials was not correlated with inhibitory control, nor with semantic fluency (both $p > .05$). Contrary to expectation, children's working memory was negatively correlated with their looking time to the DCR ($r(30) = -.50, p = .004$), and children's receptive vocabulary was positively correlated with their looking time to the SCR ($r(30) = .46, p = .011$).

Linear regressions were conducted on the proportion of children's looks to DCR and SCR in the verb window. Working memory significantly predicted children's looking time to the DCR, $b = -.343, t(1,28) = -3.11, p = .004$, and explained approximately 26% of variance in children's looking time to the DCR, $R^2 = .256, F(1,28) = 9.57, p = .004$. Receptive vocabulary significantly predicted children's looking time to the SCR, $b = -.031, t(1,30) = 2.82, p = .004$, and explained approximately 21% of variance in children's looking time to the SCR, $R^2 = .210, F(1,30) = 7.99, p = .004$.

Discussion

This study demonstrates that while 7-year-old listeners to fantastical fiction find it difficult to override semantic congruence in favour of discourse congruence, the discourse context nevertheless competes with semantic relationships based on stored knowledge to direct their interpretation of fantastical fictional events. The results also demonstrate that the importance of different types of predictive information appears to change between grade school and adulthood.

In the absence of a story, children as well as adults generated expectations for the object that served as the most typical patient of an immediately preceding verb, as expected (e.g. Mani & Huettig, 2012). Given a fantastical story, however, both children and adults used the discourse context to guide their appraisal of appropriate verb patients: they anticipated the DCR, which was congruent both with the discourse and with a constraining verb. However, children's anticipation of the discourse-congruent referent diminished over the time course of the verb phrase, whereas adults' anticipation of this object increased over the same time window, suggesting that children began to discount the early expectations that had been generated for a discourse-congruent noun.

Seven-year-olds had difficulty overriding an interpretation of the critical sentence based on stored semantic relationships and real-world knowledge,

generating expectations for the referent that was congruent with their semantic and world knowledge. Adults did not, although some late consideration of the semantically congruent referent is clearly apparent from an examination of the latter half of the verb window in Figure 2. This is not unexpected, as active prediction is often accompanied by a certain degree of thematic priming even when these effects are incongruent with sentence and discourse information (Kukona, Fang, Aicher, Chen, & Magnuson, 2011).

Children with strong pre-existing networks of semantic relationships, as indexed by receptive vocabulary, found it difficult to override these networks in favour of the discourse context. On average, they showed less consideration of the discourse-congruent referent than did children with smaller receptive vocabularies. It is also possible that children who possess a large vocabulary have a well-developed sense of the need for a clear conceptual basis for any new semantic relationship. In future research, we will ask whether longer and more causally rich stories than those presented in the current study may improve such children's performance. However, on a different measure of semantic network strength (semantic fluency), there was no relationship with the extent to which the DCR was considered. This may be because this kind of word generation task also places demands on executive control: the inhibition of irrelevant information, and the deployment of strategic planning. Given that we did not find a relationship between our measure of inhibitory control and children's looking behaviour, it is possible that in this task, the process of suppressing semantic knowledge may not require inhibition of the prepotent semantically congruent interpretation. Rather, it may involve maintaining representations of both the semantically congruent and discourse-congruent interpretation, and discounting the latter relative to the former.

Contrary to expectation, the poorer children's working memory, the more they relied on the discourse-congruent referent to interpret the unfolding critical sentence. If this finding can be replicated, several possible explanations should be explored in future research. It is possible that weak representations of the discourse entail relatively more attention to the discourse-congruent referent in attempt to support effort towards recall of the role of the object in the story. It is also possible that the stronger the discourse information in children's working memory, the greater the co-activation in memory of stored semantic information, which then remains relatively highly activated in children in comparison to adults.

The real-time processing of fantastical discourse speaks to the interaction of several abilities and knowledge types – stored semantic knowledge, vocabulary, working memory, and the moment-by-moment identification of thematic relationships – all of which influence children's mental representations of the events they hear about. This topic provides a rich opportunity to characterize the information processing skills underlying children's language comprehension at the discourse level.

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