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Investigating individual differences in children's real-time sentence comprehension using language-mediated eye movements

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Abstract

Individual differences in children's online language processing were explored by monitoring their eye movements to objects in a visual scene as they listened to spoken sentences. Eleven skilled and 11 less-skilled comprehenders were presented with sentences containing verbs that were either neutral with respect to the visual context (e.g., Jane watched her mother *choose* the cake, where all of the objects in the scene were choosable) or supportive (e.g., Jane watched her mother *eat* the cake, where the cake was the only edible object). On hearing the supportive verb, the children made fast anticipatory eye movements to the target object (e.g., the cake), suggesting that children extract information from the language they hear and use this to direct ongoing processing. Less-skilled comprehenders did not differ from controls in the speed of their anticipatory eye movements, suggesting normal sensitivity to linguistic constraints. However, less-skilled comprehenders made a greater number of fixations to target objects, and these fixations were of a duration shorter than those observed in the skilled comprehenders, especially in the supportive condition. This pattern of results is discussed in terms of possible processing limitations, including difficulties with memory, attention, or suppressing irrelevant information.

Keywords: Language development; Language impairment; Eye movements; Comprehension; Sentence processing

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Introduction

It is well established that there are large individual differences in children's ability to understand language. Perhaps one of the clearest demonstrations of this comes from the study of children who have poor comprehension: such children experience significant specific and unexpected difficulties with reading comprehension despite having fluent reading accuracy. Less-skilled comprehenders have problems with aspects of text-level processing such as difficulty with making inferences and failure to engage in constructive processing (Oakhill, 1994). Their difficulties are specific in the sense that there is a clear dissociation between reading accuracy and reading comprehension, and they occur in the context of normal nonverbal intelligence (Nation, Clarke, & Snowling, 2002). However, they also have poor listening comprehension and weaknesses in aspects of spoken language processing (Nation & Snowling, 1998a, 1999, 2000; Stothard & Hulme, 1992). Thus, less-skilled comprehenders' difficulties with reading comprehension should be seen in the broader context of difficulties with language comprehension.

Studies have highlighted the difficulties less-skilled comprehenders have integrating information within a text and with drawing inferences that depend on knowledge not explicitly mentioned in text. For example, Cain, Oakhill, Barnes, and Bryant (2001) examined less-skilled comprehenders' ability to make inferences when reading and found them to have difficulty in making both cohesive and elaborative inferences, even when background knowledge about the situations described in the texts was carefully controlled. Although it is clear that less-skilled comprehenders have trouble making inferences, we do not know when, or where, in the comprehension process this failure to integrate information occurs. Potentially, less-skilled comprehenders could fail to activate information adequately; alternatively, they may initially access information normally but fail to reactivate or integrate that information at a later stage in processing. Language comprehension is a dynamic process in which information is immediately interpreted and integrated as language unfolds in real time (e.g., Kamide, Altmann, & Haywood, 2003). Experiments that ask children to answer questions after hearing discourse or reading text can only ever measure the endpoint of comprehension, not the actual process itself.

A number of studies by Gernsbacher and colleagues have pointed to the difficulties less-skilled comprehenders have not with the initial activation of relevant information but with suppressing or inhibiting irrelevant information. For example, Gernsbacher and Faust (1991) presented (college-aged) skilled and less-skilled comprehenders with short sentences, some of which ended with a homophone (e.g., *patients*, *patience*) such as *he had a lot of patients*. Following this, a target word such as calm was presented to which participants made a semantic decision according to whether it fitted the meaning of the preceding sentence. All participants were initially slower to reject the target when it was related to the nonrelevant meaning of the homophone (e.g., slower to reject calm after hearing patients, relative to a neutral baseline). After a 1-s delay however, only less-skilled comprehenders continued to show this effect. This was taken as evidence that less-skilled comprehenders had failed to suppress the contextually irrelevant meaning of the homophone.

Other sources of evidence also point to less-skilled comprehenders' difficulties arising at a relatively late stage in processing. Long, Seely, and Oppy (1999) investigated whether college-aged less-skilled comprehenders' difficulty with suppressing irrelevant information was a consequence of a deficient automatic suppression mechanism or was due to problems at a later and more strategic stage in processing. Poor suppression was observed only when the task demanded that participants make a semantic decision concerning the meaning-based relation between a test word and a preceding sentence context; when participants were asked to simply name the target word, no interference was observed. This study raises the interesting idea that less-skilled comprehenders construct their initial sentence representations adequately but that they subsequently fail to integrate, elaborate, and link new information into their developing representations of the text, partly as a consequence of failing to inhibit irrelevant information.

Although studies by Gernsbacher, Long, and colleagues provide evidence to support this view, it is not clear whether findings from studies of college-age adults can be generalised to young children with specific comprehension difficulties. There is some evidence to suggest that young less-skilled comprehenders may not initially activate information as well as control children. Using a cross-modal priming paradigm, Nation and Snowling (1998b) found that less-skilled comprehenders' visual word recognition was less influenced by contextual facilitation: relative to both normally developing children and children with developmental dyslexia, less-skilled comprehenders were less adept at using spoken contextual cues to improve reading speed and accuracy. Similarly, less-skilled comprehenders failed to show standard semantic priming effects between word pairs sharing category overlap such as COW–GOAT and PINK–GREEN (Nation & Snowling, 1999). Although these data suggest that children defined as less-skilled comprehenders may not initially construct or activate meaning in the same way as skilled comprehenders, caution is needed as the tasks used (cross-modal priming and auditory lexical decision) are somewhat artificial and rather removed from "normal" comprehension. Thus, whether less-skilled comprehenders initially activate information appropriately as they read or listen to language remains an open question.

A paradigm that provides direct observation of online language processing involves monitoring participants' eye movements as they view a visual scene while listening to language. A number of studies have shown people's eye movements to be closely time-locked with the speech they are hearing: immediately on hearing a word that refers to a referent in the scene, adults very quickly launch an eye movement towards it (Cooper, 1974; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). This reflects the relation between attending to an object (driven by the language) and fixating upon it. By manipulating the language, and the nature of the referring objects in the scene, it is possible to measure how language is being interpreted, relative to the visual context. Although there has been considerable interest in using this paradigm to tap immediate processing (e.g., cohort effects in spoken word recognition; Allopenna, Magnuson, & Tanenhaus, 1988), it is also possible to monitor the pattern of eye movements over time, as sentences unfold, to index ongoing processing. Moreover, as task demands are minimal and head movements are not restrained, this method is well suited to use with children (Nadig & Sedivy, 2002; Trueswell, Sekerina, Hill, & Logrip, 1999).

A clear demonstration of incremental, word-by-word interpretation of sentences and the sensitivity and utility of the language-mediated eye movement paradigm comes from a study reported by Kamide et al. (2003). Looks to a semi-realistic visual scene containing a number of objects were compared while participants heard a sentence such as "the man will ride the motorbike" or "the girl will ride the carousel." The scene portrayed a man, a child (a girl), a motorbike and a carousel (both rideable), and a beer and some sweets. During the *acoustic lifetime* of "ride," looks were directed to whichever object in the scene was most plausibly ridden by whomever the subject of the sentence referred to (the man or the little girl). Thus, looks were directed more towards the motorbike when the subject was "the man," but towards the carousel when the subject was "the girl." When the verb "ride" was replaced by "taste," there were now more looks towards the beer (for the man as subject) or the sweets (for the girl as subject). These effects reflect the rapid integration of various sources of information including the meaning of the verb, the meaning of its grammatical subject ("the man" or "the girl"), the syntactic knowledge that determines that the man or girl is the person who will do the riding, and the real-world knowledge of the plausibility, given the visual scene, of what in the scene is likely to be ridden or tasted given who in the scene is to do the riding or tasting.

Thus, listeners use linguistic information contained in the verb to restrict or predict subsequent reference, based on their understanding of real-world relations relevant to the particular context embodied in the visual scene. More generally, these findings are consistent with the highly referential, incremental, and interactive nature of language processing in which different sources of information (syntactic, lexical, pragmatic, and so on) impact online processing (Ferretti, McRae, & Hatherell, 2001; MacDonald, Pearlmutter, & Seidenberg, 1994; Marlsen-Wilson & Tyler, 1987; McRae, Ferretti, & Amyote, 1987).

In the present study we asked whether children show the same sensitivity as adults to verb information after hearing verbs that, given a particular visual context, predict subsequent reference. Furthermore, we investigated whether there are individual differences in children's sensitivity to this by comparing less-skilled comprehenders with normally developing children. By monitoring eye movements as less-skilled comprehenders listen to language, we were able to observe their comprehension moment by moment and explore whether there were systematic differences in their online processing. As this study is, to the best of our knowledge, the first to use such a method to probe individual differences in development, we chose to investigate verb-mediated referential processing along the lines of Altmann and Kamide (1999), as their effects are robust, clear, and highly consistent in skilled adults. In that study, looks to a semi-realistic visual scene were compared while participants heard sentences such as "the boy will *move* the cake" or "the boy will *eat* the cake" (in effect, one half of the Kamide et al., 2003, design). In the *move* condition, looks to the *cake* (the only edible object in the scene) were launched after the acoustic onset of *cake* in the speech stream. In contrast, in the *eat* condition, looks were launched well before the acoustic onset of *cake* (these looks were consequently labelled "anticipatory eye movements"). This provided an ideal backdrop against which to consider the performance of skilled and less-skilled comprehenders. Of particular interest was whether less-skilled comprehenders show a normal pattern of anticipatory eye movements. Evidence that they show a normal pattern and time course of anticipatory eye movements would be strong support for the view that less-skilled comprehenders initially activate linguistic information appropriately (Gernsbacher & Faust, 1991; Long et al., 1999).

Method

Participants

Recruitment of sample

To select groups of children differing in comprehension skill, we screened 92 children from Primary Year 6 (aged 10 and 11 years) on three tasks. Text reading accuracy and reading comprehension were assessed using the *Neale Analysis of Reading Ability* (NARA-II; Neale, 1997). In this test, children read aloud short passages of text (reading accuracy) and are then asked questions to assess literal and inferential understanding (reading comprehension). Decoding was assessed using the *Test for Word Reading Efficiency–Phonemic Decoding* (Torgesen, Wagner, & Rashotte, 1999), which requires children to read aloud a list of nonwords under a time constraint. Nonverbal ability was assessed using a visuo-spatial task, the *Pattern Construction* subtest from the *British Ability Scales-II* (BAS-II; Elliot, Smith, & McCulloch, 1996).

Previous studies have reported that approximately 10–15% of children at this age may be categorised as less-skilled comprehenders (e.g., Nation & Snowling, 1997). In line with this, 11 less-skilled comprehenders were identified in this population (11.95%). They were matched to 11 control children according to the following criteria: all of the children in the control group had at least average-for-age nonword reading and obtained standard scores of at least 95 on the NARA-II reading accuracy and reading comprehension tests. Children in the less-skilled comprehender group were matched to the control children for nonword reading score, but scored at or below 86 on the reading comprehension test; all had reading accuracy scores of at least 95. Only children with nonverbal ability within the normal range were included in the study. The performances of the two groups on the selection tasks are summarised in Table 1. Analyses confirmed that the two groups did not differ in terms of chronological age, nonverbal ability, decoding, or reading accuracy. In contrast, the less-skilled comprehenders' reading comprehension was significantly lower than that of the control children.

Background measures

Table 1 also summarises the performances of the two groups of children on measures of language, memory, and response inhibition that were administered at the same time as the eye movement experiment. We administered language measures

Table 1
Means and standard deviations of skilled and less-skilled comprehenders on selection tasks and background measures: Ranges on selection measures shown in parentheses

	Skilled comprehenders		Less-skilled comprehenders		
	M	*SD*	*M*	*SD*	$F(1, 20)$
Selection tasks					
Chronological age	11.33	0.26	11.12	.24	4.00
Reading comprehension[a]	105.73 (98–128)	7.10	81.91 (69–86)	8.29	52.39*
Decoding[a]	113.91 (85–130)	14.34	109.45 (85–123)	11.17	<1.0
Pattern construction[b]	53.73 (35–64)	10.08	52.36 (37–70)	7.32	<1.0
Reading accuracy[a]	113.73 (106–127)	4.98	110.73 (96–131)	5.98	1.63
Background measures					
Language					
WISC comprehension[c]	10.27	2.27	6.50	2.17	11.94*
Word definitions[b]	59.18	7.82	40.18	6.43	41.37*
Similarities[b]	57.00	10.06	41.18	6.38	19.39*
Recalling sentences[c]	8.82	3.37	5.80	3.26	4.33**
Same world[c]	11.82	2.44	12.27	4.10	<1.0
Opposite world[c]	10.64	2.91	7.73	3.82	4.04***

[a] Standard score, $M = 100$, $SD = 15$.
[b] T score, $M = 50$, $SD = 10$.
[c] Scaled score, $M = 10$, $SD = 3$.
* $p < .01$.
** $p < .05$.
*** $p < .06$.

to verify the language status of the less-skilled comprehenders. In line with previous findings (Nation, Clarke, Marshall, & Durand, in press), less-skilled comprehenders performed less well on a test of spoken language comprehension (the *Comprehension* subtest taken from the *Wechsler Intelligence Scale for Children-III*^{UK}, Wechsler, 1992) and achieved lower scores on tests of vocabulary and conceptual word knowledge (*Word Definitions and Similarities* taken from the BAS-II). Less-skilled comprehenders also exhibited lower verbal memory scores, as measured by the *Recalling Sentences* subtest from the *Clinical Evaluation of Language Fundamentals* (Semel, Wiig, & Secord, 2000), a test that requires children to repeat sentences of increasing length and syntactic complexity. Finally, given the potential role that inhibition or suppression processes may play in language comprehension (e.g., Gernsbacher & Faust, 1991), we measured response inhibition using two subtests taken from the *Test of Everyday Attention* (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). In the *Same World* subtest, in which children have to name the digits 1 and 2 presented in a random order along a path under a time constraint, the less-skilled comprehenders in the present study did not differ from skilled comprehenders. In contrast, there was a marginally significant difference between the groups on *Opposite Worlds*. This task places substantial demands on inhibition mechanisms as the children are required to name every digit 1 they encounter on the path as a digit 2, and vice versa.

In summary, we selected a group of 11 skilled and 11 less-skilled comprehenders. Consistent with previous samples, the less-skilled comprehenders showed weaknesses in spoken language comprehension, vocabulary and verbal memory (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Nation et al., in press); they also showed greater difficulty with response inhibition.

Materials

Sentences

Fifty-eight sets of sentence stimuli were devised. Each set consisted of two sentences that differed only in terms of the verb: one sentence contained a neutral verb (e.g., "Jane watched her mother *choose* a cake"), whereas the other contained a supportive verb that served to restrict the following noun (e.g., "Jane watched her mother *eat* a cake"). The final word in each sentence was the target noun.

These 116 sentences were pretested to check that the target noun was not highly predictable following either the neutral or the supportive verb. Twenty-eight children (mean age 9 years, 9 months) who had not been selected to be participants in the eye-tracking study took part in a sentence completion pretest. The children were presented with an auditory sentence frame, stopping at the determiner of the target noun (e.g., "Jane watched her mother choose a ....") and were asked to complete the sentence orally with the word or words they considered to be the most appropriate way to finish the sentence. We then calculated the number of times the target noun had been provided as the completion for both the supportive and the neutral version of each sentence. On the basis of the results of this pretest, we selected 40 sentences that had very low completion rates: for the neutral sentences, only 0.54% of completions consisted of the target noun; the supportive sentences were completed with the target noun on 0.72% of occasions. Thus, the neutral and supportive sentence frames did not differ in the extent to which the target noun was predictable from the preceding context, $t(39) = -.044$, $p = 0.66$.

We constructed a further 80 sentences to act as filler items. These sentences varied in length, and the noun intended as the target was placed either near the beginning of the item (e.g., The *violin* that Neil used to play is kept in the attic) or in the middle of the sentence (e.g., The little girl watched the *beetle* crawling over the grass).

The experimental and filler items were organised into two sets of trials. Each set contained equal numbers of experimental trials with supportive and neutral verbs. For each experimental item, one version (neutral or supportive) would be presented in Set 1 while the other version would appear in Set 2 (i.e., if Set 1 contained "Jane watched her mother *eat* a cake," Set 2 would feature "Jane watched her mother *choose* a cake"). Forty of the filler items were assigned to Set 1, and the remaining 40 were allocated to Set 2. Thus, each set comprised 80 items: 20 supportive experimental trials, 20 neutral experimental trials, and 40 filler trials. These items were arranged in a random order, with the proviso that the first two items in each set should be filler trials.

The 80 experimental and 80 filler sentences were recorded digitally in a soundproof booth. The sentences were read aloud, at a fairly slow pace, by a British female speaker. These were then saved as separate 16-bit digital sound files.

Visual scenes

One hundred sixty pictures were selected from clip art collections to represent each of the 80 experimental and 80 filler target nouns. To ensure that the pictures were readily identifiable as the target nouns, 10 members of the Psychology Department at the University of York were asked to name each picture, presented one at a time on a computer screen. For each target noun, the picture was deemed acceptable if it was named consistently by at least 80% of the participants. Seven pictures failed to reach this criterion. New pictures were selected for these items and 10 different adults were asked to name them. All 7 of these pictures were named consistently at least 80% of the time.

For each of the 40 experimental and 40 filler sentences, we constructed a 640×480 pixel visual scene consisting of four quadrants, each containing a picture of an object. One picture represented the target noun, the other three were distracter items. Distracter pictures were chosen from a large pool of clip art pictures taken from categories similar to the target items and included food, animals, clothes, and furniture. As the design was within-subject and participants would see each target picture twice (in both the neutral and supportive conditions, counterbalanced across Set 1 and Set 2), for each experimental sentence, one of the distracter items also served as a target for a filler trial in the alternative set. Including a filler target as a distracter ensured that, across the whole experiment, the pictures of the target nouns were not the only objects that had been seen and responded to twice. The positioning of the targets was counterbalanced across trials so that the target was equally likely to appear in each quadrant. This was the case for both the experimental and the filler trials.

Procedure

Children were seated in front of a 17-inch touch-sensitive monitor and wore a lightweight ISCAN video-based head-mounted eye-tracker. This tracker housed a scene camera that obtained an image of the participant's field of view and an eye camera that provided an infrared image of the eye (sampling from the left eye at 60 Hz), allowing eye position to be determined by tracking the location of the centre of the pupil and the corneal reflection. The two video streams were fed into a computer, which superimposed a cross-hair onto the display of the visual scene to represent the direction of gaze at a given time. This information was recorded onto digital video tape for later analysis. Head movements were not restricted.

The children were told that they would see four pictures on the screen at the same time that they would hear a sentence. They were told to listen carefully and that when they heard the name of one of the pictures, they should press its picture on the screen. The experiment was controlled by Psyscope software (Cohen, MacWhinney, Flatt, & Provost, 1993) running on an Apple Powerbook. The touchscreen monitor was connected to the Powerbook and mirrored its display. The administration of trials within each set was as follows. Children's eye movements were calibrated at the start of the experiment, checked between each trial, and recalibrated as necessary. The calibration display consisted of five small faces of different colours, one positioned in the centre of the display and one at each corner. This display also served to capture the child's attention at the commencement of a new trial. The experimenter pressed the space bar to advance the display to each trial. For each item, the visual display appeared for 1000 ms before the onset of the auditory sentence. As the sentence played out from the Powerbook, it was recorded onto the output video channel of the eye-tracker (thereby allowing synchronisation with the subsequent analysis of gaze direction). After the child had responded by making a touchscreen response, the display disappeared and the calibration screen was displayed again.

The children were tested individually in a quiet room in their school. Each child was seen twice, with Set 1 being presented in one session and Set 2 in the other session. The order of presentation was counterbalanced across individuals (five children in each group received one order and six children in each group received the other order), with approximately 3 days between each test session. Each session lasted approximately 25 min.

Results

Videotapes were played back frame by frame and fixations to the target object were extracted. Eye movements were recorded when a saccade was made into the quadrant containing the target object; as very short fixations lasting fewer than three frames (90 ms) are not considered to be under cognitive control (e.g., Rayner, 1998), fixations shorter than 90 ms were not counted. We also removed a small number of trials ($<1\%$) when children failed to point to the correct target. As our primary interest was in determining when the children first looked to the target object relative to when they heard the verb in the speech stream, markers were placed in each speech file at verb onset, verb offset, postverbal determiner onset, and postverbal noun onset and offset (i.e., the onset and offset of the target noun). We were thus able to analyse eye movements relative to these points in the spoken sentence.

For both neutral and supportive conditions, we calculated the cumulative probability across trials of fixating on the target object for each 50-ms interval following the onset of the verb. These data are shown in Fig. 1, collapsed across both groups of children. Very clearly, looks to the target object happen earlier in the supportive condition than the neutral condition. Thus, the overall pattern of results is similar to that observed in adults by Altmann and Kamide (1999).

To explore the data in a more fine-grained way, we list in Table 2 the percentage of trials that contained at least one saccade to the target object in two different time windows. The first window was the short period of time between verb onset and verb offset (e.g., for the sentence "Jane watched her mother *eat/choose* the cake," between the onset and offset of the verb *eat* or *choose*; the verbs were well matched for length and the average length of this window was 464 ms for both neutral verbs and supportive verbs). A 2 (group: skilled vs. less-skilled comprehenders) $\times$ 2 (context: neutral vs. supportive) analysis of variance on the arcsine-transformed percentages calculated across both participants [$F1(1,20)$] and items [$F2(1,78)$] confirmed that the main effect of context was not significant, $F1 = 1.32$, $F2 < 1.0$. Although the

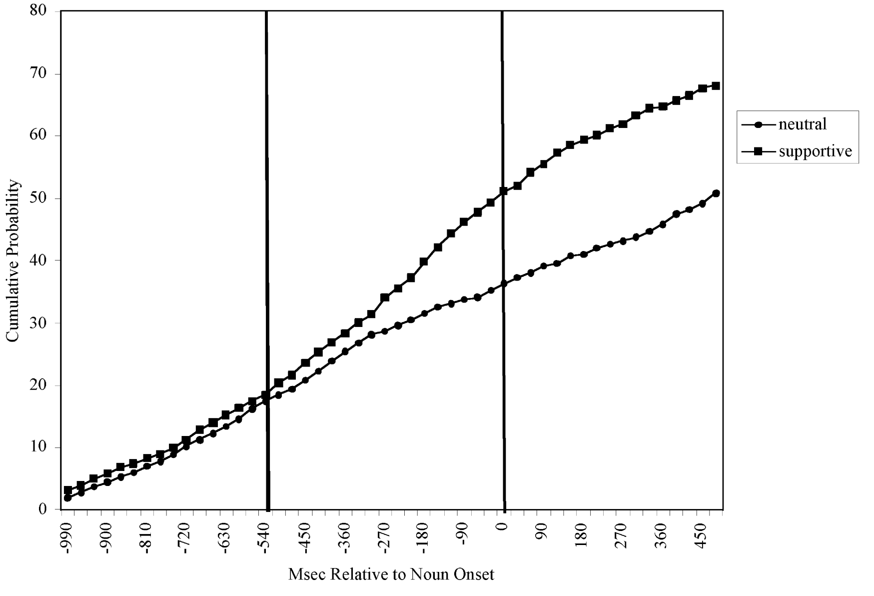

Fig. 1. The cumulative probability of fixating on the target object in neutral and supportive conditions. Note: The verb offset and noun onset are shown, averaged across trials and aligned to the nearest 30-ms bin within which they fall.

Table 2
Mean percentage of trials containing a fixation to the target object in the neutral and supportive conditions, between verb onset and verb offset and between verb offset and noun onset, for skilled and less-skilled comprehenders

	Supportive		Neutral	
	M	*SE*	*M*	*SE*
Skilled comprehenders				
Verb onset:verb offset	14.55	1.46	20.45	2.26
Verb offset:noun onset	40.00	2.21	17.95	2.02
Less-skilled comprehenders				
Verb onset:verb offset	21.14	1.52	19.09	1.51
Verb offset:noun onset	41.59	2.55	24.09	1.52

main effect of group was not significant, surprisingly, the interaction between group and context was significant, $F1 = 5.33$, $F2 = 5.74$, $p < .05$. As is clear from the means presented in Table 2, simple main effects demonstrated that this interaction arose because the skilled comprehenders made fewer fixations to the target in the supportive condition than in the neutral condition, $F1 = 5.98$, $p < .05$; $F2 = 4.31$, $p < .05$, whereas the less-skilled comprehenders showed no difference between the two conditions, both $F's < 1.1$.

The next window of time we examined was between verb offset and noun onset (e.g., between the offset of *eat* or *choose* and the onset of *cake*; the average length of window was 538 ms). For this time window, the main effect of context was strong, $F1 = 84.49$, $F2 = 54.54$, $p < .001$. Overall, less-skilled comprehenders made more looks to the target object, $F1 = 4.50$, $p < .05$; $F2 = 3.92$, $p = .051$. However, there was no interaction between group and context, $F's < 1.8$, confirming that less-skilled comprehenders made more anticipatory eye movements than the skilled comprehenders to the target in both neutral and supportive conditions.

Having established that fixations to the target were more likely in the supportive condition than in the neutral condition and that less-skilled comprehenders fixate to the target on a greater proportion of trials than control children, we proceeded to investigate the timing of eye movements in greater detail. Table 3 shows the onset of the first saccade to the target object in milliseconds, *relative* to the onset of the target noun. Saccades to the target object occurred earlier in the supportive condition than the neutral condition, $F1 = 83.33$, $F2 = 22.98$, $p < .001$, but neither the main effect of group nor the interaction between group and context was significant, all $F's < 1.0$. Thus, all children showed anticipatory eye movements and there was no difference between the two groups of children in the time taken to launch an eye movement to the target in either condition.

The analyses reported so far demonstrate that both groups of children make anticipatory eye movements and show strong context effects. Although there were no group differences on any of the first fixation time indices, less-skilled comprehenders looked at the target more often (as measured by the proportion of trials containing at least one fixation to the target object). This effect was not moderated by context: less-skilled comprehenders made more looks than skilled comprehenders in both neutral and supportive conditions.

To investigate the robustness of this observation, we calculated the number of separate fixations made to the target object by each child in the region of time between verb onset and noun onset. These data are summarised in Table 4. Once again, there was a main effect of context: children made more separate fixations to the target in the supportive condition, $F1 = 39.81$, $F2 = 32.61$, $p < .001$. This did not interact with group, $F's < 1.0$, but the main effect of group was robust, $F1 = 6.72$, $F2 = 6.82$, $p < .02$: less-skilled comprehenders made more separate looks to the target than skilled comprehenders.

Despite the fact that less-skilled comprehenders made more separate fixations to the target, when we summed the total amount of time they spent looking at the target for all fixations initiated between verb onset and noun onset, less-skilled comprehenders spent significantly *less* time looking at the target (Table 4). All children spent

Table 3
Mean onset of first saccade to the target object in the neutral and supportive conditions, relative to noun onset for skilled and less-skilled comprehenders (timings in ms)

	Supportive		Neutral	
	M	*SE*	*M*	*SE*
Skilled comprehenders	−62	29	187	35
Less-skilled comprehenders	−87	37	147	19

Table 4
Mean number of fixations (and standard error) to target initiated between verb onset and noun onset, total looking time (ms) for fixations initiated between verb onset and noun onset, and touchscreen RT (ms) in the supportive and neutral conditions for skilled and less-skilled comprehenders

	Supportive		Neutral	
	M	*SE*	*M*	*SE*
Skilled comprehenders				
Total *N* fixations to target	0.55	0.03	0.39	0.03
Total looking time	1285	91	818	61
Touchscreen RT	2183	94	2425	157
Less-skilled comprehenders				
Total *N* fixations to target	0.63	0.03	0.44	0.02
Total looking time	1036	32	802	58
Touchscreen RT	2298	78	2483	90

longer looking at the target in the supportive condition, $F1 = 39.94$, $F2 = 23.22$, $p < .001$. The main effect of group was significant, although the effect was marginal in the by-subjects analysis, $F1 = 3.46$, $p = .07$, $F2 = 10.49$, $p < .01$. This main effect was qualified by an interaction between group and context (although only marginally so in the by-items analysis), $F1 = 4.44$, $p < .05$, $F2 = 2.96$, $p = .08$. Simple main effects on this interaction demonstrated that although the groups did not differ in the neutral condition, $F1 < 1.0$, $F2 = 1.15$, less-skilled comprehenders spent significantly less time than skilled comprehenders fixating the target in the supportive condition, $F1 = 6.71$, $p < .02$, $F2 = 12.30$, $p < .001$.

Finally, we considered how quickly children responded to the target as indexed by the time taken to make the touchscreen response in each condition (Table 4). These data need to be interpreted cautiously, as our instructions did not emphasise speed of responding (children were simply told to respond by touching the screen when they were sure). Although less-skilled comprehenders launched initial eye movements earlier than control children, the two groups did not differ in the speed of their touchscreen responses, $F's < 1.5$, perhaps due to the large amount of variation in the reaction times.

Discussion

This experiment explored whether children—like adults—extract information from a verb and use this information to guide ongoing processing by predicting subsequent reference to those objects in the visual context that satisfy the verb's selectional restrictions. Very clearly, children are sensitive to verb selection restrictions and are able to integrate this with information extracted from the "real-world" visual context. Eye movements to the target in the supportive condition were launched an average of 241 ms earlier than in the neutral condition, well before the acoustic onset of the referring noun. The magnitude and timing of this effect are very similar to the differences of 212 and 245 ms shown by skilled adults in Altmann and

Kamide's study (1999, Experiments 1 & 2, respectively). Thus, our findings are consistent with the view that when a verb is encountered, thematic role information is very quickly activated and assigned on the basis of plausibility, or thematic fit, with the referring context depicted in the visual scene (Altmann, 1999; Altmann & Kamide, 1999; Ferretti et al., 2001).

We also asked whether there are individual differences amongst children and whether less-skilled comprehenders show a pattern of eye movements different from those of skilled comprehenders, reflecting differences in online processing and sensitivity to context. We found no evidence to suggest that less-skilled comprehenders are less sensitive to context: within milliseconds of hearing a supportive verb, less-skilled comprehenders, like skilled comprehenders, made anticipatory eye movements to the likely target object. If we accept that an appreciation of a verb's argument structure and associated selectional restrictions is to some extent part of the meaning of that verb (Altmann, 1999; Ferretti et al., 2001), then it is clear that less-skilled comprehenders initially activate this information as speedily as normally developing children. This is consistent with general findings from studies of college-aged less-skilled comprehenders (e.g., Gernsbacher & Faust, 1991; Long et al., 1999) and suggests that less-skilled comprehenders are able to access and deploy verb-based information in real-time and do so in a manner that is broadly similar to that of control children (but see subsequent discussion); that is, like normally comprehending children and adults, they are able to integrate verb-based information with a concurrent (visual) context.

Notwithstanding this, two features of less-skilled comprehenders' eye movement records suggest some important differences between skilled and less-skilled comprehenders. First, less-skilled comprehenders made more eye movements, both in terms of the proportion of trials that contain an eye movement to the target and in terms of the number of separate eye movements overall (i.e., the average number of eye movements to the target within each trial). This was equally true in both neutral and supportive conditions and thus was not a consequence of the language manipulation. Plausibly, this could be an index of various factors. Less-skilled comprehenders may have poorer memory for either the objects in the display or the words in the sentence, and the increased number of eye movements may reflect attempts to refresh memory traces. Consistent with other studies (Marshall & Nation, in press; Nation et al., 1999), the less-skilled comprehenders in this study showed weaker memory for meaningful information and sentences (Table 1). Plausibly, these memory deficiencies may be related to their increased number of eye movements. This would be consistent with the findings of Sedivy, Demuth, Chunyo, and Freedman (2000), who found that young children made more eye movements than adults and, interestingly, that adults could be induced to "look like" children if the processing demands of the task were increased by raising the number of objects in the array from four to seven.

More eye movements might also reflect differences in general attention, or perhaps problems with inhibiting irrelevant information—that is, the distracter pictures in the visual scene. This is particularly interesting given Gernsbacher and Faust's (1991) claim that although adults with poor comprehension activate relevant information normally, comprehension is impeded as they fail to suppress irrelevant information rapidly and efficiently. This would fit with the pattern of data seen in our experiment, with normal activation of information being indexed by fast and efficient anticipatory eye movements but a greater number of eye movements reflecting failure to suppress irrelevant information. Interestingly, the less-skilled comprehenders showed deficits on Opposite Worlds (Table 1), a task that places considerable demands on inhibition mechanisms as automatic responses must be suppressed. Although inhibition mechanisms clearly continue to develop into early adulthood (e.g., Diamond, 2002), very few studies have investigated inhibitory control mechanisms in this age group, or considered the relation between inhibition and individual differences in language comprehension. But, given Gernsbacher and Faust's findings with adults and the pattern of eye movements and response inhibition seen in this experiment, it would seem an important focus for future work.

Although further research is needed to verify and extend the present results, a number of conclusions can be made. Our data show that children are able to draw on multiple sources of information and use this information to constrain ongoing processing. Very clearly—and despite their comprehension impairments—less-skilled comprehenders were equally sensitive to this information. Thus, our experiment provides no support for the view that less-skilled comprehenders are less sensitive to contextual constraints stemming from verb argument structure. Interestingly, however, less-skilled comprehenders made more eye movements overall (and hence, shorter fixations). It is not clear why this was the case, but plausibly, it may reflect limitations with memory or attention. Finally, we have demonstrated the utility of the language-mediated eye movement paradigm for exploring individual differences in children. Recent work suggests that the paradigm can be used to investigate not only the mapping of linguistic input onto a concurrent visual scene but also the integration of the current linguistic input with previous linguistic input, and the mapping of the resulting mental representation onto the concurrent world (Altmann & Kamide, in press). We believe that future research with this paradigm with less-skilled comprehenders will therefore be able to more specifically narrow the locus (or loci) of the deficit. Without doubt, the ability afforded to us by the visual world paradigm, to tap comprehension processes *as they happen,* is vital if we are to understand the nature of normal and atypical language comprehension development.

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