Journal of Educational Psychology
2004, Vol. 96, No. 1, 31–42

0022-0663/04/$12.00 DOI: 10.1037/0022-0663.96.1.31

Children's Reading Comprehension Ability: Concurrent Prediction by Working Memory, Verbal Ability, and Component Skills

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The authors report data from a longitudinal study that addresses the relations between working memory capacity and reading comprehension skills in children aged 8, 9, and 11 years. At each time point, the authors assessed children's reading ability, vocabulary and verbal skills, performance on 2 working memory assessments (sentence-span and digit working memory), and component skills of comprehension. At each time point, working memory and component skills of comprehension (inference making, comprehension monitoring, story structure knowledge) predicted unique variance in reading comprehension after word reading ability and vocabulary and verbal ability controls. Further analyses revealed that the relations between reading comprehension and both inference making and comprehension monitoring were not wholly mediated by working memory. Rather, these component skills explained their own unique variance in reading comprehension.

Text comprehension is a complex task that draws on many different cognitive skills and processes. Unfortunately, our knowledge of the unique contribution that these different skills and processes make to reading comprehension development is limited because the majority of work in this field has focused on a single component skill (see Hannon & Daneman, 2001; Saarnio, Oka, & Paris, 1990, for a discussion of this point). In this article, we are concerned with how different language skills and processing resources are related to children's reading comprehension level, between the ages of 7–10 years.

The language skills that we focus on are higher level language skills involved in the integration of information across sentences and ideas in a text, namely, inference and integration, comprehension monitoring, and knowledge about text structure. These skills are important for comprehension because they help the reader to construct an integrated and coherent model of a text's meaning. However, young children's reading comprehension is strongly predicted by other lower level language skills, such as word reading accuracy and verbal and semantic skills. Our aim here is to determine whether the higher level skills make independent contributions to the prediction of reading comprehension over and above these other language skills, within this age range.

The other focus of this article is the relation among processing resources (working memory), reading comprehension, and the higher level language skills. We examine if there is a direct relation between verbally mediated working memory capacity and reading comprehension after controlling for verbal and semantic skills and the extent to which working memory resources underpin the relations between the higher level language skills and reading comprehension. First we discuss the relation between working memory resources and text comprehension and review the evidence for a direct relation between working memory and text comprehension in children. Then we consider how each higher level language skill is related to reading comprehension and the cognitive operations involved in each.

Working Memory and Skilled Text Comprehension

Text comprehension involves the formation of a meaning-based representation of the text, often called a mental model or a situation model (Gernsbacher, 1990; Johnson-Laird, 1983; Kintsch, 1998). The processes of integration and inference are important to the construction of an integrated and coherent model of a text. Integration between adjacent clauses is necessary to establish local coherence, and inferences about different events, actions, and states are required to make the text cohere as a whole (Graesser, Singer, & Trabasso, 1994; Long & Chong, 2001). These processes require that the relevant information, either from the text or world knowledge, is both available and accessible. Working memory serves as a buffer for the most recently read propositions in a text, enabling their integration to establish coherence, and holds information retrieved from long-term memory to facilitate its integration with the currently active text (Cooke, Halleran, & O'Brien, 1998; Graesser et al., 1994). Working memory capacity is correlated with college students' performance on standardized assessments of comprehension skill (Daneman & Carpenter, 1980,

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1983). In addition, working memory capacity is related to skills important for comprehension, such as the resolution of pronouns, memory for facts, and the inference of unknown word meanings from context (Daneman & Carpenter, 1980; Daneman & Green, 1986; Masson & Miller, 1983). Consequently, resource accounts of comprehension give a central role to processing resources such as working memory.

Working Memory and Children's Reading Comprehension

There is a strong relation between working memory (i.e., those tasks that require the simultaneous storage and processing of symbolic information) and children's reading comprehension. In contrast, comprehension does not correlate with tasks that simply involve the passive storage of information (Leather & Henry, 1994; Oakhill, Yuill, & Parkin, 1986; Swanson & Berninger, 1995; Yuill, Oakhill, & Parkin, 1989). The relation between working memory and comprehension skill has been found with tasks that require the processing and storage of words (de Beni, Palladino, Pazzaglia, & Cornoldi, 1998), sentences (Seigneuric, Ehrlich, Oakhill, & Yuill, 2000), and numbers (Yuill et al., 1989). This variability in choice of task raises the issue of which type of task is more appropriate in such investigations. A word- or sentence-based task is likely to be predictive of reading comprehension because these tasks are demanding of linguistic skills. A number-based task, which does not require the processing of words and sentences, can be used to determine whether there is a more general relation between working memory and comprehension skill. Children's verbal and numerical working memories are both related to reading comprehension (Oakhill, Cain, & Bryant, 2003; Seigneuric et al., 2000). However, children's performance on working memory tasks that require the manipulation of shapes and patterns does not explain variance in reading comprehension (Nation, Adams, Bowyer-Crane, & Snowling, 1999; Seigneuric et al., 2000). Word-, sentence-, and number-based working memory tasks are readily amenable to verbal coding (unlike spatial tasks), which might explain their association with comprehension skill. We refer to working memory tasks that require the processing of either linguistic or numerical materials collectively as *verbally mediated* working memory tasks, to differentiate them from tasks that require spatial processing.

Nation et al. (1999) suggested that the reported relation between children's working memory and their text comprehension is underpinned by verbal and semantic skills. They argued that poor comprehenders have a specific semantic weakness that restricts their ability to store verbal information in short-term memory. This weakness impairs performance on the types of verbally mediated working memory tasks used in previous research. Similarly, Stothard and Hulme (1992) proposed that working memory differences between good and poor comprehenders would disappear if differences in verbal IQ (VIQ) were controlled, though they did not present evidence to support this prediction.

The strong version of this hypothesis is, as yet, unproven. Working memory capacity assessed by verbally mediated tasks explains individual differences in children's reading comprehension over and above other well-established predictors of comprehension, such as decoding, word recognition skill, and vocabulary knowledge (Swanson & Berninger, 1995; Yuill et al., 1989). Thus, working memory resources seem to be an important and specific determinant of children's reading comprehension level. However, these working memory tasks may tap into verbal resources (see above), and both vocabulary knowledge and verbal intelligence are strong predictors of reading comprehension level (Jensen, 1980; Oakhill et al., 2003; Sternberg & Powell, 1983). Word knowledge can affect adults' performance on a measure of verbal working memory (Dixon, LeFevre, & Twilley, 1988). Clearly, the relation between children's verbal skills and their verbally mediated working memory resources warrants further investigation.

Different assessments of verbal skills and semantic knowledge include tasks that tap the ability to select a synonym or picture that matches a particular word in its written or spoken form and tasks that measure the ability to define words. Investigations into children's reading comprehension and working memory have not included multiple indicators of verbal ability (but see Dixon et al., 1988), which is an important omission in the light of the findings summarized above. In addition, working memory tasks that involve the processing and storage of numbers are weaker predictors of text comprehension than those with a linguistic content (Seigneuric et al., 2000), suggesting that the explanatory power of linguistically based working memory tasks might be considerably reduced if appropriate verbal controls were included. In this study, we have included both a sentence-span and a numerical working memory test as well as assessments of verbal ability to explore the extent to which the predictive power of the working memory tasks is mediated by verbal ability.

Component Skills of Reading Comprehension

Many skills may contribute to a child's reading comprehension level (Carr, Brown, Vavrus, & Evans, 1990; Palincsar & Brown, 1984; Perfetti, Marron, & Foltz, 1996; Saarnio et al., 1990). Taxonomies of comprehension abilities often categorize the component skills and processes as ones that occur higher or lower in the language processing chain. For example, word recognition skills are considered a lower level processing skill. In contrast, inference making is considered a higher level processing skill because it aids the construction of the meaning-based representation of the text (Hannon & Daneman, 2001; Pressley, 2000).

Working memory is a resource that affects an individual's ability to carry out many of the processes associated with the construction of the text representation. Within this resource framework, slow or inaccurate word reading is proposed to affect comprehension by using up too much processing capacity with little remaining for text comprehension processes such as integration and inference (Curtis, 1980; Hannon & Daneman, 2001; Perfetti, 1985). In accordance with this theory, word reading is the best predictor of reading comprehension level in the early years (Juel, Griffith, & Gough, 1986), but other skills become the more important predictors of comprehension level as word reading ability develops through experience (Curtis, 1980; Saarnio et al., 1990). Thus, the relative importance of different skills may change during the course of development. In this investigation, we controlled for word reading ability, in addition to verbal skills, in order to determine whether any of the higher level skills associated with meaning construction play a unique role in the determination of comprehension level.

Processing variables and knowledge may each make distinct contributions to the determination of reading comprehension (Perfetti et al., 1996). Processing failures that could lead to comprehension difficulties include inefficient lexical processing, impaired inference-making skill and comprehension monitoring ability, and limitations of working memory. Types of knowledge failure that may lead to comprehension difficulties are impoverished knowledge about word meanings or a specific domain. We consider two higher level meaning-construction skills that could be classed as processing variables—inference making and comprehension monitoring—and one that could be classed as a knowledge variable—knowledge about how narrative texts are structured. Performance on measures of these skills is related to individual differences in reading comprehension level, but there have been no studies investigating the relative contributions of these skills to text comprehension within a developmental framework.

Working memory resources are clearly important in the execution of inference and monitoring skills. A crucial question is whether individual differences in working memory capacity underlie individual differences in specific comprehension skills that require the integration of information, such as inference making and comprehension monitoring (Daneman & Carpenter, 1980, 1983; Seigneuric et al., 2000), or whether deficiencies in these skills exist in the presence of adequate working memory (and lexical processing) skills (Perfetti et al., 1996). A brief summary of each skill and the theoretical basis and empirical evidence for its relation to reading comprehension and working memory follows.

Inference Making

The construction of a meaning-based representation of a text involves going beyond the meaning of the text through the generation of inferences. There are many different classes of inference, for example, inferences that establish referential coherence, causal antecedents, and character's emotional reactions (Graesser et al., 1994). Inferences may be necessary to establish local coherence between adjacent clauses or to establish global coherence among different events, actions, and states in a text (Graesser et al., 1994; Long & Chong, 2001). In this study, we were interested in inferences that were necessary to make sense of a text and that required either the integration of information among individual sentences in the text or the integration of general knowledge with information in the text (see Appendix for examples). The ability to generate these types of inference is related to both age and reading comprehension skill (Barnes, Dennis, & Haefele-Kalvaitis, 1996; Cain & Oakhill, 1999; Cain, Oakhill, Barnes, & Bryant, 2001; Casteel & Simpson, 1991; Oakhill, 1982, 1984; Omanson, Warren, & Trabasso, 1978).

Working memory is conceptualized as the work space where integration and inference take place. Independent assessments of working memory are related to adults' ability to perform tasks that rely on these processes, but to date the contribution made by working memory to the prediction of children's inference-making skill (and ultimately their comprehension level) has not been assessed. However, working memory capacity alone may not be sufficient to ensure that a crucial inference is generated. The reader must possess the relevant world knowledge from which an inference can be drawn (Barnes et al., 1996). Strategic reading behavior may also play a role in individual differences in inference making. Adult poor comprehenders make a greater number of knowledge-based inferences when questions to promote the generation of crucial inferences are incorporated into the text (Hannon & Daneman, 1988). Children's inference making improves when they are trained to focus on key words in the text (Yuill & Joscelyne, 1988). Similarly, children's reading comprehension benefits when children are trained to generate questions to promote the interpretation of text and to facilitate prediction from text (Palincsar & Brown, 1984).

Comprehension Monitoring

Comprehension monitoring is one aspect of metacognition that concerns the comprehension of connected prose (Wagoner, 1983). Measures of comprehension monitoring usually assess a reader's ability to detect inconsistencies in text, such as scrambled sentences, contradictory sentences, or statements that conflict with external information (world knowledge). These error-detection tasks require readers to evaluate their understanding of the text and to regulate their reading to resolve any reading problems and to facilitate their understanding. Hacker (1998) proposed the term *self-regulated reading,* rather than *comprehension monitoring,* to highlight the importance of both processes.

Performance on error-detection tasks improves with age (Baker, 1984; Markman, 1981), which may be related to children's developing information processing capabilities (Ruffman, 1996; Vosniadou, Pearson, & Rogers, 1988). Children with reading comprehension difficulties are poor at detecting internal inconsistencies in text (Ehrlich, 1996; Ehrlich, Remond, & Tardieu, 1999). Such difficulties are more pronounced when the anomalous pieces of information are nonadjacent (Yuill et al., 1989), indicating that working memory capacity may influence the application of this skill. Rubman and Waters (2000) argued that effective comprehension monitoring cannot take place unless the reader has acquired the ability to integrate propositions to construct a coherent representation of a text, which may particularly affect the detection of internal inconsistencies. However, the detection of internal inconsistencies can be achieved through the comparison of literal (explicit) statements in the text, which would not require the reader to engage in the same sort of constructive processing that is necessary for inference generation.

The regulation of one's reading may also involve knowledge of appropriate repair strategies to deal with comprehension failure (Wagoner, 1983). If an individual is aware that his comprehension is inadequate, he can take appropriate steps to remedy the situation, provided he has the knowledge to do so. Knowledge about effective repair strategies and the standards used to detect errors in text improves with age (Baker, 1984; Saarnio et al., 1990). In addition, task variables such as levels of interest in the task can affect monitoring performance (de Sousa & Oakhill, 1996).

Understanding Text Structure

Knowledge about the organization of narrative texts increases throughout middle childhood (Stein & Glenn, 1982). Perfetti (1994) proposed that a possible source of comprehension failure is inadequate knowledge about text structures and genres, which may arise because of insufficient reading experience. Explicit awareness about text structure and the expectations engendered by certain common features of text may be useful aids for readers, helping them to invoke relevant background information and schemas to facilitate their construction of a meaning-based representation.

Paris and colleagues (e.g., Myers & Paris, 1978; Paris & Jacobs, 1984) have found that knowledge about the purpose of reading and knowledge about the information provided by conventional features of text are related to both age and reading comprehension. For example, older readers and better comprehenders were better able to explain the sorts of information that may be provided by the introduction and ending of a text. Children with specific comprehension difficulties demonstrate impairments in their ability to structure stories (Cain, 2003; Cain & Oakhill, 1996) and impoverished knowledge about the information contained in certain features of text (Cain, 1996). If knowledge about narrative structure is well learned and can be activated with little cost to processing capacity, it is plausible that efficient retrieval and use of such knowledge may reduce the adverse effects of limited processing capacity (see Graesser et al., 1994, for a discussion of this point).

Summary of Aims

Investigations of individual differences in children's reading ability have identified a wide range of skills that are related to reading comprehension level. In this article, we focus on the relative contribution made by the higher level language skills and processing resources outlined above to children's text comprehension during the period in which they move from beginner to independent readers. In particular, we are concerned with the predictive ability of working memory, given its prominent role in resource accounts of comprehension.

The aims are as follows: (a) to investigate whether there is a direct relation between children's working memory capacity (as measured by sentence-span and digit working memory tasks) and their reading comprehension ability, or whether any association between these two variables arises through verbal and semantic skills; (b) to determine whether higher level component skills (inference, comprehension monitoring, story structure) play a unique role in the determination of comprehension level; (c) to explore whether any relations between the higher level language skills and children's reading comprehension are mediated by processing resources (working memory). In addition, we wanted to see whether these patterns of prediction change with age.

Method

Participants

The children participating in this study were assessed as part of a longitudinal project, in which their progress was measured during the years when they had their 8th, 9th, and 11th birthdays. We report data from all three time points in this article. The initial sample comprised 102 7–8-year-olds. These children were selected from an initial assessment of all of the 7–8-year-old children attending six schools who agreed to participate in the study. These schools served socially mixed catchment areas on the south coast of England. Children who were extremely good readers, or very poor readers, were excluded. The very good readers (those whose word reading skills were more than 2 years above their chronological age) were excluded from the study because we expected that their reading ability would be beyond the scale of the standardized reading assessment given to our sample (13 years) by the final test point.

Children who did not speak English as their first language, or who had any known behavioral, emotional, or learning difficulties, were also excluded. The final selection ensured a sample comprising children with a range of word reading and reading comprehension ability. The ratio of children selected from each of the schools reflected the ratios of total numbers (within the relevant age group) in those schools.

Assessments

The assessments are described briefly below. Further detail can be obtained from Kate Cain.

Reading ability. As part of the initial screening process, children were assessed individually on the Neale Analysis of Reading Ability—Revised British Edition (Neale, 1989). The Neale Analysis provides measures of both word reading accuracy (word recognition in context) and reading comprehension (assessed by ability to answer a series of questions about each passage).

Vocabulary. The children completed two assessments of vocabulary knowledge. The Gates–MacGinitie Vocabulary subtest, Level 2, Form K (MacGinitie & MacGinitie, 1989), was administered as a group test during the initial selection phase. In this test, the child has to select one out of four words to go with a picture (7–8-year-olds) or to select a synonym of a word in a short phrase from one of four options (8–9-year-olds, Level 3; 10–11-year-olds, Levels 5 and 6). This test provides an index of a child's ability to read and understand written words in unconnected prose. We assessed receptive vocabulary using an individually administered test, the British Picture Vocabulary Scale (BPVS; Dunn, Dunn, Whetton, & Pintilie, 1982). In this test, the administrator says a word, and the child has to point to one of four pictures—the one that pictures the meaning of the word. Because the children were from a single year group, raw scores from this test were used in the analyses below.

Verbal ability. We assessed verbal intelligence using two subtests from the Wechsler Intelligence Scale for Children—Third UK Edition (Wechsler, 1992), Vocabulary and Similarities. These tests provide measures of children's knowledge of word meanings and their general knowledge and reasoning skills. The percentage of the total possible score obtained was used in the analyses below, to give equal weighting to both subtests.

Working memory. Children completed two assessments of working memory, one that involved the processing and storage of digits and one that involved the processing and storage of sentences and words. The digit working memory task was developed by Yuill et al. (1989) to be analogous to a reading-span task but without the requirement of sentence comprehension. The task includes both a storage and a processing component and discriminates good and poor comprehenders in a way that digit- and word-span tasks do not (Yuill et al., 1989). Children read groups of three digits out loud (the processing component) and are required to remember the final digit in each group for later recall (the storage component), in the order of presentation. At the easiest level, children read two groups of digits and have two final digits to recall, for example, "5–2–8," "3–7–1," recall "8–1." Thus, the task cannot be performed simply by memorizing the final digit from each group. Increasing the number of groups of digits to be read and therefore the number of final digits to be recalled increased the processing and storage demands of the task. The other working memory task was a sentence-span task, in which children were read short sentences that were missing their final word. The sentences were relatively constrained, for example, "The color of grass is . . . ." The child's task was to complete the sentence and to remember the supplied word for later recall, in the correct order.

We refer to these tasks as the digit working memory task and the sentence-span task, respectively. At Time 1, children completed three trials each of two, three, and four groups of digits or sentences. At Times 2 and 3, they completed three trials each, of three, four, and five groups of digits or sentences. Two practice items preceded the experimental trials at each level of difficulty.

Inference and integration skill. At Time 1, we assessed children's inference and integration skills using Oakhill's (1982) constructive integration task. In this task, the children listen to eight short (three-line) texts and are then asked to state whether the given sentences were ones that occurred in the texts they had been read. An example text is provided in the Appendix.

For each text, there were four test sentences of three types: two sentences that had actually been presented (literal information), one sentence that integrated information from adjacent sentences in a manner that was consistent with the overall meaning (valid inferences), and one that combined text information in a similar manner, but in a way that was not compatible with the overall meaning of the text (invalid inferences). Thus, the child's performance on the recognition sentences indicates not only memory for the surface form of the text (e.g., recognition memory for the original sentences) but also the degree to which the child has gone beyond the meaning of individual sentences by combining this information to construct an integrated representation of the text's meaning. We used the number of correct acceptances of original sentences and valid inferences minus the number of acceptances of invalid inferences (to control for guessing) as an index of the child's ability to integrate information. The maximum possible score was 24.

We were concerned that the "false memory" paradigm was subject to problems of guessing and response bias. Thus, to assess the children's inference and integration skills at Times 2 and 3, we used a task developed by Cain and Oakhill (1999). Children read three short stories and answered six questions that tapped both literal and inferential information after each one. Different stories were used at Times 2 and 3. An example text and questions are provided in the Appendix. For each text, there were two literal questions to measure memory for facts in the text and four inference questions. Two of these inference questions assessed children's ability to integrate information between two sentences, and two questions assessed their ability to integrate general knowledge with information in the text to fill in missing details. Both types of inference questions require a deeper level of understanding than do the literal questions because the inference questions demand the integration of information in the text and/or the supplementation of text information with general knowledge, whereas the literal questions can be answered by making use of more superficial information in the text and do not require that the reader go beyond the propositional content. This task enabled us to look separately at the contribution of literal and inferential skills to comprehension. The maximum possible score at Times 2 and 3 was 6 for the literal questions and 12 for the inference questions (combined).

Comprehension monitoring. Children read short stories, some of which contained conflicting information, to assess their ability to monitor their own comprehension. At Time 1, the children's task was to read the stories out loud and underline any parts that did not make sense. They were then asked to explain why they had underlined those particular parts. At Times 2 and 3, the children completed the task silently in small groups. The distance between the anomalies in the stories was increased to ensure that the task was of a suitable level of difficulty at each time point. At Times 1 and 2, there were four stories containing one inconsistency (two lines containing contradictory information) and two fully consistent stories. The maximum score was 18 at each time point. At Time 3, there were three stories, each containing two inconsistencies and two fully consistent stories. The maximum score was 8.

Knowledge of story structure. We used two different measures of knowledge about story structure, the titles task and the story anagram task. In the titles task (Cain, 1996), children were required to explain the information contained in story titles. At Time 2, they also had to explain the purpose of story beginnings and endings, and at Time 3, they were additionally asked to explain the information contained in titles relating to different story genres and to specify the type (i.e., the genre) of the story. The sentence anagram task has been used to assess the development of children's understanding of story structure (Stein & Glenn, 1982). In our version, children were given three short stories, which had been cut up into their constituent sentences, and the sentences were randomized. Their task was to arrange the sentences in the correct order, so that the story made sense. The stories comprised 6 sentences at Time 1, 8 sentences at Time 2, and 12 sentences at Time 3. The scores used in the analyses are concordance ratings, to reflect the degree to which the arranged sequence matched the correct sequence of sentences. The maximum possible score is 1, which reflects perfect concordance between the reordered sentences and the target order.

Results and Discussion

Some children did not complete every experimental task at each time point because of absence or because they moved away from the area. The data presented here include only those children who completed every task at a particular time point: Time 1, $N = 100$; Time 2, $N = 92$; Time 3, $N = 80$. (These sample sizes are adequate for reliable multiple regression analyses to be conducted, ensuring more than the minimum 10 data points per predictor variable, as suggested by Tabachnick & Fidell, 1989.)

Mean Scores Obtained for All Variables at Each Time Point

The mean scores obtained on each assessment at each time point are presented in Table 1. The reliability of the different experimental measures was assessed by calculating Chronbach's alpha over items. For most assessments, the reliability coefficient was good or very good (.60–.80). However, the measures of inference and integration produced rather low alpha levels: The alpha for the test used at Time 1 was .48 (over 24 items), and at Time 2, it was .51 (over 12 items).

There was a divergence between word reading ability and text comprehension across time. At Time 1, the age-equivalent scores for both word reading accuracy and comprehension were in line with the mean chronological age. However, at Times 2 and 3, word reading performance was above chronological age, whereas the mean reading comprehension score was below chronological age. Extremely poor word readers were excluded in the initial selection process. The divergence in word reading and text comprehension indicated that the remaining children all had the initial skills to become fluent and able word readers but that their word reading ability did not automatically enable them to develop good text comprehension skills.

Interrelations Between Variables at Each Time Point

Tables 2, 3, and 4 show the correlations (one-tailed) between the standardized assessments and experimental measures taken at each time point. Because of the large number of correlations, a significance level of .01 was adopted.

Reading comprehension, working memory, and component skills. As predicted, at each time point, consistent correlations were found between reading comprehension and the component measures of comprehension and also working memory. Although the two working memory tasks were significantly correlated with each other, the sentence-span measure was more strongly correlated with the component skills and also with reading comprehension. Indeed, the digit working memory task was only correlated with reading comprehension at Time 2. We expected the sentence-

Table 1
Means and Standard Deviations for Measures Taken at Time 1, Time 2, and Time 3

	Time 1 (N = 100)		Time 2 (N = 92)		Time 3 (N = 80)	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Chronological age (in years)	7.53	3.30	8.62	3.15	10.64	3.23
Neale word reading accuracy (in years)	7.81	6.32	9.45	12.45	11.62	14.85
Neale reading comprehension (in years)	7.31	11.24	8.54	15.81	9.26	17.69
Verbal IQ (prorated to 50)	52.13	10.95			67.25	9.81
Gates–MacGinitie	34.36	4.65	32.11	6.52	28.08	7.21
BPVS (standardized scores)	102.90	9.50	105.20	8.80	115.00	13.00
Inference and integration	14.80	3.76	8.39	1.83	6.33	2.09
Literal questions			5.17	0.84	5.40	0.76
Comprehension monitoring	14.58	3.11	14.62	2.76	3.61	1.82
Story anagram	0.80	0.16	0.87	0.08	0.92	0.11
Story titles	2.94	1.16	3.34	1.28	8.11	2.51
Working memory: Sentence span	11.40	3.01	16.77	4.18	21.60	4.98
Working memory: Digit task	10.70	3.06	16.39	5.77	21.61	4.76

Note. The apparent decrease over time in mean scores for the integration and inference and the comprehension monitoring measures reflect the different maximum scores possible. Neale = Neale Analysis of Reading Ability—Revised; BPVS = British Picture Vocabulary Scale; Gates–MacGinitie = Gates–MacGinitie Vocabulary subtest.

span measure to be more highly correlated with measures of language ability because it involved sentence comprehension. In previous work, strong relations between the digit working memory task and reading comprehension level have been found (Seigneuric et al., 2000; Yuill et al., 1989) so it is surprising that it was not such a good predictor of text comprehension in this study.

The majority of our comprehension skills were related to each other throughout the study. The exceptions were the lack of a significant relation between inference making and monitoring at Time 1 and also inference making and the story anagram task at Times 1 and 3. These two tasks were rather different in nature, so we did not expect them to be highly correlated. The inference task required the reader to go beyond the literal content of the text, whereas the comprehension monitoring task required a more superficial type of processing, specifically, the comparison of two explicit (literal) pieces of information. The story anagram task, by contrast, relied to a certain extent on knowledge about story structure. These component skills were more highly correlated with reading comprehension than with each other.

Although comprehension monitoring was correlated with the sentence-span working memory task at each time point, the inference and integration measure was not correlated with either working memory task at Time 1. The different inference measures used at Time 1 versus Times 2 and 3 may have made different demands on working memory, and there were strong correlations with the sentence-span task at both these later time points. We return to this point in the General Discussion.

Reading comprehension and word reading ability. The correlation between word reading and text comprehension was greater at Time 2, when the children were aged 8–9 years, than at Time 3. The absence of a correlation at Time 1 may be a consequence of the initial screening procedure: Children with very poor word reading were not included in the study. Indeed, the standard deviation of word reading accuracy is lower at Time 1 than at the

Table 2
Correlations Between Measures Taken at Time 1

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Neale word reading accuracy	—	.140	.235**	.686***	.114	.142	.098	.206	.057	.015	.115
2. Neale reading comprehension		—	.415***	.222	.440***	.422***	.488***	.402***	.556***	.372***	.057
3. VIQ			—	.337***	.420***	.259**	.271**	.521***	.441***	.119	−.056
4. Gates–MacGinitie				—	.257**	.054	.156	.314***	.102	.060	.084
5. BPVS					—	.203	.406***	.348***	.326***	.251**	.000
6. Integration						—	.165	.220	.240**	.066	.011
7. Comprehension monitoring							—	.355***	.384***	.250**	.016
8. Story anagram								—	.389***	.222	−.008
9. Story titles									—	.317***	.108
10. Working memory: Sentence span										—	.356***
11. Working memory: Digit task											—

Note. N = 100. Data excluded listwise. Neale = Neale Analysis of Reading Ability—Revised; VIQ = verbal IQ; Gates–MacGinitie = Gates–MacGinitie Vocabulary subtest; BPVS = British Picture Vocabulary Scale.
** $p < .01$. *** $p < .001$.

Table 3
Correlations Between Measures Taken at Time 2

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Neale word reading accuracy	—	.397***	.571***	.364***	.050	.003	.254**	.274**	.132	.321***	.132
2. Neale reading comprehension		—	.520***	.602***	.521***	.272**	.478***	.344***	.449***	.498***	.344***
3. Gates–MacGinitie			—	.637***	.322***	.130	.390***	.425***	.328***	.421***	.170
4. BPVS				—	.419***	.221	.379***	.214	.392***	.492***	.197
5. Inference making					—	.321**	.269**	.250**	.398***	.417***	.240**
6. Literal questions						—	.058	.070	.175	.180	.208
7. Comprehension monitoring							—	.292**	.484***	.403***	.193
8. Story anagram								—	.289**	.350***	.206
9. Story titles									—	.309**	.181
10. Working memory: Sentence span										—	.313***
11. Working memory: Digit task											—

Note. $N = 92$. Data excluded listwise. Neale = Neale Analysis of Reading Ability—Revised; Gates–MacGinitie = Gates–MacGinitie Vocabulary subtest; BPVS = British Picture Vocabulary Scale.
** $p < .01$. *** $p < .001$.

other time points, indicating that this variable was more constrained at the earliest time point. The weaker correlation at Time 3 may have arisen because the children at this stage in the study were aged 10–11 years and were becoming more independent readers. The average word reading age was higher than mean chronological age, indicating that, for the majority of readers in this study, word reading was fairly fluent by Time 3 and may have had less of an influence on text comprehension (e.g., Curtis, 1980; Saarnio et al., 1990).

Relation between working memory and reading comprehension. At each time point, reading comprehension was significantly correlated with the sentence-span measure of working memory. Sentence span was also significantly correlated with vocabulary, word reading ability, and/or VIQ at different time points in the study. It was important to determine whether working memory explained variance in reading comprehension scores over and above the contributions made by other verbal skills.

We conducted three fixed-order hierarchical multiple regression analyses for each time point, with Neale reading comprehension as the dependent variable. The order of the variables was selected a priori to test our experimental predictions. To control for the relation between reading comprehension and lexical–verbal skills, we entered Gates–MacGinitie Sight Vocabulary scores, BPVS Receptive Vocabulary scores, and VIQ scores first. Word reading accuracy scores (Neale Analysis) were also entered at this stage because word reading ability is a significant determinant of reading comprehension. (We do not report the individual contributions made by each control variable because this was not an aim of the article.) VIQ was not assessed at Time 2, so the Time 1 values were used in the Time 2 analysis. The sentence-span measure of working memory was more highly correlated with reading comprehension than was the digit task. The two working memory measures were very significantly correlated at each time point, and more important, both relied on verbally mediated working memory resources (Nation et al., 1999). Therefore, we entered the sum of the two working memory scores at the next step to determine whether working memory explained additional variance in comprehension. (Parallel analyses conducted with just the sentence-span scores produced the same pattern of results.) The results are summarized in Table 5 (top two rows).

At each time point, the combined working memory measure explained significant variance in reading comprehension over and

Table 4
Correlations Between Measures Taken at Time 3

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1. Neale word reading	—	.194	.246	.459***	.372***	.102	−.141	.412***	.177	.214	.082	.081
2. Neale reading comprehension		—	.588***	.627***	.511***	.612***	.388**	.535***	.299**	.470***	.451***	.091
3. VIQ			—	.707***	.595***	.454***	.184	.405**	.209	.418***	.364***	.074
4. Gates–MacGinitie				—	.674***	.475***	.215	.582***	.180	.413***	.428***	.275**
5. BPVS					—	.392***	.149	.501***	.155	.268**	.248	−.031
6. Inference making						—	.342**	.262**	.131	.292**	.336**	.039
7. Literal questions							—	.074	−.093	.163	.242	.083
8. Comprehension monitoring								—	.316**	.290**	.371***	.191
9. Story anagram									—	.260**	.160	.077
10. Story titles										—	.360***	.224
11. Working memory: Sentence span											—	.442***
12. Working memory: Digit task												—

Note. $N = 80$. Data excluded listwise. Neale = Neale Analysis of Reading Ability—Revised; VIQ = verbal IQ; Gates–MacGinitie = Gates–MacGinitie Vocabulary subtest; BPVS = British Picture Vocabulary Scale.
** $p < .01$. *** $p < .001$.

above the contribution made by the other variables. Further to the findings of Seigneuric et al. (2000), there was a specific relation between reading comprehension and verbally mediated working memory in 8-, 9-, and 11-year-olds after the contributions made by word reading and verbal ability had been taken into account.

Relation between reading comprehension and component skills. Our second aim was to determine whether any of our higher level meaning construction skills made an independent contribution to the prediction of reading comprehension ability after controlling for word reading, vocabulary knowledge, and verbal ability. This was a particularly strong test for a specific relation between reading comprehension skill and individual component skills of comprehension because of the variance that the component skills shared with verbal skills. Three sets of fixed-order hierarchical multiple regression analyses were conducted, one for each time point. These analyses were identical to the first set, except that performance on a particular component skill, rather than the working memory score, was entered after the control variables. These analyses are summarized in Table 5 (rows 3–6).

At each time point, inference-making ability, comprehension monitoring, and knowledge about story titles explained unique variance in reading comprehension, after the contribution made by the control measures had been taken into account. Performance on the story structure task explained significant variance when children were aged 7–8 years and 10–11 years, but not when they were aged 8–9 years. In general, both knowledge and processing variables made specific contributions to reading comprehension for 8–11-year-olds, over and above lower level lexical and verbal skills.

The role of working memory in relation to reading comprehension and component skills. Seigneuric et al. (2000) speculated that individual differences in children's working memory capacity might explain individual differences in specific reading comprehension skills, such as inference making and comprehension monitoring. In contrast, Perfetti et al. (1996) proposed that readers might demonstrate impaired inference making or comprehension monitoring despite possessing adequate working memory resources. To test whether working memory is the skill that underpins the relations between comprehension and component skills and whether any such relation is consistent across this age range, we conducted a third set of fixed-order hierarchical multiple regressions. Reading comprehension was the dependent variable. Word reading accuracy, vocabulary, and verbal ability were entered first, followed by the working memory scores. At the final step, the score of one of the component comprehension tasks was entered. (This analysis was not performed for the story structure variable at Times 1 and 2 because this variable did not explain significant unique variance in reading comprehension.) If working memory capacity mediates the relations between reading comprehension skill and the specific component skills of comprehension, the processing skills should not explain further variance in reading comprehension scores after the contribution made by working memory has been taken into account. Working memory was not expected to predict performance on the knowledge variables.

The results are summarized in Table 6. Inference-making skill predicted significant and considerable variance in reading comprehension after the contribution of working memory was accounted for, at each time point. The same relation was found for comprehension monitoring. Although these tasks required the integration and comparison of information where the reader had to process and store information simultaneously, performance on them was not wholly determined by working memory capacity. The Time 1 findings were as expected because working memory was not correlated with the components of comprehension at that point. At Times 2 and 3, working memory was significantly correlated with inference making and comprehension monitoring, but these latter variables made their own unique contribution to the prediction of reading comprehension. A different pattern was found for the knowledge variables. This pattern was predicted, because the story structure measures assessed use of existing knowledge, rather than processing, which we did not expect to be highly constrained by working memory capacity.

Table 5
Summary of Fixed-Order Hierarchical Multiple Regression Analyses (ΔR^2) With Reading Comprehension as the Dependent Variable and Working Memory and Component Skills as Criteria, Controlling for Word Reading, Vocabulary, and Verbal IQ

Step	Variable	Time 1	Time 2	Time 3
1–4	Neale word reading, Gates–MacGinitie, BPVS, Verbal IQ	.263***	.437***	.459***
5	Working memory	.069*	.055*	.052*
5	Inference and integration	.089**	.086***	.092***
5	Comprehension monitoring	.097***	.048**	.046*
5	Story anagram	.028, *ns*	.015, *ns*	.031*
5	Story titles	.144***	.034*	.046*

Note. Neale = Neale Analysis of Reading Ability—Revised; Gates–MacGinitie = Gates–MacGinitie Vocabulary subtest; BPVS = British Picture Vocabulary Scale.
* $p < .05$. ** $p < .01$. *** $p < .001$.

General Discussion

The data presented here add to our knowledge about working memory, reading comprehension, and component skills of comprehension in several important ways. First, we have established that working memory capacity explains unique variance in reading comprehension between the ages of 8–11 years, after the contributions made by word reading skill and verbal ability have been taken into account. Second, we have demonstrated that specific component skills of comprehension contribute unique variance to reading comprehension after word reading and verbal ability controls. Third, we have shown that the relations among inference making, comprehension monitoring, and reading comprehension are not wholly explained by variance that the component skills share with working memory. Finally, we have found a consistent pattern of prediction of reading comprehension level at each time point. These findings and their implications for our understanding of comprehension development are discussed below.

Some researchers have proposed that verbally mediated assessments of working memory are heavily dependent on vocabulary knowledge and verbal ability (Nation et al., 1999; Stothard & Hulme, 1992). In this study, the working memory task that required the manipulation of linguistic material, the sentence-span task, was more highly correlated with reading comprehension and the component skills than was the digit task (see also Seigneuric et al., 2000). This finding is not surprising, given the word and

Table 6
Summary of Fixed-Order Hierarchical Multiple Regression Analyses (ΔR^2) With Reading Comprehension as the Dependent Variable and Component Skills as Criteria, Controlling for Word Reading, Vocabulary, Verbal IQ, and Working Memory

Step	Variable	Time 1	Time 2	Time 3
1–5	Neale word reading, Gates–MacGinitie, BPVS, Verbal IQ, Working memory	.332***	.492***	.511***
6	Inference and integration	.087***	.056**	.069***
6	Comprehension monitoring	.073***	.030*	.033*
6	Story anagram			.026*
6	Story titles	.104***	.025**	.035*

Note. Neale = Neale Analysis of Reading Ability—Revised; Gates–MacGinitie = Gates–MacGinitie Vocabulary subtest; BPVS = British Picture Vocabulary Scale.
* $p < .05$. ** $p < .01$. *** $p < .001$.

sentence comprehension elements of this task, and supports, in part, the claims of Nation et al. (1999). However, the significant correlation between the two working memory assessments at each time point is consistent with the interpretation that these tasks tap a common construct. Furthermore, the results of the regression analyses with their stringent verbal ability controls lead us to reject the strong version of the verbal ability hypothesis proposed by Nation et al. and to conclude that verbal skills alone cannot account for the relation between working memory and text comprehension.

Skills that affect reading comprehension can be categorized as occurring higher or lower in the language processing chain. This system can be useful for identifying the earliest point of difficulty, if we assume that text processing is bottom-up so that a lower level impairment will lead to an impairment in the execution of a higher level skill. Our results are in line with this theoretical position: At each time point, performance on measures of word recognition and verbal skills explained a sizable proportion of the variance in reading comprehension. However, we were interested in whether lower level processes wholly account for individual differences in text comprehension or whether higher level processing and knowledge variables could play an independent role. The determination of comprehension level and the predictive ability of these higher level component skills of comprehension were not fully explained by these particularly influential lower level skills (word reading ability and verbal skills). The measures of processing skills (e.g., inference making and comprehension monitoring) and processing capacity (e.g., working memory) explained unique variance in reading comprehension ability even after the contribution made by lower level skills had been taken into account.

The relations between reading comprehension and processing skills that are important to meaning construction, namely, inference generation and comprehension monitoring, were not fully determined by a reader's working memory capacity. It is important to identify the types of processes and representations that are involved in the execution of these tasks and the other factors that may influence performance on these tasks.

Consider the modest correlations among our measures of comprehension monitoring and integration and inference making. Although working memory capacity is important to both tasks, these measures seem to tap different skills. The monitoring materials required the reader to identify anomalous pieces of information, and this comparison is of quite superficial (or literal) information, which would not require the reader to engage in the sort of constructive processing involved in the generation of inferences. Such differences in the operations involved in performing such tasks may account for the modest correlations.

One factor that may have affected performance on these two tasks is knowledge about how to generate inferences and monitor one's comprehension. Comprehension monitoring can be improved if children are told about the nature of the errors in the text and if they are instructed in the use of mental imagery when reading (see Paris, Wasik, & Turner, 1991, for a review). It is also facilitated when children are required to construct a (pictorial) storyboard of the text (Rubman & Waters, 2000). Poor comprehenders make a greater number of inferences (assessed by responses to questions) when they are instructed to look for clues when reading in order to establish specific locations and events that have been left implicit (Yuill & Joscelyne, 1988). It is more likely that these procedures were successful because they helped children to read strategically and process text constructively, rather than developed their working memory skills. Indeed, comprehension in general can be improved with instruction in how to read strategically (Paris, Cross, & Lipson, 1984). The implications for comprehension instruction are favorable: When both component skills and working memory resources appear to be inadequate, instructing children in effective ways to process text may help to circumvent any impairment associated with limited working memory capacity.

Different patterns of relation between working memory and our measures of integration and inference were apparent. Ericsson and Kintsch (1995) proposed that reading span taps into the processes necessary to store and retrieve the situation model and also world knowledge from long-term memory. These processes are necessary to perform the inference task used at Times 2 and 3, and that task was correlated with working memory capacity at both time points. In contrast, the Time 1 constructive integration measure was not significantly correlated with concurrent measures of working memory. In a study of adults' comprehension, Hannon and Daneman (2001) found a differentiation between integration and inference-making skills and the processing skills associated with them. They developed a tool to assess component processes of comprehension, namely, memory for the text, text inferencing, knowledge access, and knowledge integration. Different aspects of this measure accounted for unique variance in different experimental assessments of specific comprehension skills, such as measures of inference and integration, comparable with those used in the current study. Thus, others have also found that different types of inference and integration skills rely on different processing skills, an issue that clearly warrants further investigation in the study of comprehension development.

Knowledge about narrative text structure was positively related to reading comprehension level, even after other measures of verbal ability and language skill had been taken into account. Knowledge can help the reader to organize and relate events in a text, which then benefits her memory and understanding. The compensatory effects of prior content knowledge on memory for text are well established. Recht and Leslie (1988) found that memory for a text about baseball was influenced by readers' prior knowledge about the sport, not by their reading ability. In the same way that individuals with good knowledge about baseball will be better able to invoke specific schemas to help structure the events in a text about that sport, prior knowledge about the structures and event patterns common to narratives may facilitate comprehension in general by aiding the construction of meaning-based representations.

We found that even from a young age, children's skills that foster meaning construction make an important contribution to the determination of comprehension level over and above the contribution made by word-level and verbal skills. These findings lead us to conclude that working memory should be regarded as one of several factors that can influence comprehension ability and comprehension development. Clearly, neither good verbal skills nor good working memory resources are in themselves sufficient for the application of processes such as inference making and comprehension monitoring that are used in the construction of representations of text. Instead, further research is needed to establish which particular aspects of the comprehension-fostering skills need to be taught and included in future curricula.

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(*Appendix follows*)

Appendix

Examples of Inference and Integration Measures

Time 1: Text
The mouse ate the food.
The food was bread.
The mouse looked for some cheese.

Time 1: Recognition Sentences
The food was bread. (original)
The mouse looked for some cheese. (original)
The mouse ate the bread. (valid inference)
The food was some cheese. (invalid inference)

Time 3: Extract of Text

Mum was just in the middle of a job when Jenny walked in. "Take off those wet clothes," Mum said. "I was just sorting out the blue items to do first. I can put your jumper in with them now. It will be ready to wear again by Monday." Jenny went upstairs to dry and change out of her wet clothes. But she left a puddle of water in the kitchen by the fridge where she had been standing. Mum looked for the cleaning equipment. She found the bucket in the cupboard under the stairs.

Question to test recall of literal information: Where was the puddle of water?

Question to test integration of information between two sentences: Where did Mum look for the cleaning equipment?

Question to test integration of general knowledge with information in the text: What job was Mum doing when Jenny got home?

Note. Time 1 inference and integration materials are from "Constructive Processes in Skilled and Less-Skilled Comprehenders," by J. V. Oakhill, 1982, *British Journal of Psychology, 73,* pp. 19–20. Copyright 1982 by the British Psychological Society. Reprinted with permission.

Received May 10, 2002
Revision received April 8, 2003
Accepted April 18, 2003 ■