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Contributions of Phonological and Semantic Short-Term Memory to Sentence Comprehension in Normal and Head Injured Children

by

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Doctor of Philosophy

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Abstract

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The relation of short-term memory to sentence comprehension was investigated in 4 children who had sustained severe closed head injury. Two of the patients showed dissociation in performance on short term memory tasks. One of the patients, CS showed a pattern of performance on short term memory tasks consistent with a phonological short term memory deficit. Another patient, CB, showed a pattern of performance which suggests a deficit in semantic memory. The dissociations in short term memory tasks exhibited by these patients corresponded to a dissociation in their performance on sentence processing tasks. On a sentence anomaly judgment task in which the memory load had to be maintained before the judgment could be made CS performed similarly to the Control subjects, while CB showed a deficit which was related to memory load. The opposite pattern was observed for a verbatim sentence repetition task on which CB's performance was within the
normal range, but CS was very impaired. The results support models of short term memory that postulate separable components of semantic and phonological short term memory and the differential contribution of the two components to sentence comprehension.
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Contributions of Phonological and Semantic Short-term Memory to Sentence Comprehension in Normal and Head-Injured Children

Neuropsychological evidence suggests that there are different components of short-term memory and that these components play different roles in sentence comprehension in adults. Similar evidence for components of short-term memory and their role in comprehension in children is lacking. This paper reports a study evaluating short-term memory deficits in head-injured children and the effects of such deficits on sentence comprehension in order to gain some understanding of the structure and role of short-term memory in comprehension. Though this topic has seldom been addressed in children, there is a fairly extensive literature in adults regarding the role of short-term memory in sentence comprehension. After a brief introduction to the original model of working memory (Baddeley & Hitch, 1974), the evidence for separable components of short-term memory and their respective importance to auditory comprehension will be reviewed. This will be followed by a brief review of the relevant child literature regarding short-term memory and sentence processing, and a brief summary of findings on the
effects of head injury on short-term memory and on sentence processing in children. After the literature review, the results of a series of tasks characterizing the short-term memory performance of normal and head-injured children will be reported. Finally, the results of experiments investigating the sentence processing abilities of normal control children and 4 head-injured children will be described.

THEORETICAL FOUNDATION

Theories of working memory have tended to focus on the phonological aspects of memory. Because of many empirical findings implicating phonological coding in short-term memory, it has been assumed that the main functional component of verbal working memory is a phonological store. For example, the well known working memory model of Baddeley and Hitch (1974) postulates a peripheral storage system termed the "phonological loop" which is assumed to underlie performance in verbal short-term memory tasks, especially span tasks. The phonological loop is divided into two components, a passive storage component, into which auditory verbal material is registered, and an active rehearsal
component, which maintains the information in the storage component. This 'slave' system for verbal working memory, and a separate slave system for visual storage, the visuospatial scratchpad, are the main storage components of the model. The 'central executive' component serves to allocate attention to these slave systems and to interpret information from the slave systems in the performance of tasks. Auditory material is considered to have obligatory access to the phonological store, while visual material must be recoded via inner articulation before it is registered in the phonological store.

Data from a wide variety of sources can be found to support this type of model. The existence of a rehearsal component is supported by a number of findings from the normal population. For example, memory span has been shown to be related to articulation rate (e.g. Baddeley, Lewis, & Vallar, 1984). Longer words require more time to utter and fewer are remembered than shorter words. Further, when subjects are prevented from covertly articulating by continuously uttering an irrelevant speech sound (articulatory suppression) a decrement in span is observed.
Normal subjects have more difficulty remembering phonologically similar words than phonologically dissimilar words, (Conrad & Hull, 1964). They remember more auditorily presented items than visually presented items in span tasks (Conrad & Hull, 1968). which is attributed to the increased probability of recall of the last few items on a list with auditory presentation (the recency effect). These last few items are considered to be specific to phonological memory, which is supported by the finding that the terminal items are affected by phonological factors, such as rhyme, but not semantic factors (Brooks & Watkins, 1990). Such findings have been interpreted as reflecting the obligatory access of auditory verbal information to the phonological store. The involvement of semantic factors in recall is demonstrated by an advantage in span tasks for words as compared to nonwords, and for concrete, imageable words as compared to abstract words. If phonology alone were responsible for short-term memory performance, then semantic variables should not affect recall.

In the neuropsychological literature, patients with severely reduced span have been described whose impairments appear to arise from a phonological short-term memory deficit (Shallice &
Vallar, 1990). Such patients typically show a phonological similarity effect for auditory, but not visual material, an absent or reduced recency effect, and a reverse modality effect as well as great difficulty repeating nonwords. These findings are accounted for by the assumption that these patients have an impaired ability to retain phonological information, but they have a preserved ability to retain visual information which supports recall in visual, but not auditory tasks.

Recently, some short-term memory patients have been reported whose pattern of performance differs from the patients described above (Martin, 1987; Martin, Shelton & Yaffe, 1994; Saffran & N. Martin, 1990; N. Martin & Saffran, 1990). On short-term memory tasks some patients tend to show fairly normal effects of phonological variables, but not of semantic variables. For example, the patient AB (Martin, 1987; Martin and Romani, 1994) shows a pattern of performance which varies in several ways from the performance of patients reported to have phonological short-term memory deficits. Unlike the phonological patients, AB displays normal modality, recency, and phonological similarity effects, which are considered to be mediated by phonological short-term memory.
However, his performance on a repetition span task was as good or better with nonwords as with words, and he performed much better with a rhyme probe task as compared to a semantic probe task. In addition, he retained lists of letters and digits as well or better than he retained lists of concrete words. These stimuli are both considered to be semantically impoverished. In contrast, the phonological short-term memory patient EA, whose deficit is of approximately the same severity as AB’s, performs better with visual presentation, shows no recency effect and shows a phonological similarity effect for auditorily, but not visually, presented material.

On the semantic and rhyme probe tasks, EA’s pattern was the reverse of AB’s, in that she performed better with the semantic probe task than with the rhyme probe task. EA’s performance was much better with words than nonwords, and she was much better with recall of concrete words than of letters (Martin, 1987; Martin et al., 1994). These data suggest that there is a functional dissociation between semantic and phonological components of short-term memory.

The dissociation between semantic and phonological short-term memory components has been demonstrated in other studies. N. Martin and Saffran (1997) investigated repetition in twelve brain-
damaged individuals who were found to have varying degrees of phonological and semantic memory impairment. These patients were asked to perform a repetition span task with single words that varied in frequency and imageability. The authors expected that if phonological information could not be maintained, as in the case of the patients with phonological memory deficits, then word repetition would be especially dependent on lexical and semantic representation; hence, repetition performance should be influenced by frequency and imageability. In contrast, these variables should have relatively little effect if only phonological information is available to a patient for repetition, as in the case of individuals with preserved phonological short-term memory, but impaired semantic short-term memory. They also expected that because recall of words across serial positions is differentially affected by phonological and semantic variables, patients with deficits in the components should show correspondingly differentiated patterns of recall across serial positions. A semantic short-term memory deficit was expected to detrimentally affect recall at the beginning serial positions, while a phonological short-term memory deficit was expected to affect repetition at the terminal positions. The results of their study in
general supported their predictions. Primacy effects were positively correlated with semantic abilities, and recency effects were positively correlated with phonological abilities. As mentioned above, this suggests a reliance upon semantic information for those patients with a preserved primacy effect, but no recency effect, and the reliance upon phonological information for those patients exhibiting a recency effect, but no primacy effect.

Short-Term Memory and Sentence Comprehension In Adults.

It has been assumed by many researchers that short-term memory (usually conceived of as phonological short-term memory) plays an important role in sentence comprehension. The exact nature of the role has been the subject of much investigation in recent years (e.g., Gathercole & Baddeley, 1990; Saffran, 1990; Martin, 1993). One suggestion is that short-term memory is needed when a complete syntactic representation must be derived in order to assign roles to the nouns in a sentence, such as in the case of reversible passive sentences (e.g., "The girl was kicked by the boy"). This interpretation was supported by findings that some short-term memory patients have difficulty accurately comprehending such
constructions (e.g., Caramazza, Basili, Koller, and Berndt, 1981). It was assumed in this case that a verbatim phonological representation of the sentence had to be retained in order to maintain word order and to complete syntactic analysis.

This interpretation has been called into question by the findings of a number of studies of severely impaired phonological short-term memory patients who, in spite of their deficits, show normal comprehension. Vallar and Baddeley (1984b) described a patient, PV, who has a severely reduced span, but who shows normal performance on tests of syntactic comprehension, including reversible passive constructions. Another patient (BO) described by Waters, Caplan and Hildebrandt (1991) as having an acquired phonological short-term memory deficit, was able to comprehend complex syntactic constructions, including center-embedded sentences, in spite of a severe deficit in short-term memory. In another study, Butterworth, Campbell and Howard (1986) described a developmental subject, RE, with impaired phonological processing and a reduced memory span. She was given a variety of tasks that tested her ability to syntactically analyze, remember and comprehend long and complex sentences, as well as tasks that tested
sentence repetition. She demonstrated normal ability with syntactic
analysis and sentence comprehension but was impaired in her ability
to repeat sentences that she had comprehended, thus providing
more evidence that a verbatim representation is not necessary to
sentence comprehension.

R. Martin and her colleagues have closely investigated the
short-term memory patients EA and AB, both with single word
(described above) and sentence level processing (e.g., Martin, 1987,
1993; Martin et al., 1994). When tested for comprehension of
sentences of varying syntactic complexity, both patients showed
good comprehension abilities for a wide range of syntactic
constructions, only showing impairment with the most complex
forms. In sentence repetition a dissociation in the performance
patterns of EA and AB emerged. EA tended to retain the gist of the
sentences, paraphrasing, but not retaining the exact wording of the
sentence. AB did not paraphrase, but tended to omit content
information. A dissociation was also observed with comprehension
of semantically loaded sentences (e.g. "Which is soft, cotton or
sandpaper?") in that EA’s performance was much better than AB’s
(Martin et al., 1994).
In another study, Martin and Feher (1990) tested the hypothesis that an exact phonological representation was necessary to compute syntactic structure. In this study, they tested patients with short-term memory deficits on two sets of sentences: one set in which syntactic complexity was varied, and another in which semantic complexity was varied. The sentences were presented either auditorily or visually, and the visually presented sentences were divided into two presentation conditions. In one of the visual presentation conditions (unlimited presentation), the subject was allowed to view the sentence until a response was made; in the other (limited presentation), the sentence was presented one word at a time for 1 s per word. They found no consistent differences in performance between the limited and the unlimited conditions for the sentences varying in syntactic complexity, but a large difference for the sentences varying in semantic load. This suggests that while short-term memory is not necessary to retain syntactic information, it is important in retaining semantic information.

The above results and other similar results have led Martin and her colleagues to suggest that while phonological and articulatory short-term memory components do play an important role in
verbatim sentence repetition, they are not normally essential to sentence comprehension. However, there may be some situations in which a verbatim representation (hence phonological short-term memory) of the sentence could be important.

There is evidence that sentence processing proceeds on a word-by-word basis (Carpenter & Daneman, 1981; Marslen-Wilson & Tyler, 1980; Tyler & Marslen-Wilson, 1981). On this account, as each word is perceived, it is immediately integrated into the highest level of syntactic and semantic representation possible at that point in the sentence. Any incomplete lexical, semantic or syntactic entry must be maintained in short-term memory until enough information becomes available to allow integration into a higher level of representation. Under normal circumstances, because of the immediacy of processing, a verbatim representation (which presumably would make a heavy demand on phonological short-term memory) of the sentence would not be required for comprehension. However, in certain circumstances a verbatim representation would be useful. In sentences, for example, in which an ambiguous word or phrase is encountered, retaining a verbatim representation would allow for a reanalysis of the syntactic and
semantic structure. Or, if the processing of incoming words was slowed because of, for example, difficulties with lexical or semantic access or impaired syntactic processing, then incoming words would have to be retained verbatim until the higher level representations could be computed for the previous words.

Martin and her colleagues maintain, however, that in addition to the phonological components invoked by the tradition working memory model, there is a semantic component of short-term memory which, in contrast to the phonological component, is important to comprehension (Martin & Romani, 1994). As mentioned above, investigations of the short-term memory patient, AB, who appears to have a deficit in the semantic component of short-term memory, have shown that though he is able to repeat sentences verbatim, he is impaired in sentence comprehension. Martin and Romani (1994) did a study in which they tested the specific relationship between his semantic deficit and comprehension. Specifically, they were interested in whether it was the amount of semantic information in the sentences or the position of the semantic information in the sentence that caused comprehension difficulties for AB. Sensible and matched anomalous
sentences containing lists of adjectives that either preceded or followed a noun were presented to AB. His ability to detect the anomalous sentences was compared to that of EA, who has a specific phonological short-term memory deficit, a third aphasic patient (whose data will not be discussed here), and a group of 11 normal control subjects matched to the patients for age and education. The authors hypothesized that sentences with prenominal adjectives would require more lexical-semantic retention than would sentences with postnominal adjectives. The reasoning was that in a sentence in which the adjective precedes the noun (e.g., “She took the long, hard exam on Saturday”), complete integration into a higher level semantic unit is delayed until the noun that the adjective describes is processed. This is because the adjectives’ fully specified meaning is relative to the key noun that is described (for example, ‘long’ can refer to either time or physical dimension, and ‘hard’ can either mean ‘difficult’ or ‘solid’, depending on what is described). However, when the adjectives follow the key noun they can be immediately integrated into a higher level representation, which may require less short-term memory capacity to retain than a list of unintegrated words (the principle of chunking information; Miller, 1956). In
addition to pre- and postnominal adjectives, Martin and Romani (1994) also tested comprehension for sentences in which a group of nouns either preceded or followed the main verb. In these sentences integration of the nouns into a higher representation is delayed until their roles are determined by the key verb, thus they must be individually retained in short-term memory. For example, in the sentence "The girl, the boy and the dog ran near the river" each noun must be retained until the verb "ran" has been processed. However, in the sentence "Near the river ran the boy, the dog, and the girl" the nouns can be immediately integrated with the verb into a higher level semantic representation.

In addition to the position of the key noun or verb, the number of lexical items preceding (or following) the key word was varied. Thus, in some of the sentences there were 3 adjectives (or nouns) before or after the key word was heard ("The girl, the boy and the dog ran near the river"), and in some of the sentences, there was only 1 word ("The girl ran near the river"). Normal control subjects were expected to be mildly affected by both delayed integration and the number of lexical items in the 'list'. If the nature of the information that is necessary to retain is lexical or semantic, then a
patient with a lexical/semantic deficit, such as AB, should show a greater effect of both delayed integration and the number of lexical items than do normal controls. Thus the situation in which 3 lexical items had to be maintained with delayed integration to the key word would be the most difficult for such patients to comprehend. A patient with a phonological deficit, such as EA, was expected to show a pattern similar to that of normal controls. The results showed that normal controls were mildly affected by delayed integration, as well as by the number of lexical items. However, there was little evidence of an interaction between these two variables at the individual subject level. Patient EA had a pattern of performance similar to that of the controls, that is, she was worse in the delayed integration condition than in the immediate integration condition, and was worse with the greater number of lexical items, but, like the normal controls, there was no interaction between the variables. Though AB made about the same number of errors overall as EA, his pattern of performance was strikingly different. While he showed a strong effect of the number of lexical items, this effect was entirely due to his performance in the condition where the lexical items occurred prior to the key word, that is, in delayed integration condition. The
dissociation in the patterns of performance of these two patients, one with a phonological deficit, and one with a semantic deficit, provided strong support for separable phonological and semantic components of short-term memory, and suggests that it is the semantic component that is crucial to comprehension, rather than the phonological component.

Short-Term Memory and Sentence Processing In Children

The nature of developmental changes in language processing has been the topic of a number of investigations. Some evidence suggests children and adults show similarities in text comprehension processes. In one study, Tyler and Marslen-Wilson (1981) assessed the influence of syntactic and semantic context on detection of a target word. Subjects of different age groups monitored pairs of sentences for a target word in three prose conditions. One condition was normal prose; in a second condition, the syntactic structure of the sentence was preserved, but the actual words used rendered the text meaningless. And finally, in the third condition the words from the syntactic prose sentences were randomly mixed to form a passage that had neither meaning nor syntactic structure. The
contrast between syntactic prose and random word order for the different age groups was intended to determine the role and the availability of syntactic structural analyses at each age level. Similarly, the contrast between normal and syntactic prose for the different age groups investigated the general role of interpretative (semantic) variables in immediate processing at each age level. The results showed that monitoring latencies were facilitated in normal prose relative to syntactic prose, and syntactic prose was facilitated relative to random word order. Reaction times also decreased as age increased. However, there was no interaction of age with prose condition, indicating that the amount of facilitation between prose conditions was the same for all age groups.

In addition to the prose type conditions, Tyler and Marslen-Wilson (1981) varied the position of the target word in the sentence such that though the target word always occurred in the second sentence, it could be in one of four positions, varying from very early in the sentence to very late in the sentence. This allowed for a comparison across ages of the time course of the development of the syntactic and semantic structures that facilitated target monitoring. They found that in the normal and syntactic prose, reaction time
became progressively faster throughout the course of the sentence, but in the random word condition, the reaction times remained stable across word positions. When the absolute differences in reaction times due to age differences were removed, all age groups showed the same increases in reaction time across word position. Thus, it appears that from very early after word onset the semantic and syntactic properties of a word were being assessed against its sentential and discourse context in both the younger and the older children, and this is a pattern similar to that seen in adults (Marslen-Wilson & Tyler, 1980).

In another version of the same experiment, Tyler and Marslen-Wilson (1981) had children monitor sentences for exemplars of categories. In this experiment, the effects of age were duplicated, with younger children much slower in responding than older children. They also found that the normal prose was facilitated relative to syntactic prose, but the advantage for syntactic prose over random word order was not significant, suggesting that monitoring responses were facilitated by semantic constraints, but not by syntactic constraints alone. In contrast to the Identity monitoring task, the category monitoring task resulted in an interaction of age
with prose type such that older children showed more facilitation than younger children for the normal prose over the syntactic, indicating a greater advantage of semantic context for the older children. The word position effects indicated that the locus of this effect was in the first two word positions. The authors suggested that these finding might reflect younger children’s lesser capacity for (or slower) semantic processing.

In spite of this evidence suggesting that children and adults are able to access similar types of information during sentence processing, the conclusion that the relationship between short-term memory and sentence comprehension in children is qualitatively similar to that in adults cannot be drawn, given the number of studies that have demonstrated developmental differences in short-term memory processes (e.g., Case, 1985; Halford, Mayberry & Bain, 1988; Cowan, Keller, Hulme, Roodenrys, McDougall, & Rack, 1994; Gathercole, Adams, & Hitch, 1994). For example, age differences in span have been reported and variously attributed to increased short-term memory capacity (Case, 1972), differences in rehearsal processes (e.g., Henry, 1992), more efficient processing of lexical material (e.g., Case, 1985, 1992; Thatcher, 1992), and more efficient
executive processes (Cowan, 1992; Cowan, et al., 1994). In one investigation of the processes underlying developmental differences in span, Cowan et al. (1994) demonstrated that young children do not differ from older children in the speed of articulatory/phonological processing as assessed by spoken word duration during serial recall, but do differ in the duration of interword pauses during recall. This difference was taken to reflect differences in search or executive processes underlying ordered recall.

The importance of short-term memory to both spoken and written language has been demonstrated in normal children (e.g., Mann, Cowin, & Schoenheimer, 1989) and in language impaired children (Baddeley & Wilson, 1993; Gathercole, Willis, Baddeley, & Emslix, 1994). Baddeley and co-workers have performed several studies that demonstrate that impairments to (phonological) short-term memory in children are associated with poor development of vocabulary and language skills (e.g., Baddeley & Wilson, 1993; Gathercole & Baddeley, 1990, 1995).

Although sentence comprehension in children has been addressed in some developmental studies, these investigations have
tended to focus on the developmental differences between grammatical/syntactic and semantic processing abilities in children (Tyler & Marslen-Wilson, 1981; Bates, MacWhinney, Devescovi, Caselli, Natale & Venza, 1984; de Villiers & de Villiers, 1972) or metacognitive components of language comprehension (Tunner, Pratt, & Herriman, 1984; Walczyk & Hall, 1991; Flavell, Green, & Flavell, 1985; Dennis, et. al., 1996) rather than the relationship between sentence comprehension and short-term memory. However, there have been a few studies that bear on this issue. In one such study Kabrich and McCutchen (1996) investigated children with mild mental retardation. Among these children, those who displayed some of the typical performance patterns associated with phonological short-term memory deficits also showed a deficit in sentence comprehension, even when matched with normal control children on word recognition scores. Another recent study of children with specific language impairment (SLI) and normal control children (Montgomery, 1995) reported a correlation between the ability to repeat single non-words varying in syllable length (an index of phonological short-term memory) and comprehension ability for sentences with redundant information (which were
therefore longer than similar sentences with no redundant information). SLI children performed more poorly than the normal control children in both tasks. The author attributed the poorer performance of SLI children to a deficit in phonological short-term memory capacity. However, in this study the possibility of other, lower level deficits (e.g., phonological processing, or articulatory deficits) that might contribute to poor performance at several levels were not ruled out. It should be noted that in these studies, short-term memory is assumed to be solely phonologically based, thus the possibility of involvement of a semantic component (or other components) was not considered.

There is a surprising lack of research with normal children regarding the role of short-term memory in comprehension at the sentence level, and apparently none at all regarding the relative contribution of phonological and semantic short-term memory to sentence comprehension. Though there is little direct evidence to address this issue, it might be hypothesized that the developmental differences that exist between adult and child language processing could affect the relative importance of semantic and phonological short-term memory to sentence comprehension such that they are
different in children and adults. For instance, though the type of higher level processing engaged in with children and adults may be similar in kind (Tyler & Marslen-Wilson, 1981), if the processing of the incoming words of a sentence is slower in children than in adults because of, for example, slower lexical or semantic access, the current incoming words might have to be retained verbatim until higher level representations are computed, thus forcing greater reliance upon phonological short-term memory in children than in adults.

Short-term Memory, Sentence Comprehension, and Pediatric Head Injury

Memory impairments are among the most pervasive consequences of head injury in children (Mateer, Kerns, & Eso, 1996). Deficits in short-term memory, both verbal and non-verbal, are prevalent among brain injured children (Levin et al., 1988). The specific nature of the short-term memory impairments as a consequence of head injury has been studied relatively little. However, in one group study (Levin, Fletcher, Kusnerik, Kufera, Lilly, Duffy, Chapman., Mendelsohn, and Bruce, 1996), the California
Verbal Learning Test (CVLT) was given to two groups of children, one group with severe head injury as assessed by the Glasgow Coma Scale, and another group of mildly head-injured children. The CVLT is a test of memory in which mixed lists composed of exemplars of three different natural categories (e.g., fruits, furniture and sweets) are presented auditorily to children for immediate recall. It was found that, on average, children with severe head injury recalled less and were less likely to use semantic clustering as an aid in recall than were children with mild head injury. These findings suggested the possibility that the poor recall performance of the severely head-injured children might be related to a either a semantic short-term memory or semantic processing deficit.

Research regarding sentence comprehension in head-injured children is very limited. In one study, Dennis, Barnes, Donnelley, Wilkinson, and Humphreys, (1996) administered a sentence anomaly detection task to head-injured and age-matched normal children. They found that head-injured children were in general worse in detecting both grammatical and semantic anomalies than were normal children. The relationship of anomaly detection to short-term memory was not considered in this study.
The study most relevant to the current proposal was one in which the relationship of short-term memory to sentence processing in normal and head-injured children was investigated using a sentence anomaly task similar to that used by Martin and Romani (1994), described above. In this study (Hanten, Song, & Levin, in press), children heard sentences which either did or did not contain grammatical or semantic anomalies. The semantic sentences were similar to those used by Martin and Romani (1994) in that they contained a 'list' of lexical items that either could be immediately integrated, or for which integration was delayed. The authors were interested in not only effects of short-term memory, but the more metacognitive effects of language processing as assessed by an anomaly identification and repair task, and how these aspects of language processing differed in head-injured and normal children. The relevant finding was that within the semantic condition, collapsed across both sensible and anomalous sentences, normal children did not show a significant effect of short-term memory load on the ability to detect anomalies, but severely head-injured children did. At the individual level, while only 3 of 12 control children performed worse in the delayed integration than the immediate
integration condition, 10 of 12 head-injured children showed this pattern. This study not only supports previous research as to the prevalence of short-term memory deficits among head-injured children, but, more importantly, provides evidence that short-term memory deficits have notable consequences for sentence comprehension. However, this study did not specifically address the short-term memory patterns of children, nor were the findings in the sentence comprehension task related to span.

Although the high incidence of memory deficits resulting from brain injury has been established, the nature of the deficits has rarely been investigated. In adults, many of the advances in understanding processes of short-term memory have been the result of a rich research tradition in cognitive neuropsychology. The corresponding research in pediatric populations is sparse. As alluded to above, making assumptions about cognitive processes in general, and specifically sentence processing in children based on findings from adult studies could be problematic for several reasons, including a lack of understanding about children's development of or reliance on short-term memory and its differential components.
There are two primary aims for this study. The first is to more specifically characterize the nature of the deficits in short-term memory exhibited in head-injured children. In adult neuropsychological populations, a dissociation has been found between phonological and semantic components of short-term memory (Martin, 1987, 1994; Saffran & N. Martin, 1990; N. Martin & Saffran, 1990). In children, the deficits in short-term memory that have been described are assumed to be unitary, and purely phonological in nature. The possibility of a semantic component of short-term memory apparently has not been investigated. The hypothesis under consideration is that in children, as in adults, there are different components of auditory-verbal short-term memory, and these components can be differentially affected by head injury. The present study is aimed at more fully exploring the nature of short-term memory in children by using the neuropsychological approach. Specifically, detailed case studies are reported which investigate specific patterns of performance relating to semantic and phonological variables in short-term memory tasks in several children who appear to have short-term memory deficits as a result of brain injury. If short-term memory in children is unitary and
phonologically based, as it has been assumed to be, then the patterns of performance in different head-injured children might be expected to be quantitatively different from each other and from those seen in normal children, but should be qualitatively similar. A finding of patterns of performance that vary both quantitatively and qualitatively in different head-injured children and in normal children might be interpreted as support for differential components of short-term memory in children similar to that found in adults. Because the precise nature of short-term memory in normal children has been incompletely specified, including a group of normal controls is important. This will allow the estimation of a range of normal performance for a particular age group. In addition, because there are few studies that address the effect of semantic, lexical and phonological variables on short-term memory in normal children, this aspect of the study will provide valuable information as to the normal development of processes involved in short-term memory.

The second goal is to investigate the relative contributions of phonological and semantic short-term memory components to sentence comprehension in children. In adults, phonological short-term memory has been shown to play a minimal role in
comprehension (e.g., Martin, 1987; Butterworth, Campbell & Howard, 1986), while semantic short-term memory appears to be necessary for good comprehension (Martin & Romani, 1994). However, in children the importance of phonological short-term memory to the acquisition of language skills during development suggests that it is possible that they are more reliant upon phonological short-term memory than are adults for sentence comprehension. The results of a study by Huttenlocher and Lui (1979) might be interpreted as support for this notion. Using a variety of memory tasks, the authors found that 5 year-olds appear to process words less extensively than do older children. They proposed that though the basic semantic organization of nouns remains constant with age, the amount of active processing of a word’s semantic properties that young children are able to engage in when they encounter a word is more restricted and of shorter duration than that of older children and adults. This finding suggests the possibility that phonological information may be more reliable and easier to maintain for younger children, which would foster a tendency to rely upon it for sentence comprehension. Further, as suggested above, if lexical/semantic processing is slower and more effortful in children than in adults,
the children's ability to integrate words immediately may be compromised, resulting in the necessity of maintaining a phonological representation of each word until such time as it can be integrated. In either case, a prediction might be made that, in contrast to adults, children who have a deficit in phonological short-term memory may well display some comprehension problems.

GENERAL APPROACH

The current study uses a number of word and sentence processing tasks to investigate components of short-term memory in head-injured and normal children as well as the relative contributions of semantic and phonological components of short-term memory to sentence processing ability in children. The materials for the tasks are similar to those used by Martin and Romani (1994) to assess the abilities of the semantic short-term memory patient, AB, and the phonological short-term memory patient, EA. However, the materials were modified as needed to be suitable for testing children of various ages. A case study approach is used in which four children who have suffered closed head injury (CHI), three of whom appear to have short-term memory deficits, are
investigated in detail with regard to the nature of their deficits and the consequences for sentence processing. The tasks used in this investigation are divided into background tasks, span tasks to characterize the specific nature of the short-term memory deficits and experimental tasks, in which the effects of the described deficits on sentence comprehension are investigated.

Subjects

The head-injured children were recruited from a cohort of children that were enrolled from consecutive traumatic brain injury admissions to Hermann Hospital in Houston, Parkland Hospital and Children's Medical Center in Dallas as part of a larger study of the neurobehavioral outcome of pediatric closed head injury being conducted by Dr. Harvey Levin at Baylor College of Medicine. Exclusionary criteria for the larger study included a preexisting neuropsychiatric disorder (including previous hospitalization for a head injury), preexisting mental deficiency (i.e., mental retardation), and any premorbid learning/language disabilities. The basis for selection of head-injured children was a lowest post-recessitation Glasgow Coma Scale (GCS) score of between 3 and 8 (severe), and
their performance on tasks included in the Baylor neurobehavioral outcome battery which identified children who appear to have either short-term memory or comprehension deficits. A preliminary review of the neurobehavioral data available revealed four severely head-injured children of similar ages (ranging from 9 years 9 months to 10 years 9 months) who appeared to be suitable for case studies. All four children and their families agreed to participate in the study.

Demographic and clinical descriptions of these children are shown in Table 1. Three of these children (CB, CS and MC) displayed patterns of performance for various tasks that suggested that they had a

| TABLE 1. Demographic and clinical features of head-injured children. |
|--------------------------|---------------------------|-----------------|------------------|-----------------|
| AGE @ TEST | AGE @ INJURY | INTERVAL | GCS | MRI DATA |
| CB 9.9 4.3 | 5.6 | 7 | skull-FX, R frontal, shearing and gliosis |
| CS 10.8 9.6 | 1.2 | 7 | R cerebral peduncle, contusion, L thalamus, contusion |
| MC 10.9 8.9 | 1.0 | 7 | R parietotemporal occipital FX |
| JG 10.1 5.5 | 4.6 | 4 | L cerebellum hemisphere, encephalomalacia, L cerebellum hemisphere, atrophy |

short-term memory and/or comprehension deficit. All three were impaired on a sentence anomaly detection task in which short-term memory load was varied (Hanten, Song, & Levin, in press). For these children performance was worse under conditions in which lexical
items could not be immediately integrated with a key word to form a higher level representation as compared to a condition in which the lexical items could be immediately integrated, suggesting a deficit in short-term memory. Two of the children (CS and CB) were also impaired, as compared to age matched control children, on a short-term memory task in which letters were presented one at a time and children matched targets with either 1, 2 or 3 intervening items. The fourth head-injured child, JG, showed no evidence of a short-term memory deficit, but was included in this study for purposes of comparison.

In addition to the CHI children, 14 age-matched control children were recruited from the Houston community. The Hollingshead Four Factor Index of social status (Hollingshead, 1974) was used to estimate the socioeconomic status of the CHI and control children. The index is a weighted average of the parents’ education and occupation that is widely used to estimate socioeconomic level. For example, a family in which the mother and father each have high school educations, and the father is a sales representative and the mother a secretary would have an index score of approximately 40. A family whose parents both have graduate or professional degrees,
and the mother is an attorney, and the father is a university
professor would have an index score of approximately 66. Table 2
reports the Hollingshead Index for the control and CHI children.

| TABLE 2. Comparison of socioeconomic status of control and CHI children as measured by the Hollingshead Four Factor Index of social status. |
|------------------|------------------|
| SCORE            | Score           |
| Controls         | 48.25            |
| range            | 32 to 66         |
| CB               | 45               |
| CS               | 45               |
| MC               | 54               |
| JG               | 46               |

All the children (CHI and control) were tested in 2 or 3 sessions
of no more than 3 hours long. The sessions were spaced
approximately 2 weeks apart. Total time ranged from 6 hours (for
several of the control subjects) to 9 hours (for one CHI child).

BACKGROUND TASKS

I. Phonological Discrimination Task

Subjects made 'same-different' judgments to the auditory
presentation of two nonsense words, which were either identical or
varied by one phoneme. The purpose of this test was to identify low-
level perceptual phonological deficits that might account for or contribute to poor performance on the sentence processing tasks.

**Method**

**Materials and design.** Same/different judgments for 30 auditorily presented one or two syllable nonword pairs were made by each child. Fifteen of the nonwords pairs were matching (e.g., 'bolap/bolap') and 15 differed, with a nonword differing from its paired nonword by a single phoneme (e.g., 'cuzlin/cozlin'). The pairs were recorded on Macintosh 8500 computer with SoundEdit Pro software, and were presented with PsyScope 1.1 software over external speakers.

**Procedure.** The child was seated at the computer and told that s/he would hear 2 nonsense words and must decide if the words were exactly the same or not. If they were the same, then s/he should press the green “yes” button, but if the two words were not the same. s/he should press the red “no” button. The buttons were the computer keys “z” and “/” which were covered by red and green pieces of tape with the words “yes” and “no” printed on them. The first item of the pair was presented, there was a 1 s pause, then the second item was presented, and the child responded. After the
response the computer asked "Ready?" the child pressed the
spacebar to continue the task, thus the task proceeded at the child's
pace. There were 2 practice trials, followed by 30 randomly mixed
experimental trials.

Results and Discussion

As shown in Table 3, all four of the CHI children were within
the range of performance of the control children, though CS was at
the lower end of the range. Given the CHI children's proficiency with
vocabulary, any deficits displayed in the short-term memory tasks or
in sentence comprehension tasks would not likely be the result of
lower level perceptual difficulties.

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>91</td>
<td>87 - 100</td>
</tr>
<tr>
<td>CB</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td>97</td>
<td></td>
</tr>
<tr>
<td>JG</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 3. Percentage correct responses on phonological discrimination task for control and CHI children.
II. The Peabody Picture Vocabulary Test (PPVT)

Because phonological short-term memory has been related to vocabulary acquisition, it might be predicted that children who have acquired phonological short-term memory deficits may show an impairment in vocabulary acquisition dating from the time of injury. Children who have acquired a deficit at an early age would be expected to be more affected than children who have acquired the deficit at a later age. That is, those with an early injury would be predicted to show more impoverished vocabulary as compared to normal uninjured children. In order to test for this possibility, the PPVT, which is a widely used standardized measure of vocabulary competence, was administered to each child. Of the 4 CHI children tested here, two of them had sustained injuries within 1-2 years prior to testing (CS and MC) whereas the other two had sustained injuries more than 4 years earlier (CB and JG). It should be noted that children who exhibited poorer vocabularies as compared to normal children were not excluded from the study. As described later, an additional vocabulary test specific to the experimental tasks was administered to all children as a screening task.
Method

Materials and procedure. This task was administered according to the standard procedure. That is, the child was shown a page on which 4 objects or scenes are depicted. The experimenter read a single word, and the child pointed to the picture on the page that best represented the word. The task was unspeeded. The level at which the child was started on the task is determined by age/grade level norms. The test words are presented in order of increasing difficulty. The task is discontinued when the child makes errors on 6 of 8 consecutive trials. The child's performance is compared to standardized norms, in which 100 is the mean, and the standard deviation is 15.

Results

The standard scores for the control and CHI children are shown in Table 4. The mean of the controls was somewhat higher than the standardized norms. The CHI children were within the range of performance exhibited by the control children except for MC, whose score is notably below the mean and beneath the range of the controls. The low score for MC may reflect that the PPVT was given
to her only 2 months post injury, prior to the testing for the current study.

TABLE 4. Standard scores on the PPVT task for control and CHI children.

<table>
<thead>
<tr>
<th>Controls</th>
<th>113.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>range</td>
<td>90 to 157</td>
</tr>
<tr>
<td>CB</td>
<td>91</td>
</tr>
<tr>
<td>CS</td>
<td>95</td>
</tr>
<tr>
<td>MC</td>
<td>64</td>
</tr>
<tr>
<td>JG</td>
<td>102</td>
</tr>
</tbody>
</table>

The other CHI children were given the PPVT at the time of testing for the current study, thus were tested at least a year after injury. There was no indication that the children who had had injuries more than 4 years ago had any striking deficits in vocabulary.

SPAN TASKS

Memory span has been used to predict performance on a variety of tasks and activities assumed to rely on short-term memory. As discussed in the introduction, data from brain damaged adults suggest that there are separable phonological and semantic components to span. Patients with phonological short-term memory deficits show greater span for visually, as compared to auditorily
presented items. In addition, most patients who have been characterized as having phonological short-term memory deficits have great difficulty with repeating lists of nonwords, and show a phonological similarity effect for auditory, but not visual, materials. In contrast, patients with semantic short-term memory deficits show little advantage for words over nonwords, have uniform phonological similarity effects across presentation modalities, and display a typical auditory advantage in span tasks. The dissociation between semantic and phonological short-term memory also shows up in recall with word lists varying in frequency and imageability.

Phonological short-term memory patients, who are thought to rely on semantic information, gain a substantial advantage from the semantic information in high imageability words over low imageability words, whereas semantic short-term memory patients gain a much smaller advantage from imageability (Martin and Lesch, 1996).

The following section reports the results of the CHI and control children’s performance on a variety of tasks designed to characterize short-term memory performance, and, in particular, to determine if the cause of a deficit can be linked to poor retention of either
phonological or semantic representations. The tasks are (1) a repetition span task which assesses relative span for words and nonwords, as well as for rhyming and nonrhyming letters. (2) a second repetition span task which assesses the span of word lists varying in age of acquisition and imageability, testing the importance of lexical and semantic information to recall, (3) matching digit span, which tests the child’s memory for digits, without relying on verbal production, and finally, (4) a nonverbal, visual task to test short-term memory in the nonverbal domain and to test for deficits that generalize across stimulus types. In each of the span tasks performance is measured by either estimating span for a criterion performance level (usually 60% correct), or by comparing performance of subjects at a specified span. In the experiments following, both of these measures have been used. For some contrasts, a comparison of the control subjects’ performance with the CHI children’s performance at a specific span was most meaningful, whereas in others, the overall level of performance as indicated by estimated memory span was preferable. The types of measures used and the computational procedures of the measures are outlined in the Results section for each task.
I. Repetition Span Tasks with Words vs. Nonwords and Nonrhyming Letters vs. Rhyming Letters

Adult patients with phonological short-term memory deficits have difficulty repeating nonwords because they are forced to rely on phonological codes exclusively. Although normal controls also perform better on words than on nonwords (the lexicality effect), the difference in performance on the two tasks is much less than for patients with phonological short-term memory deficits. If any of the CHI children have phonological short-term memory deficits, they might be expected to show a pattern similar to that of adult patients, that is, very poor performance with nonwords as compared to words. Predictions about word/nonword repetition in children with semantic short-term memory deficits are more complicated. Some studies have indicated that semantic knowledge in children develops slowly, and that 5 year old children have less well developed semantic representations than do older (12 year old) children (Huttenlocher & Lui, 1981). Thus the advantage for words over nonwords may be smaller in children than in adults. If so, then a lessening of the lexicality effect may be difficult to detect in head-injured children. Nonetheless, it could be hypothesized that CHI
children who have semantic short-term memory deficits will not be able to derive the same benefit as normal control children from semantic information. Thus it is predicted that the lexicality effect will be less with the repetition span tasks in children exhibiting semantic short-term memory deficits.

Another of the distinguishing characteristics of adult patients with phonological short-term memory deficits is a phonological similarity effect with auditory but not visual materials. Patients with semantic short-term memory deficits show the same pattern as normal adult subjects, that is, a phonological similarity effect in both auditory and visual modalities. Presumably, because phonological short-term memory patients have difficulty maintaining phonological codes, they rely instead on visual codes (with visual presentation), and thus do not show a phonological similarity effect in the visual modality. Auditory material, already coded phonologically, is assumed to gain obligatory access to phonological storage. It must either be used in its phonologically coded form, which a phonological short-term memory patient would have difficulty maintaining, or be translated into some other code—a process that would require more time and effort and therefore would
also result in decreased performance. It has been found that normal children display an effect of phonological similarity which is similar to that seen in adults (Hulme, 1984). Therefore, it is expected that the pattern of performance in head-injured children will be similar to that seen in adult brain-injured populations. That is, children with phonological short-term memory deficits would be expected to show a phonological similarity effect for auditory, but not visually presented material, while children with semantic short-term memory deficits would be expected to show an effect with both auditory and visually presented materials.

**Method**

**Materials and procedure.** The different conditions for the following repetition span task followed the same general procedure. The stimuli for the trials were drawn from a fixed set of items. A trial was the presentation of a string of items at a rate of one item per second. At the end of each trial the child repeated the string of items in the correct order. In the visual condition, the child viewed the items as they were presented on a computer screen. In the auditory condition, the experimenter read the items aloud as they appeared on the computer screen (out of the child’s view). There
were 5 blocked trials for each type of stimulus at each span length. The word set was composed of single syllable words taken from a low age of acquisition (range 12.5 to 40 months) set of words. The words are GET, HOG, MAP, DAD, SUN, TOP, PAW, FIT, BIG, RAN. The nonwords were constructed by semi-randomly mixing the phonemes of the word set to form a set of nonwords that matched the word set in terms of number and frequency of phonemes. The nonwords are FET, DIT, GOG, PAP, RAD, MUN, BOP, TAW, HIG, SAN. There were 5 blocked trials for each type of stimulus at each span length and in each modality condition. The session started with a span of 2 items, and increased by one item until the subject repeated 60% or less of the trials at that span.

A set of 8 items was constructed for each of the rhyming and nonrhyming letter conditions from which the stimuli for the trials were drawn. For each trial in the rhyming letter condition, the items were randomly drawn from the letter set B,C,Z,G,P,V,T,E, and in the nonrhyming condition, from the letter set Y,O,R,N,A,H,F,L. The letters were presented in uppercase type in the visual condition. The procedure was otherwise identical to that for the word/nonword repetition span task.
Scoring. In order to prevent floor and ceiling effects from obscuring the results, measures for the repetition span tasks were computed differently for different comparisons. The rational for each computation and the computational procedure are discussed in each Results section.

Results

Assessing phonological similarity, lexicality and modality effects in control children. In order to establish the normal pattern of phonological similarity effects for the control children, the span at which a child would achieve 60% lists correct was estimated. The estimation was calculated by interpolating between the first span length on which the child was correct on 60% or less of the lists and the previous span length. For example if a child performed at 40% correct on span 5 and 100% on span 4, then his or her estimated span at 60% would be 4.67. The same scoring procedure was followed for the rhyming and nonrhyming letters. The means resulting from these computations are shown in Table 5.
TABLE 5. Average estimated span (at 60% correct) of controls for different stimulus conditions in the repetition span task.

<table>
<thead>
<tr>
<th></th>
<th>AUDIO</th>
<th>NONW</th>
<th>NRLET</th>
<th>RHYLET</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUD</td>
<td>5.2</td>
<td>4.1</td>
<td>6</td>
<td>5.2</td>
</tr>
<tr>
<td>VIS</td>
<td>5.6</td>
<td>4.1</td>
<td>6.5</td>
<td>5.4</td>
</tr>
</tbody>
</table>

The word vs. nonword and the rhyming letter vs. nonrhyming letter differences were analyzed separately by two-way ANOVAs to examine lexicality and phonological similarity effects, and the effect of modality. The analyses revealed that, on average, the control children showed a pattern of performance similar to that found in normal adults. Nonrhyming letters were recalled significantly better than rhyming letters, $F(1,13) = 32.75$, $p = .0001$, $MSe = 0.37$, replicating the typical phonological similarity effect found in adults. The effect of modality was significant, $F(1,13) = 7.43$, $p = .02$, $MSe = 0.23$, such that visual items were better recalled than auditory, a reversal of the usual effect found in adults. There was no significant interaction between modality and phonological similarity effects, $F(1,13) = 2.08$, $p = .17$, $MSe = 0.32$.

Words were recalled significantly better than nonwords, $F(1, 13) = 52.18$, $p = <.0001$, $MSe = 0.44$, (again replicating the adult
lexicality effect) but there was no effect of modality, $F(1,13) = 1.02$, $p = .33$, $MSe = 0.41$. and no interaction between modality and lexicality effects, $F(1,13) = 3.07$, $p = .10$, $MSe = 0.19$.

Assessing phonological similarity, lexicality and modality effects in CHI children as compared to control children. Scores were computed separately for each child so that a direct comparison of span for the different stimulus types and the effect sizes for lexicality and phonological similarity could be made between the CHI children and the controls. In order to compare effect sizes at similar levels of performance, the span at which a child correctly recalled 60% of the lists was estimated according to the procedure described above.

In addition to comparisons of estimated span, to more closely examine the patterns of performance of the CHI children, the average percentage of items recalled was computed for the CHI and control children. This was accomplished by averaging across the percentage items correct on the span on which the subject was correct on 60% or less of the trials, and the percentage items correct on the previous span. Thus the percentage items correct is calculated on the same span lengths as the estimated span.
Lexicality effects in CHI as compared to control children.

Control children. The average estimated span collapsed across visual and auditory presentation conditions was greater for words (5.4) than for nonwords (4.1), with a mean difference in span of 1.3. This pattern was present in 13/14 (93%) of the controls with auditory presentation and 14/14 (100%) with visual presentation.

The percentage words correctly recalled on the relevant spans shows a pattern similar to that of the estimated span for the controls. That is, a greater percentage of words recalled than nonwords recalled with both auditory and visual presentation. The average lexicality effect was 11.6% collapsed across auditory and visual conditions. Table 6 shows the advantage of words compared to nonwords (lexicality effect) for estimated span at 60% lists correct for auditory and visual presentation.

CHI children. Clearly, CS and CB were very impaired on these span tasks, as can be seen in Table 6. The estimated span for CB for each of words and nonwords was less than the mean and below the range of the controls for both auditory and visual presentation conditions. The difference in CB’s auditory word and nonword
estimated span was 1.0. Though a pronounced lexicality effect, it was similar to the mean and within the range of the controls.

TABLE 6. Estimated span and percentage items correct of words and nonwords at span length for controls and CHI children. Lexicality effects as determined by differences in word and nonword estimated span and percentage items correct are also displayed.

<table>
<thead>
<tr>
<th>AUDITORY</th>
<th>ESTIMATED SPAN</th>
<th>% ITEMS CORRECT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WORD</td>
<td>NWORD</td>
</tr>
<tr>
<td>Controls</td>
<td>5.2</td>
<td>4.1</td>
</tr>
<tr>
<td>range</td>
<td>4 to 7</td>
<td>3 to 5</td>
</tr>
<tr>
<td>CB</td>
<td>3.3</td>
<td>2.3</td>
</tr>
<tr>
<td>CS</td>
<td>3.0</td>
<td>1.3</td>
</tr>
<tr>
<td>MC</td>
<td>5.0</td>
<td>4.4</td>
</tr>
<tr>
<td>JG</td>
<td>6.5</td>
<td>5.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VISUAL</th>
<th>ESTIMATED SPAN</th>
<th>% ITEMS CORRECT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WORD</td>
<td>NWORD</td>
</tr>
<tr>
<td>Controls</td>
<td>5.6</td>
<td>4.1</td>
</tr>
<tr>
<td>range</td>
<td>4.5 to 8</td>
<td>3.5 to 5.3</td>
</tr>
<tr>
<td>CB</td>
<td>3.3</td>
<td>2.5</td>
</tr>
<tr>
<td>CS</td>
<td>2.7</td>
<td>1.3</td>
</tr>
<tr>
<td>MC</td>
<td>5.3</td>
<td>3.0</td>
</tr>
<tr>
<td>JG</td>
<td>5.0</td>
<td>5.3</td>
</tr>
</tbody>
</table>

With visual presentation, the advantage in span of words vs. nonwords was smaller (.83), and well within the range of the controls. The lexicality effects were similar when calculated on the percentage of items recalled. There was a pronounced effect with
auditory presentation (22%), though within the range of the controls. With visual presentation, the effect was much smaller (7%), but also within the range of the controls.

Patient CS was also very impaired in this task. Her estimated span was below the mean and range of the controls for both words and nonwords with auditory and visual presentation conditions. However, at the relevant spans (in her case, span 1 and 2) she recalled nearly 100% of the words, but performed very poorly with nonwords with both auditory and visual presentation. She showed a large lexicality effect with both auditory and visual presentation calculated by both estimated span and by percentage items recalled. With auditory presentation, the advantage for words in estimated span (1.67) was greater than that shown by any of the controls. With visual presentation, the lexicality effect on estimated span (1.34) was near the mean of the controls. However, when the lexicality effect is calculated on the percentage of items recalled at the relevant span both the auditory and visual effects are just outside the range of the controls. With visual presentation, the effect is again very large, 30%, which is greater than the mean and outside of the range of the controls. It should be noted that in spite of the
fact that CS recalled nearly 100% of the words correctly at the relevant span, this means only that she could repeat up to two words accurately. Further, with both auditory and visual presentation CS’s span for nonwords was less than 2 (control mean span = 4.1) and she was only able to repeat 4 of 5 single nonwords correctly. Thus, though CS has a lexicality effect similar to the largest of the controls, this measure nonetheless probably underestimates the degree of CS’s impairment with nonwords. Further, though CS and CB have similar spans for words, CS shows a much greater effect of lexicality than does CB, due to her very poor performance with nonwords.

Patient MC performed within the range of the controls for all presentation conditions except for visual nonwords, where she was just below the range of the controls. The difference in MC’s word and nonword estimated span was .6 for auditory presentation and 2.33 for visual presentation. The auditory span difference is small and within the range of the controls, but the visual advantage is pronounced, though also within the range of the controls. Calculation of the lexicality effect on the percentage of words recalled eliminates the large discrepancy between auditory and visual lexicality effects. However, MC’s lexicality effect is still within
the range of the controls with auditory presentation, and just outside the range with visual presentation.

Patient JG's estimated span was near or above the mean, and within the range of the controls with all presentation conditions. JG showed a small advantage in estimated span (0.3) for nonwords over words, though when the percentage of words recalled is considered, the pattern is more like that of the controls, that is, a greater percentage of words than nonwords is recalled (lexicality effect = 8.5%). With auditory presentation, he showed a normal advantage of estimated word span over nonword span (1.1), close to the mean of the controls, which is replicated with the percentage items recalled (lexicality effect = 20%).

**Phonological similarity effects in CHI and control children.** In order to estimate the effect of phonological similarity on span, scores were computed for rhyming and nonrhyming letters with a procedure similar to that for estimating word/nonword effects described above. That is, both the estimated span and the percentage of items recalled at the relevant spans are calculated. These data are displayed in Table 7.
Control children. Estimated span was greater for nonrhyming letters (6.2) than for rhyming letters (5.3) collapsed across auditory and visual modalities. Eleven of 14 children (79%) showed an effect of phonological similarity with auditory material, and all but one of the control children showed the effect with visual material (93%). The mean effect was very slightly greater with visual (1.2) than with auditory presentation (.7), and the range was greater for the visual than the auditory presentation.

CHI children. Again, CB and CS scored very poorly as compared to the controls and the other CHI children. As seen in Table 7, with both nonrhyming letters and rhyming letters, CB's estimated span was slightly below the range of the controls with both auditory and visual presentations. The percentage of items recalled was also below the mean and below the range of the controls. With auditory presentation, CB shows a phonological similarity effect with estimated span (1.3) that was greater than the mean of the controls, and outside their range. However, when the percentage of items recalled is considered, the effect size is well within the normal range (2 to 17%). With visual presentation CB shows a negative effect of
phonological similarity, calculated either by estimated span or percentage items recalled.

---

**TABLE 7.** Estimated span and percentage words correct of nonrhyming letters and rhyming letters for controls and CHI children. Phonological similarity effects as determined by differences in nonrhyming letter and rhyming letter estimated span and percentage items correct are also displayed.

<table>
<thead>
<tr>
<th>AUDITORY</th>
<th>ESTIMATED SPAN</th>
<th>% ITEMS RECALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NR LET</td>
<td>RHYLET</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>range</td>
<td>4.7 to 8</td>
<td>4.5 to 6</td>
</tr>
<tr>
<td>CB</td>
<td>4.3</td>
<td>3.0</td>
</tr>
<tr>
<td>CS</td>
<td>3.0</td>
<td>2.3</td>
</tr>
<tr>
<td>MC</td>
<td>6.0</td>
<td>4.3</td>
</tr>
<tr>
<td>JG</td>
<td>7.5</td>
<td>6.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VISUAL</th>
<th>ESTIMATED SPAN</th>
<th>% ITEMS RECALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NR LET</td>
<td>RHYLET</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>range</td>
<td>5.3 to 8</td>
<td>4.7 to 7</td>
</tr>
<tr>
<td>CB</td>
<td>3.5</td>
<td>4.4</td>
</tr>
<tr>
<td>CS</td>
<td>4.0</td>
<td>3.7</td>
</tr>
<tr>
<td>MC</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>JG</td>
<td>6.0</td>
<td>5.3</td>
</tr>
</tbody>
</table>

CS was beneath the mean and the range of the controls on all stimulus types on estimated span. With auditory presentation, CS shows a phonological similarity effect with estimated span (.7) that was very similar to the mean, and well within the range of the
control children. However, when percentage items recalled is considered, she shows a phonological similarity effect (18%) that is slightly greater than that of any of the controls (range = 2 to 17) or other CHI children. In contrast to the mean of the controls, CS has a reduced phonological similarity effect with visual materials (0.3) though just within the range of the controls (0 to 2.3). CS’s also shows a lack of a phonological similarity effect with visual materials when calculated on percentage of words recalled.

MC is near the mean and well within the range of the controls on all stimulus types. She showed a phonological similarity effect with auditory presentation in both estimated span (1.7) and percentage words recalled (12%). Like CB and CS, MC showed a very reduced or absent phonological similarity effect for visual presentation with both estimated span (0) and percentage words recalled (2).

JG is near or above the mean with all stimulus types and presentation conditions. With estimated span, he shows a substantial phonological similarity effect with auditory materials (1.1) that is near the high end of the range of the control children. When calculated by percentage words recalled, the effect is more
modest and very near the mean of the controls. With visual 
presentation, JG has a smaller phonological similarity effect, but still 
within the range of controls, calculated on both estimated span and 
percentage of words recalled.

**Summary of Repetition Span Tasks**

Control children generally followed the patterns of 
performance that have been observed with adults for these types of 
stimuli. Span was greater for words than for nonwords, span for 
nonrhyming letters was greater than span for rhyming letters, and 
this was true with both auditory and visual presentation. The two 
divergences from the usual (adult) pattern were the absence of 
modality effects with the word and nonword stimuli, and the 
presence of a visual rather than auditory, advantage with 
nonrhyming and rhyming letters.

The CHI children's performance varied from the controls in 
several ways. First, two of the children, CB and CS, showed overall 
spans that were generally much reduced as compared to the 
controls. The other two children, MC and JG, showed normal, or 
even superior, spans on these materials.
Second, although the CHI children generally showed a normal increase in span of words vs. nonwords in both auditory and visual modalities, the effect for CS in both auditory and visual conditions was exaggerated. MC also showed a large word span advantage with visual word and nonword materials. CS’s exaggerated effect can be attributed to her severe impairment in the repetition of nonwords. MC’s effect (with visual presentation) however, is not due to complete inability with nonwords but was a relative impairment with nonwords as compared to her performance with words.

All of the CHI children showed phonological similarity effects on materials presented in the auditory modality, with CS showing an exaggerated effect when calculated on the percentage of words recalled. With visually presented materials, neither CS nor CB showed effects of phonological similarity—a pattern that has previously been associated with patients having phonological short-term memory deficits.

Finally, CS and CB showed differing patterns with the different stimulus types. On both auditory and visual word span, CS and CB show very similar levels of performance, but CS shows a much greater decrement in performance on nonword span than does CB.
This might be interpreted as an indication of the greater degree to which CS relies on semantic information for recall. Both CB and CS show phonological similarity effects for auditory presentation, but not for visual presentation, suggesting that they both rely on phonological codes to a lesser degree than do the controls.

II. Age of Acquisition and Imageability Effects On Span

Age of acquisition (AoA) has been reported to highly correlate with frequency and to account for a large portion of the variance of the lexical effects attributed to frequency on recall and recognition tasks (Morrison, Ellis, & Quinlan, 1992). In adults there is an advantage for high frequency words over low frequency words, corresponding to an advantage of early AoA words over late AoA words, and an advantage for highly imageable words over abstract words. Apparently, very little research has been done testing these effects in children. One study (Troia, Roth, & Yeni-Komshian, 1996) tested the effect of word frequency on young children’s word reading, and found that children named high frequency words faster than low frequency words. No studies were found in a search of the literature that related frequency effects and/or imageability or
concreteness effects to repetition or recall in children. However, a plausible expectation might be that children respond in a similar way, perhaps even more strongly, than adults to frequency (or AoA) and imageability differences in words.

The rationale for this task is that as words become less imageable, the reliance on phonological codes increases, therefore patients with phonological short-term memory deficits have increasing difficulty with the repetition of words that are less imageable. It appears that adult semantic short-term memory patients do not show a large effect of imageability on span, presumably because they cannot maintain the semantic information in highly imageable words long enough to gain an advantage over low imageability words. It has been found that among short-term memory deficit patients, imageability effects for single words and for 2 item word lists correlate with ability on semantic tasks, including some that draw on working memory. In other words, the more poorly a patient performs on tasks that require semantic processing, including semantic short-term memory, the smaller the effect of imageability on word recall (N. Martin and Saffran, 1997). Though the extent to which children process semantic information in
memory tasks may be an issue, it is expected that among children, those with phonological short-term memory deficits will demonstrate better recall with High Imageability words than with Low Imageability words. Although this pattern is expected with normal children as well, the effect should be more pronounced in children with phonological short-term memory deficits because of their greater reliance upon the semantic codes. Children with semantic short-term memory deficits will show no such advantage. The effects of AoA may be generally expected to show more Early AoA words being recalled than Late AoA words. However, it would be plausible to expect that children who had acquired a phonological short-term memory deficit at a very early age might show greater effects of AoA than other children.

**Method**

**Materials and procedure.** Words that varied in imageability and AoA were taken from the Oxford Psycholinguistic Database. Lists were constructed by varying Imageability and AoA such that four different types of words lists were formed: High Imageability/Early AoA (HI-E), High Imageability/Late AoA (HI-L), Low Imageability/Early AoA (LI-E), and Low Imageability/Late AoA (LI-L).
For the High Imageability words, the Imageability ratings (on a scale of 100 to 700 with 100 being the lowest possible imageability rating) ranged from 512 to 636. For the Low Imageability words, the range was from 294 to 429. For High AoA words the ratings (on a scale of 100 to 700 with 100 being the earliest AoA rating) ranged from 403 to 583. Low AoA words ranged from 178 to 272. In this span task, words were presented auditorily one at a time at a rate of 1 per s. A tone signaled the end of the presentation, then the child repeated the list. The session began with a span of 2 items and was incremented by 1 item until the child recalled 60% or less of the lists of a given span. There were 5 trials at each span length. A trial was scored as correct if the correct words were recalled in the correct position.

Results and Discussion

Effects of Imageability and AoA. Scores were computed separately for each child so that a direct comparison of the effect sizes for Imageability and AoA could be made between the CHI children and the controls. In order to compare effect sizes at similar levels of performance, the span at which a child would achieve 60%
lists correct was estimated (as described above for the effects of phonological similarity and lexicality on span).

As with the previous experiment, the average percentage of words recalled of the relevant span lengths (span at which 60% or less of the lists were recalled and the previous span) was computed for the CHI and control children in order to more closely examine the effects of Imageability and AoA on recall.

Table 8a shows the estimated span means for each condition and the marginal means for the Imageability and AoA conditions for the controls. Table 8b shows the percentage words recalled for each condition and the means collapsed across Imageability and AoA conditions at span length.

Control children. Analysis of variance on the control children's estimated span data revealed that there was a significant main effect of AoA, $F(1,13) = 7.9$, $p = .01$, $MSe = .51$, and a significant interaction between AoA and Imageability, $F(1,13) = 5.8$, $p = .03$, $MSe = .32$, such that Late AoA words benefited more from Imageability than did Early AoA words. There was no main effect of Imageability, $F(1,13) = .47$, $p = .5$, $MSe = .98$. Overall, 10 of 14 children (71%) recalled more High Imageability words than Low
Imageability words, and 11 of 14 (79%) children recalled more Early AoA words than Late AoA words. Paired t-tests revealed a significant effect of AoA on Low Imageability words, t(13) = 3.21, p = .01, and a significant effect of Imageability on Late AoA words, t(13) = 2.15, p = .05. No other effects were significant.

The percentage of words recalled data shows a pattern similar to the span findings. There was a greater effect of AoA (4.%) than of Imageability (2.5%) with Imageability having an effect on Late AoA words but not on Early AoA words. AoA had a greater effect on Low Imageability words than on High Imageability words. In all, 9 of 14 control children (64%) showed an effect of Imageability and 11 of 14 children (79%) showed an effect of AoA.

The effects in this experiment, while replicating the overall trends in the adult data were small and variable across subjects. Also, ceiling effects complicate the interpretation of the word control data. Thus it is difficult to detect a reduced or absent effect in the children with CHI. The data from the children with CHI is discussed below in terms of overall patterns, concentrating on the estimated span results. However, the strength of the conclusions that can be gleaned from these data is clearly less than that from the lexicality-
phonological similarity data where stronger effects were observed in
the controls.

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**TABLE 8a.** Estimated span for Imageability and AoA lists for control subjects.
Means and ranges (in parentheses) for the individual conditions are displayed in
the cells, with mean Imageability at each level of AoA and mean AoA at each level
of Imageability shown in the margins. The main effects of Imageability and AoA
are in bold type.

<table>
<thead>
<tr>
<th>HIGH IMAGE</th>
<th>LOW IMAGE</th>
<th>MEAN AOA ACROSS IMAGE</th>
<th>EFFECT IMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EARLY AOA</td>
<td>5.1 (3.5 to 8.0)</td>
<td>5.2 (4.0 to 8.0)</td>
<td>5.2</td>
</tr>
<tr>
<td>LATE AOA</td>
<td>4.9 (4.0 to 6.5)</td>
<td>4.4 (3.0 to 7.0)</td>
<td>4.6</td>
</tr>
</tbody>
</table>

MEAN IMAGE ACROSS AOA

| EFFECT AOA | \( .2 \) | \( .9 \) | \( .6 \) |

(-1.7 to 1.6)

(-.05 to 2.0)

---

**TABLE 8b.** Percentage words recalled of Imageability and AoA lists for controls.
Means and ranges (in parentheses) for individual conditions are displayed, with
mean Imageability at each level of AoA and mean AoA at each level of Imageability
shown in the margins. The main effects of Imageability and AoA are in bold type.

<table>
<thead>
<tr>
<th>HIGH IMAGE</th>
<th>LOW IMAGE</th>
<th>MEAN AOA ACROSS IMAGE</th>
<th>EFFECT IMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EARLY AOA</td>
<td>94 (87 to 100)</td>
<td>94 (79 to 100)</td>
<td>94</td>
</tr>
<tr>
<td>LATE AOA</td>
<td>93 (84 to 98)</td>
<td>88 (74 to 93)</td>
<td>90</td>
</tr>
</tbody>
</table>

MEAN IMAGE ACROSS AOA

| EFFECT AOA | \( 1 \) | \( 7 \) | \( 4 \) |

(-5 to 10)

\( 2.5(-4 \text{ to } 14) \)

*CHI children.* The CHI children's data is reported in Table 9
which shows the estimated span for each condition, and the
percentage words recalled (in parentheses). The effect size for Imageability was calculated by subtracting the average of Low Imageability lists from the average of High Imageability lists. The effect size for AoA was calculated by subtracting the average of Late AoA lists from Early AoA lists.

As shown in Table 9, CB is well within the range of the controls for recall of Low Image-Late AoA words, but is either below the range or at the bottom of the range for all other word types. He shows a modest overall effect on estimated span of Age of Acquisition, but an effect in the wrong direction for Imageability. The values for both effects are within the range of the controls. CB's pattern of effects for estimated span is similar to the controls in that AoA influenced recall of the Low Imageability words, but not the High Imageability words. The reverse imageability effect is consistent with a difficulty in maintaining semantic representations.

CS shows an overall effect of AoA, but in contrast to CB, she also shows an overall influence of Imageability. In fact, the imageability effect for CS was greater than the mean for controls. Another dissociation between CB and CS's patterns of performance is found in the influence of AoA. For CB (and controls) AoA affects
recall more on the Low Imageability lists, whereas for CS, AoA affects recall only on the High Imageability lists. This may suggest that with Low Imageability lists, CS is unable to maintain a representation even well enough for AoA to have an effect. The effect of Imageability is greater on Early AoA words, than on late AoA words with respect to estimated span, but when the percentage words recalled is considered, the effect shows up in both Early and Late AoA lists. The larger than average effect of imageability is consistent with a phonological short-term memory deficit.

Overall MC demonstrated an odd pattern of performance. For three of the four cells, she performed at the level of control subjects. For some reason, she performed poorly on the high imageability-late AoA condition, recalling none of the 4-item lists correctly. Such a result is hard to interpret given her good performance on the low-imageability-late AoA lists. That is, there are no grounds for predicting imageability to have a large reverse effect for late AoA words. The overall pattern of effects that she shows--a reverse imageability effect, and a substantial AoA effect--are due to her low performance in this one condition. It is possible that her poor performance in this condition can be attributed simply to a lack of
TABLE 9. Mean effects of Imageability and AoA for control and CHI children.

<table>
<thead>
<tr>
<th></th>
<th>HI IMAGE</th>
<th>LO IMAGE</th>
<th>MEAN AOA</th>
<th>IMAGE EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARLY AoA</td>
<td>3.5 (85)</td>
<td>4.0 (95)</td>
<td>3.8 (90)</td>
<td>-.5 (-10)</td>
</tr>
<tr>
<td>LATE AoA</td>
<td>3.5 (89)</td>
<td>3.3 (61)</td>
<td>3.4 (75)</td>
<td>.01 (28)</td>
</tr>
<tr>
<td>IMAGE ACROSS AOA</td>
<td>3.5 (87)</td>
<td>3.6 (78)</td>
<td></td>
<td>-.2 (9)</td>
</tr>
<tr>
<td>EFFECT OF AOA</td>
<td>0 (-4)</td>
<td>0.7 (34)</td>
<td>.35 (15)</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARLY AoA</td>
<td>4.3 (95)</td>
<td>3.0 (81)</td>
<td>3.7 (88)</td>
<td>1.3 (14)</td>
</tr>
<tr>
<td>LATE AoA</td>
<td>3.0 (88)</td>
<td>3.0 (78)</td>
<td>3.0 (83)</td>
<td>.0 (10)</td>
</tr>
<tr>
<td>IMAGE ACROSS AOA</td>
<td>3.7 (93)</td>
<td>3.0 (80)</td>
<td></td>
<td>.7 (13)</td>
</tr>
<tr>
<td>EFFECT OF AOA</td>
<td>1.3 (7)</td>
<td>0 (2)</td>
<td>0.7 (5)</td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARLY AoA</td>
<td>5.3 (93)</td>
<td>5 (94)</td>
<td>5.2 (93)</td>
<td>.3 (-.6)</td>
</tr>
<tr>
<td>LATE AoA</td>
<td>3.0 (70)</td>
<td>5 (94)</td>
<td>4.0 (82)</td>
<td>-.2 (-.4)</td>
</tr>
<tr>
<td>IMAGE ACROSS AOA</td>
<td>4.1 (82)</td>
<td>5.0 (94)</td>
<td></td>
<td>-.9 (-.12)</td>
</tr>
<tr>
<td>EFFECT OF AOA</td>
<td>2.3 (23)</td>
<td>0 (0)</td>
<td>1.2 (11)</td>
<td></td>
</tr>
<tr>
<td>JG</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARLY AoA</td>
<td>6.0 (83)</td>
<td>4.5 (76)</td>
<td>5.3 (80)</td>
<td>1.5 (7)</td>
</tr>
<tr>
<td>LATE AoA</td>
<td>6.0 (96)</td>
<td>5.5 (91)</td>
<td>5.0 (94)</td>
<td>.5 (4)</td>
</tr>
<tr>
<td>IMAGE ACROSS AOA</td>
<td>6.0 (90)</td>
<td>5.0 (84)</td>
<td></td>
<td>1.0 (6)</td>
</tr>
<tr>
<td>EFFECT OF AOA</td>
<td>0 (-13)</td>
<td>-1 (-15)</td>
<td>-.5 (-14)</td>
<td></td>
</tr>
</tbody>
</table>

attention when those materials were administered. Another possibility is that given her poor vocabulary (as indicated by the PPVT) this condition happened to include words unknown to her.
JG overall performed very well with these materials. He scored above the mean for controls in three of the four conditions, and within their range for the other condition. Age of acquisition affected recall in JG such that in estimated span with Low Imageability words there is an advantage for late AoA words (the reverse of the expected effect), but there is no AoA effect at all on High Imageability words. Imageability affects recall such that there is an advantage for High Imageable words with both Early (span increase of 1.5) and Late AoA words (span increase of .5). The pattern is similar when the percentage of words recalled for the relevant spans is considered. Though JG shows an effect of Imageability on both Early and Late AoA words (the expected pattern), he shows a reverse effect of Age of Acquisition, recalling more Late than Early AoA words in both High and Low Imageability lists, which was outside of the range of the controls.

Performance of CB and CS on Imageability/ AoA lists. To compare the abilities of the two CHI children with short-term memory impairment to the controls on the Imageability and AoA lists, the number of lists correct for span 4 was computed for each condition. Span 4 only was used for this particular comparison
because this was the highest span on which data for all the children was available in all conditions.

CB and CS are each impaired in some conditions (relative to the controls) and show an interesting dissociation in their performance patterns. As can be seen in Figure 1, CB is below the mean and below the range for every stimulus type condition, except the Low Imageability- Early AoA list condition, on which he performed at the low end of the range. In contrast, CS is within the range for both of the High Imageability list conditions, but below the range for both of the Low Imageability list conditions.

FIGURE 1. Average lists recalled (of 5) by controls and CB and CS for each condition of the AoA/Imageability task at span 4.
The dissociation in CB's and CS's patterns of performance supports a distinction in the components of short-term memory which have been affected in these two children. The large imageability effect for CS is consistent with a phonological retention deficit and a reliance on semantic codes. The absence of an imageability effect for CB indicates a contrasting difficulty in maintaining semantic codes.

**Serial Position effects.** Serial position effects were analyzed only for the Low Imageability- Early AoA word lists. The Low-Imageability-Early AoA word lists were chosen because the data contained a range of errors that allowed for the observation of serial position effects, yet all the control children were able to complete a span of 5. Table 10 shows the serial position effects and recency effects as measured by the difference between the pre-terminal item and the terminal item for the control children and for the CHI children. The data in Table 10 are words correct averaged across all the lists at span 5 for the controls and for MC and JG, and for span 4 for CB and CS (who did not complete span 5 lists).
TABLE 10. Serial position and recency effects for control and CHI children. The last column reports recency effects as determined by the advantage for the terminal item over the preterminal item.

<table>
<thead>
<tr>
<th>SERIAL POSITION</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>RECENCY EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>4.4</td>
<td>3.9</td>
<td>3.9</td>
<td>3.4</td>
<td>4.1</td>
<td>0.71</td>
</tr>
<tr>
<td>range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1 to 3</td>
</tr>
<tr>
<td>CB(4)</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>3.2</td>
<td>x</td>
<td>-1.6</td>
</tr>
<tr>
<td>CS(4)</td>
<td>4.7</td>
<td>4.2</td>
<td>4.0</td>
<td>2.0</td>
<td>x</td>
<td>-2.0</td>
</tr>
<tr>
<td>MC</td>
<td>5.0</td>
<td>4.0</td>
<td>4.8</td>
<td>3.0</td>
<td>4.0</td>
<td>1.0</td>
</tr>
<tr>
<td>JG</td>
<td>5.0</td>
<td>3.0</td>
<td>5.0</td>
<td>3.0</td>
<td>3.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Similar to adults, the controls display a recency effect limited to the terminal item. The recency effect is thought to represent the contribution of phonological short-term memory. Individually, 10 of 14 children (71%) showed a recency effect, 3 (21%) showed no recency effect and 1 child (7%) showed a negative recency effect. Thus, most of the children are exhibiting normal contributions of phonological short-term memory to recall. In addition to the controls, MC also shows a normal recency effect, indicating that she also is able to make normal use of phonological short-term memory in recall.

In contrast to the controls, CB and CS both show strong negative recency effects (-1.6 and -2.0, respectively). CB’s effect is
limited to the terminal item, but CS shows a slightly different pattern. Though she recalls the first item with the same probability as do the other CHI children and controls, each succeeding item is recalled with decreasing probability until she is only able to recall the terminal item with a probability of 40%. This pattern is similar to patterns of serial recall displayed by adults with phonological short-term memory deficits (N. Martin & Saffran, 1996) thus supports the notion that CS has a phonological short-term memory deficit. CB also displays a negative recency effect, thus further suggesting that at least part of his short-term memory deficit may be attributable to an impairment in phonological short-term memory.

III. Matching Span With Digits

Thus far, the span tasks that have been reported indicate that at least two of the CHI children have significant memory impairments. However, all of these tasks have required the output response in spoken form. In order to determine whether the impairments observed in CS and CB could be the result of difficulty in producing words rather than a memory problem, the children (CHI and controls) were tested on a matching digit span task, which
required only minimal output ("yes" or "no"). If the deficits observed in CS and CB disappear (that is, relative to the controls) when verbal output is no longer required, then some doubt is cast upon a purely memory based explanation of their deficits. However, if the deficits persist when verbal output is not required, then the difficulties experienced by CB and CS cannot be attributed to output problems, but may more certainly be attributed to the inability to maintain information in short-term memory.

Subjects were asked to determine if two sets of digits that were presented either auditorily or visually were identical or different. The purpose of this task was to determine digit span in the absence of speech production, and to further investigate modality effects in children.

**Method**

**Materials and procedure.** Lists were composed of randomly ordered single digits that were paired with either an identical list, or a non-matching list in which two of the digits' positions were transposed. The position of the transposed digits varied from trial to trial such that the transposition occurred in each position equally across trials. Thus the number of trials in each position was
determined by the list length, but the minimum number of trials at any list length was 7. In the auditory condition, subjects heard a string of single digits presented at a rate of 1 digit per second. There was then a 2 s pause, which was followed by the presentation of another string of digits. The subject responded “yes” if the two strings were identical, and “no” if they were not. The session started with a list length of 2 items, and increased by one item until the subject failed to respond correctly to 75% (or less) of the trials at that span.

The visual presentation condition was identical to the auditory condition except the subject viewed the presentation of the digit strings on a computer screen. Each child completed the auditory task first, then was tested with visual presentation.

Results

To compare the CHI children to the control children, the words recalled per list was averaged across spans of 4, 5 and 6. All lists at these spans were completed by all children, thus direct comparisons could be made among children.

Comparison between CHI and control children on digit matching span. The percentage correct lists are shown in Table 11.
CS is below the mean and below the range of controls with auditory and visual presentation. CB is below the mean, and at the bottom of the range with visual presentation, and is below the mean, but within the range with auditory. Both MC and JG perform either near or above the mean of the controls with both auditory and visual presentation.

TABLE 11. Comparisons between control and CHI children on digit matching span.

<table>
<thead>
<tr>
<th></th>
<th>AUDITORY</th>
<th>VISUAL</th>
<th>EFFECT SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>87</td>
<td>77</td>
<td>10</td>
</tr>
<tr>
<td>range</td>
<td>67 to 100</td>
<td>63 to 94</td>
<td>-6 to 23</td>
</tr>
<tr>
<td>CB</td>
<td>73</td>
<td>63</td>
<td>10</td>
</tr>
<tr>
<td>CS</td>
<td>67</td>
<td>67</td>
<td>0</td>
</tr>
<tr>
<td>MC</td>
<td>86</td>
<td>70</td>
<td>16</td>
</tr>
<tr>
<td>JG</td>
<td>89</td>
<td>88</td>
<td>1</td>
</tr>
</tbody>
</table>

**Modality effects in control and CHI children.**

*Control children.* With auditory presentation, controls responded correctly to 87% (range 67 to 100%) of the trials, as compared to 77% (range 63 to 94%) of the trials with visual presentation. On an individual basis, 13 of the 14 control subjects (93%) showed an effect of modality, with 11 (79%) showing auditory
advantage and 2 (14%) showing visual advantage. The remaining child performed equally well in the two conditions. Analysis of variance revealed a significant effect of modality, $F(1,13) = 17.05$, $p = .001$, $MSe = 39.6$.

*CHI children.* The results for the CHI children were mixed. CB exhibits a fairly strong modality effect, responding correctly to 73% of the auditory trials, and 63% of the visual trials. CS performs equally with auditory and visual presentation, responding to 67% of the trials correctly in each modality. MC shows a substantial auditory advantage (85% with auditory vs. 70% with visual), but JG shows a diminutive effect of modality (1%).

**Discussion**

The primary issue addressed with the task is the possibility of output difficulties accounting for deficits in span that have thus far been observed in two of the CHI children, CB and CS. The data presented here do not support an interpretation that relies on output difficulties as an explanation for the observed deficits. Had the deficits in CB and CS been attributable entirely to output problems, then their performance in this task should have been within the range of the controls. The results demonstrate that
without an output requirement they both still showed deficits in either the visual or auditory presentation modality, or in both (in CS's case). Thus it appears that the deficits seen in CB and CS are not the result of output difficulties. However, it should be noted that CB is within the range of the controls on auditory digit matching, so there is a possibility that some of the impairment that he has displayed may be the result of mild output problems.

Of further interest in these data is the contrast between the two children who show a memory deficit, CB and CS. Whereas CB shows a modality effect very similar to that of the control children, CS shows none.

The control children showed robust effects of auditory advantage in the digit matching span task. The differences in the modality effects seen in this task and that of the repetition span task will be addressed further in the Summary and Discussion of span tasks.

IV. Non Verbal Visual Span Task

A nonverbal span task was used to determine whether the deficits displayed by the patients are specific to the language
domain. In general, it was expected that the deficits displayed are specific to the language domain, therefore performance on this task by the head-injured children should not differ from the control children.

**Method**

**Materials and procedure.** The child was presented a display block of 1 in. black and white squares arranged in 2 rows printed on a sheet of plain white paper. Each block had 2 squares arranged vertically, but the number of squares in the block was varied horizontally according to span length. The pattern of black and white squares was determined randomly, but there were always equal numbers of black squares and white squares, and this number varied according to the span. A trial consisted of the presentation of a study block pattern for 3 s, a 2 s pause, and then recall of the block pattern on a response sheet. The response sheet had a printed outline of the block with none of the black squares filled in so at the time of test the subject reproduced the block pattern by marking in the squares. Appendix 1 shows an example of a study trial and a test sheet from span 5. A trial was scored as correct if the pattern produced by the subject exactly matched that of the study block
pattern. One point was assigned to each black square position, thus there were exactly the number of points available in each trial as there had been black squares on the study trial. Each subject’s trial score was determined by comparing the study trial black square positions to same positions on the subject’s test sheet. A point was awarded for each black square position that had been correctly filled in, but no points were subtracted for filling in blocks in the wrong positions (i.e., blocks that should have been left white). The session began with a block span of 2 squares per row, and was incremented by 1 square per row until the subject completed a span of 7. There were 4 trials per span length.

Results

Control children. The average percentage of correct responses across all spans was 93%, with the range of performance 81% to 99%.

CHI children. All the CHI children performed within the range of the controls. CB was 89% correct, CS was 87% correct, MC was 88% correct and JG was 100% correct across all trials. Thus it appears that the deficits in span shown by CB and CS are specific to the language domain.
Summary and Discussion of Span Tasks.

The data presented here describe and characterized the short-term memory performance of 4 children who have sustained severe closed head injuries as well as a group of matched controls. The patterns of performance revealed by these data are displayed in Table 12, along with the patterns of performance previously described for patients with phonological short-term memory deficits and patients with semantic short-term memory deficits. Two of the children, MC and JG, do not show evidence of short-term memory deficits. The other two children, CB and CS, appear to have short-term memory deficits as compared with age- and SES- matched uninjured control children. In addition, CB and CS show dissociations in their performance on some tasks which suggests that there are differences in the underlying basis of their deficits.

CS shows a profile that is generally consistent with a phonological short-term memory deficit, while CB has some characteristics of a semantic short-term memory deficit, and possibly some impairment in phonological short-term memory as well. The section following reviews the evidence for these conclusions after
discussing the data characterizing the performance of normal
children on the short-term memory tasks used in this study.

<table>
<thead>
<tr>
<th>PHONO. STM EFFECTS</th>
<th>IDEAL PHONO. STM PATIENT</th>
<th>IDEAL Semantic STM PATIENT</th>
<th>CONTROL CB</th>
<th>CS</th>
<th>MC</th>
<th>JG</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUDITORY PHONO. SIM VISUAL</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>PHONO SIM. RECENCY EFFECT</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>MODALITY EFFECT</td>
<td>VIS</td>
<td>AUD</td>
<td>AUD</td>
<td>AUD</td>
<td>VIS</td>
<td>AUD</td>
</tr>
<tr>
<td>POOR NWORD REP.</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>SEMANTIC STM EFFECTS</td>
<td>WORD&gt;NWORD</td>
<td>++</td>
<td>=</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>IMAGEABILITY</td>
<td>++</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td>LETTERS &gt; WORDS</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

*Control children.* On the repetition span task the control children displayed a pattern of results which confirmed the predictions based on performance of adults subjects. That is, on average, they showed better performance with words than with nonwords, and a decrement in performance with rhyming as compared to nonrhyming letters. In addition, control children
showed a small advantage with letter stimuli over word and nonword stimuli, presumably because of the reduced memory load with the shorter, simpler phonological representations inherent in single letters. Individually, almost all the control children showed the advantage of words over nonwords (93% and 100% respectively for auditory and visual presentation). A large proportion of the controls (70%) showed a phonological similarity effect with both auditory and visual presentation, with another 15% showing the effect with auditory presentation only, and 15% with visual only. These data suggest that normal children rely heavily on phonological short-term memory for span tasks, but that semantic factors also play a role. The role of semantic factors is supported with the data from the AoA/Imageability task. Imageability conferred an advantage in recall for the control children with late acquisition words (but not early acquisition words). Not surprisingly, there was also an advantage for the Early AoA words over the Late AoA words.

The data relating to modality effects in the control children are mixed. Collapsed cross the different conditions the controls showed no significant advantage for either auditory or visual presentation. Further, when each child’s performance is individually compared
among tasks, no single child showed a preference for either auditory or visual consistently across stimuli types (although 2 children were consistent in showing no preference for either across all stimulus types). Reliable modality effects for the control children were found for the digit-matching task. However, in the repetition span tasks modality effects seemed to depend on the type of stimulus. With nonrhyming and rhyming letters, there was a statistically reliable modality effect. However, it was the reverse of what is usually observed in adults, that is, there was a significant advantage for visual presentation rather than auditory presentation. With words and nonwords there was no significant effect of modality. Thus, on the basis of these data it is difficult to claim that auditory advantage in short-term memory tasks is the normal pattern in children and that the presence of visual superiority is indicative of a special situation. The possible exception is the digit matching span task, on which most controls showed an auditory advantage, and CS, alone among the CHI children, showed no modality effect.

Though the mixed pattern of modality effects is difficult to interpret within the current study, some research has been done which bears on the issue of modality effects in children. Traditional
modality effects in have been reported previously for children with immediate recall of digits (Gillam, Cowan, and Marler, 1998). However, unusual modality effects have also been reported previously. Penney (1999) recently reported findings of visual advantage on preterminal items in immediate serial recall in less skilled readers, as compared to more skilled readers, who showed the normal auditory advantage for the last 3 serial positions in recall. Though Penney’s study was with college students, it might generalize to children. If less skilled adult readers tend to display visual superiority, then perhaps children, whose reading skills vary considerably, might also be expected to show a mixed pattern of modality effects. Additional support for this interpretation is provided by a study done by Hitch, Woodlin and Baker (1989). They sought to clarify a developmental difference between children’s apparent reliance on visual representations at an early age (7 years) and reliance on phonological representations at an older age (12 years) in recall tasks. They examined the relative degree of interference to recall in 11 year-old children caused by a task performed in the interval between list presentation and recall. The task could be one which was the same modality as the list
presentation, or a different modality or mixed modality. Hitch et al. (1989) found that children of this age experienced greatest interference from the mixed modality interval task. They interpreted this finding as confirming the presence of a small but reliable contribution of visual memory in immediate recall in 11 year olds. These studies suggest that younger children may rely on visual memory to a large degree, and that with age, the reliance on visual memory decreases as reliance on phonological memory increases. It is probable that the age at which the transition from visual codes to phonological may vary from child to child, thus the effects of modality of presentation would also vary from child to child even within a group of similarly aged children. In the current study, the children range from the ages of 9.5 years to just over 11 years. Based on the literature bearing on this subject, it seems likely that the children whose data is considered here may still be in transition from visual to phonological codes, which might explain some of the variation displayed in the modality effects.

Finally, the serial position data for the Low Imageability-Early AoA words suggest that children conform to the pattern of recency effects generally seen in adults, that is, an advantage of the terminal
item in recall over the preterminal item. Among the control
children, 10 of 14 showed a recency effect, 3 showed no recency
effect and only 1 child showed a negative recency effect. Thus we
would expect most children to display recency effects in recall on
these types of materials, indicating that they are able to normally
maintain phonological representations in span tasks.

*CHI children*. As indicated above, MC generally showed no
indications of a short-term memory deficit, though she did have
some unusual patterns of performance in some tasks. JG was
included in this study because previous testing indicated that he did
not have a memory deficit, and the results of the current study
indicate that his memory span is normal or superior, though, like
MC, he displays some unusual patterns in his span task performance.
These two patients’ results will be discussed briefly, then the
remainder of the section will focus on a more detailed examination
of the results of CB and CS, who both appear to have deficits in
short-term memory.

With auditory presentation, MC performed close to or above
the mean and within the range of the controls on words, nonwords,
and nonrhyming letters. With auditory rhyming letters she was just
below the range. With visual presentation, MC performed near the mean and within the range on words and nonrhyming letters. She was slightly below the range with visual nonwords and rhyming letters. She shows a 30% difference in word and nonword performance, which is approximately equal to the effect shown by the control subjects, and is well within the range of the controls. MC displayed a phonological similarity effect with auditory materials, but no effect with visual materials. This pattern, though somewhat unusual, was also displayed by some of the controls. MC’s overall pattern of performance on the AoA/Imageability word lists is somewhat more difficult to interpret. She basically performed equally across three of the conditions (and not due to ceiling effects!), and within the range of the controls. This pattern would suggest no effects of Imageability or AoA on recall. However, on the High Imageability-Late AoA word lists, her performance was far below the range of the controls. In fact, this was the only condition in any of the span tasks on which she appeared to be very impaired. MC’s serial position effects on the Low Imageability-Late AoA word lists were normal, in that she showed a recency effect similar to that shown by the controls, indicating a normal reliance on phonological
short-term memory in these span tasks. On the digit matching span and visual nonverbal span, MC's performance was similar to the controls.

It is tempting to interpret MC's very poor performance on the High Imageability-Late AoA lists as indicating that on the one particular set of trials MC was distracted or otherwise not performing up to her usual capacity. However, for the present, we will assume that further testing will be required to interpret MC's data on Imageability and AoA lists. MC was originally selected for this study because in an earlier study she displayed a pattern of performance on a sentence anomaly detection task that suggested that she may have a short-term memory deficit. However, the data presented here indicate that her level of performance is generally similar to the control subjects. One explanation for the discrepancy between the current study and the previous study is that the data on which she was selected for this study was collected when MC was less than a year post-injury. It has been generally assumed that spontaneous recovery of cognitive functions after closed head injury in children can continue for up to a year after injury. This may account for the discrepancy in MC's current and previous performance.
JG's span was equal to or, in many cases, better than the controls in all the span tasks. In spite of showing no particular deficit in span, JG did show some interesting effects. He showed a very large phonological similarity effect with auditory material, but almost no effect with visual stimuli. He also showed a dramatic word superiority effect in both auditory and visual conditions, equal to or greater than the effect shown by any of the controls. In addition, JG did not show a recency effect, and showed no modality effect in digit matching span. He did show effects of imageability on recall, greater than those shown by the controls. These patterns of performance are not dissimilar to those associated with phonological short-term memory deficit. Though it certainly cannot be said that JG has a short-term memory deficit, his pattern of performance might be interpreted to suggest that he relies heavily on semantic short-term memory, rather than phonological short-term memory. It does, however raise the interesting question of how JG manages to achieve superior span on so many of the tasks if he has relatively impaired phonological short-term memory.

One other interesting aspect of JG's performance appeared on the AoA/Imageability tasks. His performance with the
AoA/Imageability lists was very good, but unusual in that he showed a large advantage for words that were Late AoA rather than Early AoA, the reverse of the pattern that is expected, and that was displayed by the controls. One possibility is that the Late AoA words were more interesting to JG, thus he tried harder. All his previous test scores indicate that he has superior intellectual abilities, thus he may be bored by the very familiar Early AoA words, thus tend to not pay as much attention to them.

CS shows a pattern of performance very like the pattern that has been described for adults suffering phonological short-term memory deficits. Her span is generally down, usually falling well below the mean and below the range of the controls. In fact, she was below the mean and the range for all stimuli in all the verbal span tasks, except for the High Imageability-Early AoA words. However, on the Nonverbal Visual span task her performance was normal.

Similar to previously described adult phonological short-term memory patients, CS shows a very large advantage for words over nonwords with both auditory and visual presentation. On 8 of 10 trials in the auditory condition (across spans of 2 and 3) she recalled only 1 nonword (or less), and performed similarly in the visual
condition (on 7 of 10 trials). A severe impairment in repeating nonwords is consistent with a phonological short-term memory deficit.

CS shows a phonological similarity effect with auditory but not visual presentation—also a pattern associated with phonological short-term memory patients. This might be explained by a somewhat preserved ability to retain visual verbal information. If CS is not using phonological codes in the visual condition, then she should not be affected by phonological similarity. However, in the auditory condition, with the presumably obligatory registering of phonological codes, she is more likely to attempt to utilize the phonological information. If the phonological codes are unreliable or degrade rapidly, phonologically similar items would quickly lose what few distinguishing features they have, resulting in increased confusions.

In addition to poor nonword repetition, phonological similarity effects for auditory but not visual presentation, phonological short-term memory patients tend to show large effects of imageability and a reverse modality effect. In the AoA/Imageability task, CS shows a pronounced benefit from imageability with both
early and late AoA word lists, again reflecting a strong influence of, or reliance on, semantic representations. Furthermore, on the only task that controls showed clear modality effects (digit matching span), CS showed a reverse modality effect.

Finally, adult patients tend to show a negative or absent recency effect across serial positions. CS displays a strong negative recency effect extending back to the first serial position, and a strong primacy effect, which is thought to reflect semantic influences on recall.

Taken together, and based on previous studies with adult patients, the data suggest that CS has a fairly specific phonological short-term memory deficit.

CB shows a less specific pattern. Though obviously impaired in his short-term memory abilities, the underlying basis for the impairment is somewhat muddy. Though some of his results are similar to CS's, there are some interesting dissociations in the two patients' patterns of performance. Though his estimated span is below the range of the controls for most conditions, this is somewhat modified by consideration of the percentage of words recalled in each condition. With the percentage of words recalled data, CB is
generally better with words than nonwords, with a robust word
superiority effect with auditory presentation, and a much smaller
effect with visual presentation. However, in contrast to CS, who was
equally bad with visual and auditory nonwords and below the range
of the controls on both, CB performs within the normal range on
auditory nonwords, and is at the mean with visual nonwords, in
terms of percentage of words recalled.

CB shows a pattern similar to CS with rhyming and
nonrhyming letters. That is, he shows a phonological similarity
effect with auditory, but not visual presentation. And, like CS, he
does show a negative recency effect, though not as dramatic. As
mentioned before, these last two patterns have been associated with
a phonological short-term memory deficit.

On the other hand, some other of his results suggest a deficit in
retaining semantic information. Most notably, on the
AoA/Imageability lists, he appears to derive little benefit from
imageability with either early or late acquisition words and, in fact,
performs quite similarly across the different word type conditions.
This is inconsistent with a purely phonological short-term memory
deficit. In addition, on the repetition span task he retained lists of
nonrhyming letters, considered to be semantically impoverished stimuli, better than he retained lists of concrete words. Though this general pattern is similar to that of the controls, CB’s advantage for letters over words was even greater than the controls. This would be expected if he has difficulty in maintaining semantic information and instead relies, at least in part, on phonological representations for recall, and is similar in some regards to the pattern displayed by the semantic short-term memory patient, AB (Martin & Romani, 1994). CB’s matching digit span results indicate a pronounced auditory advantage, in direct contrast to CS, and contrary to the pattern usually seen with phonological short-term memory patients.

As compared to CS, CB shows less variation across stimulus types, and is no better (in fact, is worse) with words than with semantically neutral stimuli such as letters. However, he does show some effect of both semantic and phonological variables, i.e., better word than nonword, and better nonrhyming letter than rhyming letter performance. Thus CB’s data argue against a pure deficit of either phonological or semantic short-term memory. One interpretation of CB’s results might be that he has mild to moderate deficits in both semantic short-term memory and phonological short-
term memory, which would result in a reduced memory span in most tasks.

SENTENCE PROCESSING TASKS

In the section above, two CHI children, CB and CS, were found to have short-term memory deficits. The two CHI children display different patterns of performance with regard to phonological and semantic variables in recall, with CS showing a relatively pure deficit in phonological short-term memory and CB displaying evidence for both semantic and phonological short-term memory deficits, though a lesser impairment of phonological short-term memory than shown by CS. These data suggest that in children, as in adults, there are separable components of short-term memory.

Research relating span to sentence processing in adults has suggested that separable components of short-term memory make different contributions to sentence processing (Martin & Romani, 1994). The following section relates the memory span performance of CB, CS and the other CHI children, as well as the control children, to sentence processing competence.
The following tasks assume that semantic and syntactic information are extracted from each word in an utterance as it is perceived. The interpretation of the sentence is constructed on a word-by-word basis to the maximum extent possible at that point in the sentence (Carpenter & Daneman, 1981; Marslen-Wilson, & Tyler, 1980; Tyler & Marslen-Wilson, 1981). Traditionally, sentence meaning is thought to be represented in the form of propositions. On this view, once propositions are formed they become part of long term memory. As discussed in the introduction, sentence structure can be manipulated such that the integration of word meanings into propositions can be immediate or delayed (e.g., “The old, red, rusty pail was...” vs. “The pail was old, red and rusty...”). (See Martin & Romani, 1994.) The memory load can be manipulated so that either one content item or three must be maintained in short-term memory (“The rusty pail...” vs. “The old, red, rusty pail...”). The tasks below manipulate memory load by varying the placement and number of content words. Three tasks were used, Sentence Anomaly Detection, Sentence Picture Verification and Sentence Repetition. A child with a semantic short-term memory deficit would be expected to show an effect of memory load in sentence comprehension. Regarding
phonological short-term memory, children may have a lag in lexical processing that gives rise to an increased reliance on phonological short-term memory (because of the need to maintain a verbatim representation until integration of lexical items can be completed). In this case, it might be expected that a deficit in phonological short-term memory in children would give rise to impaired performance in sentence comprehension. Though some effect of the manipulation of delayed vs. immediate integration would be expected it would not be as dramatic as that seen for a semantic short-term memory deficit. It would be expected that children with semantic short-term memory deficits will show an impairment in detecting anomalies in the Sentence Anomaly task, and this will be particularly severe with delayed integration when the memory load is greatest, i.e., when 3 items must be maintained.

In the Sentence-Picture Verification task, children hear a sentence, then must decide which one of 2 pictures the sentence matches. One of the pictures matches the sentence, and one is a distracter, such that, for example if the target sentence was “The green turtle crawled next to the brown snake”, the distracter sentence would depict a brown turtle crawling next to a green snake.
The sentences are either high memory load or low memory load. Memory load is varied by increasing the number of adjectives that must be maintained prior to integration with the key noun ("The short, old man painted the house" vs. The old man painted the house"). It is expected that children with semantic short-term memory deficits would be affected the most because if they cannot hold on to semantic information long enough to integrate the adjectives with the correct noun, they would not have enough information to choose the correct picture. Children with phonological short-term memory deficits may also show a slight deficit, especially in the case where the sentences are longer therefore the lag time in processing might be greater. Their performance with the easier sentences, those with fewer adjectives, should be unimpaired, because they should be able to integrate the semantic information available to derive the correct meaning of the sentence.

There is very little data to draw on to make predictions for the Sentence Repetition task. Though normal adults would have little trouble repeating sentences of the length and complexity used in this task, there is some reason to believe that children may need to rely
on phonological short-term memory to a greater degree (thus maintain a greater load in short-term memory) as a result of slower processing of information. Studies with normal adults suggest that a conceptual representation of a sentence plays an important role in sentence repetition (Potter & Lombardi, 1990). However, a phonological record of the sentence also contributes to accurate repetition (Katz & Martin, 1998). Indeed, the phonological patient EA (discussed in the introduction) was very impaired in sentence repetition and often paraphrased sentences rather than repeating them verbatim. Phonology may play even a more important role in children's repetition than in adults' because of slower processing of information. However, regardless of the level of accuracy in repetition achieved by control children, it may be predicted that children with a semantic short-term memory deficit, such as CB, would be expected to be slightly impaired on this task, but only for those sentences in which a great deal of semantic information must be retained. In contrast, a child with a phonological short-term memory deficits, such as CS, would be expected to be quite impaired on this task.
I. Sentence Anomaly Task

Semantic Properties/Vocabulary Screening. The purpose of the screening test was twofold. The first purpose was to make the distinction between a semantic knowledge deficit and a semantic short-term memory deficit. The second purpose was to allow for the determination of vocabulary competence specific to the Sentence Anomaly task. This was to account for the possibility of children accepting or rejecting a sentence simply because they were not familiar with one of the items in the sentence.

Method

Materials and procedure. Children were asked to make judgments about the properties of the referents of all the content words that occurred in the Sentence Anomaly task. The properties were taken from Sentence Anomaly task, and all the properties and content words in Sentence Anomaly task were tested. In addition, for each property tested, there was at least one filler for which the property was positive, and at least one that was negative. So, for example, if one of the sentences in the Sentence Anomaly task was “Rocks, sticks and leaves floated down the river”, the corresponding property judgment/vocabulary task item would be “Which of these
things can float? Rocks? Boats? Sticks? Leaves? Bricks? Paper?" The child responded after each item. This format eliminated any effect of memory load. Although the Properties/Vocabulary task is not a comprehensive test of semantic knowledge nor vocabulary, the purpose of this task is primarily to test the semantic knowledge of the words necessary to perform the Sentence Anomaly task, and to allow discrimination between lack of semantic knowledge from inability to maintain semantic knowledge in short-term memory.

Results

As can be seen from Table 13, all children, both the normal controls and the CHI children performed very well on the Semantic Properties/Vocabulary task, indicating proficiency with the specific vocabulary needed to perform the Sentence Anomaly Task.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>% Correct</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>range</td>
<td>94 to 100</td>
</tr>
<tr>
<td>CB</td>
<td>97</td>
</tr>
<tr>
<td>CS</td>
<td>100</td>
</tr>
<tr>
<td>MC</td>
<td>95</td>
</tr>
<tr>
<td>JG</td>
<td>100</td>
</tr>
</tbody>
</table>
Thus, differences in performance on the Sentence Anomaly Task cannot be attributed to vocabulary deficiencies.

**Sentence Comprehension Task.** In this task the child heard a number of sentences and judged whether each was an acceptable sentence or an unacceptable sentence. Memory load was varied according to the procedure outlined below.

**Method**

**Materials and procedure.** A set of 128 sentences was constructed in which half of the sentences contained violations of a semantic or pragmatic rule. In the anomalous sentences, half the anomalies occurred before the word with which they had to be integrated to yield a proposition (either a noun or verb) and half after the word with which they had to be integrated. The purpose of this manipulation was to vary the memory load that had to be maintained until the acceptability of the sentence was determined. Thus, in the case where the key word was a noun (The shiny jewel pleased the woman"), the adjective describing the noun could either come before or after the noun. When the key word was a verb ("They shut the carpets before they left the house"), the nouns to be integrated with the verb could come before or after the verb. If the
anomaly occurred after the main word with which it had to be integrated (e.g., "Before they left the house they shut the drawers, windows and carpets"), the amount of information necessary to maintain in short-term memory before making a judgment was minimal, as each word could be integrated immediately with the key word to check for inconsistencies (Immediate integration condition). However, if the anomaly occurred prior to the key word (e.g., "The carpets, drawers and windows were shut before they left the house"), integration with the key word was delayed so that all of the words had to be maintained until the key word was heard before a judgment could be made (Delayed integration condition). That is, until the word ‘shut’ is heard, the person hearing the sentence cannot tell if an anomaly is present. In addition to the relative position of the key word, memory load was also manipulated by the amount and distance from the key word of the relevant information. Some sentences had a memory load (hence, distance from the key word) of 3 items (e.g., “The carpets, drawers, and windows were shut before they left the house”) and some of 1 (e.g., “The carpets were shut before they left the house”). From each of 16 basic sentences, variations were derived such that there were 4 Anomalous and 4
Sensible sentences. In each of the Anomalous and Sensible conditions, there were 2 Immediate integration sentences and 2 Delayed integration sentences. In each of the Immediate and Delayed integration conditions, 1 sentence had a memory load of 1, thus was a distance of 1 item from the key word (Distance 1) with which it had to be integrated. The other had a memory load of 3, so was 3 items from the key word (Distance 3). Thus there were 128 test sentences in all (16 basic sentences X 8 variations). Examples of each of the sentence types are shown in Appendix 2. In addition, there were 40 filler sentences of various types, half with anomalies, half without. The child was instructed to listen carefully, and to press the spacebar just as soon as he/she knew whether the sentence was acceptable or unacceptable. A tone from the computer provided feedback to the child to indicate if his/her judgment was correct.

Results

Scoring. If a sensible sentence was judged to be anomalous or if an anomalous sentence was judged be sensible, an error was recorded. Scores are reported in terms of percentage errors.

Control children. The overall performance of the controls was good, with errors on only 7% (range = 1% to 12%) of the sentences
averaged across conditions. Figure 2 shows the percentage errors for each condition collapsed across sensible and anomalous sentences.

FIGURE 2. Percent errors for control children on Sentence Anomaly Task by Distance and Integration conditions.

The few errors committed by the controls showed a pattern consistent with the predictions. That is, they were more accurate in the Immediate condition (6% errors) than in the Delayed condition (7.5% errors), and made more errors with the Distance 3 sentences (7% errors) than the Distance 1 sentences (6% errors), although these effects did not reach significant by ANOVA. The control children generally showed a pattern similar to that of normal adult
subjects. that is, effects of both Integration condition and Distance, but no interaction between Integration and Distance conditions. Table 14 shows the mean errors for each condition of the Sentence Anomaly Task for controls and the children with CHI. The effects of Integration and Distance are shown in the margins.

*CHI children.* Across all sentence conditions, CB made 19% errors. This is greater than the mean and the range of the control subjects. The pattern of performance displayed by CB was consistent with predictions. He was more accurate in the Immediate condition (16% errors) than in the Delayed condition (22% errors), and made more errors with Distance 3 sentences (20% errors) than Distance 1 sentences (17% errors). In contrast to the controls, in the Immediate condition CB was better with Distance 3 sentences than with Distance 1 sentences, though it is not clear why. Unlike controls, CB showed a large effect of Distance in the Delayed condition, making nearly twice as many errors in the Distance 3 Delayed condition as in the Distance 1 Delayed condition. The effects of Integration and Distance for CB are displayed in Table 14.
TABLE 14. Percentage errors by condition of the Sentence Anomaly task and effects of Integration and Distance. Ranges for the controls are shown in parentheses.

<table>
<thead>
<tr>
<th>CONTROLS</th>
<th>IMMED.</th>
<th>DELAY</th>
<th>EFFECT OF INTEGR.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIST1</td>
<td>5 (0 TO 9)</td>
<td>7 (0 TO 13)</td>
<td>2 (-6 TO 6)</td>
</tr>
<tr>
<td>DIST3</td>
<td>7 (0 TO 16)</td>
<td>8 (0 TO 19)</td>
<td>1 (-9 TO 13)</td>
</tr>
<tr>
<td>EFFECT OF DIST</td>
<td>2 (-3 TO 9)</td>
<td>1 (-6 TO 13)</td>
<td></td>
</tr>
<tr>
<td>CB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIST1</td>
<td>19</td>
<td>15</td>
<td>-3</td>
</tr>
<tr>
<td>DIST3</td>
<td>13</td>
<td>28</td>
<td>15</td>
</tr>
<tr>
<td>EFFECT OF DIST</td>
<td>-6</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIST1</td>
<td>9</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>DIST3</td>
<td>12</td>
<td>6</td>
<td>-6</td>
</tr>
<tr>
<td>EFFECT OF DIST</td>
<td>3</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIST1</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>DIST3</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>EFFECT OF DIST</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>JG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIST1</td>
<td>12</td>
<td>3</td>
<td>-9</td>
</tr>
<tr>
<td>DIST3</td>
<td>6</td>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td>EFFECT OF DIST</td>
<td>-6</td>
<td>-3</td>
<td></td>
</tr>
</tbody>
</table>

CS made 9% errors, averaged across all sentence conditions. Though this is greater than the mean, it is well within the range of the control subjects (1% to 12%). Averaged across Immediate and Delayed conditions, CS showed no effect of Distance (9% errors for
each), and across Distance conditions, did not show the predicted effect of Integration (Immediate = 11% errors, Delayed = 8% errors).

So, though CS’s performance is slightly worse than the mean of the controls for most conditions, she is generally unaffected by the Distance manipulations.

MC’s performance was excellent, with an average of only 2% errors. Such a small number of errors does not lend itself to meaningful analysis, except to point out that MC is highly competent in this task.

Across all sentence conditions JG averaged 5% errors. He was more accurate with greater memory load (Distance 1 = 8% errors, Distance 3 = 3% errors), and is more accurate with Delayed sentences (1.5% errors) than with Immediate sentences (9% errors).

**Summary and Discussion**

The results showed that the controls were slightly, though not significantly, affected by delayed integration, as well as by distance. However, there was little evidence of an interaction between the two variables at the individual level. Failure to find a significant effect of Distance and Integration for the controls suggests the effects were small relative to the individual variation across sentence types.
FIGURE 3  Percentage of errors in the Sentence Anomaly Task for the two CHI children displaying memory deficits. CB and CS.

CS performed at the lower end of the control’s range. She showed no effect of distance, but was slightly worse with Immediate integration. The same pattern is observed for MC and JG. There is no obvious explanation for worse performance in the Immediate condition. In contrast, though CB made slightly more errors than the other patients and the controls in most of the task conditions, his performance in the Delayed condition was strikingly impaired, especially in the Distance 3 condition.

The dissociation in performance patterns on the Sentence Anomaly task between CS and CB is similar in some aspects to
dissociation in the patterns of performance reported by Martin and Romani (1994) for the phonological short-term memory patient, EA, and the semantic short-term memory patient, AB, in which, though both patients showed an impairment on the task, AB's performance was related to the distance manipulation, whereas EA's was not. In the current study although both CB and CS show similar degrees of deficit with the span tasks (with CS being somewhat more impaired than CB) there is a striking dissociation in their performance on the Sentence Anomaly task (Figure 3) with CB showing a strong impairment related to Distance, and CS being relatively unaffected by the same manipulation.

III. Sentence-Picture Verification

In this task the child heard a sentence and then had to determine which of two pictures matched the sentence.

Method

Materials and procedure. A set of 8 basic sentences was selected from which the 48 test sentences were derived. The test sentences consisted of 6 variations of each of the 8 basic sentences. In the variations of the basic sentences memory load was
manipulated by the number of adjectives that must be maintained before integration could proceed. However, in all the sentences the memory load preceded the noun, thus integration was always delayed. In 3 of the sentence variations (LMI, LMII, and LMIII) a maximum of 1 adjective preceded the noun(s) (Low memory load), and in the remaining 3 sentence variations (HMI, HMII, and HMIII) a maximum of 2 adjectives preceded the noun(s) (High memory load). A set of pictures corresponding to the sentences was also constructed such that there were two pictures each depicted on a page of plain white paper. One of the pictures matched the sentence, and the other was a distracter similar to the target picture, but in which one or more of the adjectives depicted in the target sentence were ‘moved’ so that they described the alternate noun. That is, if the adjective in the target sentence described the subject of the sentence, then in the distracter, the same adjective was applied to the object of the sentence. For example, given the sentence “The old man painted the house”, the target picture showed an old man painting a house, and the distracter showed a (young) man painting an old house. Thus the meaning of the sentence could not be understood from the semantic properties of the words in the sentence, but had to be
understood from the integrated meaning of the words. The position of the target and distracter were alternated randomly such that on some of the test sheets the target was in the upper position, and in others, on the bottom. Table 15 shows an example of each variation of a sentence.

<table>
<thead>
<tr>
<th>MAX. ADJ.</th>
<th>Sentence variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LM I The green turtle crawled near the snake.</td>
</tr>
<tr>
<td>1</td>
<td>LM II The turtle crawled near the green snake.</td>
</tr>
<tr>
<td>1</td>
<td>LM III The green turtle crawled near the brown snake.</td>
</tr>
<tr>
<td>2</td>
<td>HM I The small green turtle crawled near the brown snake</td>
</tr>
<tr>
<td>2</td>
<td>HM II The green turtle crawled near the small, brown snake.</td>
</tr>
<tr>
<td>2</td>
<td>HM III The small green turtle crawled near the large, brown snake.</td>
</tr>
</tbody>
</table>

**Procedure:** The experimenter read a test sentence. Then the child was shown a test sheet with two pictures, a target picture and a distracter, and had to choose which picture depicted the sentence that was just read. The task was unspeeded, and the child was allowed to take as long as necessary to make a decision. The
sentences were read in random order and all 48 sentences were tested in one session. Responses were recorded on a score sheet.

**Results**

*Control children.* Overall, the controls responded correctly to 97% of the sentences, with a range of 91 to 100% averaged across all sentence variations. On Low memory load sentences they were correct on average for 98% (range 95 to 98%) of the sentences. On High memory load sentences, they were correct on average for 95% (range 88 to 100%) of the sentences, thus showing a slight effect of memory load, though this difference did not reach significance, $F(1, 13) = 3.01, p = .11$. Table 16 shows the percent correct sentences by sentence type for the control children and the CHI children.

<table>
<thead>
<tr>
<th>TABLE 16. Percentage correct by sentence variation type.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Controls</td>
</tr>
<tr>
<td>range</td>
</tr>
<tr>
<td>CB</td>
</tr>
<tr>
<td>CS</td>
</tr>
<tr>
<td>MC</td>
</tr>
<tr>
<td>JG</td>
</tr>
</tbody>
</table>
CHI children. As in the Sentence Anomaly task, the results showed that CB was disproportionately affected by memory load. He correctly responded to 88% of the sentences averaged across sentence types which was below the range of the controls (range = 91 to 100%). On Low Memory load sentences, he was correct on 92%, (control range =88 to 100%), but on High Memory load sentence he was correct on only 83% (control range = 88 to 100%). Thus, the effect of memory load was greater for CB (9%) than the mean of the controls (3%), and outside the range of the controls (0 to 8 %).

In contrast to CB, CS correctly responded to 100% of the sentences on this task, as did JG. MC correctly responded to 98% of the sentences averaged across sentence variations. On Low Memory load sentences she was correct on 100%, and on High Memory load sentences she was correct on 96%. Thus it appears that other than CB, the CHI children were not impaired on the Sentence Picture Verification task.

Discussion

Although performance overall was very high for the Sentence Picture Verification task, there was some variation in the conditions within the task. Of the controls, 13 of 14 performed better with
conditions in which a lesser memory load had to be maintained to achieve comprehension. Of the two CHI children who appear to have no short-term memory deficit, MC performed well above the mean of the controls, and JG performed flawlessly.

Of particular interest is the performance of CB and CS, both of whom have exhibited deficits in the short-term memory tasks. CS, whose memory span profile is consistent with a phonological short-term memory deficit, performed this task without error, thus exhibiting no apparent comprehension problems relating to her short-term memory deficit. On the other hand, CB, whose memory span profile suggests that he may suffer from a deficit in both phonological short-term memory and semantic short-term memory, has some difficulty on this task relative to the controls and to the other CHI children. Assuming that impaired semantic short-term memory contributes to CB’s short-term memory deficit, the dissociation in patterns of performance between CB and CS is consistent with findings that suggest that comprehension relies more on semantic short-term memory than on phonological short-term memory.
IV. Sentence Repetition Test

Adult studies have demonstrated that verbatim sentence repetition relies on phonological short-term memory (Martin, 1993). Patients with phonological short-term memory deficits were found to be unable to repeat sentences that they were able to comprehend, in contrast to patients with semantic short-term memory deficits who performed much better on sentence repetition than on comprehension tasks (see above). In this task, children were asked to repeat sentences, on some of which they had already made anomaly judgments. Though there is no basis on which to predict the performance of control children, it is expected that children with phonological short-term memory deficits will have greater difficulty with this task than will children with semantic short-term memory deficits and normal children.

Method

Materials and procedure. Children were asked to repeat 26 sentences, 14 of which were taken from the test sentences of the Sentence Anomaly task. The remaining 12 were fillers from the Sentence Anomaly task, or new sentences that were constructed so that they varied in syntactic complexity. The 14 sentences from the
Sentence Anomaly Task were chosen to represent each of the memory load and integration conditions. The remaining sentences varying in syntactic complexity ranged from simple active sentence through more difficult reversible passives. However, complexity was not systematically varied. Accuracy of repetition was measured on a word-by-word basis.

**Results**

Two measures are reported: (1) the total number of sentences repeated verbatim correctly, and (2) the total number of word errors committed by the subjects. Words were counted as correct if the correct word was in the correct position. The numbers and general types of word errors are displayed in Table 17. Appendix 3 shows a detailed breakdown of the word errors by error type.

*Control children.* As seen in Figure 4, on average, the controls made very few errors, correctly repeating 21 of the 26 sentences correctly (range = 18 to 26). The majority of the errors were omissions of words of a phrase (e.g., “next to the” in “Some pansies, next to the roses and daisies were eaten by the children yesterday”) and substitutions of function words (“by” for “near”) (Appendix 3).
The third most common error among the controls was the omission of a noun in a list (e.g., "tomatoes" in "The tomatoes, strawberries and melons were ripened by the sun in the summer").

FIGURE 4. Number of sentences (of 26) correctly repeated in Sentence Repetition task by CHI children and controls.

*CHI children.* CB repeated a total of 19 sentences correctly (Figure 4) which is below the mean of the controls, but within the range. As seen in Table 17, CB's total number of word errors was greater than the mean, but within the range of the controls. The detailed breakdown of his errors (Appendix 3) revealed that, like the controls, he made the most errors (6) with omission of words of a
phrase. His second most common error (3) was substitution of function words. Of the 7 sentences that CB missed, 5 were high memory load (i.e., Distance 3 sentences) from the Sentence Anomaly task and the remaining 2 were filler sentences.

CS's errors were much greater in number than the mean of the controls, and far outside their range of performance, both for sentences correct (14), shown in Figure 4, and total number of word errors (65) (Table 17). Her greatest number of errors (Appendix 3) was with the omission of words of phrases (45) and second most common (5) was the omission of nouns in a list. Unlike CB, there was no particular sentence type that CS missed. Of the 12 sentences that she missed, 4 (of 8 possible) were high memory load sentences, 2 (of 4 possible) were low memory load sentences. The remaining 6 sentences she missed were a mixture of fillers and new sentences. Thus CS's pattern on this task was not related to memory load, and it departed dramatically from her performance on the Sentence Anomaly task.

MC repeated 21 of 26 sentences correctly and made only 6 word errors, which is less than the mean of the controls. Her most common errors (3) were substitutions among function words. JG
also performed very well, repeating 22 of 26 sentences correctly (Figure 4). His most common error was the omission of a word.

<table>
<thead>
<tr>
<th>TABLE 17. Number of word errors by general category in the Sentence Repetition task for control and CHI children.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMISSIONS</td>
</tr>
<tr>
<td>Controls</td>
</tr>
<tr>
<td>0 to 18</td>
</tr>
<tr>
<td>CB</td>
</tr>
<tr>
<td>CS</td>
</tr>
<tr>
<td>MC</td>
</tr>
<tr>
<td>JG</td>
</tr>
</tbody>
</table>

Discussion

In the literature on adult brain injury, a dissociation between the ability to comprehend sentences and the ability to repeat sentences verbatim has been related to different patterns of performance in short-term memory tasks. Patients whose patterns of performance suggest that they have a phonological short-term memory deficit show a pattern of preserved sentence comprehension, with a deficit in verbatim repetition of sentences. The opposite pattern has been observed in patients with semantic short-term memory deficits where repetition is better preserved than
comprehension. In our study of head-injured children a similar dissociation is seen between two children with impaired short-term memory (see Figure 5). CS, who appears to have a phonological short-term memory deficit, is very impaired in sentence repetition (as compared to the control children), but is unimpaired on sentence comprehension. CB, whose pattern of performance on span tasks suggests that at least a portion of his deficit can be attributed to a semantic short-term memory deficit, appears to be somewhat impaired on sentence repetition, but is much more impaired on sentence comprehension (Figure 5).

FIGURE 5 Comparison of performance patterns for CB and CS on Sentence Anomaly Task and Sentence Repetition Task.
Thus it appears that the same dissociation between semantic and phonological components and their relationship to sentence repetition seen in adults is also found in children. However, it should be noted that while the basic pattern of performance seen in brain injured adults is repeated here in brain injured children, there are notable differences in their specific performance. For example, EA, the phonological short-term memory patient, tended to paraphrase and to make semantic substitutions. CS, who we believe has a similar phonological short-term memory deficit, was much more likely to omit words and phrases, rather than to make semantic substitutions. This might be explained by assuming that in children—maybe particularly in children who have phonological short-term memory deficits—a less-developed vocabulary (as compared to adults) would restrict the number of alternatives to words or phrases whose phonological representation had been degraded. With choices for substitutions or paraphrases very limited, the child would possibly tend to omit words and phrases, rather than try to come up with a replacement. Such a situation would give rise to the pattern of errors in sentence repetition displayed by CS.
Summary of Sentence Processing Tasks

*Control children.* On the three sentence processing tasks, control subjects displayed patterns of performance which were generally consistent with the predictions based on the adult and normal child literature. In the Sentence Anomaly task, though performance was very near ceiling overall, and there were no statistically significant differences, the means differed in predictable ways. Averaged across sensible and anomalous sentences, subjects were more accurate with sentences in which integration of key words could proceed immediately, that is no words had to be maintained in short-term memory before comprehension was achieved. They were also affected by memory load such that sentences in which the memory load was 3 items were responded to less accurately than sentences in which the memory load was only 1 item. And finally, subjects’ accuracy was slightly less in the condition in which integration was delayed and the Distance was the greatest.

In the picture-sentence verification task, although the pattern of performance across the individual conditions is a bit unclear, the primary manipulation bore out the predictions that sentences in which subjects had to maintain 1 adjective in memory were
responded to slightly more accurately (98%) than were sentences in which 2 adjectives had to be maintained (95%).

The Sentence Repetition task revealed that children normally have no difficulty repeating sentences of this length and complexity verbatim. Of their errors, it was most likely that a control subject would substitute a single word for another.

*CHI children.* Among the CHI children, two of the children, MC and JG, performed similarly to (or better than) the control children on the sentence processing tasks. They both showed patterns of performance that were consistent with those seen in the control children (except when ceiling effects obscured patterns of performance).

The other two CHI children, CB and CS, showed a dissociation between their performance on comprehension tasks and the verbatim repetition of sentences. CS, whose performance on the memory span tasks is consistent with a phonological short-term memory deficit, performed similarly to control subjects on two of the sentence tasks: the Sentence Anomaly task and the Sentence Picture Verification task, both of which assess comprehension. However, her performance was quite impaired on the Sentence Repetition task. In
contrast, CB, whose memory span profile suggests that he may suffer from a deficit in both semantic short-term memory and phonological short-term memory, showed the exact opposite pattern. He was very impaired on both of the comprehension tasks, relative to the controls and to the other CHI children, but his performance on the Sentence Repetition task, though below the mean of the controls, was well within the range. This pattern of performance is similar to that seen by patients thought to have semantic short-term memory deficits.

GENERAL DISCUSSION

Previous studies of adults with brain injury have demonstrated a dissociation between semantic and phonological components of short-term memory (Martin, et. al, 1994; N. Martin & Saffran, 1990; Saffran & N. Martin, 1990). These lines of evidence provided by studies of adult patients are supportive of a model of short-term memory within the language domain in which different components of short-term memory have separate capacities for maintaining different types of information, such as phonological and semantic representations. The separable components of phonological short-term memory and semantic short-term memory have been shown to
have differential effects on sentence comprehension and verbatim repetition in adults (Martin & Romani, 1994), but these relationships have not previously been explored in children. The study presented here is concerned with components of short-term memory and their effect on sentence comprehension in normal and brain-injured children.

A primary issue was whether or not separable components of short-term memory can be demonstrated in children. The data presented here suggest that 9 to 11 year old children are affected by phonological and semantic variables in short-term memory in much the same manner as are adults. They show the same patterns of lexical advantage, phonological similarity, and imageability in recall, as well as effects of age of acquisition corresponding to frequency effects on recall. With some tasks (digit matching), they also show effects of modality, though this effect is far from uniform across stimuli types. The findings on the CHI children reported here are also supportive of separate components of short-term memory. One CHI child, CS, showed a pattern of performance on the span tasks which very closely resembles the pattern demonstrated by adult patients with phonological short-term memory deficits as is
displayed in Table 12. The other child, CB, shows a pattern of performance that suggests a semantic short-term memory deficit in conjunction with a milder phonological short-term memory deficit. Further, evidence for the separation of phonological and semantic short-term memory components and their differential contribution to sentence processing is provided by the sentence processing tasks. CS mirrored the pattern of adult patients with phonological short-term memory deficits, that is, her performance on the sentence comprehension tasks was very similar to the control subjects, but her verbatim sentence repetition was very impaired. In contrast, CB was very impaired relative to the control subjects on both sentence comprehension tasks (Sentence Anomaly Detection and Sentence-Picture Verification), but performed within the range of the controls on the Sentence Repetition task. Thus, these data support the notion that, at least by the age of 9 or 10 years old, children, like adults, have separable components of short-term memory that can be differentially affected by brain injury, and thus give rise to different patterns of impairment in language processing.

These findings fit within a model of short-term memory in which different levels of representation are independent, but interact
to support comprehension. Such a model has been proposed (Martin & Romani, 1994) in which the different levels of representation are differentially subject to decay or interference. At the phonological level, information is lost fairly quickly, but information at higher semantic levels persists for a longer duration. This model accounts for the differential effects of brain injury reported here and elsewhere by assuming that different levels of representation can be differentially affected. For example, CS's results might be accounted for by positing unusually rapid decay from phonological short-term memory, which would give rise to poor performance in tasks that rely primarily on an intact phonological representation. This would include repetition of stimuli that were semantically impoverished, such as nonwords, or stimuli whose representations were not very distinguishable from one another, such as rhyming letters, as well as the verbatim repetition of sentences. In addition, the recency effect, which is thought to rely on phonological short-term memory should be absent. However, tasks that allowed for or depended on the maintenance of semantic representations should not be greatly affected by the rapid decay of phonological information.
A deficit at the semantic level should show a different pattern. The abnormally rapid decay of information from the semantic level would give rise to an impairment in tasks that require the maintenance of semantic information, such as when individual meanings of words must be maintained until they can be integrated into a higher level of representation for sentence comprehension. It might also be expected that some of the usual effects of semantic variables would be missing, such as the effects of imageability and lexicality on recall. The pattern of results shown by CB can best be explained by a deficit at the semantic level, coupled with a mild deficit at the phonological level. An inability to maintain semantic representations would account for the absence of effects of imageability in the repetition of the Imageability/AoA word lists. Likewise, his poor performance in the Sentence Anomaly task, and especially in the Delayed condition with the greater Distance, can be accounted for by the failure to maintain semantic representations long enough for integration to be accomplished. CB’s performance on the Sentence Picture Verification task would similarly be affected. However, with only a mild deficit in maintaining phonological representations, his verbatim sentence repetition should only be
slightly impaired, as was the case. But the phonological deficit would make phonological codes somewhat unreliable, thus he would tend to exhibit some of the same characteristics as a phonological short-term memory patient, but less pronounced.

A second issue addressed in this study is the relative importance of phonological and semantic short-term memory to sentence processing in children. A fairly large body of evidence has supported the importance of short-term memory to both spoken and written language in normal children (e.g., Mann, Cowin, & Schoenheimer, 1989) and in language impaired children (Baddeley & Wilson, 1993; Gathercole, Willis, Baddeley, & Emslie, 1994). Baddeley and co-workers have performed several studies that demonstrate that impairments to short-term memory in children are associated with poor development of vocabulary and language skills (e.g., Baddeley & Wilson, 1993; Gathercole & Baddeley, 1990). One limitation of these studies, however, is the assumption of a single component (phonological) of short-term memory. Thus any observed deficit in language processing attributed to phonological short-term memory may actually reflect a deficit to semantic short-term memory or phonological short-term memory or both. However,
the ability to repeat nonwords has consistently been linked to poor language acquisition skills in children, thus it safe to assume that in children, as well as in adults, vocabulary acquisition does rely on phonological short-term memory. But this assumption cannot be extended to all language processing domains. Nonetheless, given the link between language acquisition and phonological short-term memory, we might make some predictions about children such as CS, who have acquired a phonological short-term memory deficit at an early age. It might be expected that at the time of injury (or soon after) these children would show normal development on tests of vocabulary. However, with time they may show an abnormal decrease in the rate of vocabulary acquisition.

Some evidence suggests that children and adults show similarities in the types of information accessed during text comprehension (Marslen-Wilson & Tyler, 1981). However, other evidence suggests that though the types of information processing engaged in during comprehension are similar in adults and children, the speed at which those processes proceed, or the capacity for processing may differ in children and adults (Tyler & Marslen-Wilson, 1981). Such speed or capacity restraints may give rise to
differing degrees of reliance on various components of short-term memory for adults and children. Adults do not normally rely on phonological short-term memory for comprehension (Martin & Romani, 1994). However, it might be hypothesized that in children, if the phonological processing of the incoming words of a sentence is slower because of slower semantic or lexical access, or slower integration processes, then incoming words might have to be retained in a phonological form for a longer time than would be necessary in adults, which could give rise to a greater reliance in children upon phonological short-term memory in sentence processing than that seen in adults.

The results from the current study do not support this hypothesis. The data reported here suggest that sentence comprehension in children, as in adults, relies to a large extent on semantic short-term memory, especially when span-like lists within a sentence have to be maintained prior to integration. The evidence for differential contributions of semantic and phonological short-term memory comes from the dissociation in performance exhibited by CS and CB on the sentence comprehension tasks. CS demonstrates remarkably preserved comprehension abilities in spite
of a fairly severe phonological short-term memory deficit, performing within the normal range on the Sentence Anomaly task, and without error on the Sentence Picture Verification task. In contrast, CB, who has a reduction in span very similar to CS's (in fact, somewhat less severe), but whose deficit appears to involve semantic short-term memory, shows an pronounced impairment on both the Sentence Anomaly task and the Sentence Picture Verification task relative to the control subjects. If phonological short-term memory were involved in sentence comprehension to any great extent, then it would be expected that CS, with a phonological short-term memory deficit, would show impaired performance on the comprehension tasks. Further, if phonological short-term memory could be relied upon, then one might expect that CB, with partial information from both semantic and phonological short-term memory might have preserved comprehension abilities. The fact that CB shows an impairment, while CS does not constitutes evidence for the differential influence of semantic and phonological short-term memory on sentence comprehension in children.

The final issue addressed by this study concerns group vs. case study approaches to cognitive deficits, brain localization, and the
implications for remediation. Group based studies reporting memory deficits as a consequence of head injury necessarily overlook the tremendous variation among the individuals in a group. The current study used a case study approach to investigate the effects of severe closed-head injury in four children on short-term memory and sentence comprehension abilities. Though two of the CHI children investigated here showed pronounced impairments in short-term memory, the other two, in spite of their severe injuries showed no indications of a deficit in either short-term memory or in sentence comprehension abilities. So, while head injury may be strongly associated with memory deficits of various kinds, it is not an inevitable consequence of severe head injury in children.

Even between the two children in the present study who demonstrated short-term memory deficits, the pattern of performance differed, as did their lesion site. In the adult literature, phonological short-term memory deficits have been linked to brain lesions localized to the temporal parietal region, while semantic short-term memory deficits have been associated with frontal or prefrontal regions of the brain. Our findings with the CHI children investigated here are consistent with the adult literature, in that the
dissociation between their performance patterns is matched by a
dissociation in their brain lesion sites. CS’s brain imaging data
indicates that she has damage to the left thalamus, and no indication
of frontal involvement, while CB shows primarily frontal damage.
These data hint at the possibility that the region of lesion
localization may be predictive of the underlying mechanisms of
short-term memory deficits. Such findings, in conjunction with the
data reported here, have implications for clinical studies of the
consequences of head injury on the cognitive abilities of children.
The findings reported here support the use of the case study
approach to the extent possible in studies of cognitive deficits, and
especially short-term memory deficits. The dissociations observed in
the performance patterns of CB and CS would not have been
uncovered in a group study approach wherein all individuals’ data
are averaged together. Generally, the intention of clinical studies is
to promote the ultimate development of remediation techniques for
children suffering the consequences of brain injury. If it is assumed
that remediation of a deficit can only be successful to the extent that
the underlying cause of the deficit is clearly understood, then the
demonstration that short-term memory deficits cannot be uniformly
attributed to a single cause is important to further research in this area.
REFERENCES


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_Cognitive Neuropsychology_. 8, 81-126.
APPENDICES

Appendix 1. Example of test stimuli from the Nonverbal Visual span task. Examples of the study sheet and the test sheet for span 7 are shown.

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<table>
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Appendix 2. Example of Sentences from the Sentence Anomaly Task.

DIST1-ANOM-DELAY Rocks grew behind the house in the yard.
DIST1-ANOM-IMMED They grew rocks behind their house.
DIST1-SENSE-DELAY Flowers grew behind the house in the yard.
DIST1-SENSE-IMMED They grew flowers behind their house.
DIST3-ANOM-DELAY Rocks, bushes, and trees grew behind the house in the yard.
DIST3-ANOM-IMMED They grew flowers, trees, and rocks behind their house.
DIST3-SENSE-DELAY Flowers, bushes, and trees grew behind the house in the yard.
DIST3-SENSE-IMMED They grew flowers, trees, and bushes behind their house.
APPENDIX 3. Detail of errors committed by Control and CHI children on the Sentence Repetition Task.

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