

# Short-Term Memory, Phonological Processing, and Reading Ability

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*Verbal short-term memory deficits are a common characteristic of children with reading problems and may markedly increase the difficulty of learning to read. Previous work suggests that the basis of the short-term memory deficit may involve limitations in phonetic coding. In the present paper, a series of experiments are reviewed which examined the role of phonological processes in short-term memory. First, a developmental study is described in which a significant relationship was found between phonetic processes and verbal memory span, but not between phonetic processes and nonverbal memory. Second, additional studies are reviewed which collectively found that children with reading problems are less accurate at phonetic encoding than are good readers, and that performance on phonetic processing corresponds with verbal memory span. No reading group differences were obtained on nonverbal perception or memory tasks. These findings suggest that both developmental and individual differences in verbal memory span are related to the efficiency of phonological processes. Practical implications of current cognitive research are discussed.*

In the last 15 years exciting progress has been made in understanding the factors in learning to read. A strong case can now be given for the importance of linguistic skills in reading ability (e.g., Liberman 1983; Mann 1984; Perfetti 1985; Stanovich 1985; Vellutino 1979). One of the most robust findings in this area is that there is a relationship

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between level of reading ability and performance on short-term memory (STM) tasks, with better reading skill being associated with superior STM. This has been observed in adults (Baddeley, Thomson, and Buchanan 1975; Daneman and Carpenter 1980), and more extensively in children (see Jorm 1983 and Stanovich 1982 for reviews). Deficits in STM for individuals with reading problems have been demonstrated with digit span measures, letter strings, sentence tasks, and recall for pictures of familiar objects. Interestingly, the memory problem for poor readers generally has been found to be specific to linguistic material or to other material that is easy to represent linguistically. When instead the memory task consists of nonsense figures, photographs of strangers, or symbols from an unfamiliar writing system, recall has not been found to be closely related to reading ability (Katz, Shankweiler, and Liberman 1981; Liberman et al. 1982; Vellutino et al. 1973).

The repeated finding that short-term memory deficits for language co-occur in children with reading problems raises an important point. Rather than poor readers having difficulties restricted to identifying printed words, the STM deficits suggest a broader problem in processing language. In keeping with this, STM limitations have been suggested to contribute to other language impairments of poor readers such as both spoken and written language comprehension (Perfetti and Lesgold 1977; Shankweiler and Crain in preparation). The presence of language deficits extending beyond failures in word decoding indicates that it is necessary to look for a more general processing problem. With this in mind, our research has not pursued other legitimate questions such as how readers process text (Liberman 1983) or how the STM deficits might be related to the decoding problem (Perfetti 1984), but has focused on investigating the origin of the poor readers' underlying deficit in verbal short-term memory.

We have supposed that the basis of the short-term memory deficit in poor readers may involve limitations in phonetic coding. In this paper, a series of experiments in which we examined the phonetic skills of good and poor readers and investigated the role of phonetic coding in short-term memory will be described. However, first a brief review of the prior evidence linking the poor readers' verbal STM deficit to faculty coding processes is in order.

### Background Evidence

To account for the verbal memory deficit, it has been hypothesized that less efficient coding processes in short-term memory may be the basis for some of the language deficiencies characteristic of poor readers. In tests of this hypothesis, the effect of phonological con-

fusability on recall was evaluated by giving good and poor readers strings of rhyming and nonrhyming items. It was reasoned (c.f., Baddeley 1966; Conrad 1972) that if good readers are better able to form phonetic presentations, they should recall more than poor readers on phonetically distinct (nonrhyming) stimuli. However, when the test is saturated with confusing (rhyming) items, the good readers' superior phonetic skills should actually work against them, resulting in more similar performance for the reading groups. This prediction was confirmed in several studies (Liberman et al. 1977; Mann, Liberman, and Shankweiler 1980; Mark et al. 1977; Olson et al. 1984).<sup>1</sup>

One of the most noteworthy experiments, from our present perspective, demonstrated that the reading group differences in performance level and in sensitivity to phonetic similarity were virtually identical for visual presentation and for auditory presentation (Shankweiler et al. 1979). Thus it has been suggested that poor readers have a general problem with the use of a phonetic code, independent of how material is presented, not a difficulty that is restricted to the reading process itself.

Analysis of the errors good and poor readers make on short-term memory tasks provides additional evidence that poor readers have less efficient phonetic coding (Brady, Mann, and Schmidt 1985; Brady, Shankweiler, and Mann 1983). This interpretation is supported by the observation that both reading groups make errors that indicate use of a phonetic coding strategy. For example, like good readers, poor readers are apt to make transposition errors, recombining the phonetic information from adjacent items in the list, especially when items have phonetic features in common. While the nature of errors suggests that both reading groups are employing a phonetic coding strategy, poor readers' low efficiency in phonetic coding is revealed by a greater frequency of errors.

In sum, past research has shown that poor readers have a specific difficulty with verbal memory tasks; they show reduced sensitivity to rhyme; verbal STM is deficient regardless of whether verbal or auditory presentation is used; and poor readers produce a greater frequency of phonetic errors of transposition. This evidence converges to suggest that poor readers have a language problem in the phonological domain that is not restricted to reading tasks.

### Processing in Short-Term Memory

In recent years my colleagues and I have been interested in trying to find out more about the nature of the phonetic coding problem of

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<sup>1</sup>While the hypothesis concerning the phonetic coding ability of good and poor readers has been supported by several lines of evidence (to be discussed in this

poor readers. Our aim, as stated earlier, has been to understand better the basis of the short-term memory deficits common for these individuals. If we consider the requirements of an STM task, we can, at least conceptually, consider different processes that are involved, any one of which might be the source of a deficit. For example, in order for something to be remembered, it must first have been perceived. The stimulus, whether it is seen or heard, has to be perceived and represented phonetically. So a deficit might arise from problems in initial phonetic encoding. (In making this assumption, it is perhaps necessary to underscore the evidence that humans have a ubiquitous tendency to use phonetic codes whenever possible. Even when alternative strategies might have seemed likely, such as in reading by congenitally deaf individuals or for readers of a logographic script such as Chinese, evidence of phonetic coding has been obtained [Hanson, Liberman, and Shankweiler 1984; Tzeng, Hung, and Wang 1977]). Or, once a phonetic representation is created, it has to be retained, and a deficit might stem from a limitation in rehearsing or retrieving the information in memory.

We have viewed short-term memory, or working memory, as a limited capacity system (Baddeley and Hitch 1974) that briefly stores information in a phonetic code. Since the amount of information it can handle is limited, the functional capacity of STM can be expected to affect performance on a number of cognitive tasks such as listening comprehension, decoding written language, and reading comprehension. (The role of memory in reading has been discussed in detail elsewhere [e.g., see Liberman et al. 1977; or Perfetti and Lesgold 1977]). Further, within STM the resources or attention required by aspects of processing (such as encoding, storage, and retrieval) are assumed to become more automatic with experience and to require less resource allocation (LaBerge and Samuels 1974; Perfetti 1985). These characteristics, widely supported in the cognitive literature, are taken to reflect normal constraints on human information processing.

Within this framework, we have explored the question of whether the poor reader's phonetic coding deficit in memory might arise from less efficient encoding processes. Part of the impetus for this approach came from experimental evidence with adults that perceptual difficulty can determine memory performance. In a study by Rabbitt (1968), memory span was measured for lists of digits that were presented clearly or degraded by the addition of noise. In addition, the ability of subjects to identify the individual digits was determined in a condition in which the subjects repeated the individual items. Noise levels that caused no effect on perception of the single items significantly im-

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paper), it is now apparent that the "rhyme effect" per se is subject to age effects (Olson et al. 1984) and task factors (Hall et al. 1983).

paired recall of strings of the same stimuli. Therefore, adding noise, and increasing the perceptual difficulty, reduced memory span. Rabbit argued that in a limited capacity system, if perception (or encoding) is difficult, fewer resources will be available for memory.

Research on individual differences in adults has further supported a connection between phonetic processing and memory span. It is known that adults' memory span can be predicted on the basis of the number of words that a subject can read in approximately two seconds (Baddeley et al. 1975). In the same vein, Hoosian (1982) reported a negative correlation between naming speed for digits and digit span. In both studies, phonetic processes involved in encoding and articulating a response were statistically related to memory performance. These results are compatible with the view that perception and memory processes in STM share limited resources.

### Developmental Factors in Short-Term Memory

Similar arguments have been made to explain the commonly observed developmental differences in memory span. It is well-known that measures of memory span show considerable improvement from early childhood to adulthood. It is estimated that span approximately triples from an average of slightly more than two items at age two to an average of nearly seven items at adulthood (Dempster 1981). Related to the approach that Rabbit's work suggests, one hypothesis about the cause of this increase is that, with experience, the component processes in STM come to operate more efficiently, reducing the resource demands and resulting in a developmental increase in functional storage space.<sup>2</sup> Pertinent to our interests, encoding processes are presumed to increase in efficiency, contributing to a concomitant improvement in memory capacity. These developmental changes in STM are assumed to occur at an automatic, nonstrategic level. We were

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<sup>2</sup>A second category of explanation of developmental increases in memory focuses on strategic or mnemonic variables that are under conscious direction. These include rehearsal, chunking, organization, and retrieval strategies. According to this view, as children get older they become increasingly aware that particular strategies will aid recall and increasingly able to employ the appropriate procedure. It is clearly the case that children do improve in the use of these metacognitive skills (Chi [1976] reviews this evidence). However, it does not look as though this is the sole basis for the age differences in span. For example, Samuel (1978) equated children's use of the organization control process by temporally grouping items in recall lists. This procedure improved recall for all the age groups tested (ranging in age from 6 to 29), and thereby preserved the age differences. Similar results have been obtained by Huttenlocher and Burke (1976) and by Engle and Marshall (1983). So strategic variables, while showing increments with age, do not seem to account completely for developmental differences in span.

interested in pursuing this explanation (as will be described shortly) because looking at the basis of developmental improvements offers a way to examine the role of phonetic processes in STM.

Two recent experiments have produced compelling developmental evidence that perceptual processes may be importantly related to memory capacity. Testing children from three to six years of age, all of whom are unlikely to use mnemonic strategies, Case, Kurland, and Goldberg (1982) observed a strong correlation between how fast the children could repeat words and the size of their memory span: the older children, who could repeat faster, remembered more words. The authors argued that the basic encoding and retrieval operations in STM show a developmental increase in "operational efficiency," resulting in more functional storage space. In a convincing test of this, Case and his colleagues equated 6-year-olds and adults on speed of counting by manipulating word familiarity (adults were forced to count in an unfamiliar language). Correspondingly, memory span with these stimuli was also demonstrated to be no different for the two age groups. In a second study, it has likewise been reported that although younger children recall less, the same linear function relates speaking rate to short-term memory for subjects ranging in age from four years old to adulthood (Hulme et al. 1984). The results of these studies indicate that the buffer component of working memory is phonologically organized, and that developmental increases in memory span are related to the efficiency of phonological processes.

### Current Research

Reiterating the main points of the paper thus far, there are three interesting conclusions to be drawn. First, poor readers have a short-term memory deficit that is specific to tasks requiring phonetic coding. Second, adults' performance in verbal short-term memory is related to their perceptual abilities. Third, there is some evidence that developmental increases in STM may be the by-product of increases in the efficiency of phonetic encoding. Influenced by these findings, our experimental work has proceeded in two directions: 1) we focused on the developmental link between phonetic processes and verbal STM to determine more precisely how closely they are connected with one another; and 2) we examined the role of perceptual processes in the short-term memory deficits of poor readers. In the remainder of the paper, the results of these experiments will be summarized.

### Development of Phonetic Skills and Memory Span

The developmental relationship between phonetic processes and memory span was examined in a study with 4½-year-olds,

6½-year-olds, and 8½-year-olds (Merlo and Brady in preparation). A number of tasks were used to evaluate the correspondence of different aspects of phonetic and memory processes. The phonetic tasks included word repetition with monosyllabic and multisyllabic words, and repeated production of disyllabic tongue twisters (e.g.,/sishi/). The responses were scored for reaction time and for the number of correct productions. In this way both speed and accuracy of phonetic processing were measured, allowing separate analyses for these two elements of phonetic efficiency. In the word repetition tasks, response time would reflect both encoding and articulation. We were interested in isolating these components of word repetition speed. To that end, a control task was included in which the children would hear a non-speech tone to which they were to respond with a prespecified word (either monosyllabic /cat/ or multisyllabic /banana/). In this task, no speech signal has to be encoded; hence it provides an indication of the output or articulatory process.

The goal in this experiment was to examine the developmental link between the phonetic processes of encoding and articulation, and verbal short-term memory capacity. To assess verbal STM, word strings of familiar concrete nouns were given. A nonverbal STM task, the Corsi block test (Corsi 1972), was included for comparison to help ascertain whether increases in phonetic processes were related to increases in verbal memory. In this test nine identical black blocks are mounted in a scattered arrangement on a wooden surface. The experimenter points, one by one, to a series of blocks. The subject must then repeat this sequential pattern.

All of the measurements on the phonetic and memory tasks showed improvement with age. The linear correlations between verbal STM (VSTM) and each of the measures of phonetic processing skill were all found to be significant: as VSTM increased, verbal reaction and response time decreased, as did the number of errors. It was necessary to check that the variation in age, or some cognitive factor that improves with age, was not a spurious basis for the reported significant relationships among VSTM and the phonetic processing measures. To assess this, a series of correlational analyses were conducted with the effects of age controlled statistically. The resulting partial correlation coefficients showed that when the effects of age were removed, a statistically significant linear relationship continued to exist between VSTM and phonetic processing. The highest correlations were obtained on the accuracy measures for the more demanding tasks: multisyllabic words and tongue twisters. On the speed of processing measures there was an interesting split. The reaction time scores were significantly correlated with verbal memory span after age

was partialled out, with two exceptions. These were the control tasks in which the subjects said a word as soon as they heard a tone. This lack of relationship demonstrates that the process tapped by these measures (speaking rate) was not closely related to memory. In any case from the overall results, it seems reasonable to conclude that the ability to process phonetic information efficiently plays at least a partial role in verbal short-term memory functioning.

The importance of this connection between phonetic processing and VSTM is shown by contrasting these results with the correlations with nonverbal memory (the Corsi test). When age was partialled out, verbal and nonverbal memory spans were not significantly correlated, nor was nonverbal memory performance closely related to the phonetic processing measures. Only one variable, monosyllabic reaction time, produced a significant correlation with nonverbal memory (with this number of comparisons that could be a chance result). Certainly the general picture for the relationship of phonetic skills to nonverbal memory was very different.

Demonstration of the close ties between performance on the phonetic tasks and verbal STM span strengthens the evidence that phonetic encoding processes in memory contribute to the basis of individual differences in memory capacity. These results both corroborate and extend previous research findings (Case et al. 1982; and Hulme et al. 1984) that showed evidence for developmental improvements in word repetition speed and in verbal STM. In the Merlo and Brady study (in preparation), these findings were confirmed with a variety of phonetic tasks, and there was also evidence for age-related increases in accuracy. Thus older children had longer memory spans and were able to repeat verbal stimuli more accurately and rapidly than younger children. The importance of the relationship between the phonetic variables and memory was underscored by demonstrating that relationship even when age was removed as a factor, and showing no such link with nonverbal memory. Thus when we examine short-term memory developmentally, there is strong evidence that the efficiency of phonetic processes is centrally related to verbal short-term memory span.

### **Phonetic Processes, Memory Span, and Reading Ability**

As noted in the section on background evidence, the results of several studies indicate that the problems poor readers demonstrate in verbal STM are related to their use of phonetic coding. In light of the evidence of the developmental relationship between phonetic processes and verbal memory, we can ask more analytic questions about the phonetic basis of the poor readers' memory deficit. One such



question is whether reading group differences in memory span arise from the perceptual requirements in STM: do good and poor readers differ in the efficiency of phonetic encoding?<sup>3</sup>

*Effects of noise on phonetic encoding.* A few years ago we began to investigate the phonetic skills of children varying in reading performance. In Brady et al. (1983), third-grade children varying in reading ability were tested on a word repetition task consisting of monosyllabic nouns chosen to control for phonetic and syllabic construction and for word frequency. Since the perceptual abilities of poor readers are within normal limits, we anticipated that detecting a phonological deficit in poor readers with a perceptual task might require an especially demanding task. Therefore, the words were recorded in two noise conditions to vary the perceptual difficulty. In one condition, the words were presented clearly; in the second, amplitude-matched noise was added to each stimulus. On the no-noise task, both the good and the poor readers had nearly perfect performance. The addition of noise made it harder for all the subjects to identify the words, but reduced the poor readers' accuracy significantly more than that of the good readers.

The study showed that the perception skills of poor readers are less effective, but that this difference is only observable when the task is difficult. To determine whether poor readers have a general problem with auditory perception, these same subjects were tested on perception of environmental sounds (e.g., human activities [knocking on a door]; animal noises [frogs croaking]; mechanical sounds [a car starting up and driving off]). Once again the stimuli were presented against a background of silence and in (white) noise. As was found with the speech stimuli, performance on environmental sounds was high in the noise-free condition and deteriorated with noise. However, the reading groups did not differ significantly from each other on either condition. If anything, the poor readers identified the sounds-in-noise somewhat more accurately than their better-reading peers. This pattern of results suggests that the difficulty poor readers manifest in perceiving speech-in-noise is not the consequence of generally deficient auditory perceptual ability, but is related specifically to the processing requirements for speech. Thus, paralleling the memory

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<sup>3</sup>As in the developmental literature, researchers have also asked whether differences in reading skill might be related to differences in the use of cognitive strategies (i.e., conscious control processes such as rehearsal). As Stanovich (1985) has noted in a review (see also Jorm 1983), there is evidence that poor readers are less likely to employ cognitive strategies deliberately that enhance memory performance, and this must be acknowledged as a factor in poor readers' inferior recall. However, there are also studies demonstrating that when good and poor readers are equated on the use of particular strategies, differences in performance level are still present (Cermak et al. 1980; Cohen and Netley 1981; Torgesen and Houck 1980).

results, poor readers have a problem specific to language that entails phonetic coding.

*Effects of phonological difficulty on phonetic encoding.* We hypothesized that poor readers may have a problem forming a phonetic representation in short-term memory, whether they are establishing a speech label for a visual stimulus (a letter or a word or a nameable picture), or whether they are listening to a spoken word. Given that however language is perceived it is necessary to encode the material, we conjectured that the deficiency of poor readers in processing phonological structures is a constant feature. Further, this problem may limit the resources in memory and impair recall on memory tasks. We speculated that the poor readers' encoding problem for speech was present for all language tasks, but was only discernible if the task were sufficiently difficult. To test this line of reasoning, it was necessary to determine whether differences in perception can be demonstrated even under clear listening conditions. In the previous study, with both groups at near ceiling performance levels on the noise-free condition, the task may not have been sensitive enough.

If reading group differences in perceptual processing efficiency are present for clear listening, let's consider how such differences might occur: poor readers might be slower at encoding a phonetic item and/or the quality of the phonetic representation might be less fully accurate. With relatively easy phonetic material and no time limitations, poor readers could possibly perform adequately with either or both of these processing limitations.

With these questions in mind, Brady, Poggie, and Merlo (in press) examined third-grade good and poor readers on a speech perception task designed to discover whether reading group differences are evident, under some circumstances, when stimuli are presented clearly. Three kinds of stimuli were presented: monosyllabic words, multisyllabic words, and pseudowords. In this way the phonological demands of the task were varied in case monosyllabic words (previously tested) were not sufficiently difficult to process to reveal potential group differences. Therefore the length of the stimuli was increased in the multisyllabic condition, and the familiarity was decreased by using novel constructions (that could occur in English) in the pseudoword condition. Both of these are known to increase processing demands. Reaction time measures were collected to assess processing speed and the responses were scored for accuracy.

When the perceptual skills of good and poor readers were examined, we found that the poor readers were significantly less accurate on the more difficult multisyllabic and pseudoword stimuli. While there were group differences in accuracy, no difference between good and poor readers was obtained for speed of responding. These findings

suggest that the critical differences in phonological processing between good and poor readers are related to the accuracy of formulating phonetic representations, not with the rate of processing them. This result complements and clarifies the earlier finding of inferior speech perception by poor readers with speech-in-noise. In sum, it seems when the speech items are somewhat difficult to perceive for any reason, either because of the signal-to-noise ratio, or the phonological complexity or novelty, children with reading problems do significantly less well. Thus when the task is demanding, the lesser ability of poor readers to extract and process the phonetic information from the stimulus items becomes apparent.

*Phonetic encoding and STM.* Our motive for looking at perceptual skills was to address whether the poor readers have encoding deficits that may contribute to their characteristic limitation in verbal STM. Having demonstrated phonological deficits in poor readers on perceptual tasks, the next step was to see how closely perception and memory performance correspond for children who vary in reading ability. We must return at this point to the developmental study by Merlo and Brady to which we referred earlier. As part of that study, two additional groups of 8½-year-olds were tested: good readers and poor readers. Recall that in that study children were tested on both phonetic and memory tasks. The phonetic tasks were word repetition for monosyllabic and multisyllabic words, repetition of tongue twisters, and words spoken when a nonspeech tone was heard. Speed and accuracy measures were collected. The memory tasks were word strings and the nonverbal Corsi test.

As expected, the reading groups differed significantly on verbal memory, but did not differ on nonverbal STM. On the phonetic tasks, the results replicated the pattern in the study described just prior to this (Brady et al. in press). Poor readers were significantly less accurate in phonetic processes, and this was again apparent on the more demanding tasks. Once again the reading groups did not differ on speed of processing. Therefore we have a consistent result that poor readers, though not slower, have less accurate phonetic coding, and verbal short-term memory deficits. It is noteworthy that significant correlations were obtained for the reading groups between the accuracy scores on the more demanding measures of phonetic skill and the verbal STM performance: multisyllabic errors and VSTM,  $r = -.52$ ; tongue twister errors and VSTM,  $r = -.40$ . These correlations imply that the reading group differences in verbal short-term memory are associated with differences in phonetic encoding processes common to perception and memory tasks.

### Concluding Remarks

To summarize, in this paper we referred to extensive evidence that poor readers have verbal short-term memory deficits. In trying to investigate the basis of the memory deficit, we have adopted a cognitive framework for viewing short-term memory as a limited capacity system. Within that system, if initial encoding is less efficient, the ultimate resources for memory and comprehension will be reduced. In the research presented here, this approach was supported in a developmental study showing a close link between the efficiency of phonetic skills and the available storage capacity in short-term memory. Turning to children with reading problems, we then demonstrated that poor readers are relatively less efficient at phonetic processes (as seen in the accuracy measures), and that this performance corresponds with their reduced memory space (as seen in the correlations between accuracy and memory span).

The identification of less accurate phonetic encoding by children who are poor readers provides a parsimonious account of their difficulties on a number of language tasks involving memory and/or perception, including sentence comprehension (see Shankweiler and Crain [in preparation] for elaboration of this idea). Further, the present research adds to the burgeoning evidence that poor readers have difficulty in the phonological domain. The problems in phonetic processing, here observed in verbal short-term memory and in speech perception, have also been noted in other language tasks: poor readers are generally lacking in metalinguistic awareness of phonological structure, produce more errors when naming objects, and are less accurate at comprehension of spoken sentences. As Liberman and Shankweiler (1985) discuss in a review of these findings, all of the difficulties appear to stem from deficiencies involving the phonological component of the language. To build on the current knowledge about the origin of reading disability, it would be valuable to explore the interrelationship of these diverse abilities in normal development and in children encountering difficulty in reading; and to understand the underlying phonetic and memory processes better.

### Practical Implications

Practitioners working to alleviate reading problems in children will reasonably be asking if the current research, though short of complete knowledge, has any practical application. We have seen that poor readers are less efficient at phonetic coding and have memory deficits. The developmental literature suggests that with experience encoding operations increase in efficiency, and memory span in-

creases. Thus, it may generally be useful to employ more memory games and tasks in school to provide greater practice (cf., Mann and Liberman 1984). For those individuals with memory deficits, it becomes particularly important in reading acquisition (as Perfetti and Lesgold [1979] and Perfetti [1985] have stressed) to overlearn decoding skills to increase encoding speed. In this way the individual can compensate for a further limitation in STM, which is already, by its nature, brief and limited in capacity.

While these recommendations perhaps are not curative, understanding the underlying problems for children with reading difficulty can serve as an important aid in avoiding inappropriate diagnoses and inappropriate treatment. There are some practical implications in this direction from the cognitive research. In closing, these will be briefly described:

1. Evidence is steadily mounting that the problem poor readers have is specific to language. Many prereading programs incorporate practice in labelling environmental sounds. Our research indicates this is a separate, unrelated skill: that children with reading problems are not having a difficulty with nonspeech sound categorization, thus suggesting a teacher would be better off spending time on relevant language tasks such as auditory training on phonological awareness (see Liberman et al. [1980] for examples).
2. If the errors poor readers made on STM tasks provided evidence that these children were using some other strategy, such as visual or semantic coding, one might conclude they should be taught by a different method. But evidence that poor readers use deviant coding strategies has not been obtained in the research surveyed here. Error analyses confirm that good and poor readers use the same strategies, but poor readers are less accurate.
3. Sometimes the well-intended motive to teach "to the child's strength" goes off-track. Obviously a practitioner needs to deal pragmatically and sensitively with the child's self-esteem and self-confidence, but what has been observed is that the poor reader needs help in phonological processes. The memory research, and that on linguistic awareness, points directly to this. Avoidance of the problem will not improve the essential phonological skills.
4. A similar comment can be made about the recommendation to "teach to the right hemisphere." From what is known about language processing, it is evident that when humans are presented with a letter or word, whether by eye or by ear, a phonetic representation is formed in short-term memory. Neurological

studies confirm that this involves regions of the left cerebral hemisphere (Milner 1974). Going to the whole word method of instruction in no way bypasses linguistic processing: the child is simply left with the more difficult task of figuring out phonic relationships and decoding skills without helpful instruction, but the left-hemisphere linguistic processes involved have not been eliminated.

5. Another lesson from the research on phonological deficits pertains to the issue of "visual learners vs. auditory learners," "visual and auditory dyslexics," etc. On the visual and auditory short-term memory tasks for verbal material, poor readers were found to have a *general* phonetic coding deficit. The modality of presentation did not matter.

Why might the misunderstanding about visual and auditory learning have come about? If the verbal material has been presented visually (either letters, or words, or, maybe especially, pictures), the person testing the subject may focus on the visual nature of the task and interpret a performance deficit as visual in origin. But again, from the studies that have been reviewed, it is known that the child will encode the presented material phonetically. So linguistic processing is central to this visual task. It is important to recognize the language requirements of visual tasks, so as not to draw the wrong conclusion and possibly recommend an inappropriate activity for remediation.

6. In the perception studies, the necessity of having sufficiently sensitive tasks for identifying deficits has been demonstrated. In three different studies, poor readers have been observed to have perceptual problems, but these were only discernible on the more demanding tasks. Many of the standard tests for screening children have rather easy tasks that may demarcate large developmental differences, but not be sensitive to important individual differences. Therefore, it is appropriate to consider whether a task has been sufficiently difficult before concluding that a child has adequate skills in a given area.

### References

- Baddeley, A. 1966. Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. *Quarterly Journal of Experimental Psychology* 18:362-365.
- Baddeley, A. and Hitch, G. 1974. Working memory. In G. A. Bower, (ed.). *The Psychology of Learning and Motivation*, Vol. 8. New York. Academic Press.
- Baddeley, A., Thomson, N., and Buchanan, M. 1975. Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior* 14:575-589.

- Brady, S., Mann, V., and Schmidt, R. 1985. Errors in short term memory for good and poor readers. *Haskins Laboratories Status Report on Speech Research* SR-81: 85-103.
- Brady, S., Poggie, E., and Merlo, M. In press. An investigation of speech perception skills in children who differ in reading ability. *Haskins Laboratories Status Report on Speech Research*.
- Brady, S., Shankweiler, D., and Mann, V. 1983. Speech perception and memory coding in relation to reading ability. *Journal of Experimental Child Psychology* 35:345-367.
- Case, R., Kurland, D., and Goldberg, J. 1982. Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology* 33:386-404.
- Cermak, L., Goldberg, J., Cermak, S., and Drake, C. 1980. The short-term memory ability of children with learning disabilities. *Journal of Learning Disabilities* 13:25-29.
- Chi, M. T. H. 1976. Short-term memory limitations in children: Capacity or processing deficits? *Memory and Cognition* 4:559-572.
- Cohen, R. and Netley, C. 1981. Short-term memory deficits in reading disabled children in the absence of opportunity for rehearsal strategies. *Intelligence* 5:69-76.
- Conrad, R. 1972. Speech and reading. In J. F. Kavanaugh, and I. G. Mattingly (eds.). *Language by Ear and by Eye: The relationship between speech and reading*. Cambridge, Mass.: MIT Press.
- Corsi, R. M. 1972. Human memory and the medial temporal region of the brain. Unpublished doctoral dissertation, McGill University.
- Daneman, M. and Carpenter, P. 1980. Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior* 19:450-466.
- Dempster, F. N. 1981. Memory span: Sources of individual and developmental differences. *Psychological Bulletin* 89:63-100.
- Engle, R. and Marshal, K. 1983. Do developmental changes in digit span result from acquisition strategies? *Journal of Experimental Child Psychology* 36:429-436.
- Hall, J., Wilson, K., Humphreys, M., Tinzmann, M., and Bowyer, P. 1983. Phonemic-similarity effects in good vs. poor readers. *Memory and Cognition* 11:520-527.
- Hanson, V. L., Liberman, I. Y., and Shankweiler, D. 1984. Linguistic coding by deaf children in relation to beginning reading success. *Journal of Experimental Child Psychology* 37:378-393.
- Hoosian, R. 1982. Correlation between pronunciation speed and digit span size. *Perceptual and Motor Skills* 55:1128.
- Hulme, C., Thomson, N., Muir, C., and Lawrence, A. 1984. Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology* 38:241-253.
- Huttenlocher, J., and Burke, D. 1976. Why does memory span increase with age? *Cognitive Psychology* 8:1-31.
- Jorm, A. 1983. Specific reading retardation and working memory: A review. *British Journal of Psychology* 74:311-342.
- Katz, R., Shankweiler, D., and Liberman, I. 1981. Memory for item order and phonetic recoding in the beginning reader. *Journal of Experimental Child Psychology* 32:474-484.
- LaBerge, D. and Samuels, S. 1974. Towards a theory of automatic information processing in reading. *Cognitive Psychology* 6:293-323.
- Liberman, I. 1983. A language-oriented view of reading and its disabilities. In H. Myklebust (ed.). *Progress in Learning Disabilities*, Vol. V. New York: Grune and Stratton.
- Liberman, I., Mann, V. A., Shankweiler, D., and Werfelman, M. 1982. Children's memory for recurring linguistic and nonlinguistic material in relation to reading ability. *Cortex* 18:367-376.
- Liberman, I. and Shankweiler, D. 1985. Phonology and the problems of learning to read

- and write. *Remedial and Special Education* 6:8-17.
- Liberman, I. Y., Shankweiler, D., Blackman, B., Camp, L., and Werfelman, M. 1980. Steps toward literacy. In P. Levinson, and C. H. Sloan, (eds.). *Auditory Processing and Language: Clinical and research perspectives*. New York: Grune and Stratton.
- Liberman, I., Shankweiler, D., Liberman, A. M., Fowler, C., and Fischer, F. W. 1977. Phonetic segmentation and recoding in the beginning reader. In A. S. Reber, and D. Scarborough, (eds.). *Toward a Psychology of Reading: The Proceeding of the CUNY Conference*. Hillsdale, N.J.: Erlbaum.
- Mann, V. 1984. Reading skill and language skill. *Developmental Review* 4:1-15.
- Mann, V. A. and Liberman, I. Y. 1984. Phonological awareness and verbal short-term memory: Can they presage early reading problems? *Journal of Learning Disabilities* 17:592-599.
- Mann, V., Liberman, I., and Shankweiler, D. 1980. Children's memory for sentences and word strings in relation to reading ability. *Memory and Cognition* 8:319-335.
- Mark, L. S., Shankweiler, D., Liberman, I. Y., and Fowler, C. A. 1977. Phonetic recoding and reading difficulty in beginning readers. *Memory and Cognition* 5:623-629.
- Merlo, M. and Brady, S. In preparation. Reading ability and short-term memory: The role of phonetic processing.
- Milner, B. 1974. Hemispheric Specialization: Scope and limits. In F. O. Schmitt and F. G. Wording (eds.). *The Neurosciences: Third Study Program*. Cambridge, Ma.: MIT Press.
- Olson, R., Davidson, B., Kliegl, R., and Davies, S. 1984. Development of phonetic memory in disabled and normal readers. *Journal of Experimental Child Psychology* 37:187-206.
- Perfetti, C. 1985. *Reading Ability*. New York: Oxford University Press.
- Perfetti, C., and Lesgold, A. 1977. Discourse, comprehension, and sources of individual differences. In M. A. Just and P. A. Carpenter (eds.). *Cognitive Processes in Comprehension*. Hillsdale, N.J.: Erlbaum
- Perfetti, C. and Lesgold, A. 1979. Coding and comprehension in skilled reading and implications for reading instruction. In L. B. Resnick, and P. Weaver, (eds.). *Theory and Practice in Early Reading*. Hillsdale, N.J.: Erlbaum.
- Rabbitt, P. M. A. 1968. Channel-capacity, intelligibility and immediate memory. *Quarterly Journal of Experimental Psychology* 20:241-248.
- Samuel, A. G. 1978. Organizational vs. retrieval factors in the development of digit span. *Journal of Experimental Child Psychology* 26:308-319.
- Shankweiler, D. and Crain, S. In preparation. Language mechanisms and reading disorders: a modular approach.
- Shankweiler, D., Liberman, I. Y., Mark, L. S., Fowler, C. A., and Fischer, F. W. 1979. The speech code and learning to read. *Journal of Experimental Psychology: Human learning and memory* 5:531-545.
- Stanovich, K. 1982. Individual differences in the cognitive processes of reading: I. Word decoding. *Journal of Learning Disabilities* 15:485-493.
- Stanovich, K. 1985. Explaining the variance in reading ability in terms of psychological processes: What have we learned? *Annals of Dyslexia* 35: 67-96.
- Torgesen, J. and Houck, D. 1980. Processing deficiencies of learning-disabled children who perform poorly on the digit span test. *Journal of Educational Psychology* 72:141-160.
- Tzeng, O. J. L., Hung, D. L., and Wang, W. S. Y. 1977. Speech recoding in reading. *Journal of Experimental Psychology: Human Learning and Memory* 3:621-630.
- Vellutino, F. 1979. *Dyslexia: Theory and research*. Cambridge, Mass.: MIT Press.
- Vellutino, F., Pruzek, R., Steger, J., and Meshoulam, V. 1973. Immediate visual recall in poor and normal readers as a function of orthographic-linguistic familiarity. *Cortex* 9:368-384.