

# Reading Ability and Short-Term Memory: The Role of Phonological Processing

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**ABSTRACT:** The aim of the current study was to further explore the connection between verbal short-term recall and phonological processing for two purposes: (a) To investigate the basis of short-term memory deficits for children with reading disability, and (b) To further explore the origin of developmental verbal memory span increases.

Using a variety of memory and phonological tasks, reading group comparisons were conducted testing third-grade good readers and poor readers, and developmental changes were studied with pre-kindergarten, first-grade and third-grade children. The main finding was that a strong relationship was observed between efficiency of phonological processes and capacity of verbal memory supporting the hypothesis that reducing phonological processing requirements in verbal short-term memory increases available resources for storage. No such relationship was found between phonological processing and nonverbal memory. This conclusion was supported by two findings: (a) The verbal short-term memory deficits in poor readers significantly correspond with less accurate phonological processing, and (b) Developmental increases in verbal STM are accompanied by more accurate and rapid execution of phonological tasks.

**KEYWORDS:** Reading ability, Short-term memory, Phonological processes, Memory development, Operational efficiency

Deficiencies in the verbal short-term memory (VSTM) of children with specific reading disabilities have been repeatedly documented. Past research suggests that this verbal STM deficit may be linked to a lack of proficiency in the use of a phonological code. Similarly, developmental gains in verbal STM span have been associated, in part, with increases in the efficiency of linguistic processing. The aim of the current research was to further explore the connection between verbal short-term recall and phonological processing for two reasons: (a) To investigate the basis of VSTM deficits for children with reading disability, and (b) To further explore the origin of developmental verbal-memory span increases. However, before the experiments are described, a brief review of the evidence on poor readers' STM abilities and on the development of STM in normal children will be presented.

## BACKGROUND

Children with reading problems have shorter STM spans on average than do good readers of comparable age (see Jorm 1983, Stanovich 1982 for reviews). This pattern has been obtained with digit span measures, letter strings, sentence tasks, and recall for pictures of familiar objects.

Interestingly, poor readers have deficient recall on STM tasks both for visually and auditorily presented stimuli suggesting that the memory problem is not limited to printed material (Shankweiler, Liberman, Mark, Fowler and Fischer 1979). However, when stimuli are used that are not easy to represent linguistically, recall has not been found to be related to reading ability. This has been observed when the memory task consisted of photographs of strangers, nonsense figures, or symbols from an unfamiliar writing system (Katz, Shankweiler and Liberman 1981, Liberman, Mann, Shankweiler and Werfelman 1981, Vellutino, Pruzek, Steger and Meshoulam 1973). Thus the memory deficit for poor readers is not restricted to reading tasks, but appears to be specific to verbal memory processes.

Olson, Davidson, Kliegl, and Davies (1984) have noted that the growth pattern of poor readers' verbal STM skills seems to lag behind normal STM development. While memory span has been observed to increase linearly for both normal children and reading disabled children, the STM skills for disabled readers at any given age are comparatively deficient. A delayed developmental pattern for poor readers is also evident in the effect of phonological confusability on recall. Among normal children, the typical five year old child recalls equal numbers of items from rhyming lists and from nonrhyming lists whereas older children, aged eight to eleven, recall significantly more nonrhyming items (Conrad 1971). The superior recall for nonrhyming stimuli emerges several years later in poor readers (Olson et al 1984, Siegel and Linder 1984).

These findings suggest that factors which contribute to developmental differences in verbal STM skill may also account for reading group differences in linguistic STM. Three kinds of explanations have been offered to account for developmental and reading group differences in verbal STM performance. These will be briefly described.

### *Mnemonic Strategy Use*

The differential use of various mnemonic strategies has been offered as one explanation for developmental increments in STM span. According to this view, children become increasingly aware that certain strategies will enhance recall, and are thus increasingly able to employ an appropriate technique. Clearly, mnemonic strategy use does advance as children become older. This has been observed in more frequent spontaneous use

of rehearsal strategies, and in better use of imposed or subjective organization (see Chi 1976 for a review).

Differential employment of control processes has also been proffered by a number of researchers to explain contrasts in STM for good readers and poor readers. Good readers have been found to use rehearsal more spontaneously and efficiently than do children with reading problems (Tarver, Hallahan, Kauffman and Ball 1976, Torgesen and Goldman 1977). In addition, Torgesen (1978-79) reports that good readers are more likely than poor readers to use a chunking strategy or to consciously impose an organizational plan on materials to be recalled.

However, there are additional findings, as well as some interpretive difficulties, suggesting that mnemonic strategy use is not the sole basis for individual differences in span. First, Lange (1978) noted that several studies found adolescents and adults more likely to use a subjective organization strategy than were five to twelve year olds. Yet the investigations failed to discern improvement in the spontaneous use of that technique during the elementary school age period. This is a period in which STM span has been found to increase dramatically (Dempster 1981).

A second conflicting piece of evidence comes from a series of experiments which have equated children's use of certain control processes during STM tasks. In one such study, Samuel (1978) temporally grouped items in recall lists. Children ranging in age from six to nineteen all benefited equally from this grouping technique, thus maintaining observed age differences (see also Huttenlocher and Burke 1976, Engle and Marshall 1983).

Similar results have been obtained when subjects have been good readers and poor readers. Both reading groups have been shown to benefit equally from experimenter imposed chunking and grouping strategies, thereby preserving observed group differences in STM span (Torgesen and Houck 1980). Likewise, when the use of mnemonic techniques is prevented, both good readers and poor readers exhibit a decline in digit span (Cohen and Netley 1981, Torgesen and Houck 1980).

### *Capacity*

The capacity of STM is another factor which has been considered to play a role in span differences (Miller 1956). Proponents of capacity explanations for STM limitations hold that a certain number of memory slots are available prior to the presentation of any stimuli. Developmental differences in span are interpreted as due to the presence of a greater number of these slots as a function of age (e.g. Pascual-Leone 1970, Halford and Wilson 1980). This position is consistent with the observation of developmental increases in recall, and also fits the observed differences in STM span among good and poor readers. However, a series of experiments

conducted by Baddeley, Thomson and Buchanan (1975) demonstrated that the number of items to be retained was not a powerful predictor of STM span. Instead, temporal duration of the item list was a stronger determinant of span. Thus it seems an alternative explanation must account for individual differences in STM performance.

### *Operational Efficiency*

A third approach proposes that observed developmental capacity differences may be due to "... a decrease in the amount of capacity required to execute transformations rather than an increase in overall capacity per se" (Dempster 1981 p. 86). In this vein, Case, Kurland and Goldberg (1982) suggest that memory is served by a limited capacity system and that memory operations such as encoding and retrieval become more efficient with experience. As a result, the amount of operating resources needed to complete STM tasks decreases with age and there is a functional increase in storage capacity.

Three kinds of evidence are compatible with this hypothesis. First, it has been observed with adults that if the ease of encoding stimuli is made more difficult by changing the perceptual demands, short-term recall will suffer (Luce, Feustel and Pisoni 1983, Mattingly, Studdert-Kennedy and Megan 1983, Rabbitt 1968). These findings support the hypothesized tradeoff of resources between encoding and storage. Second, children with articulation disorders have been found to have impaired short-term memory performance (Locke and Scott 1979). Third, there are indications that for both adults and children the intrinsic efficiency of phonological processes (i.e., speaking rate) correlates positively with memory span (Baddeley et al 1975, Hulme, Thomson, Muir and Lawrence 1984).

In keeping with this, Case et al (1982) demonstrated that developmental advances in phonological processes may be centrally related to increases in memory capacity. Testing three-to-six year old children, all of whom are unlikely to use mnemonic strategies, these authors 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, recalled more of the words. In a convincing test of this relationship, Case et al found that when adults' speaking rate was slowed to the rate for 6 year old children by giving the adults more difficult items, that memory span with these stimuli was also matched for the two age groups. Although the encoding processes involved in memory were only evaluated by word-repetition speed, these results indicate that developmental increases in memory span may be linked to the efficiency of underlying processes.

Recent research suggests that the operational efficiency model may apply only to the precognitive requirements of establishing and maintaining a phonological representation of stimuli for short-term use. An

extensive series of experiments have been conducted demonstrating that performance on problem-solving tasks such as class inclusion, conservation, and probability judgment does not relate to recall of background facts using short-term memory measures (Brainerd and Kingma 1984, 1985). The thrust of these findings is that working memory capacity should not be conceptualized as a generic pool of resources that supports all cognitive activities, including STM and higher processes.<sup>1</sup> A related issue emerges from the studies cited earlier which find that poor readers have deficits on verbal recall tasks, but not on memory tasks for stimuli that cannot readily be given a phonetic code. In other words, poor readers do not evidence broad memory impairment, but have deficits specific to verbal processing. Thus, as others have suggested, a more modular approach to working memory, and to the concept of limited resources, looks to be necessary. (See Baddeley 1986 for an example of a working memory model with separate subsystems for phonological and visuo-spatial processing.)

Returning to the issue of developmental increases in memory span, it appears the focus needs to amend from a broad view of operational efficiency to a narrower question concerning the structure of the phonological system involved in verbal memory. The concept of limited resources seems to have validity within the framework of verbal memory capacity and the underlying phonological processes such as coding and retrieval, as the studies cited earlier demonstrate (e.g. Case et al. 1982). It remains to further study developmentally the degree of overlap for the processing requirements common to perception and to production of speech, as well as for the short-term recall of verbal material.<sup>2</sup>

Let us consider the reading group literature to examine whether the memory differences of good readers and poor readers might also be accounted for by the efficiency of underlying phonological processes. This remains to be fully addressed, but current findings are compatible with this hypothesis. First, following from the evidence that linguistic information in STM is typically stored in the form of a phonological code, several studies have focused on the use of phonological coding by good readers and poor readers. Error analyses revealed that both reading groups were using speech coding strategies, but poor readers were less accurate (Brady, Mann and Schmidt 1978). Similarly, as mentioned earlier, a number of experiments have reported that the effects of phonetic confusability on recall are generally reduced for children with reading problems (Brady, Shankweiler and Mann 1983, Liberman and Shankweiler 1979, Mann, Liberman and Shankweiler 1980, Mark, Shankweiler, Liberman and Fowler 1977, Olson et al 1984, Shankweiler et al 1979, Siegel and Linder 1984).<sup>3</sup> Both findings indicate less effective use of phonological coding in STM.

A second line of investigation has demonstrated speech perception

deficits for poor readers, possibly reflecting a general difficulty encoding language (Godfrey, Syrdal-Lasky, MacKay and Knox 1981, Palley 1986, Read, personal communication, Snowling, Goulandris, Bowlby and Howell 1986, Werker and Tees 1987). Brady et al. (1983) found poor readers were less accurate at identifying words-in-noise, and other studies revealed poor readers to be less accurate at repeating multisyllabic words and nonsense words (Apthorp 1988, Brady, Poggie and Rapala (in press), Snowling 1981). It is, of course, difficult to determine whether the problem arises during the perception or production components of such tasks, or to the common requirement of formulating a phonological representation. Indeed, there are clinical reports that individuals with reading difficulty often display misarticulations in their speech (Blalock 1982, Chasty 1986, Johnson and Myklebust 1967, Klein 1986), as well as empirical demonstrations that dyslexics are slower and less accurate at repeating phrases (Catts 1986, Catts manuscript submitted). Finally, additional evidence of a link between phonological processes and memory capabilities with respect to reading level has been tentatively supported by positive correlations between digit naming speed and memory span (Spring and Capps 1974, Spring and Perry 1983, Torgesen and Houck 1980), although Stanovich (1985) notes inconsistencies in this outcome. In sum, phonological difficulties in memory, in speech perception, and in speech production have been observed in children with reading difficulties and there have been occasional reports of correlations between these measures.

To review, in seeking an explanation of the STM deficits characteristic of poor readers, we have considered the explanations proposed for developmental changes in memory performance. Both the developmental research and the reading group research point toward a role of phonological processing in memory capacity. However, in each field the questions have been incompletely addressed. The developmental studies have concentrated on the correspondence between speaking rate and memory, emphasizing the importance of speed of articulation. The reading studies have more extensively investigated phonological processes in speech perception and speech production that may relate to memory performance, but have generally examined each area in isolation.

## RESEARCH GOALS

The current research was designed to more thoroughly investigate whether developmental and reading group differences in verbal STM span may relate to the efficiency of related phonological processes. Using a more extensive battery of tests than has previously been employed, a cross-sectional developmental study was carried out to closely examine the association between verbal STM and phonological processes in speech

perception and speech production. Both speed and error measures were collected to allow a fuller comparison of performance variables. Non-verbal control tasks were included to determine whether correlations between verbal STM and measures of phonological processing can be attributed to shared linguistic processing requirements or to more general cognitive functioning. Complementing the developmental study, a comparison of third-grade good readers and poor readers was conducted using the same test battery to directly assess whether poor readers' difficulties in STM are associated with deficits in other phonological processes.

## METHOD

### *Subjects*

A total of 74 children from a suburban school district in southeastern Connecticut and from a suburban preschool in southern Rhode Island served as subjects in the study and comprised five subject groups. There were three developmental groups and two reading groups. (See Table 1 for descriptive characteristics of the five groups.)

The three groups selected for participation in the developmental portion of the current investigation were chosen to represent samples of children in pre-kindergarten, first-grade and third-grade. Children were selected for group membership if they met four criteria:

*Age.* Pre-kindergarten subjects had to be between four years, zero months and four years, eleven months of age. First-graders were required to be between six years, zero months and six years, eleven months, while the age limits for third-graders were from eight years, zero months to eight years, eleven months.

*IQ.* To be eligible for inclusion in the study children had to score within the average to above average range of intellectual functioning (85–125) as measured by the Peabody Picture Vocabulary Test-Revised (Dunn 1981). The IQ requirement was meant to limit intellectual differences between groups. An analysis of variance procedure found no significant group differences in IQ.

*Hearing.* Since perceptual tasks were included in the experimental procedure, no children with hearing impairments were included as subjects. An audiometer was used to screen for hearing deficits. Each potential subject's right and left ears were tested with tones at five different frequencies: 500 Hz (25dB), 1000 Hz (20dB), 2000 Hz (20dB), 4000 Hz (20dB) and

8000 Hz (20dB). A child was excluded from the study if he or she was unable to detect two or more of the ten tones.

*Speech Production.* Finally, because speech production measures were used in this study, children who were eligible for, or were receiving, remedial services for disorders of speech were not considered as potential subjects.

Table 1. Descriptive statistics and Anova results

	Pre-K (n = 15) M(SD)	First (n = 15) M(SD)	Third (n = 15) M(SD)	Good readers (n = 14) M(SD)	Poor readers (n = 14) M(SD)	F (df)
Age (months)	55.7	79.5	102.9	103.8	105.0	—
IQ (PPVT-R)	102.8 (10.1)	111.8 (13.6)	104.6 (13.7)	111.0 (6.3)	107.3 (11.3)	0.14 (4,69)
Word Identification	— —	— —	3.2 (0.7)	5.2 (1.2)	2.5 (0.5)	24.80* (1,14)
Word Attack	— —	— —	3.5 (1.4)	7.5 (2.9)	2.2 (0.5)	20.80* (1,14)
VSTM	50.3 (11.3)	68.9 (8.2)	73.9 (6.3)	77.8 (8.0)	69.9 (10.1)	22.38* (4,69)
NVSTM	56.2 (5.7)	61.5 (5.9)	67.9 (3.1)	69.3 (4.1)	68.5 (3.7)	21.42* (4,69)
MONRT	1.1 (0.1)	0.9 (0.2)	0.9 (0.1)	0.8 (0.1)	0.9 (0.1)	8.79* (4,69)
MULTRT	1.1 (0.1)	1.0 (0.1)	1.0 (0.1)	0.9 (0.1)	0.9 (0.1)	10.92* (4,69)
TTS	14.6 (3.9)	12.3 (3.7)	10.4 (2.1)	9.7 (2.8)	10.4 (2.1)	6.55* (4,69)
MONCO	0.7 (0.1)	0.5 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	26.86* (4,69)
MULTCO	0.7 (0.1)	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)	0.4 (0.1)	18.75* (4,69)
MONE	7.0 (3.2)	4.8 (2.6)	2.9 (2.3)	3.5 (2.6)	2.6 (1.6)	7.83* (4,69)
MULTE	3.5 (2.3)	2.5 (2.1)	1.3 (1.1)	0.9 (0.9)	1.8 (1.5)	5.89* (4,69)
TTE	64.6 (32.7)	27.3 (18.0)	24.0 (17.8)	14.8 (11.8)	35.5 (15.4)	12.75* (4,69)

\*p < 0.05.

In addition to the developmental study, a comparison of third-grade good readers and poor readers was made. Children to be placed in these two reading groups were required to meet the selection criteria outlined above and were also chosen based on reading skill. Reading group assignment was made on the basis of scores on the Word Identification and Word Attack subtests of the Woodcock Reading Mastery Test, Form A (Woodcock 1973). Children identified as poor readers were functioning at least 6 months below grade level on both subtests. Children assigned to the good reader group were all reading at least 6 months above level on these same measures. As noted above, no significant differences in IQ were found between the five groups involved in the developmental and reading studies.

### *Measures: Memory*

Two memory tasks were presented to each of the subjects participating in the experiment. Verbal STM was assessed by word list recall. A nonverbal memory task was included as a control measure to assess whether a relationship between verbal STM and phonological processing is due to shared linguistic processing factors or to general cognitive factors.

#### *Verbal Short-Term Memory Task (VSTM)*

Verbal STM span was assessed by means of a word list recall task. Word lists consisted of concrete nouns (e.g. ball, cat, boy) that have a relatively high frequency in children's literature (Carroll, Davies and Richman 1971), so that even the youngest subjects would be very familiar with the items. Ten lists comprised of four words each and ten lists of five words were prepared and recorded by the experimenter onto audiotape. With each list, presentation rate was about one word per second. An order free scoring procedure was used since a strict order scoring procedure would have been subject to floor effects for the four-year-old subjects. A subject's score was counted as the total number of words correctly recalled, independent of order. The reliability of this task, using the alpha coefficient formula was estimated to be 0.90.

#### *Nonverbal Short-Term Memory Task (NVSTM)*

Nonverbal STM skill was examined using the Corsi blocks. In this task, there are nine, black, one-inch cubes randomly spaced and mounted on an 8 by 11 inch platform. Following a procedure used by Milner (1971) and Mann and Liberman (1984), the experimenter points one by one to a number of different blocks. Subjects were required to replicate four, five or six block sequential patterns, with five trials at each length. A subject's

score was counted as the total number of correctly recalled block positions. Reliability for this task was calculated to be 0.93.

*Measures: Phonological Tasks*

Perception and production tasks were selected and designed so that two aspects of processing could be studied for each task: speed and accuracy of recoding.

*Monosyllabic and Multisyllabic Word Repetition Tasks (MONRT, MONE, MULTRT, MULTE)*

Word repetition tasks were presented to assess speech perception ability. To vary the difficulty of the encoding requirements for the words, word length was varied (monosyllabic vs. multisyllabic). Accordingly, two sets of stimuli were used, both of which had been employed in earlier studies (Brady et al. 1983, Brady et al. 1987). The monosyllabic stimuli contained 48 one syllable words that had been selected to control for phonological construction, syllabic pattern and word frequency. The second word list was comprised of 24 three- and four-syllable words, with an equal number of high and low frequency words for each word length. The two stimuli lists were constructed in the following way.

First, items were recorded by a male speaker as the last word in a meaningful sentence. After digitizing each sentence using a waveform editing device, the words to be used as stimulus items were removed from the sentence. Each stimulus item was then recorded onto one channel of a magnetic audiotape, according to a previously determined random order. On the second channel of the same tape, pulses were recorded to coincide with the beginning of each stimulus item. These pulses were used for measuring subjects' reaction time.

For these tasks subjects were asked to repeat each word as rapidly as possible. Responses were scored for reaction time (the onset of the subject's vocal response to the nearest millisecond) and for accuracy. Respective alpha coefficients of 0.94 and 0.90 for the monosyllabic (MONRT) and multisyllabic (MULTRT) word repetition *speed* measures affirm the internal consistency of these tasks. Using the K-R 20 formula, the internal consistency of the monosyllabic *error* measure (MONE) errors was calculated at 0.76. For multisyllabic *errors* (MULTE) a K-R 20 coefficient of 0.73 was found.

*Articulatory Initiation Rate Tasks (MONCO and MULTCO)*

On the word repetition tasks there are multiple factors in performance, including phonological encoding and output or articulation processes. In

an attempt to separate word identification or encoding processes from the speed of initiating an articulatory gesture, two control tasks were employed which eliminated the speech encoding requirement. For each of these tasks a series of 10 brief 2000 Hz tones was recorded at random intervals onto audiotape, to which subjects would be asked to respond by saying a familiar word. In the monosyllabic control task (MONCO), the word /cat/ was the specified response. In the second condition, (MULTCO), subjects were to respond with a multisyllabic item, the word /banana/. To allow subjects' reaction times to be recorded, a pulse, coinciding with the tone, was recorded on the second channel of the audiotape.

Reaction times were measured for each trial. Reliability was estimated by using the K-R 20 formula. The calculated value for the monosyllabic word initiation task (MONCO) was 0.86. A coefficient of 0.88 was found for the multi-syllabic measure (MULTCO).

#### *Tongue Twister Task (TTS and TTE)*

The speed of initiating a response, as measured in the previous tasks, may tap an aspect of phonological processing that differs from the demands of continuously generating a phonological response. To evaluate this, the duration and accuracy of repeated production of disyllabic utterances was measured. Stimuli consisted of thirteen two-syllable tongue twisters (Kupin 1979). The two-syllable length was chosen because all of the age groups included in the present study typically demonstrate facility recalling word strings of this size (Dempster 1981). In addition, phrases were comprised of nonsense syllables in order to "... neutralize any effects of higher-level processing" (Kupin 1979 p. 37). For each phrase, subjects first repeated the phrase once to ensure that they had accurately perceived it. Subjects were then required to carefully and quickly repeat the tongue-twister-like phrases (e.g. /si-shi/) until they were told to stop. Rapid repetitions were terminated following the 12th (or shortly thereafter) production of the phrase. The first 12 repetitions of each phrase were used for data analyses. Temporal duration of the responses were recorded and averaged (TTS) and number of errors were tallied (TTE). Errors were mispronunciations (i.e., changes of the phonetic construction) of the expected word or syllable. Faltering by stuttering or stammering was not termed a misproduction. The tongue twister repetition speed task was appraised for reliability, and an alpha coefficient of 0.95 was found. For the tongue twister error measure an alpha coefficient of 0.71 was found.

#### *Apparatus*

A reel to reel tape recorder was used during the VSTM and perception tasks. Stimuli were presented to the subject via stereo headphones from

one channel of the tape. For the perception tasks, the other channel, containing the recorded pulses, was connected to a timer. Each pulse activated a counter on the timer. Also connected to the timer was a microphone containing a voice key, which when triggered by the subject's response, stopped the counter. A digital display of the subject's reaction time score appeared on the face of the timer and was recorded by the experimenter.

For the tongue twister task, a stopwatch was used to time subjects' response. In addition, a tape recorder was used to preserve each child's responses for the purpose of later transcription and scoring. This was found to be necessary during pilot testing because of the rapidity and complexity of the subjects' spoken responses.

### *Procedure*

Each subject was tested individually on three separate occasions. During the first session, the children were administered the Peabody Picture Vocabulary Test-Revised (Dunn 1981). Third-grade subjects were also given the Word Identification and Word Attack subtests of the Woodcock Reading Mastery Test (Woodcock 1973). Finally, the nonverbal STM task, the Corsi blocks, was presented.

During the second session, several tasks were administered:

- a) First, the hearing screening was conducted, and those who passed continued with the experiment.
- b) These children were then presented with ten of the twenty VSTM word sets.
- c) For half of the subjects, the monosyllabic word repetition task was then presented. To control for order effects, the other half of the children were administered the multisyllabic word repetition task and the control tasks during this second meeting.
- d) Finally, children were asked to repeat approximately half of the tongue twister phrases. Fifty percent of the subjects were presented with the first six phrases and the others had the last seven tongue twisters administered to them during this session.

The third and last session included presentation of the remaining VSTM lists as well as the perception task(s) that had not been previously administered. In other words, if a subject had completed the monosyllabic word task during the previous session, she was presented with the multisyllabic word task and the articulatory initiation measures during the third meeting. Finally, the tongue twister phrases that had not previously been administered were presented during this session.

## RESULTS

The purpose of the present study was twofold; to examine the relationship between verbal STM and phonological processing, using a developmental approach, and to extend this question to the study of phonological processes in reading disabled children.

*Relationship Between VSTM and Phonological Processing*

As expected, performance on the various cognitive measures improved with age. Pearson product-moment correlation coefficients computed between age and the scores of the nine verbal processing measures were all found to be significantly different from zero at the  $p < 0.05$  level. (The computed coefficients are listed in Table 2.) Our interest was in the degree of correspondence between developmental gains in VSTM and those in other phonological processes. Accordingly, a series of Pearson product-moment correlation coefficients were calculated between VSTM and each of the eight measures of phonological processing skill using data from all 74 subjects. These were all found to be significant at the  $p < 0.05$  level. The negative direction of the coefficients indicates that as VSTM skill increases, verbal reaction and response time decreases, as do number of errors. Alternately stated, these results suggest that, at least for this sample of subjects of varying age, the relations between VSTM and the speed and accuracy of phonological processing is positive.

In general, these results support the hypothesis that there is a substantial developmental component to phonological processing. As children grow older their ability to efficiently analyze, synthesize and produce linguistic information improves. However, these results are also compatible with the explanation that the variable of age, or rather some cognitive functioning factor that improves with age, may be the basis for the reported significant relationships among VSTM and the phonological processing measures. In order to evaluate this possibility, the relationship between VSTM and the various measures of phonological processing skill were reevaluated controlling for 'age'. The resulting partial correlation coefficients (presented above the diagonal in Table 2) imply that when age is controlled, a statistically significant relationship continues to exist between VSTM and phonological processing. This suggests the existence of a meaningful association between VSTM and phonological processing.

This conclusion is corroborated by the results of a final set of Pearson product-moment correlational comparisons. Nonverbal STM was initially compared with each of the nine measures of linguistic processing. Resulting coefficients, listed in the left hand column of Table 3, were all significant at the  $p < 0.05$  level. However, when age was controlled for in a

Table 2. Pearson product — moment correlations (below diagonal), first-order correlations with age partialled (above diagonal); for all 74 subjects

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Age	—										
2. VSTM	0.67*	—	0.20	-0.25*	-0.32*	-0.35*	-0.21	-0.17	-0.25*	-0.43*	-0.42*
3. NVSTM	0.76*	0.61*	—	-0.24*	-0.18	-0.08	-0.01	-0.02	-0.09	0.12	-0.04
4. MONRT	-0.52*	-0.51*	-0.53*	—	0.65*	0.30*	0.47*	0.53*	-0.14	0.20	0.10
5. MULTRT	-0.61*	-0.59*	-0.56*	-0.76*	—	0.37*	0.44*	0.43*	0.10	0.04	0.10
6. TTS	-0.52*	-0.57*	-0.44*	-0.49*	-0.57*	—	0.19	0.35*	0.13	0.37*	0.12
7. MONCO	-0.75*	-0.60*	-0.57*	0.66*	0.69*	0.50*	—	0.68*	-0.12	-0.14	0.13
8. MULTCO	-0.68*	-0.54*	-0.53*	0.69*	0.66*	0.57*	0.84*	—	-0.02	-0.11	0.19
9. MONE	-0.61*	-0.55*	-0.51*	0.22	0.43*	0.41*	0.39*	0.40*	—	0.15	0.42*
10. MULTE	-0.45*	-0.58*	-0.27*	0.25*	0.30*	0.52*	0.25*	0.23*	0.38*	—	0.06
11. TTE	-0.53*	-0.62*	-0.45*	0.35*	0.39*	0.36*	0.47*	0.48*	0.60*	0.29*	—

\*p < 0.05

subsequent partial correlational analysis, eight of the resulting comparisons were found to be nonsignificant. (Results are included in Table 2).

The lack of a general relationship between *nonverbal* memory and phonological processing contrasts sharply with the steadfast association found for *verbal* recall and phonological processes. This indicates that while there are age-related improvements in a variety of cognitive skills, the observed relations between VSTM and the phonological processing tasks is likely to reflect shared linguistic processing factors.

### *Developmental and Reading Group Comparisons*

In order to further examine phonological and memory processes, subjects were divided into five groups. The pre-kindergarteners, first-graders and third-graders were the subjects in the developmental study. The other two third-grade groups, differing in reading ability, were part of a study of reading group differences in memory and phonological functioning. A series of analyses of variance were conducted with group, the independent variable, having five levels.

In order to compare groups on a linear combination of the linguistic processing measures, a one-way multivariate analysis of variance (MANOVA) was conducted. The nine criterion variables were the linguistic measures: VSTM, MONRT, MULTRT, MONE, MULTE, MONCO, MULTCO, TTS, and TTE. Planned follow-up procedures to the MANOVA included nine one-way univariate analyses of variance intended to examine group differences on each of the separate processing measures. An ANOVA procedure, in which nonverbal STM served as the dependent measure (again with group as the independent variable) was also conducted.

The MANOVA was found to be significant using WILKS' LAMBDA Criterion [ $F(36, 230.33) = 4.28, p < 0.05$ ]. This implies that there are significant group differences on a linear combination of the nine criterion variables.

The nine follow-up ANOVAS, in which each of the nine linguistic variables alternately served as the dependent measure, with group as the independent variable, were all statistically significant at the  $p < 0.05$  level. The ANOVA in which NVSTM served as the dependent variable was also significant at this level. These findings indicate that there are significant group differences for each of the dependent measures. Results are presented in Table 1.

In order to identify the specific group differences that were the source of the significant ANOVA tests, the Newman-Keuls procedure was used.

### *Memory Tasks*

As expected, a comparison of groups differing on the variable of age showed that the third-grade group scored significantly better on the *VSTM* task than did the pre-kindergarten children at the  $p < 0.05$  level. In addition, the first-graders also recalled more words than did pre-Kindergarten subjects.

On the verbal STM task significant group differences were also found between third-grade good readers and third-grade poor readers. Good readers recalled significantly more items than did poor readers, a result that is in accord with previous research.

A Newman-Keuls test using *nonverbal* memory as the dependent variable demonstrated that the normal third-grade group scored significantly higher than the first-grade and pre-kindergarten groups on that measure. In addition, first-graders, on average, correctly recalled more block positions than did subjects in the pre-kindergarten group. As anticipated, no differences were found between groups of third-graders differing in reading ability.

Thus far, the presented findings suggest that older children out-perform younger ones on verbal and nonverbal recall tasks. Poor readers perform less well than good readers on verbal memory tasks, but similarly in nonverbal recall.

### *Phonological Tasks*

(a) *Developmental Comparison.* Examination of developmental group differences in phonological accuracy indicated significant differences between third-graders and preschool children on the tongue twister, multisyllabic and monosyllabic error measures. Third-graders were consistently more accurate than were the younger children. In addition, first-grade subjects made significantly fewer errors than pre-kindergarten children on the tongue twister and monosyllabic error measures. These results are in accord with the findings of the correlational analyses reported earlier: there is an age-related increase in the ability to accurately produce spoken language. In particular, the current results suggest that the largest changes may be found between the youngest group and the two older groups.

The developmental comparisons of processing rate indicated the third- and first-grade groups achieved significantly faster phonological processing times than did the pre-kindergarten group on all measures (MONRT, MULTRT, TTS, MONCO and MULTCO), implying that developmental gains in speed of processing are further substantiated, and appear to be greatest between the ages of about four and six for this sample of subjects. Thus with developmental comparisons it was found that both speed and

accuracy of phonological processing operations improve with increasing age, with the biggest gains occurring in earlier years.

(b) *Reading Groups Comparison.* When reading group similarities and differences on the accuracy measures of the phonological tasks were examined, impressive differences were found between good and poor readers' mean scores on the tongue twister errors measure. Poor readers made significantly more tongue twister errors than did good readers.

Interestingly, a significant relationship was also found when decoding skill, as measured by the Word Attack subtest of the Woodcock Reading Mastery Test, was correlated with accuracy on the tongue twister task. A Pearson product-moment correlation coefficient of 0.40 ( $p < 0.05$ ) was found. This indicates that children who were more proficient at deciphering nonsense words (i.e., good readers) were also more likely to make fewer mistakes in the production of confusing phonological material.

No significant reading group differences were found on either the multisyllabic errors measure or the monosyllabic errors measure. However, a posteriori analyses of the relationship between good readers' and poor readers' scores on the Word Attack subtest of the Woodcock Reading Mastery Test and their scores on both of these error measures were conducted. These analyses resulted in a significant correlation between Word Attack score and MULTE errors ( $r = -0.33$ ,  $p < 0.05$ ). This suggests that as subjects' reading skill in decoding nonsense words increased, the frequency with which they made errors in repeating auditorily presented multisyllabic words decreased. There was not a significant finding when the MONE errors measure was considered. In short, the results suggest that there is a noteworthy relation between reading ability and word repetition accuracy on the more demanding multisyllabic task.

When processing speed was considered, no differences between groups of third-grade good readers and poor readers were observed on any of the processing rate measures. This either implies that speed of processing may not be a crucial factor in explaining the linguistic processing differences found between good readers and poor readers, or that these measures are not sufficiently sensitive to detect reading group differences.

In sum, the pattern of results for good readers and poor readers suggests that when task demands are high as a result of phonological complexity or redundancy, poor readers demonstrate lesser ability to accurately process phonological stimuli. In addition, processing rate may not be as sensitive a measure of good and poor readers' phonological processing differences. These results corroborate recently completed work by Brady et al, in press.

*The Relation Between VSTM and Phonological Processing for Good Readers and Poor Readers: Correlational Comparisons*

At this point in the study, having found evidence for differences in the phonological processes of good readers and poor readers, we wanted to directly examine the possible link between their VSTM abilities and their performance on phonological processing tasks.

A set of Pearson product-moment correlational analyses was completed comparing the verbal STM scores of the 14 good readers and 14 poor readers with their scores on the phonological processing measures. It was anticipated that significant correlations would be found between VSTM and the phonological tasks on which the good readers outperformed the poor readers. Those tasks, as documented in the previous section, were tongue twister errors and multisyllabic errors. The results of the correlational analyses matched expectations. (See Table 3.) With only one excep-

*Table 3.* Pearson product — moment correlations between VSTM and linguistic variables for good readers and poor readers ( $n = 28$ )

	MONRT	MULTRT	TTS	MONCO	MULTCO	MONE	MULTE	TTE
VSTM	-0.28	-0.23	-0.50*	0.02	-0.24	-0.12	-0.51*	-0.40*

\* $p < 0.05$

tion (which will be discussed below), there were no significant correlations between VSTM and any of the other measures of phonological processing.

Calculation of  $r^2$  for each of the significant correlations demonstrated that a fair proportion of the variance in VSTM ability could be accounted for by phonological processing accuracy. The value of  $r^2$  for VSTM and tongue twister errors is 0.15. For VSTM and MULTE the value of  $r^2$  was 0.25. These findings are striking in that they suggest that the accuracy differences in phonological processing detected between good and poor readers with the ANOVA and Newman-Keuls procedures may be importantly related to the well-documented VSTM differences between these groups.

As mentioned, there was one other significant correlation which was for VSTM and tongue twister response time. This outcome means that subjects who take a longer time to repeatedly utter a tongue twister phrase also tend to remember fewer items on a verbal short-term recall task. One plausible explanation for this connection, which is consistent with the other results of this study, is that phonological processing accuracy difficulties can contribute to slow tongue twister response times. When

subjects made errors on the tongue twister task, they frequently were observed to hesitate and self-correct. This lengthened the amount of time needed to complete the task. A check of the correlation between tongue twister response times and tongue twister error was found to be positive and significant ( $r = 0.36$ ,  $p < 0.05$ ). This corroborates the behavioral observation and supports the proposed explanation that the phonological accuracy difficulties which contribute to slower TTS scores partly explain the reported association between TTS and VSTM.

## DISCUSSION

The primary interest of the present study was to explore the basis of the short-term memory deficits characteristic of children with specific reading disabilities. Earlier work indicated that the verbal memory problem of poor readers may be related to less skilled use of phonological coding. In the current investigation this hypothesis was evaluated in two ways:

- a) The role of phonological processing in VSTM was examined developmentally by testing pre-kindergarten, first-grade and third-grade children on a series of phonological and memory tasks, and
- b) Third-grade good and poor readers were tested on this same set of tasks, thus allowing a comparison of the phonological and memory processes of children who differ in reading ability.

The major findings and their implications will be briefly discussed here. First, developmental comparisons using groups of preschoolers, first-graders and third-graders revealed age-related changes both in verbal and nonverbal memory span. Developmental increases were also observed in speech perception and production, though these were more variable in their rate of change. Second, it was determined that, in general, children who are proficient on a verbal STM task also excel on tasks measuring phonological processing. More specifically, the relationships between VSTM skill and phonological processes remained significant when potentially mediating factors were controlled (such as age and its corollaries: experience, motivation, practice, attention span, mnemonic strategy use and/or cognitive maturation). The unique role that phonological processes seem to play in verbal tasks is underscored by the finding that improvements in VSTM are specifically associated with increases in phonological processing abilities, rather than with general cognitive growth as measured on the nonverbal STM task. These outcomes imply that the VSTM/phonological processing relationship is not spurious, nor an artifact of some nonspecific age-related factor, but appears to reflect fundamental processes requisite in verbal processing.

The developmental data indicate the need to go beyond speed measures (e.g., rate of articulation) in examining the role of phonological processes

in VSTM. Certain of the speed measures (MONCO and MULTCO) were not significantly related to VSTM span when the effect of age was partialled out, and the speed measures did not all show a steady decrease in duration across the three ages (though this may reflect the need for more sensitive measures of processing speed). In contrast, all of the error measures had a significant correspondence to VSTM span and there were regular decreases in error scores on VSTM, perception, and production tasks. It will be important in future work, therefore, to expand developmental accounts beyond the speed-of-processing explanations that have prevailed (e.g. Baddeley 1986, Case et al 1982, Hoosian 1982, Hulme et al 1984), and to consider whether the ability to accurately form phonological representations taps different processing requirements.

Comparisons of the short-term memory performance of third-grade good and poor readers showed the expected reading group differences in verbal short-term recall, and the anticipated lack of group differences in nonverbal memory. Examination of other phonological processes also revealed differences between reading groups. Specifically, consistent discrepancies in the accuracy with which they performed complex phonological tasks were observed, with poor readers making more errors. It is noteworthy that accuracy performance by good readers and poor readers on perception and production tasks explained a fair proportion of the variance on VSTM performance. Reading groups were not, however, significantly distinguished by speed of processing, as we and others (Catts, manuscript submitted) have previously found.

In closing, the present investigation has provided important information pointing to the role of phonological processing in VSTM capacity. The study was conducted under the framework of the operational efficiency position, though we restricted the claim to the phonological system rather than to a generic pool of resources for all cognitive processes. The present findings are compatible with the view that:

- a) There are limits in the resources available for phonological processing;
- b) That developmental and reading group differences in VSTM correspond to the efficiency of phonological processes; and
- c) That nonverbal memory processes are served by separate cognitive functions.

However, this is a very minimal conceptual framework, and much work remains on the nature of the working memory system and on the factors accounting for developmental gains in capacity. For example, as noted earlier, the role of both speed and accuracy in phonological processing needs to be further studied to determine how these processing variables relate to the functioning of the phonological system and to the construct of efficiency. In addition, it will be necessary to further study the basis and extent of the commonalities across speech perception, speech production and verbal memory. Our findings fit the hypothesis that the need to

phonologically encode the stimulus is shared across all the tasks, and that this may be the basis of the correlations we obtained. Yet we appreciate that other factors such as rehearsal and retrieval need to be studied in this light to evaluate alternative explanations.

In addition to developmental research, the present findings suggest it would also be worthwhile to further explore whether the deficits of poor readers on verbal memory tasks are to be explained in terms of lower efficiency on a continuum of normal phonological processing. Lastly, it will be important to relate the deficits of poor readers on these more basic phonological processes to the robust evidence that poor readers also have deficits in metaphonological awareness (i.e., that they lack explicit awareness that words are composed of phonological elements). (See Liberman and Shankweiler 1985, Wagner and Torgesen 1987, for discussions of this issue.) Longitudinal and training studies tracking the emergence and interrelations of phonological and metaphonological abilities would provide valuable information on these questions.

#### NOTES

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<sup>1</sup> Brainerd and Reyna (1988) have recently proposed a reconstructive processing model in which performance on numerical short-term memory tasks can be the outcome of activating the same information-processing operations used to solve earlier math problems. This is an interesting extension of reconstructive processing to short-term memory, and is one that warrants future consideration as a potential factor in developmental changes in short-term memory performance, as well as in reading group differences on memory tasks. However, a number of studies utilizing higher order language measures have reported a correspondence between span measures of memory and performance on comprehension measures of syntactic knowledge (Fowler, in press, Mann, Shankweiler and Smith, 1985, Shankweiler and Crain, 1986). Thus, it will be important to carefully evaluate task requirements (e.g., verbal, nonverbal, mathematical) in assessing the characteristics and components of working memory.

<sup>2</sup> It should be noted that in addition to the developmental research presented here, evidence for the relations among phonological processes and STM has also emerged

from the study of concordant error patterns in STM tasks and in spontaneous speech production. Reviewing this evidence, Ellis (1979) suggests that a similar operating system serves the production and storage of phonetic codes in verbal STM and in the structuring and "storage of pre-planned sequences of impending speech in normal speech production" (p. 159). In Ellis' model, the processing stages (e.g., perceptual analysis) and pathways involved in short-term recall of linguistic material are analogous to those used during speech production.

<sup>3</sup> The rhyme effect, or phonological similarity effect, has been replicated by a sufficient number of studies to suggest it is a genuine effect. As we note there is also other convergent evidence that poor readers' STM deficits relate to phonological processes. However, it is clear that the phonological similarity effect per se is poorly understood. In addition to the age effects noted earlier (see also Johnston, 1982), difficulties replicating the phonological similarity effect have been related to subject characteristics (Hall, Wilson, Humphreys, Tinzmann, and Bowyer, 1983) and to task factors (Brady et al., 1987, Ellis, 1980, Hall et al., 1983, Watkins, Watkins, and Crowder, 1974).

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