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ABSTRACT

A study investigated the development of information processing as it relates to the development of reading skills by studying how good readers and poor readers utilized orthographic information. Subjects, 90 good and poor readers from grades 2, 4, and 6, participated in four 30-minute sessions in which they were required to make a same/different judgment after the presentation of two letter-strings were displayed successively on the computer monitor. An analysis of variance on the accuracy and latency measures indicated: (1) orthographic information continued to develop throughout grades 4 and 6; (2) poor readers were less skilled than good readers in orthographic information usage and made more phonemic, visual, and letter-order errors; (3) all subjects were affected to some degree by the greater load placed on working memory by longer letter-strings; and (4) the role of visual processing in orthographic information usage was further supported by the results obtained on a multiple regression which included cognitive, linguistic, visual processing, and memory test measures. (Six tables and 12 figures of data are included; 15 references are attached.) (RS)

A Developmental Study of the Processing of Orthographic Information in Children with Varying Reading Ability

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Information about the frequency of letters in particular sequences or spatial positions is a source of information found exclusively within words in print. The usage of this orthographic information (OI) is highly correlated with reading ability (Niles & Taylor, 1977; Allington, 1978; Leslie & Shannon, 1981) and typically, readers in grades 1 and 2 demonstrate the ability to recognize word-like letter-strings as compared to letter-strings which do not conform to the structure of English words (Juola, Schadler, Chabot & McCaughey, 1978).

The present investigation aimed to evaluate the development of OI processing as it relates to the development of reading skills by studying how good readers (GR) and poor readers (PR) in grades 2, 4, and 6 utilize OI. This study was designed to examine (a) the relationship of OI to reading measures; (b) the processing stage at which OI is utilized--whether it occurs at the pre-lexical stage of extraction/interpretation, memory storage, or at the response level (Krueger, 1975); (c) whether OI is encoded visually or phonemically, phonemic coding by novice-readers and visual coding by expert readers (Doctor & Coltheart, 1980). Furthermore, this study aimed to shed some light on the controversy which exists regarding OI usage by poor readers: whether they are deficient in OI usage (Ryan, Miller & Witt, 1984) or more sensitive to OI (Stanovich & West, 1979; Horn & Manis, 1985) as some investigators believe.

Method

Subjects

School children from grades 2, 4, and 6 were screened on measures of cognitive and linguistic development, achievement, and visual processing measures (see Table 1) in order to generate *good readers* and *poor reader* groups in each grade. The final sample of 90 subjects consisted of 15 subjects per grade in each reader group. Reader groups were matched on age and receptive vocabulary and differed by at least one standard deviation on a standardized comprehension reading test. All subjects were at least average in intelligence.

Pre-experimental Measures	Grade 2	Grade 4	Grade 6
Tests of Language			
PPVT-R (Receptive Vocabulary)	—	—	—
WISC-R, Vocabulary (Expressive vocabulary)	X	—	—
CELF: Sentence repetition	X	—	—
CELF: Sound discrimination	—	—	—
DTLA-2 (Word Opposites).	X	—	—
Tests of Reading/Spelling Achievement			
WRAT: Word identification	X	—	—
WRAT: Spelling dictation	X	X	—
Gates-MacGinitie Reading Tests	X	X	X
Tests of Visual Processing			
Test of Visual Perception Skills:			
Visual Discrimination	X	—	—
Visual Memory	X	—	—
Visual Spatial Relations	X	—	—
Ravens Coloured Progressive Matrices	—	—	—
Bender (visual-motor perception).	—	—	—
Coding- WISC-R (visual-motor mapping).	—	—	X
Tests of Memory			
Memory for designs (Visual memory).	—	—	X
Digit Span- WISC-R (Auditory Sequencing).	X	—	—
Rapid Automatized Naming (Name retrieval).			
Letters			
Time	—	—	—
Errors	—	—	—
Numbers			
Time	—	—	—
Errors	—	—	—
Colours			
Time	—	—	—
Errors	—	—	—
Objects			
Time	—	—	—
Errors	—	—	—

Table 1: Listing of pre-experimental measures administered to subjects. 'X' identifies a significant group difference within a grade (alpha level is .05)

Apparatus and Task

A computer-based experimental battery resembling a computer "game" was constructed for the purpose of this research to examine the subjects' knowledge and use of OI. The task required subjects to make a same/different judgement after the presentation of two letter-strings displayed successively on the computer monitor. A fixation point accompanied by a 'beep' preceded the display of the target-item which was presented for 60 msec. Following the offset of the target-item, a variable delay of 1 or 5 seconds preceded the display of the test-item. (see Figure1). The test-item remained in view until subjects depressed one of two keys to indicate whether the two items were the *same* or *different*. The two response-delays were equally distributed over the entire experiment. Keys were alternated. After each response, subjects received feedback through earphones regarding the accuracy of their response. If a correct response was made, they heard a high-pitched tone. If the response was incorrect, they heard a low-pitched tone. After a two second interval, the next target-item was displayed. Adequate measures were taken to insure that all subjects were familiar with the procedure before the experiment began. A practice set including all the conditions likely to be encountered in the experiment preceded the beginning of each session.

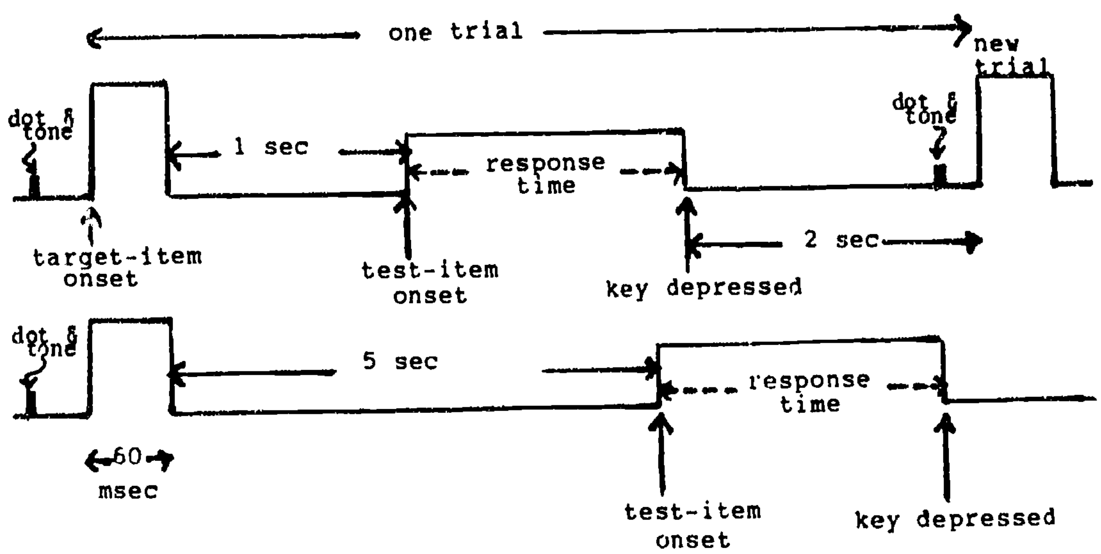


Figure 1: The structure of a trial

Stimuli

The stimuli consisted of 3-letter and 6-letter strings which were presented in 12 blocks of 20 trials so that an entire block of each string-size was presented at one time. Stimuli were word-like items of high (eg., ion) and low (e.g., aur) orthographic structure

	Grade 2 (N=30)		Grade 4 (N=30)		Grade 6 (N=30)	
	GR	PR	GR	PR	GR	PR
	N=15	N=15	N=15	N=15	N=15	N=15
1-second response-delay (120 Trials)						
3-letter strings (60 trials)						
HFHS (12 Trials)						
HFLS (12 Trials)						
LFHS (12 Trials)						
LFLS (12 Trials)						
CS (12 Trials)						
6-letter strings (60 trials)						
HFHS (12 Trials)						
HFLS (12 Trials)						
LFHS (12 Trials)						
LFLS (12 Trials)						
CS (12 Trials)						
5-second response-delay (120 Trials)						
3-letter strings (60 trials)						
HFHS (12 Trials)						
HFLS (12 Trials)						
LFHS (12 Trials)						
LFLS (12 Trials)						
CS (12 Trials)						
6-letter strings (60 trials)						
HFHS (12 Trials)						
HFLS (12 Trials)						
LFHS (12 Trials)						
LFLS (12 Trials)						
CS (12 Trials)						

Table 2: The Experimental Design

obtained from Mayzner and Tresselt (1965) tables and consonant strings (e.g., fsr) of 0-order approximation (Hirata & Bryden, 1971). In addition to this frequency variation, OI was further manipulated to include a high and low spatial-position component by presenting strings which normally occur in the first three-position in words in contrast to strings which are expected at the end of a word. Five levels of OI were contained in the stimulus set: high-frequency/high-spatial, HFHS (e.g., likine); high-frequency/low-spatial, HFLS (e.g., ighwat); low-frequency/high-spatial, LFHS (e.g., cighth); low-frequency/low spatial, LFLS (e.g., wnyvog); and consonant-strings, CS (e.g., tqgpxl) containing no OI (see Table 2).

The response alternatives for the same or different judgements were distributed so that half of the responses were 'same' and the other half 'different'. The *different* trials were designed so that test-items varied visually, phonemically, or letter-order by substituting one letter in the internal structure of the string with its visual or phonemic equivalent, or making one change in letter-order (see Table 3). This was accomplished by generating a set of all letters which are visually or phonemically similar to each letter in the alphabet (obtained mostly from Dunn-Rankin, 1978 and Dale, 1976). Then, this set was reduced to discard visually similar letters which were also phonemically similar, and vice versa, to arrive at one phonemic or one visual equivalent for each letter. Accuracy and latency measures were collected.

Procedure

Subjects participated in two 30-minute sessions to complete the pre-experimental test battery and two further 30 minute sessions, approximately two days apart, to complete the 'computer' games. During the experimental sessions, the students completed 10 practice trials followed by 6 blocks of 20 trials, for a total of 240 trials. Children were awarded a sticker following each test session.

Results

An analysis of variance on the accuracy and latency measures was completed on the data set containing the performance of 90 subjects on 240 experimental trials with the following repeated measures (see Table 2): string-length (2 levels), stimulus-type (5 levels), and response-delay (2 levels). To insure against any speed/accuracy trade-off in subject performance, analyses of the response-time measure were completed on only the correct responses. In addition, a ceiling effect was anticipated in the grade 4 and 6 performance on 3-letter strings. But, it was believed that evaluating grade 2 performance on the 6-letter strings exclusively might yield a floor effect since 6-letter strings (if processed letter by letter) approach the capacity limit of working memory (Baddeley & Hitch, 1974). For this reason, both conditions were included in the study and were subsequently analyzed separately.

Target-item		**ite**
Same Trial		**ite**
Different Trial		
	Phonemic	**ide**
	Visual	**ife**
	Letter-Order	**ief**

Target-item		**ovekes**
Same Trial		**ovekes**
Different Trial		
	Phonemic	**oveces**
	Visual	**ovehes**
	Letter-Order	**ovkees**

Table 3: Examples of test-item alternatives in 3-letter and 6-letter trials

Both the good reader (GR) and poor reader (PR) groups attained a high level of accuracy on the 3-letter strings although GR's performance was still significantly higher than PR's by 5.5% (see Figure 2). A similar difference of 5.7% was obtained in their performance on 6-letter strings. So, despite the greater load placed on working memory by the 6-letter strings, the disparity between reader groups remained at the same level. There were no group differences on the response time measures for correct responses. These findings imply that the differences which exist between good and poor readers do not include a working memory process since processing strings of both lengths produced an essentially similar disparity between groups.

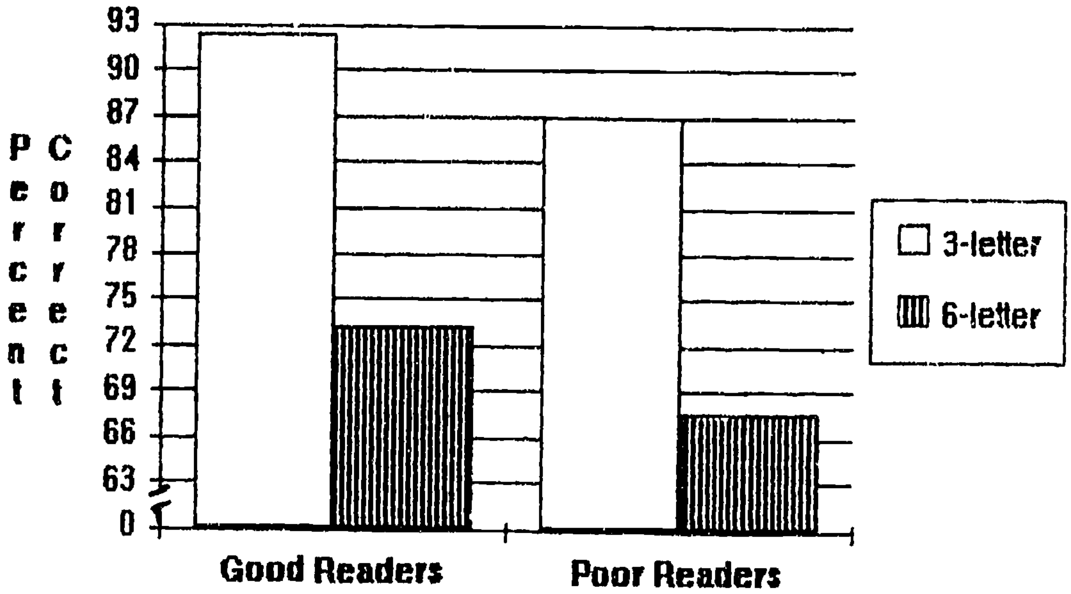


Figure 2: Group performance on 3-letter and 6-letters strings, accuracy measure

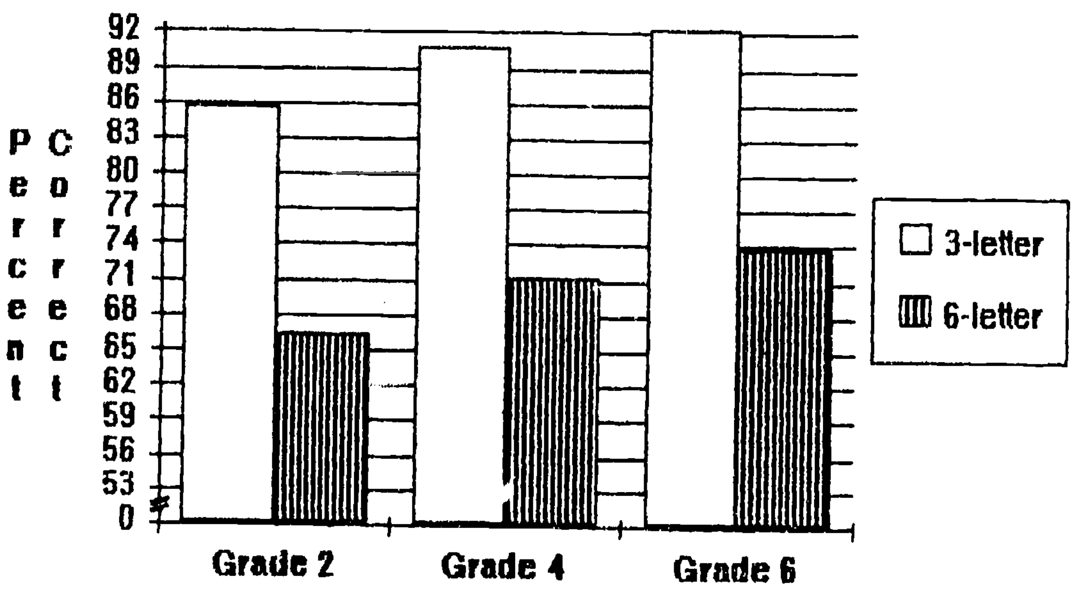


Figure 3: Grade performance on 3-letter and 6-letters strings, accuracy measure

The performance of grade 2 subjects was least accurate and slowest on both string-size conditions (see Figure 4). Grade 4 and 6 subjects performed similarly on the accuracy measure but grade 4's response time was significantly slower (246.8 msec on 3-letter and 333.8 msec on 6-letter strings) than grade 6; and on 6-letter strings, the response time difference between grade 2 and 4 performance was not significant. It is expected that grade differences in response time reflect, at least in part, a developmental difference in reaction time (Woodworth & Schlosberg, 1964). Since grade 4's response time was similar to grade 2's on 6-letter strings (although their accuracy was at the level of grade 6's), it would appear that the OI advantage first presents itself in the accurate recognition of a string prior to producing the speed advantage which is commonly attributed to OI usage.

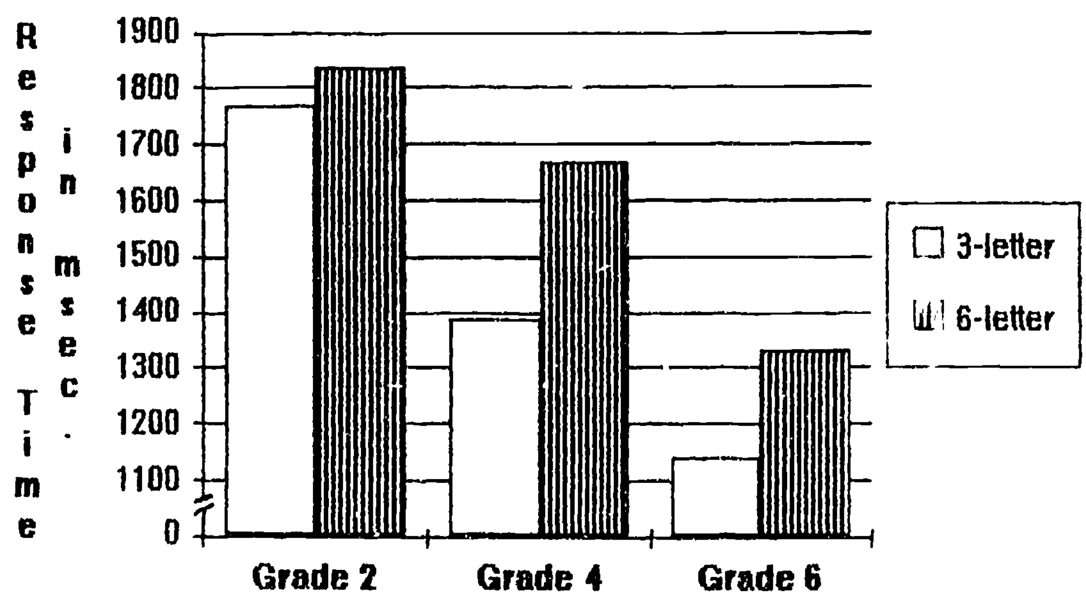


Figure 4: Grade performance on 3-letter and 6-letters strings, measure of response time for correct responses

In both string-size conditions, subjects performed more accurately and fastest on strings containing the highest level of OI (HFHS) in contrast to strings containing no OI (CS). On 6-letter strings (see Figure 5), grade 4's performance was 17.8% higher on HFHS than CS while grade 6 and grade 2 performance was 12.8% and 6% higher, respectively. Grade 2's obtained the greatest speed advantage (between HFHS and CS) and grade 6's the least, on 3-letter strings; but, grade 2's did not demonstrate a response time difference between 3- and 6-letter string performance. Only grades 4 and 6 obtained faster response times on 3-letter strings. This confirms our original concern that 6-letter strings would prove to be quite difficult for grade 2 subjects.

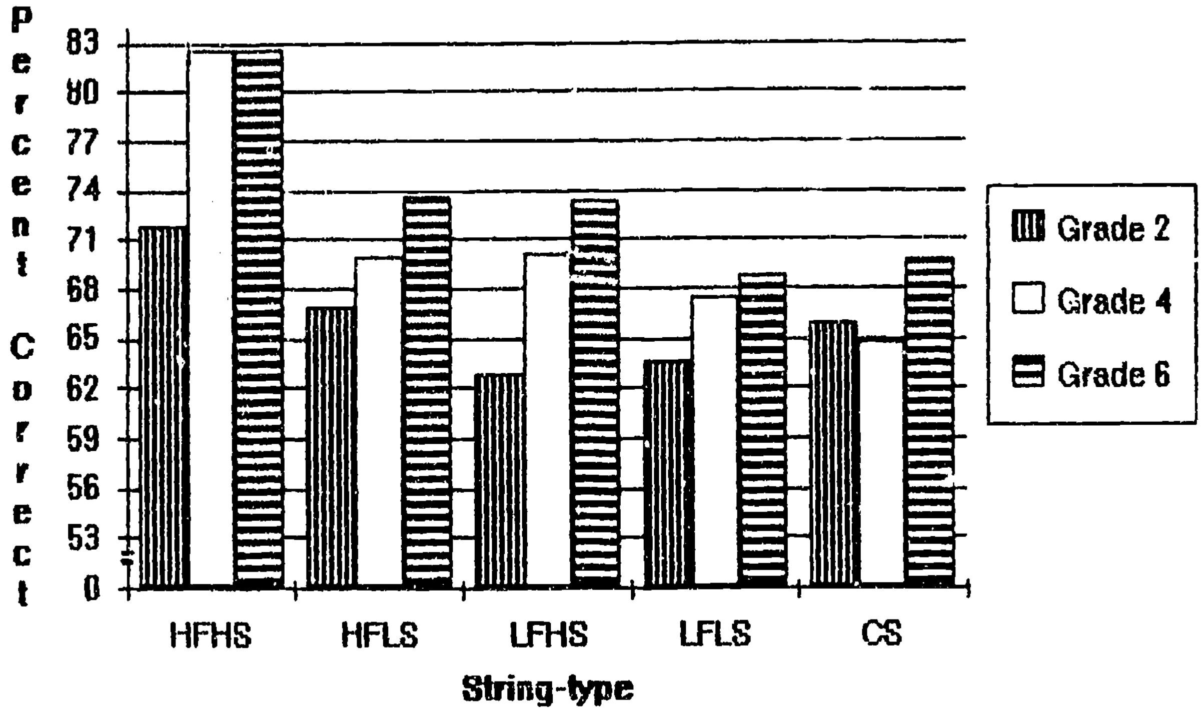


Figure 5: Grade performance on 6-letters strings of varying string-type, accuracy measure

The performance of grades 4 and 6 was equally affected when one source of OI (frequency or spatial information) was reduced. However, grade 2 performance was most hampered by the loss of frequency information. This was an unexpected finding since the strings which contained the highest degree of pronounceability were HFHS (e.g., likine) and LFHS (e.g., eighth) since these strings represent a closer approximation to words. Therefore, the frequency of letter sequences was a more meaningful source of information to grade 2 subjects than the pronounceability of the letter-string (or the spatial information) while grades 4 and 6 subjects incorporated both frequency and spatial information in their performance.

For HFHS strings, 6-letters long (see Figure 6), an orthogonal analysis yielded a significant grade effect and grade by group interaction. A rather large difference in accuracy emerged between reader groups in grade 2 (15%) while reader group differences at the grade 4 and 6 levels were each 5.6%. This finding implies that PR, by grade 6, continue to maintain the same level of disparity with GR as evident at the grade 4 level.

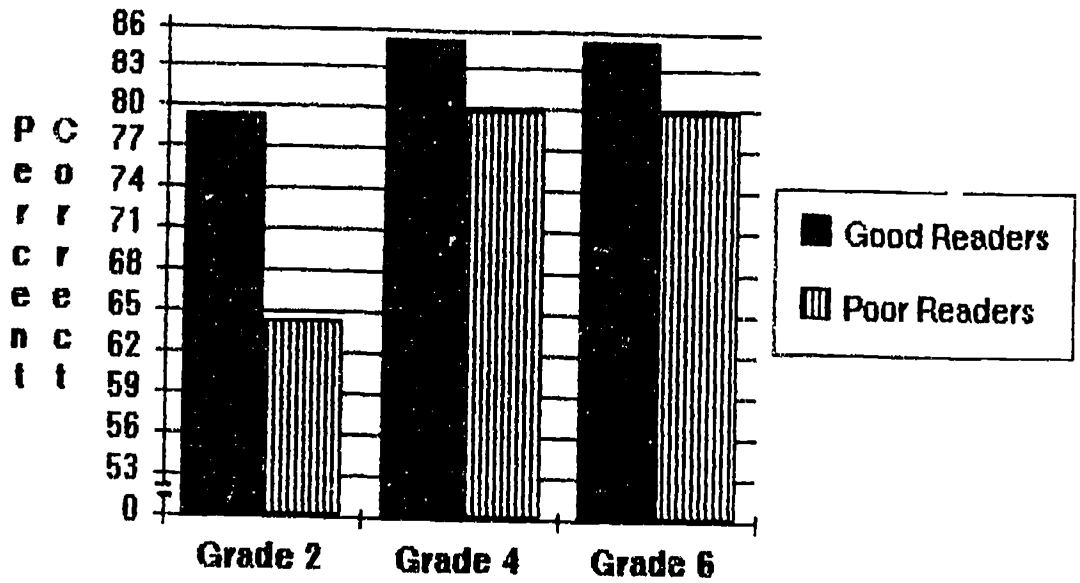


Figure 6: Grade by group performance on 6-letters strings containing the highest levels of OI (HFHS), accuracy measure

In general, both accuracy and response time performance was superior under the 1-second delay condition in contrast to the 5-second delay. On 3-letter strings (see Figure 7), only grade 2's response time was negatively affected by the longer delay and this was also evident on 6-letter strings. Performance on 6-letter strings was more hampered by the longer delay than 3-letter strings. But, the response delay had no effect on HFHS strings while CS enjoyed a 10.4% advantage at the 1-second delay (see Figure 8). This indicates that strings containing high levels of OI are more resistant to decay than strings containing no OI. The 1-sec delay had an equal effect on LFHS and HFLS (strings with one reduced factor of OI); but at the 5-sec delay, performance on LFHS strings was reduced to the level of LFLS strings. This finding further reinforces the contribution of frequency information in maintaining a string in working memory.

Both reader groups were similarly affected by response-delay (see Figure 9). This finding implies that reader group do not differ in their ability to hold letter-strings in memory. This is contrary to the findings of Morrison, Giordani and Nagy (1977) who reported that differences in grade 6 good and poor readers existed at the memory level. This lack of reader group differences also casts doubt on the notion that OI is utilized primarily at the memory level (rather than the extraction/interpretation stage) since poor readers differ from good readers along other dimensions.

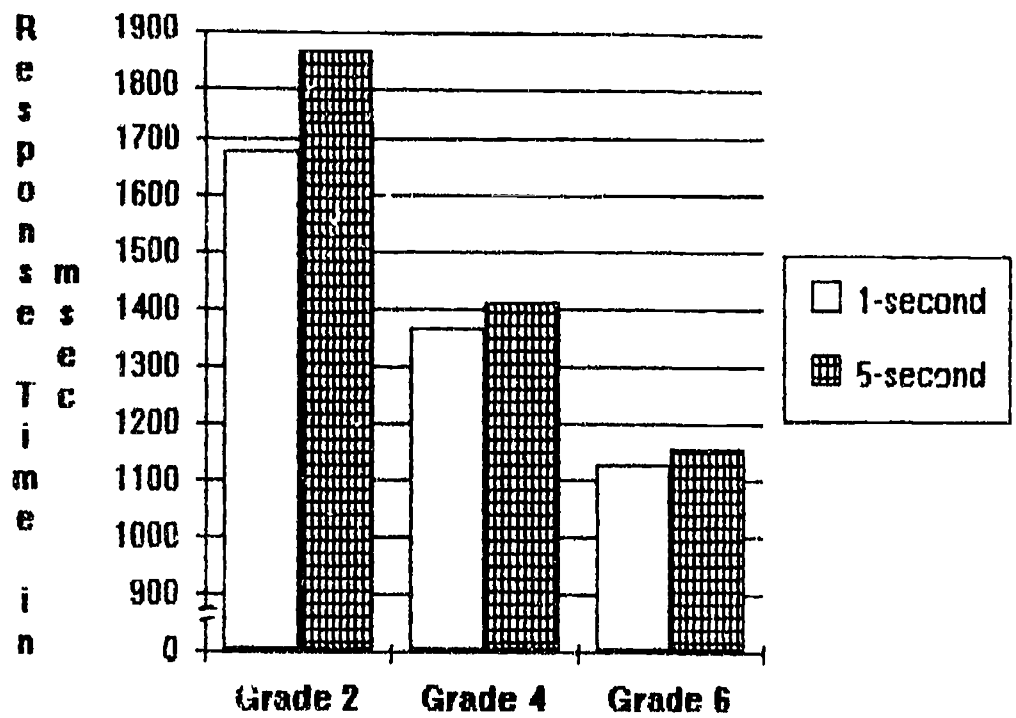


Figure 7: Grade performance on 3-letters strings with 1-second and 5-second response-delays, measure of response time for correct responses

The effects of the visual, phonemic and order manipulation which was inserted in the test-items for *different* trials, basically indicated that visually similar items were most often confused with target-items while the letter-order manipulation was the least confusing. Generally, PR more errors than GR in all conditions (with a few exceptions). An error on a *different* trial was committed if subjects identified a target and test-items as 'same' when in fact they were 'different'. In essence, subjects making such errors did not observe the subtle difference between the target and test-items. Figure 10 depicts

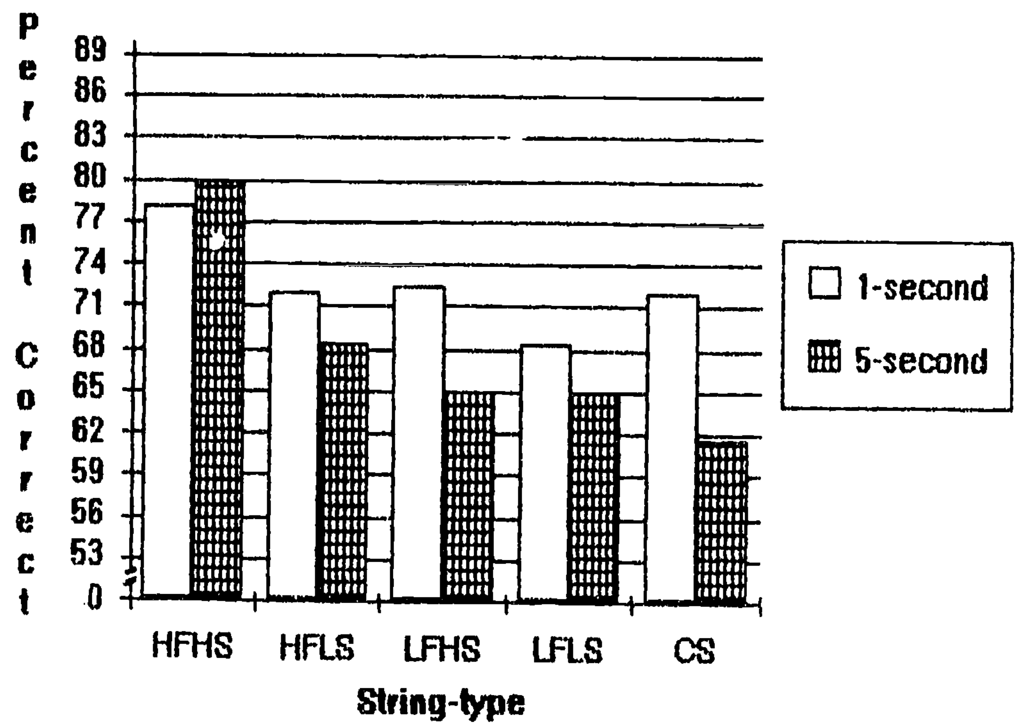


Figure 8: The effect of response-delay on 6-letters strings varying in levels of OI, accuracy measure

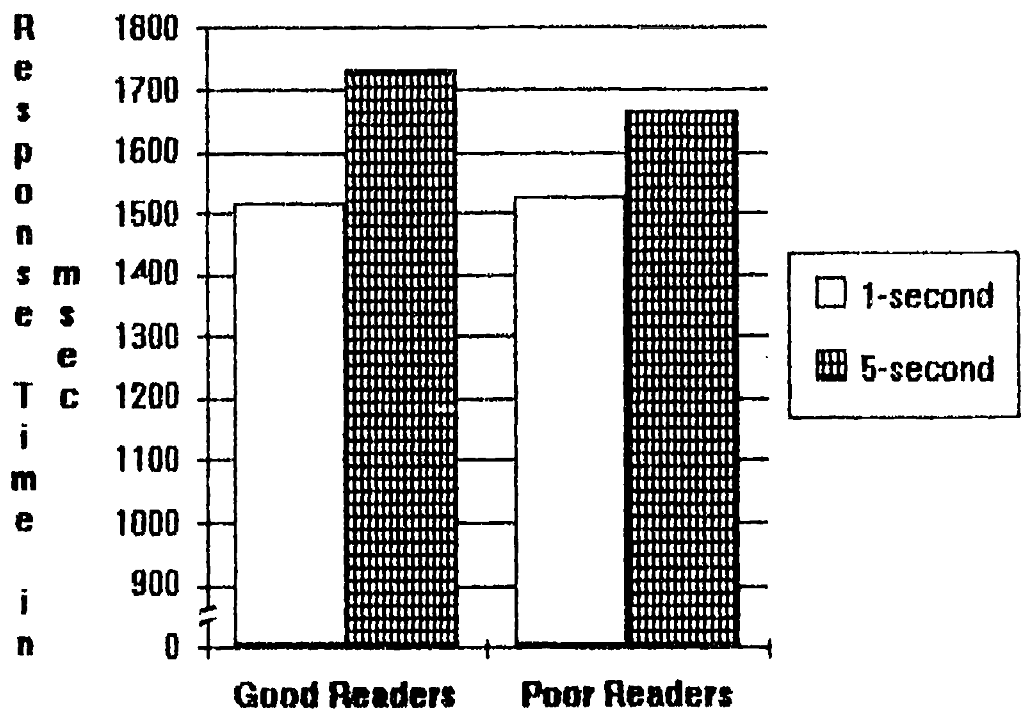


Figure 9: Group performance on 6-letters strings with 1-second and 5-second response-delays, measure of response time for correct responses

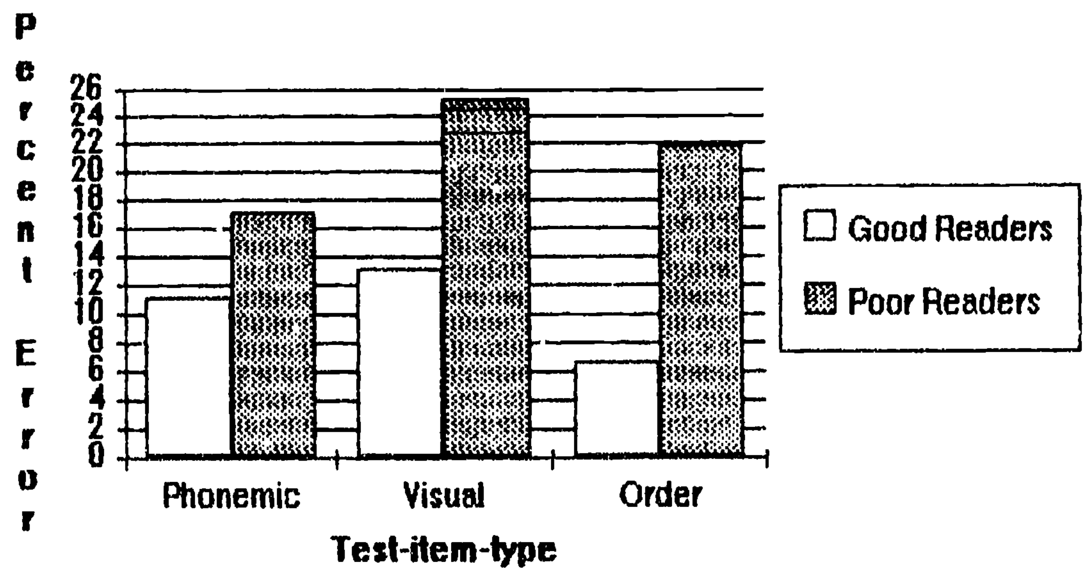
reader group performance of grade 2 subjects on the error measure collected on *different* trials. Comparing reader groups on 3-letter strings, GR made 6% fewer errors than PR on phonemic items while they made 12.3% fewer errors on visual items and 15% fewer errors on letter-order items. GR made a comparable number of phonemic and visual errors and fewer letter-order errors, PR made a rather large number of visual and letter-order errors. On 6-letter strings, the discrepancy between reader groups is minimized by the greater number of errors made by both groups. GR differed from PR in phonemic and letter-order errors but both groups made a significantly higher number of visual errors. At the grade 4 level (see Figure 11), GR and PR demonstrated no differences in phonemic and letter-order errors but GR made 5.6% fewer visual errors. Grade 4 GR made an equal amount of phonemic and visual errors while letter-order errors were slightly higher. In contrast, grade 4 PR made a comparable number of visual and phonemic errors and slightly fewer letter-order errors. Grade 6 (see Figure 12) students made an equal number of phonemic and visual errors. GR made 4.7% fewer phonemic and 6% fewer visual errors. However, no significant differences emerged on letter-order.

A stepwise multiple regression was performed on the measures of cognitive and linguistic development, achievement, and visual processing which were collected prior to the experiment, and the experimental measures. Table 4, 5, and 6 provides R^2 for analyses undertaken on the 3-letter and 6-letter string performance separately, for each grade. Test measures which contributed to the grade 2 and 4 accuracy performance included reading, visual processing and memory measures while these test measures made a lesser contribution to grade 6 performance which appears to be qualitatively different.

Discussion

Although it has been suggested that knowledge of OI is reasonably well established by third grade (Niles & Taylor, 1977; Juola, Schadler, Chabot & McCaughey, 1978; Stanovich, West & Pollack, 1978), the evidence gathered in this investigation implied that it continues to develop throughout grades 4 and 6. Grade 4 subjects obtained accuracy levels which were comparable to grade 6 performance but they had yet

3-letter strings



6-letter strings

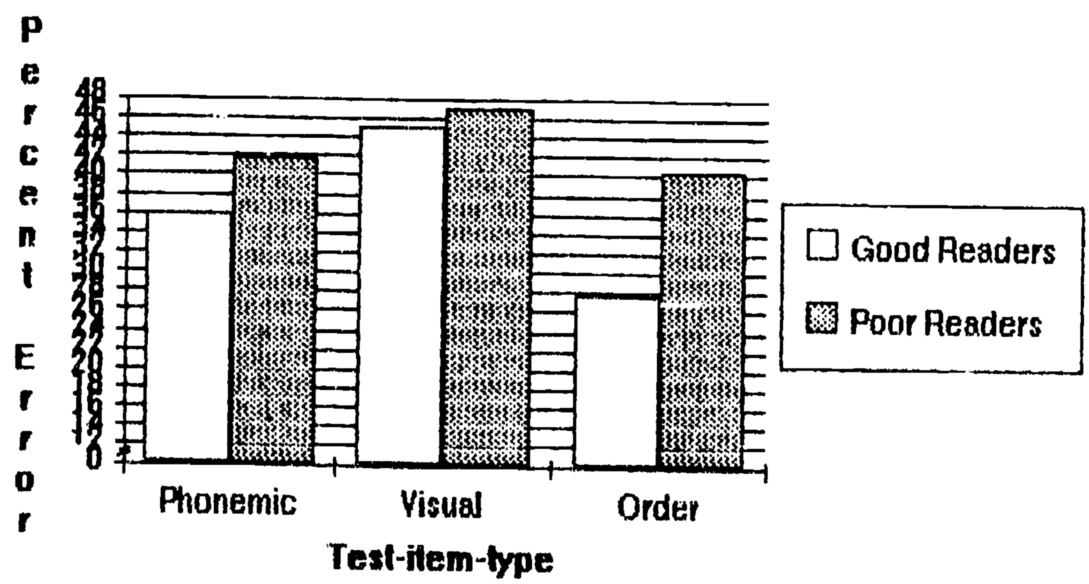
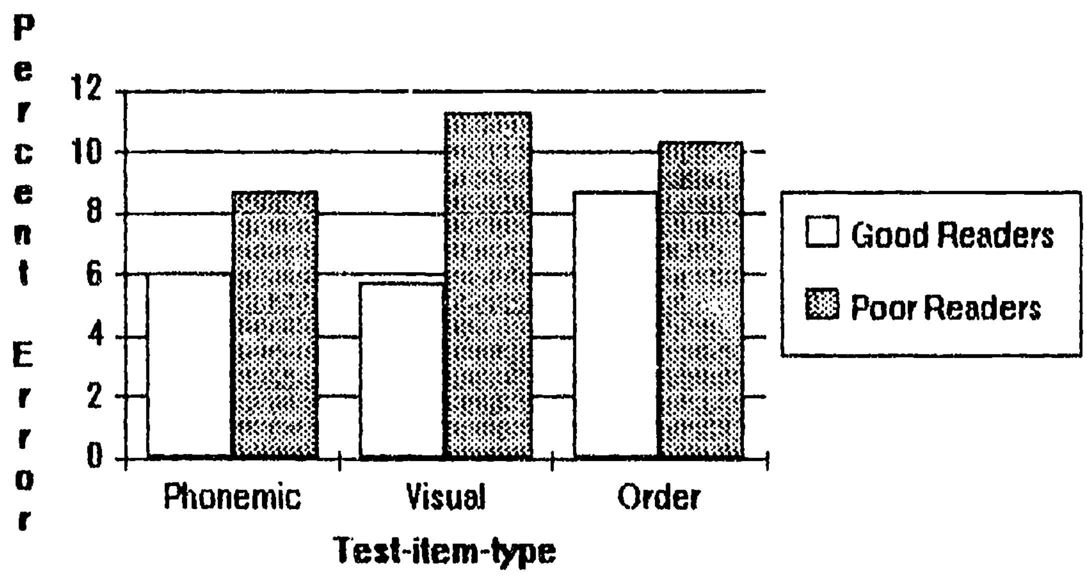


Figure 10: Grade 2 performance on *different* trials with 3-letter and 6-letter strings showing types of errors, error measures

to acquire the speed advantage which is associated with OI usage. This finding supports Samuels, Bremer and Laberge (1978) who concluded that the performance of fourth-graders represented an intermediary stage in OI usage.

Poor readers were found to be less skilled in OI usage as they consistently made

3-letter strings



6-letter strings

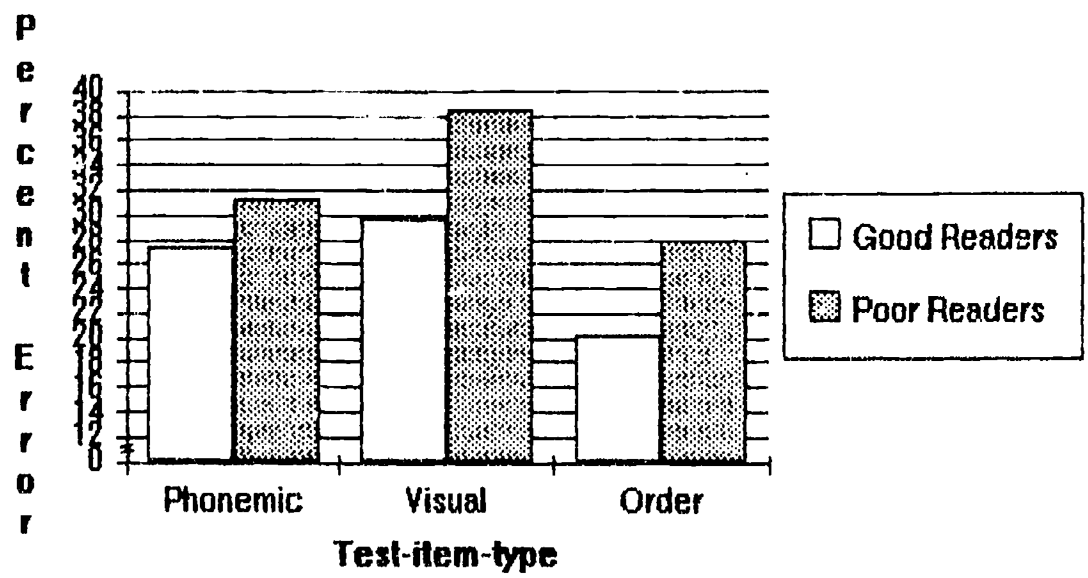
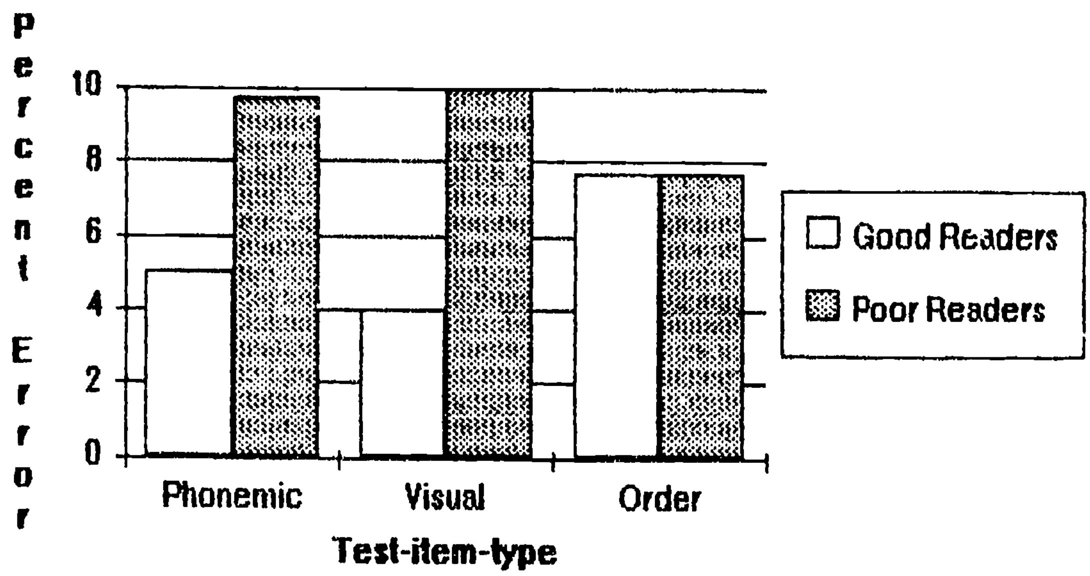


Figure 11: Grade 4 performance on *differer* trials with 3-letter and 6-letter strings showing types of errors, error measures

more errors on both 3-letter and 6-letter strings; and they generally made more phonemic, visual and letter-order errors. This result was consistent with the findings of Ryan, Miller and Witt (1984) but it did not support the claim that poor readers are more sensitive than their skilled counterparts (Stanovich & West, 1979; Horn & Manis, 1985).

3-letter strings



6-letter strings

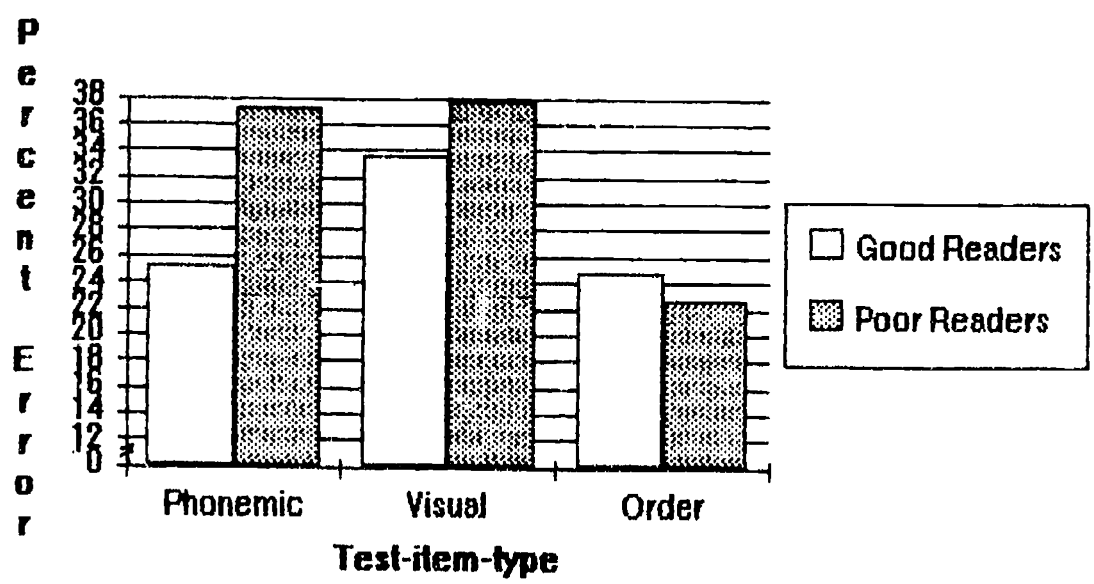


Figure 12: Grade 6 performance on *different* trials with 3-letter and 6-letter strings showing types of errors, error measures

Morrison, Giordani and Nagy (1978) proposed that differences between good and poor readers exist at the memory level. In the present study, memory factors were assessed with a string-length (3-letter and 6-letter) and a response-delay (1 sec and 5 sec) manipulation. Although all subjects were affected to some degree by the greater load

Pre-experimental Measures	**3-letter strings**	
	R^2	Cum. R^2
Reading comprehension (GMRT)	.33	.33
Visual Spatial (TVPS)	.08	.41
Rapid Naming Objects: time	.07	.48
Visual Memory (TVPS)	.08	.57
Reading comprehension (GMRT)-removed	.01	.56
Rapid Naming Numbers: time	.07	.63
Memory for Designs	.05	.68
Sentence Repetition (CELF 10)	.04	72
Reading comprehension (GMRT)	05	.76
Visual Spatial (TVPS)-removed	.01	.75
Bender	.03	.78
	6-letter strings	
Digit Span (WISC-R)	.33	.33
Memory for Designs	.07	.40
Visual Memory (TVPS)	.08	.48
Rapid Naming Objects: error	.08	.56
Sentence Repetition (CELF 10)	.07	.63

Table 4: Pre-experimental measures which contribute to the accuracy performance of grade 2 subjects on 3-letter and 6-letter strings

placed on working memory by longer letter-strings and the time delay, good readers and poor readers were not differentiated along this dimension.

The error measure which was collected on *different* trials in order to examine the quality of errors made, highlighted a visual dimension which is contained in OI usage. Both reader groups made a relatively large number of visual errors on 6-letter strings. In addition, poor readers generally made more phonemic, visual and letter-order errors than good readers. The role of visual processing in OI usage was further supported by the results obtained on a multiple regression which included cognitive, linguistic, visual processing and memory test measures. Visual processing and memory measures contributed to a greater extent than anticipated to the performance of subjects on the OI task.

Pre-experimental Measures	3-letter strings	
	R^2	Cum. R^2
Visual Memory (TVPS)	.24	.24
Reading comprehension (GMRT)	.16	.40
Coding (WISC-R)	.09	.49
Spelling (WRAT)	.11	.60
Sentence Repetition (CELF 10)	.05	.65
Rapid Naming Letters: time	.05	.70
Bender	.03	.73
Word Opposites (DTLA)	.03	.75
	6-letter strings	
Coding (WISC-R)	.39	.39
Rapid Naming Numbers: error	.09	.49
Visual Discrimination (TVPS)	.06	.55
Reading (WRAT)	.05	.60
Bender	.06	.65
Memory for Designs	.04	.69
Spelling (WRAT)	.03	.72

Table 5: Pre-experimental measures which contribute to the accuracy performance of grade 4 subjects on 3-letter and 6-letter strings

Pre-experimental Measures	3-letter strings	
	R^2	Cum. R^2
Digit Span (WISC-R)	.22	.22
Reading (WRAT)	.09	.31
	6-letter strings	
Rapid Naming Numbers: time	.19	.19
Rapid Naming Objects: error	.08	.27
Vocabulary (WISC-R)	.10	.37
Reading (WRAT)	.05	.43
Spelling (WRAT)	.09	.52

Table 6: Pre-experimental measures which contribute to the accuracy performance of grade 6 subjects on 3-letter and 6-letter strings

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