Temporal Processing in Dyslexia

Kimron L. Shapiro, Nancy Ogden, and Faine Lind-Blad

The temporal processing capabilities of 15 children with dyslexia versus 15 age-matched and 15 reading-matched controls in a word identification task were examined. The hypothesis underlying the present experiment was that word recognition would be inferior in children with dyslexia, relative to controls, when the task demanded the temporal integration (sequencing) of two-syllable words. Such a hypothesis must predict that one-syllable word recognition does not distinguish between these two populations and that these effects cannot be accounted for in terms of eye movement differences. To test this hypothesis, one- and two-syllable words displayed for 100, 300, and 3,000 msec were required to be identified. The results yielded evidence of decreased accuracy of word identification by the children with dyslexia in the two-syllable, 300-msec condition, as predicted. A second experiment was unable to uncover any differences in eye movement behaviors that could account for the effects observed in the first experiment. The results are discussed in terms of potential sequential processing deficits in individuals with dyslexia.

Approaches to the study of dyslexia have converged from a diverse variety of sources, including perceptual, neuropsychological, linguistic, oculomotor, and cognitive. The present research report takes a cognitive approach, with a specific focus on the role temporal processing may play in dyslexia. Dyslexia is defined as an inability to learn to read, spell, and write with normal proficiency, with at least a 1-year discrepancy between actual and age-expected levels of performance for children up to 10 years of age, and at least 2 years delay for those older than 10 years (Rosenthal, Boder, & Callaway, 1982).

A theory of temporal order or sequencing dysfunction as a major contributor to dyslexia gained momentum from a number of investigations (Bakker, 1972; Corkin, 1974; Das, Leong, & Williams, 1978). The normal reading process is believed to involve two information processing strategies: simultaneous and sequential. The simultaneous operation consists of the parallel processing of certain letters within a word. The sequential operation involves the serial processing of letters within a word (in the beginning or neurologically impaired reader), or syllables within a word (in the skilled reader). It has been proposed that skilled reading requires both simultaneous and sequential processing of stimuli, and that an over- or underreliance on one process or the other is likely to impair efficient reading (Aaron, 1982). This proposition, that an imbalance in information processing strategies gives rise to dyslexia, has been referred to as the *imbalance hypothesis.* Evidence in support of a dual process in reading and an imbalance of these processes in children with reading disability has been reported by Johnson and Myklebust (1967). These investigators observed that some children cannot analyze a word into its parts or synthesize sounds into words (sequential processing). Other children who can analyze or synthesize a word have been found to have poor visual memory for words (simultaneous processing). Similar findings were also reported by Boder (1973) in her identification of the dysphonetic (sequential deficit) and dyseidetic (simultaneous deficit) subtypes of dyslexia.

More recent studies by Hooper and Hynd (1985, 1986) failed to find unequivocal support for Boder's (1973) original subtyping of dyslexia, but both Hooper and Hynd and Wolf (1986) found evidence for sequential deficits in dyslexics, which corroborated conclusions drawn from earlier studies. Hooper and Hynd (1985) used Boder's (1973) subtype classification and looked for differences among these subtypes using the Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983). Although Hooper and Hynd did not find that the K-ABC differentiated among the Boder subtypes, they concluded that sequential processing deficits distinguished dyslexic from nondyslexic readers. Similarly, Wolf (1986) found a rapid alternating stimulus-naming task to be able to distinguish between the same two populations. Moreover, the design of her study allowed the elimination of several alternative explanations for the observed deficits, including differences in visual perception, symbol identification, and the speed of articulation onset. Similar to Hooper and Hynd (1985), Wolf (1986) concluded that sequencing ability accounted for the observed differences.

The tasks used in Wolf's experiment required the naming of letters, numbers, colors, and objects. Those used by Hooper and Hynd (1985) required tasks such as hand movement, number recall, and Gestalt closure. Although all of these tasks require sequencing of one sort or another, they are still removed from the actual process of reading even though it is to this process that they draw inference. Moreover, it is interesting to note that these tasks allow the appropriate sequencing strategies to be determined largely by the subject, rather than by the experimenter. Various other researchers have used methodologies to investigate the same phenomena that require subjects to adopt a sequencing strategy based on the temporal parameters of the stimuli (e.g., DiLollo, Hanson, & McIntyre, 1983; Godfrey, Syrdal-Lasky, Millary, & Knox, 1981; Tallal, 1980).

The study by DiLollo et al. (1983) demonstrated that temporal processing deficits in individuals with dyslexia are revealed in both slower rates of visual information processing and increased visible persistence during a nonreading task. Subjects performed two tasks that involved visual backward masking and two tasks that required temporal integration. In the backward masking tasks, subjects with dyslexia required a longer stimulus-onset asynchrony (SOA) as compared to nondyslexic readers to escape the effects of the mask. This was taken to indicate slower rates of visual information processing. Similarly, in the temporal integration tasks, subjects with dyslexia needed longer interstimulus intervals

(ISI) to separate the events, providing evidence of longer duration of visible persistence in subjects with dyslexia than in those without. Thus, both tasks indicate the existence of temporal processing deficits in a dyslexic population. However, since neither task required subjects to read, extrapolations to a more complex task like reading are only inferential.

Results from several investigations indicate that when a word is read, a number of letters within the word are processed in a parallel fashion during a single fixation of the eye (e.g., Aaron, 1982). Further, Aaron has shown that recognition time for tachistoscopically presented stimuli increases as a function of word length, indicating that simultaneous processing gives way to sequential processing beyond certain word lengths. Taken together, the results from the DiLollo et al. (1983) study and Aaron's (1982) study lend support to the present hypothesis that word stimuli require both simultaneous and sequential processing and that individuals with dyslexia may experience difficulty with the latter, although not with the former (see Pirozzolo, 1979, for a discussion of this issue).

Thus the present study used a *reading task* (word identification) to investigate the hypothesis that individuals with dyslexia differ from nondyslexics in their ability to process temporally closely spaced information (sequential processing), but that their ability to process a single "unit" of visual information (simultaneous processing) does not differ from that of nondyslexics. The presentation of simultaneous information was accomplished by requiring the identification of short (one-syllable) words, whereas sequential information was presented in the form of long (two-syllable) words that required an eye movement (hence sequential processing) for their identification. To determine if two-syllable words posed some special problem for individuals with dyslexia aside from their sequential information processing requirement, both short and long words were presented for identification, at an exposure duration sufficiently long enough to allow sequential information processing (in the case of long words) and at an exposure duration too short to allow such processing to occur.

EXPERIMENT 1

Experiment 1 employed a method similar to that used by DiLollo et al. (1983) to explore the temporal processing capabilities of individuals with dyslexia versus nondyslexics. In the present experiment, however, a word identification task was used in an attempt to establish a predictive relationship between temporal processing deficits and processes involved in normal reading.

Method

Subjects. The experimental subjects were 15 children with dyslexia (5 females, 10 males) ranging in age from 10.3 to 14.9 years (mean = 12.3), chosen from the Calgary Catholic School Board, Calgary, Alberta, Canada. The subjects' age, IQ, reading level, and word recognition level are presented in Table 1. All children were awaiting placement in resource rooms and operationally classified as dyslexic by meeting the following criteria: (a) average to above average intelligence, as measured by the Wechsler Intelligence Scale for Children–Revised (WISC-R) (Wechsler, 1974); (b) uncorrected or corrected Snellen acuity of 20/30 or better in both eyes; (c) a lag of at least 2 years in word recognition, but at or above a Grade 4 level as measured by the Ekwall Reading Inventory (Ekwall, 1977); and (d) absence of sociocultural deprivation, behavioral disturbances, or organic abnormalities.

Fifteen nondisabled reading-level Grade 4 children (5 females, 10 males) ranging in age from 9.3 to 11.3 years (mean = 10.2), and 15 nondisabled reading-level Grade 6 children (5 female, 10 male) ranging in age from 11.2 to 12.7 years (mean = 12.2) served as controls. Thus, the Grade 4 children served as reading-matched controls whereas the Grade 6 children served as age-matched controls. All control subjects were quasi-matched with experimental subjects for equal abilities on the same measures indicated in Table 1 (see Note 1).

Apparatus. The stimulus words were generated by a Digital PDP-11/73 minicomputer and were displayed on a Tektronix 602 oscilloscope equipped with a fast decay (P15) phosphor. Subjects sat in a semidark room with a 40-watt incandescent lamp providing background illumination. Subjects viewed the dimly lit display surface at a distance of 30 cm. A chin rest was used to stabilize extraneous head movement. Subjects initiated each display by depressing a hand-held button-press controller.

Stimuli. The stimuli consisted of 180 English words, divided into two equivalent lists, ranging in length from three to nine letters each. The two independent

TABLE 1
Characteristics of Students with Reading Disabilities

Student	Age	IQ	Reading level	Word recognition
1	13.3	95	Low-5	Mid-6
2	14.3	100	High-6	Mid-6
3	14.5	100	Low-5	High-6
4	14.6	100	Low-7	Low-5
5	14.9	100	Low-5	Low-5
6	10.2	111	Low-3	Low-4
7	11.5	98	High-3	Low-4
8	11.1	123	High-4	Low-4
9	12.0	113	High-2	Low-4
10	12.0	100	Low-3	High-3
11	12.0	100	Low-3	Low-5
12	11.5	109	Mid-3	Low-5
13	11.9	104	Mid-3	Low-4
14	11.6	101	Mid-4	Low-5
15	10.7	119	High-2	Low-4
	(M = 12.3) (SD = 1.5)	(M = 105) (SD = 8.2)	(M = Mid-4) (SD = 1)	(M = Mid-4) (SD = 1)

Note. All reading and word recognition scores (including M and SD) are by grade level.

90-word lists were prepared from the Ekwall Reading Inventory and were chosen on the basis of their recognition scores equating them for familiarity. During the derivation of these lists, words not familiar to at least 65% of students at the Grade 4 level were moved to a higher grade level. Words of each length were distributed randomly throughout the lists.

Words appeared in uppercase alphabetic characters that subtended from 5.71° to 16.70° visual angle depending on word length. A fixation point was present at the first-letter position to the extreme left of the display screen. Thus words ranging in length from three to four letters (subtending from approximately 5.71° to 7.52°) were designed to demand only a single "unit" of visual input, whereas words ranging in length from seven to nine letters (subtending from approximately 13.16° to 16.70°) were designed to demand a second unit of visual input. Five- and six-letter words were used in an attempt to obtain validation of the visual unit boundaries between single- and double-unit words. Experimental corroboration of these units of visual input is provided by Experiment 2.

Procedure. The experimental session comprised four consecutively administered blocks and required subjects to identify words presented one at a time on a visual display terminal. In the first block, a practice session of 20 trials was given to familiarize the subject with the procedure. Following this, two experimental blocks, each consisting of a 90-item list of words, were administered. The stimuli in each of the two lists were presented at a constant exposure duration. Words in the first experimental block were presented for 100 msec each, whereas words in the second experimental block were presented for 300 msec. The order of presentation of the lists was counterbalanced across subjects. The final block consisted of a presentation of all 180 words from both 90-word lists, each word presented for 3,000 msec. This extended exposure duration was designed to provide ample time for accurate word identification by all subjects and was done to ensure that failure to read a word was due to the temporal constraints of the experiment and not to recognition inability, per se. A rest period of 3 minutes was given after each block. The entire procedure lasted about 15 minutes.

The sequence of events in a trial was identical for all conditions and for all subjects. Each subject was instructed to stare at the fixation spot and depress the hand switch when ready to initiate the next trial. At this time a single word was displayed. The subject's task was to read the word out loud as soon as it was perceived, while the experimenter recorded correct-incorrect word identification. Only on a very few trials did the subject correct a word identified, and, on all of these trials, the correction occurred immediately after the first response. In these few cases, the second response was entered into the analysis. During the variable duration interstimulus interval, which averaged 2 sec, the screen remained blank except for the fixation point. This procedure was repeated until all words in a given list were displayed. No feedback about performance was given during the experiment.

Results

Three- and four-letter words were classified as short words, whereas words ranging in length from seven to nine letters were classified as long words (see the discussion of Experiment 2 for a further treatment of this issue). An equal number of short and long words (i.e., 60 of each type) comprised the two classifications. On the basis of results from Experiment 2, word lengths of five and six letters resulted in ambiguous units of visual input (i.e., sometimes requiring one fixation and other times requiring two) and thus were not entered into the present analysis.

Accurate word identification by the Grade 4 reading-matched controls ranged from 99.8% (SD = 0.9) for short words at 300 msec to 84.3% (SD = 1.1) for long words at the 100-msec display exposure duration. The Grade 6 age-matched controls had accuracy scores of from 99.3% (SD = 1.9) for short words presented for 300 msec to 88.9% (SD = 5.6) for long words presented at 100 msec. The subjects with dyslexia revealed a high score of 98.1% (SD = 3.1) for short words at 300 msec, and a low score of 83.4% (SD = 5.0) for long words at the 100-msec duration. The mean percentage of words identified correctly by word length and display time for the three groups is shown in Table 2.

A 3 x 2 x 2 (Group x Display Duration x Word Length) ANCOVA was performed, with age as the covariate. The covariate was significant, $F(1,41) = 32.4$, $p < .001$, indicating that age is a good predictor of performance. Although the mean of the subjects with dyslexia was the same as that of the age-matched controls, the group with dyslexia was composed of a few older children (range from 10.3 to 14.9 years) than were found in the control group (range from 11.2 to 12.7 years). Given that performance would be expected to improve with age, this potentially causes a problem for any study where a factor other than age is the favored alternative in the older group. Such a concern does not pose a problem for the interpretation of the present results, however, since the older, dyslexic group performed worse (not better, as

TABLE 2
Mean Percentages and Standard Deviations for Word Identification Scores by Children With and Without Dyslexia in Experiment 1

	Read-match control		Age-match control		Dyslexic	
	Mean	*SD*	Mean	*SD*	Mean	*SD*
Short words						
100 msec	98.90	1.61	98.01	2.46	98.13	3.08
300 msec	99.78	0.85	99.33	1.87	96.39	4.45
Long words						
100 msec	84.25	1.09	88.90	5.65	83.36	4.99
300 msec	95.47	5.48	98.01	2.46	84.13	2.94

Note. "Short words" refers to words of three or four letters in length. "Long words" refers to words of seven, eight, or nine letters.

would be predicted by age) than the younger, control group. Nevertheless, the following results present F ratios for all the variables after the effects of the covariate have been factored out.

The main effect of group was significant, $F(2,42) = 5.5$, $p < .01$. This indicates that the group with dyslexia, averaged across all variables, was less accurate at word identification than either of the control groups.

The main effect of display duration also was significant, $F(1,42) = 28.4$, $p < .001$, indicating that word identification was more accurate across conditions with the longer, 300-msec display. The interaction effect of Group x Display Duration was significant, $F(2,42) = 9.6$, $p < .001$, and Scheffé tests revealed that both reading-matched controls and age-matched controls improved with the longer display duration. In contrast, subjects with dyslexia failed to benefit overall by the longer display. They exhibited performance equivalent to that of both reading- and age-matched controls at the shorter display duration but were significantly worse than both control groups with the longer display.

The significant main effect of word length indicated that subjects were statistically more accurate in reporting short words than long words, $F(1,42) = 49.7$, $p < .001$, averaged across the other conditions. The interaction effect of Group x Word Length also was significant, $F(2,42) = 3.6$, $p < .05$. Scheffé tests revealed that both reading-matched controls and subjects with dyslexia improved with respect to word identification as they went from long to short words, regardless of display time. In contrast, age-matched controls were equally accurate with long and short words. Furthermore, the interaction effect of Word Length x Display was significant, $F(1,42) = 30.5$, $p < .001$. Scheffé tests revealed that, whereas there was no difference between 100- and 300-msec display times for short words, word identification was significantly better for long words at the longer display time than at the shorter display time.

Finally and most importantly, there was a significant triple interaction among the group, word length, and display variables, $F(2,42) = 4.0$, $p < .05$. Scheffé tests showed that there were no improvements in short word identification among all three groups as they moved from the short to the long display duration. In fact, all three groups were able to identify between 96.4% and 99.8% of the short words presented to them. However, when performance among these groups for long words is examined, important differences emerge. Both the age- and reading-matched control groups show a significant improvement in word identification ability as they move from the short to the long display duration. In marked contrast, the children with dyslexia failed to improve with the longer display duration. This interaction is shown in Figure 1; the percentage of words identified correctly is shown as a function of display duration for short words (Panel A) and long words (Panel B).

The results of the 3,000-msec display duration analysis reveal only five errors across all subjects in all conditions. This indicates that virtually all words were identifiable by all subjects, given a sufficient amount of time to study the word. However, to ensure that even these few errors did not contribute to an erroneous interpretation of the data, word identification is reported for each subject as a percentage of words correctly identified during the 100- and 300-msec display conditions as a function of the number correctly identified during the 3,000-msec display duration.

Discussion

The results of Experiment 1 show that the children with dyslexia were less accurate than controls in reading words requiring a second fixation, when there was a sufficiently long display duration in which to make the second fixation. On the other hand, the children with dyslexia performed in the same way as did the controls both with short words requiring only one fixation (both short and long display durations) and with long words when there was an insufficient display duration to make a second fixation. This suggests that the new retinal image acquired during the second fixation acted to interfere with word processing in the subjects with dyslexia.

This finding is consistent with previous findings that individuals with dyslexia show slower rates of processing rapidly changing, or sequential, information (DiLollo et al., 1983; Godfrey et al., 1981; Tallal, 1980). Furthermore, this finding is consonant with the hypothesis that during a very brief display duration, only simultaneous processing of individual units of information is occurring. As word length increases with a concomitant number of units to be processed, both simultaneous and sequential processing may be required and the performance of individuals with dyslexia suffers (see the General Discussion for a further discussion of this issue).

EXPERIMENT 2

Experiment 2 investigated an alternative hypothesis that might serve to explain the results of the first experiment. Although the data suggest that temporal processing deficits were the cause of the experimental subjects' attenuated recognition ability, it is possible that discrepant eye movement behaviors between the students with and without dyslexia could account for the observed differences. Thus, in Experiment 2 we sought to evaluate this alternative by examining a number of measures of eye fixation and eye movement ability from a random subset of the subjects in Experiment 1. These measures were examined while the subjects performed the identical word recognition task employed in the previous experiment.

Method

Subjects. The subjects were 15 of the children from the previous experiment, five chosen randomly from each of the dyslexic, age-matched, and reading-matched groups (see Experiment 1 for a complete description of these subjects).

Apparatus. The apparatus used in Experiment 2 was the same as that used in Experiment 1, with the addition of the eye movement monitor. Eye movements were recorded using an Eye Trac 210 (Applied Science Laboratories) infrared eye movement monitoring device and stored on videotape. The eye movement monitor has a resolution of plus or minus 1° of visual angle. The eye movement

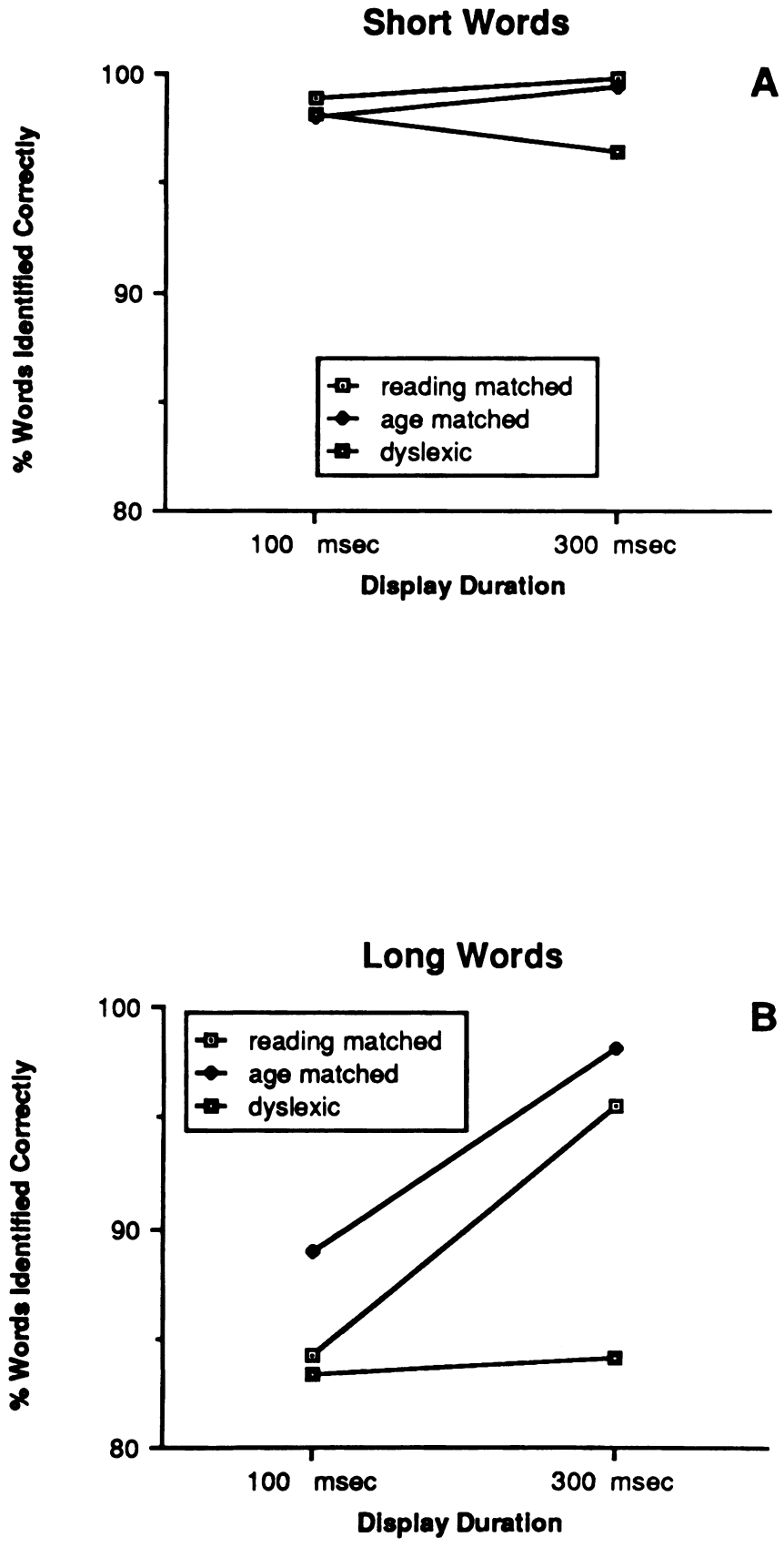

Figure 1. Panel A. Mean percentage of short words identified correctly at 100-msec and 300-msec display durations by reading-matched, age-matched, and dyslexic subjects. Panel B. Mean percentage of long words identified correctly at 100-msec and 300-msec display durations by reading-matched, age-matched, and dyslexic subjects.

signal recorded during the word recognition task was superimposed over the video recording, yielding a composite recording of both the stimulus display and the eye movements. A chin rest and head restraint were used to support the subject's head during eye movement recordings.

Procedure. The procedure was identical to that used in Experiment 1, except for certain steps involving use of the eye movement monitor. The Snellen acuity test was omitted in the present experiment. The procedure consisted of a brief phase where the eye movement monitor was fitted and calibrated; this was followed by one eye-movement-monitored block of the same word recognition task used in Experiment 1. Next, a 3,000-msec word identification task was presented, also identical to that used in the previous experiment. Since an eye movement takes approximately 250 msec to initiate and complete, only the 300-msec stimulus duration was used in the present experiment.

Subsequent to the experiment, the video/eye movement tape was analyzed for each subject. For each word, the experimenter (a) measured the fixation duration for each syllable and (b) judged the saccadic accuracy (whether or not the eye movement landed within a specified close-fitting elliptical boundary around the second syllable of the word). A second observer judged a series of randomly chosen words to enable an interrater reliability measure to be calculated. As in the previous experiment, we computed a percentage recognition score for each subject based on the number of words correctly identified during the 3,000-msec phase. This provided an opportunity to replicate the results of the first experiment with regard to word recognition.

Results

Turning to the eye movement data first, a 3 x 2 (Group x Word Length) ANOVA revealed no significant differences among any of the groups for either fixation duration or saccadic accuracy ($p \geq .10$). An examination of the eye movement data revealed that three- and four-letter words were given only a single eye fixation, whereas, seven-, eight-, and nine-letter words required an eye move-

ment for a second fixation. Since five- and six-letter words resulted in a word-by-word varying number of eye fixations (either one or two), these words were considered of an intermediate length and were not entered into the analyses of this or the previous experiment. The inter-rater reliability measure of the eye movement data based on a randomly chosen 50% of the words was 0.98, indicating a high degree of correlation between the two raters.

As in Experiment 1, three- and four-letter words were classified as short words, whereas words ranging in length from seven to nine letters were classified as long words for the purpose of the word identification analysis. The two classifications comprised an equal number of short and long words (i.e., 60 of each type).

A 3 x 2 (Group x Word Length) ANOVA was performed on the data. In addition to a significant main effect of both group and word length, the interaction effect between group and word length, $F(2,3) = 86.81$, $p < .001$, also was significant. Thus, whereas both the age- and reading-matched controls were perfectly accurate (100%) in their identification of both short and long words, the subjects with dyslexia were as accurate statistically (97%) as the controls with short words but were significantly less accurate (85%) with long words. This interaction can be seen in Figure 2; the mean percentage of short and long words identified correctly at a 300-msec display duration by control subjects and subjects with dyslexia is plotted. These results replicate those obtained in the first experiment with the same display duration (300 msec).

Discussion

The word identification analysis of Experiment 2 replicates the findings from Experiment 1 that individuals with dyslexia exhibit a decrement in word recognition performance with long words, given a sufficiently long display *time to* read them, that is not experienced by either reading- or age-matched controls. The deficit is not revealed, however, in a comparison between subjects with and without dyslexia, when their task is to identify short words at the same 300-msec duration. Furthermore, the eye movement analysis of the present experiment reveals that there are no significant differences between dyslexic subjects' eye movements and those of both the reading- and age-matched controls. Although only 5 subjects per group were examined for eye movement differences, not only were there no statistical differences among any of the groups, but there were less than 10 trials (out of a possible 900) where any eye movement differences of either accuracy or duration were revealed. Thus, a possible tendency of individuals with dyslexia to fixate the first syllable exclusively or the inability to fixate *accurately* both syllables is not a likely ex-

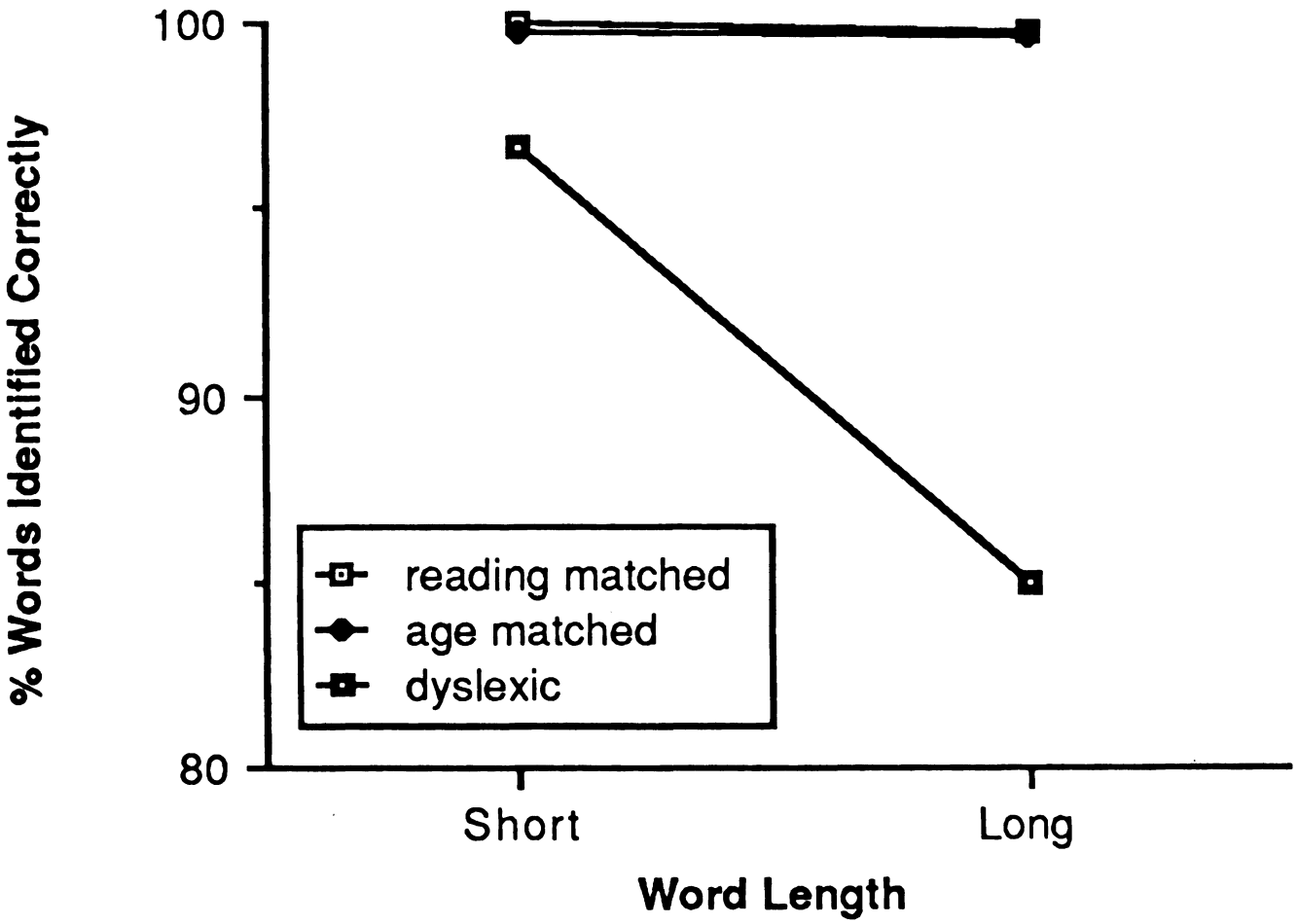

Figure 2. Mean percentage of short and long words identified correctly at a 300-msec display duration by reading-matched, age-matched, and dyslexic subjects.

planation for the observed differences with regard to word identification. Moreover, the number of eye movements witnessed to short and long words again corroborates our intent of providing one or two units of visual input, respectively, in our attempt to examine temporal processing demands on reading.

The number of eye movements is considered to be a better test of our temporal processing hypothesis, since there is considerable debate in the literature concerning measures of visual angle or number of characters present and their relationship to effective visual span. The literature suggests that effective visual span for a given eye position is no more than six characters, independent of viewing distance (McConkie, 1983). Thus, our choice of three- and four-letter short words and from seven- to nine-letter long words would seem to fit within the above criteria. Moreover, the number of eye movements observed for each word length fits our operational definition of either one or two units of visual input, respectively, and thus seems a better test of our hypothesis. For an extensive treatment of this issue, the reader is referred to Morrison (1983) and McConkie (1983).

GENERAL DISCUSSION

The general hypothesis of this study concerning potential temporal processing deficits in individuals with dyslexia is supported by the results of the two experiments presented above. In Experiment 1 it was observed that students with dyslexia were deficient with respect to both age- and reading-matched controls, insofar as they were less able to identify long words displayed at a duration sufficiently long to necessitate sequential information processing. Whereas the performance on long words of both control groups improved with increasing exposure duration, the subjects with dyslexia failed to take advantage of the longer duration.

Experiment 2 replicates these results at the longer display duration and also provides data suggesting that there are no significant differences in eye movement or fixation behavior between the subjects with and without dyslexia that could account for the word recognition differences observed in Experiment 1 (see Note 2). This is important because a failure to make accurate and/or rapid eye movements to the second syllable could account for the differences observed between these two populations but would not necessitate a temporal processing account. Moreover, the differences in word identification ability observed between the subjects with dyslexia and controls in both Experiments 1 and 2 cannot be due to differences in the ability of any of these groups to correctly identify words if given a sufficient amount of time to do so. This is revealed by examining the data with regard to word recognition in the 3,000-msec display duration condition, which provided ample time to identify all words, yet revealed no significant differences among any of the three groups.

It is important to point out that certain investigators have shown that individuals with dyslexia do tend to spend an excessive amount of time on a given fixation, relative to nondyslexics, although there are no apparent differences in either saccadic accuracy or latency (Adler-Grinberg & Stark, 1978; Raymond, Ogden, Fagan, & Kaplan, 1988). Adler-Grinberg and Stark (1978) showed in an untimed reading task that individuals with dyslexia spent an average fixation duration of 340 msec compared to 280 msec for nondyslexics. The implication of this finding is that individuals with dyslexia may prefer to spend more time per fixation in order to compensate for their temporal processing deficits. Such increased fixation time, however, could result in seriously attenuated performance when these individuals attempt to read at a rate commensurate with that of their nondyslexic counterparts. The difference between Adler-Grinberg and Stark's findings and our own with regard to this one measure likely can be accounted for by the different reading requirements of each study. Whereas the former was untimed, ours was temporally constrained, and probably for this reason our results did not reveal fixation inequities between the dyslexic and control groups.

The 11% to 14% difference in word recognition ability between the subjects with dyslexia and the reading- and age-matched controls may appear at first to be a statistically, but not clinically, significant difference. It is defensible, however, to argue that a difference in long word recognition ability of this magnitude could affect reading comprehension severely enough to cause problems for individuals experiencing such a temporal deficit. Obviously, the greater the frequency of long words, the more one would predict that such a deficit would be problematic with respect to both overall comprehension and recall. Since the words contained in the lists in this experiment were selected for their ability to be comprehended by normally achieving 12-year-old readers, and 16% of them were identified incorrectly by the subjects with a reading disability, many reading passages encountered by these individuals would pose an even greater problem.

It may be argued that the results of this study were due to factors other than dysfunctional overuse of a simultaneous processing strategy or a failure to use a sequential processing strategy. If dyslexia is due to a perceptual deficit, as proposed by some (Hermann, 1959; Orton, 1925, 1937; Zurif & Carson, 1970), the decreased accuracy exhibited by the subjects with dyslexia could be a result of their inability to perceive the information or of confusing what is perceived, under any circumstances. However, this hypothesis is disconfirmed by the fact that the subjects with dyslexia were able to perceive correctly a high proportion of all short words and were even able to identify long words, given a sufficiently long display duration. If a general perceptual deficit did exist, one would not expect such a large number of correctly identified words at any combination of word length and display duration. Again, the results of the present experiments point to a deficit that occurs only when temporal constraints similar to those experienced during the normal reading process are encountered.

A second alternative explanation for the present findings is that the inferior performance of the subjects with dyslexia was due to decreased attention span (Rosenthal et al., 1982). During testing, the subjects with dyslexia were observed to change some of their answers after the word was no longer visible, although, as the data show, often they still were incorrect. This could be taken to be the

result of a lack of attention to the information being presented or to boredom with the procedure. It is unlikely that subjects were bored, as the procedure was very fast and subjects showed no indication of sustained inattention. Moreover, a longer display duration should yield better performance than the short duration, as more time and hence attention would be available for reading. However, the poorer performance of the subjects with dyslexia at the 300-msec than at the 100-msec display duration disconfirms this hypothesis.

In summary, the results of the present study support the contention that a temporal processing deficit may exist in some significant proportion of individuals with dyslexia that may be due to an overuse of the simultaneous processing strategy or, alternatively, an inhibition or misuse of sequential processing. Such a deficit has been attributed by some to bilateral or mixed hemispheric representation of the two processing strategies (Pirozzolo & Rayner, 1980; Witelson, 1977; Zangwill & Blakemore, 1972). Explanations based on deficits in sequencing have been proposed by other investigators. For example, Wolf (1986) found deficits in a rapid alternating stimulus naming measure between subjects with and without dyslexia and concluded that rapid set switching was based in the automatic process of sequential scanning. Similarly, Hooper and Hynd (1985) found that nondisabled readers performed significantly better on the K-ABC on all measures requiring sequential processing. The results of the present study are consistent with the conclusions drawn by these other investigators. Temporal processing, as defined by the present experiment, was prevented or facilitated, respectively, by the parameters imposed on the presentation of the stimuli (i.e., 100 or 300 msec to identify the word). Thus, stimulus presentation times were chosen to allow sequencing to either play or not play a part in the task in a similar fashion as did the task requirements of both Wolf's (1986) and Hooper and Hynd's (1985, 1986) experiments. The precise basis of the sequencing problem may be one of the above-mentioned deficits or some other sequencing problem (e.g., interhemispheric transfer), but that is beyond the scope of the present research report. The present study's significance lies in its extension of the findings of various investigators who have found temporal processing (or sequential) differences between individuals with and without dyslexia to similar differences between the same two populations, using words required for reading as stimuli.

ABOUT THE AUTHORS

Kimron L. Shapiro *is an associate professor of cognitive psychology at the University of Calgary. His research interests lie in various aspects of cognition, both basic and applied.* **Nancy Ogden** *recently obtained her MSc at the University of Calgary and is currently pursuing a PhD. Her major interests lie in the area of applied visual perception.* **Faine Lind-Blad** *received her BA with first-class honors in psychology from the University of Calgary in 1986. She is currently preparing to attend medical school at the same university. Address: Kimron L. Shapiro, Department of Psychology, University of Calgary, 2500 University Dr. NW, Calgary, Alberta, Canada T2N 1N4.*

AUTHORS' NOTES

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NOTES

1. Permission to use the control subjects was obtained only after the researchers agreed not to access any performance measures of the children, for reasons of confidentiality. All control subjects, however, were chosen by school principals, with the stipulation that they have an IQ between 100 and 110, as well as average reading and word recognition scores for their respective grade levels.

2. Pirozzolo (1979) concluded that deficits in eye movements occur primarily in the visual-spatial, as opposed to the auditory-linguistic, individual with dyslexia. If this is true, one might argue that the present study found no eye movement differences because it used subjects experiencing the latter and not the former deficit. First, it is not likely that subjects chosen for this experiment were auditory-linguistic subtypes exclusively, since they were chosen randomly with regard to this subtyping criterion. Second, the present study makes no claim that temporal processing deficits can account for all reading problems experienced by individuals with dyslexia. The contention is that such sequencing deficits may account for word identification errors in those subjects who show no perceptual (e.g., eye movement) deficits.

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