Word processing in dyslexics

An automatic decoding deficit?

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ABSTRACT: Dyslexic children (n = 21, mean age = 10.2 years) were compared with normal readers of the same age, normal readers of the same reading-age, and poor readers of the same reading-age on measures of phonological decoding and automatic word processing. Three different tasks, varying in phonological demand, were used: a naming task, an auditory-visual matching task, and a lexical decision task. On each task, word-pseudoword profiles were obtained to test phonological decoding skills and unspeeded-speeded profiles were assessed to test automaticity in word processing. Main results indicated that dyslexics have a deficit in automatic phonological decoding skills. The results are discussed within the framework of the phonological deficit and the automatization deficit hypothesis.

KEY WORDS: Automatic word processing deficit, Dyslexia, Phonological decoding deficit, Reading-Level-Match and Age-Match design

INTRODUCTION

Probably the most investigated problem in dyslexia research has been phonological coding skill. Phonological skills involve an abstract form of mental conceptualization of speech and are important for later reading achievement (see for a review Goswami & Bryant 1990). Many studies demonstrate that dyslexics suffer from a deficit in phonological processing, both in spoken language and in reading. In spoken language, the deficit can be observed in tasks which tap skills such as nonword repetition (Snowling 1981), rhyme judgment (Holligan & Johnston 1988), and phonemic segmentation (Bradley & Bryant 1978; Olson, Wise, Conners, Rack & Fulker 1989). In the area of reading, the phonological deficit is indicated by poor reading of words which, particularly in the initial stages of reading development, demand decoding, such as words with double consonants in the initial and end positions (Van der Leij & Smeets 1992), regular words (DiBenedetto, Richardson & Kochnower 1983; Kochnower, Richardson & DiBenedetto 1983), and pseudowords (Baddeley, Ellis, Miles & Lewis 1982; Holligan & Johnston 1988; Olson, Kliegl, Davidson & Foltz 1985; Olson, Wise, Conners & Rack 1990; Snowling 1980, 1981).

Although phonological processing is important in learning to read, it is not the only skill which determines reading ability. To become a proficient reader, children do not only need a good sense of the phonological representations of words, they also have to be able to process these words rapidly and

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with minimal effort. After words have been processed with high accuracy, rapid processing is the next stage in reading development towards automatized reading, which is the final stage in word processing (Ehri & Wilce 1983; LaBerge & Samuels 1974). Automatic processing of words frees attentional capacity for higher order reading processes and provides a solid basis for better reading comprehension.

Several studies have demonstrated slow processing of words and pseudowords exhibited by dyslexic readers (Bouma & Legein 1980; Lovett 1987; Manis 1985). Other studies suggest that slow processing by dyslexics is not restricted to identification of printed words but extends to a more general speed deficit in retrieving names of visual objects, colors, digits, and letters (Bowers & Swanson 1991; Denckla & Rudel 1976; Felton & Wood 1989; Spring & Capps 1974; Spring & Davis 1988; Spring & Perry 1983; Wolf 1986; Wolf, Bally & Morris 1986). These studies indicate that the reading problem dyslexics have does not lie only in decoding but also probably arises from poor automatic skills in lower order reading processes, such as name retrieval ability. Nicolson & Fawcett (1990) showed that dyslexics also have poor automatic skills in motor balancing and claim that dyslexia is caused by an automatic processing disability which hinders skill acquisition in general.

Aside from the question as to whether poor automatization in dyslexia is domain specific or not, Bowers & Swanson (1991) provides some evidence that automatic skills in name retrieval ability and phonological awareness are two independent skills which contribute variance in reading ability independently from each other. This suggests that dyslexics may have at least two different deficits: a lower order automization deficit and a phonological deficit. Probably, the combination of both deficits leads to the kind of poor reading skills exhibited by dyslexic readers.

The main objective of the present study was to examine whether dyslexic readers are subject to a combination of both deficits, that is a deficit in automatic phonological decoding skills. Two alternative hypotheses were tested. The first was that dyslexics have a phonological decoding deficit independent of automatic word processing. This question determines the extent to which both deficits are independent. The second hypothesis dealt with the question of whether dyslexics have a deficit in general automatic word processing which is not restricted to the decoding process. This issue pertains to the domain specificity of the automatization deficit. To investigate these questions, we compared dyslexics with different control groups on measures of phonological decoding and automatic word processing assessed by different tasks. Before going on to the details, we first have to explain what the deficit notion implies and how a deficit can be demonstrated.

According to the deficit hypothesis, dyslexia is caused by a deficit in the underlying reading mechanisms and, consequently, dyslexics will try to compensate for their deficit. In the light of this line of thought, dyslexia is a unique disorder, distinguishable from normal reading and other types of less-skilled reading in the need for compensation strategies. The opposite view is put forth by the hypothesis that dyslexia is not caused by a deficit, but arises as a result of a developmental lag. The lag hypothesis claims that dyslexic readers indeed develop slower than normal readers, but that they essentially use normal processes in learning to read without any need for compensation strategies. To differentiate between the lag or deficit hypothesis, we used the following methodology.

In order to investigate whether dyslexia is a unique disorder, different from other readers, dyslexics must be compared with various control groups. A comparison with average readers of the same age, the so-called Age-Match design, could provide a global indication of whether dyslexics are behind developmental expectation on the skill being tested. However, since the design cannot determine whether group differences are the result of specific characteristics of the dyslexic group or whether they are simply the result of differing reading levels between dyslexics and peers, it cannot differentiate between the lag or deficit hypothesis. This problem is resolved in the Reading-Level-Match design, whereby dyslexics are compared with younger readers of the same reading level. If dyslexics show poorer performance in comparison to the younger readers, group differences could not be attributed to differing reading levels but probably could be attributed to specific characteristics of the dyslexic group, i.e. a deficit. Usually, the younger reading-age group consists of readers with average reading skills. However, if the reading-age group were also to consist of poor readers, below average in reading skills but not as bad as dyslexics, the design would serve as a stronger indicator of the uniqueness of dyslexia as dyslexics would not differ only from normal readers but also from other types of less-skilled readers. By argument, it is hard to claim that dyslexia is the result of a developmental lag when the problem is absent or less severe in populations who are less developed because they are younger. For methodological discussions on this design see Backman, Mamen & Ferguson (1984), Bryant & Goswami (1986), Goswami & Bryant (1989), Jackson & Butterfield (1989), and Mamen, Ferguson & Backman (1986). In the present study, we used a combination of the Age-Match design and the Reading-Level-Match design. Dyslexics were compared with three control groups consisting of normal readers of the same age, normal readers of the same reading-age, and poor readers of the same reading-age.

We feel that the the merits of the Reading-Level-Match design are best utilized if its logic is made to touch the notion of compensation, a concept that accounts for the essential difference between the lag and deficit hypothesis. It would be necessary, therefore, to equate groups of dyslexic and younger readers on a reading task which allows some kind of compensation on the skill of interest. Subsequently, group differences have to be explored on experimental reading tasks which permit relatively less compensation, or in other words, tasks which are supposed to tap the deficient skill(s).

Combining the Age-Match and the Reading-Level-Match design, the deficit hypothesis predicts that the dyslexic group will perform worse than both the chronological-age group and the reading-age groups on experimental tasks which leave minimal room for compensatory processing. Accordingly, through compensation they can reach reading-age level performances on the equating task which allows for such compensation. The deficit hypothesis also predicts poorer performance on the part of the dyslexic group in comparison to the reading-age group of poor readers, but predicts that the latter will resemble the reading-age group of normal readers. In contrast, the lag hypothesis predicts that dyslexics will perform poorer than the chronological-age group as their development is undeniably slower than that of normal readers, but that they will perform as poorly as the reading-age groups on the experimental tasks. As argued above, the crucial point about the experimental tasks is that they permit less compensation strategies than the equating task, used to equate groups on reading age. If, according to the lag hypothesis, dyslexics do not need compensation strategies, they would not be sensitive to differences in task demand regarding compensatory processing. Therefore, if dyslexics resemble other groups on the equating task they must also resemble them on the experimental tasks.

In addition to allowing for compensatory processing in the task used to equate dyslexics with reading-age controls, it is also important that the skills tapped by this task are closely related to the skills one is interested in. Stanovich, Nathan & Zolman (1988) argued that different kinds of reading problems can be expected on the basis of whether Comprehension-Level-Matches or Decoding-Level-Matches are used. The point is that if one is interested in investigating skills related to phonological decoding, a Decoding-Level-Match is more appropriate than a Comprehension-Level-Match. The same line of reasoning holds for the reverse case. In their review article about Decoding-Level-Match studies, Rack, Snowling & Olson (1992) pointed out that differences in the kind of equation task, even subtle ones within the decoding domain, lead to differing results on group comparisons. They showed that the studies supporting a phonological decoding deficit in dyslexics have all equated dyslexics with reading-age controls on the oral reading of isolated words presented in a list and subsequently found dyslexics to make more errors in pseudoword reading. The procedure of equating groups on word reading and then exploring differences in pseudoword reading reflects the Reading-Level-Match logic of using equation and experimental tasks which are closely related but differ in opportunities for compensation. Word reading allows relatively more compensation than does pseudoword reading. Dyslexics may be able to read words in the long run by seeing these words over and over again. In this time consuming process, they can learn to make use of the orthographic and semantic features of words and hence use these resources to compensate for a phonological deficit. Pseudoword reading, on the contrary, places heavy demands on phonological decoding because of its unfamiliar visual and sound structure. Logically, an unexpectedly large difference between word and pseudoword reading, in favor of the first, may indicate a deficit in phonological decoding skills.

We will now return to the objective of the present study, namely the question of whether dyslexics have a deficit in automatic phonological decoding skills. Dyslexics were compared with normal readers of the same age, normal readers of the same reading-age, and poor readers of the same reading-age in order to examine the uniqueness of dyslexia. Since we were interested in both phonological decoding and automatic word processing, the task used to equate dyslexics with reading-age controls involved a speeded word task in which isolated words were presented in list form. We then explored group differences in speeded and unspeeded reading of words and pseudowords on three different tasks. As in most Decoding-Level-Match studies, we used the word-pseudoword profile as an index of phonological decoding skills. We took poorer performance on pseudoword reading than what could normally be expected on the basis of word reading to indicate a deficit in phonological decoding.

We examined automatic word processing by putting time constraint on input processing to disturb the reading process. In this way, we were able to place demand on the rapid processing of words. Rapid processing is one of the key features of automatic processing, in addition to such factors as minimal demand on processing capacity, absence of voluntary control, and insensitivity to interruption by competing activity in the same domain (Jonides, Naveh-Benjamin & Palmer 1985; Schneider 1985; Shiffrin, Dumais & Schneider 1984). The time constraint in the present study was achieved by means of a flashed format presentation of isolated words and pseudowords at an exposure duration of 200 ms. If word processing is automatized, performance in the constrained, speeded condition would be accurate and would not differ very much from the unconstrained, unspeeded condition. Hence, unspeeded-speeded profiles were obtained to assess automaticity of word processing.

In order to examine whether problems in automatization are restricted to the process of phonological decoding or are extended to word processing in general, we tested the extent of phonological decoding by using three different tasks which varied in the demand they placed on it. These tasks are given here in decreasing order of phonological difficulty and are as follows: a naming task, an auditory-visual matching task (AV task), and a lexical decision task. We tested the following hypotheses:

1. If dyslexics have a deficit in automatic phonological decoding skills then: (a) dyslexics should, at least in the most demanding phonological task, differ from all control groups on the word-pseudoword profile in the speeded condition but should not in the unspeeded condition; the profile should point out that dyslexics have problems with pseudoword processing as compared to word processing; the problem should be at its worst in the naming task, not as bad in the auditory-visual matching task, and less so in the lexical decision task; (b) poor readers should have, at least in the

most demanding phonological task, a speeded word-pseudoword profile similar to that of the reading-age group with normal readers and different from that of the reading-age group with dyslexic readers.

2. If dyslexics have a deficit in mere phonological decoding, spearate from automatic word processing, the criteria mentioned in 1) should also apply to the unspeeded condition.
3. If dyslexics have a deficit in general automatic word processing, not restricted to the process of decoding, then: (a) dyslexics should, on all tasks irrespective of phonological task demand, differ from all control groups on the unspeeded-speeded profile; the profile should point out that dyslexics have problems in the speeded condition as compared to the unspeeded condition; (b) poor readers should have unspeeded-speeded profiles similar to those of the reading-age group with normal readers and dissimilar to those of the reading-age group with dyslexic readers.

METHOD

Subjects

All groups were tested in May/June, at the end of the school year. See Table 1 for subject characteristics. Twenty-one dyslexics aged nine to eleven were selected from a special school for Primary Learning Disabled Children. These children had severe reading and spelling problems which could not be accounted for by factors such as intelligence, home or school background, or any neurological, sensory or emotional disturbances. For a futher description of the Dutch system of special education see Van der Leij (1987). The control groups were recruited from two regular schools. The Reading-Age group with normal readers (normal RA) were first graders; the Reading-Age group with poor readers (poor RA) were second graders; and the Chronological-Age group (CA) were fourth and fifth graders. It is important to note that all subjects in the experiment received reading instruction at school which emphasizes phonetically-based reading skills. Therefore, it is most unlikely that group differences arise from differences in reading method.

To match the dyslexic group with the two reading-age groups, a Dutch reading task called the EMT was used (Brus & Voeten 1973). The EMT is a standardized measure of speeded word reading and is highly reliable ($r = 0.89$). The test requires the child to read a list of unrelated words within one minute. The reading score is the number of words correctly read aloud within one minute. The EMT permits the following kinds of compensations: words instead of pseudowords are used so that orthographically and semantically based strategies can be evoked; low accuracy can be compensated for by high reading speed and vice versa to reach similar scores; self corrections were allowed so that subjects were not urged on smooth naming. In Table 1, the EMT scores are presented in words per minute (wpm). These scores are converted in the next column into reading-grade equivalents, according to American standards. The Peabody Picture Vocabulary Test (PPVT) was used to test passive word vocabulary. The performances on this test are presented in Table 1 in PPVT IQ scores. There were no significant differences between groups on this IQ measure.

Table 1. Subject characteristics

Groups	N	Age (in months)	EMT (in wpm*)	Reading grade equivalent	PPVT IQ
RA	16	85 (3.96)	24.4 (7.89)	2.1 nd grade	96.4 (14.4)
Poor	15	98 (3.48)	29.6 (7.73)	2.4 nd grade	99.6 (18.9)
Dyslexic	21	122 (8.04)	27.7 (6.81)	2.3 nd grade	109 (14.1)
CA	15	121 (8.64)	64.2 (12.1)	4.6 nd grade	109 (12.5)

* wpm = words per minute.
The numbers within brackets are standard deviation scores.

General procedure

The same subjects were tested on three different tasks, which were, in order of testing, a naming task, an auditory-visual matching task, and a lexical decision task. Each task was administered in separate sessions of 10 minutes, preceded by four practice trials in each of the unspeeded and speeded condition. The stimuli were presented in discrete-trial format on an Apple Macintosh micro computer. Stimuli were displayed in the centre of the screen and subtended at a visual angle of approximately 2°. Subjects were seated at a distance of 40 cm from the screen. The words were presented in lower-case characters, with point size 48 and a proportional font comparable to the font used in Dutch reading books at school.

The onset of a trial was preceded by a warning tone of 600 Hz with a duration of 200 msec, followed by a one-second interstimulus interval, and then by a frame which was as large as the length and width of the word that was about to appear in it. After the word was displayed within its frame, removal of the word depended on the condition in which the word was presented. In the unspeeded condition, both the frame and the word were removed from the monitor by the onset of a response. In the speeded condition the word disappeared after 200 msec and was replaced by a backward-masking stimulus, a nonsense pattern which consisted of partial features of letters (i.e., circles and lines). The mask was displayed within the same frame as the word for a period of 200 msec. Afterwards, the masking stimulus disappeared and an empty frame remained, which was not removed until the onset of the subject's response. The subjects were instructed that the onset of their own responses terminated the frame display. After a response was made, a three-second delay followed until the warning tone announcing the next stimulus appeared. The unspeeded condition always preceded the speeded condition.

In each experiment, different words and pseudowords were used. A mixed-list procedure was used in which an equal proportion of words and pseudowords were presented in one list, in random order. It is assumed that such a list approximates natural reading settings because it elicites the flexible use of both the lexical and the nonlexical strategy (Dorfman & Glanzer 1988). The words were high-frequency CVC nouns, even for the youngest group, the first grade subjects. The first graders had encountered these words in their school books anywhere from a minimum of 5 times to a maximum of 100 times (mean = 25, SD = 42). Pseudowords were derived from the words presented in the same list by changing one letter counterbalanced across positions. The resulting string was always a regular, orthographically legal and pronounceable nonword.

EXPERIMENT I

In the first experiment subjects were given a naming task. This task places most demand on phonological processing as it requires overt pronunciation.

Method. Subjects were instructed to read the words aloud as quickly and accurately as possible. Error rates were scored by hand. Eighty words were presented, 40 high-frequency words and 40 pseudowords, equally divided across unspeeded and speeded condition, and presented in four blocks of twenty trials. The subjects were given a ten second break after a block of twenty trials. The proportion of trials within one block was according to the general procedure: each block contained a mixed list, half of which consisted of high-frequency words and half of pseudowords, presented in random order.

Results. A 4 (group) × 2 (time constraint) × 2 (lexicality) ANOVA was run on the percentage of correct responses. All main effects and all possible combinations of effects were sigificant. There was also a significant three-way interaction group × times constaint × lexicality, $F(3,63) = 8.35$, $p < 0.001$ (Figure 1). Analyses of the interaction showed the following results: Separate Newman-Keuls post hoc analyses ($\alpha = 0.05$) for each combination of time constraint and lexicality showed that the dyslexic group performed lower than the control groups, whereas the control groups did not differ significantly from each other. Thus, dyslexics made more errors than the control groups in reading words and pseudowords in both the unspeeded and speeded condition.

Further analyses showed significant interactions of group with time constraint in pseudoword reading, $F(3,63) = 7.84$, $p < 0.001$, but not in the word reading. Likewise, group interacted significantly with lexicality in the speeded condition, $F(3,63) = 12.4$, $p < 0.001$, but not in the unspeeded condition. The interactions demonstrated that all groups had better word performances than pseudoword performances, and the scores were better in the unspeeded condition than in the speeded condition. However, dyslexics were significantly more impaired than the control groups in reading pseudowords in the speeded condition (Figure 1).

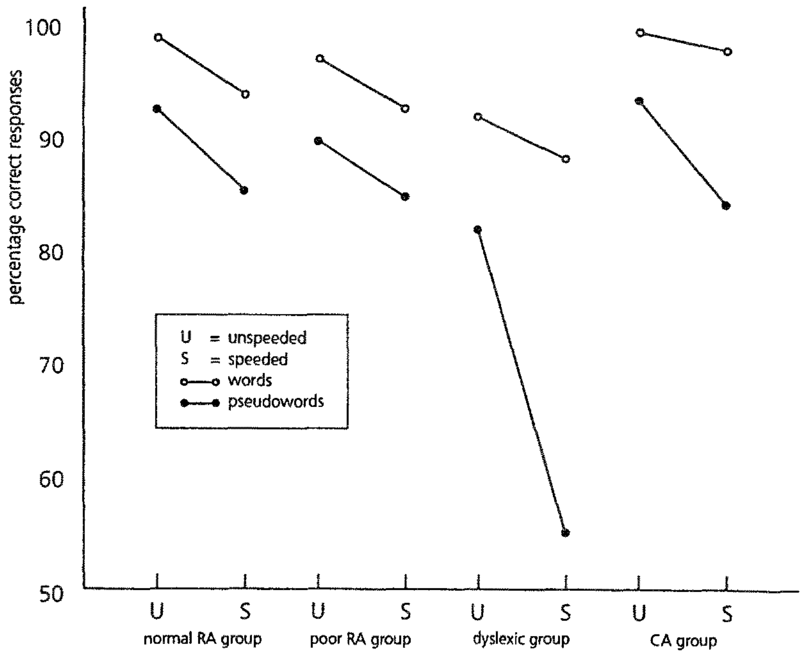

Figure 1. Word and pseudoword naming as a function of time constraint in different groups.

Discussion. The results on the naming task indicated that the overall word and pseudoword performances of dyslexics were lower than those of all control groups. They also differed in the profile of performances, which is our primary focus of interest. The results demonstrated that the dyslexic group differed from all the control groups on the word-pseudoword profile, but only in the speeded condition. Dyslexics were particularly impaired in pseudoword reading when these words had to be processed rapidly. The performances of the poor readers resembled those of the reading-age group with normal readers. Probably due to the easy material (CVC words), the poor readers and the younger normal readers performed as well as the older normal readers. Despite the easy material, dyslexics performed worse than the control groups. The results indicate that dyslexics have a deficit in automatic phonological decoding skills.

EXPERIMENT II

In this experiment, group differences were tested on an auditory-visual matching task (AV task). The task requires that a visual word be matched with a spoken word. The two words were presented in two different modalities, thereby requiring the subject to translate the representations into one format. We assume that this kind of translation, whether it be visual into sound or sound into visual, is an important aspect of phonological processing in reading. Since overt pronunciation is avoided, the AV task demands less as regards phonological processing than the naming task. Still, a kind of implicit phonological coding is required in the AV task.

Method. Two words were presented simultaneously; one in auditory modality and the other in visual modality. The subjects were instructed to press the 'yes' button if the word they saw on the screen sounded exactly the same as the word they heard through the headphones, and if not, to press the 'no' button. The instructions emphasized accuracy as well as speed. In the speeded condition, the visual word was presented at an exposure duration of 200 msec. Auditory stimuli were stored on hard disk by using an analog-to-digital converter which sampled naturally spoken words at a rate of 22 KHz. Subjects heard the spoken words through a headphone. The computer registered whether responses were correct or not. Self corrections were permitted within three seconds after the first press; the computer registered only the last press. Forty-eight pairs of CVC words were presented in two blocks of twenty-four trials, one block in each of the unspeeded and speeded conditions. A block of 24 trials was made up of equal proportions of signal and noise trials, divided as follows: 6 'same' trials of high-frequency words, 6 'same' trials of pseudowords, 6 'different' trials consisting of a combination of a high-frequency word and a pseudoword, and 6 'different' trails consisting of two different pseudowords.

Results. A 4 (group) × 2 (time constraint) × 2 (lexicality) ANOVA was run on A' statistics. A' is a non-parametic measure of sensitivity in signal detection theory (Pollack & Norman 1964) which requires minimal assumptions about the underlying distributions. A score of 0.5 is to be interpreted as chance performance, whereas a 1.0 score indicates perfect performance. In computing the A's, the proportion of 'yes' responses to 'same' items were converted into hit rates and the proportion of 'yes' responses to 'different' items were used for the false alarm rates. There was a significant main effect of group, $F(3,62) = 7.75$, $p < 0.001$. Since there were significant interactions with time constraint and lexicality, separate Newman-Keuls post hoc analyses were computed for each combination of time constraint and lexicality (Table 2). The analyses showed two significant patterns. First, the CA group outperformed the remaining groups in pseudoword performance, both in the unspeeded and the speeded condition. Second, the control groups outperformed the dyslexic group in the speeded condition with words. There was a significant group × time constraint interaction, $F(3,62) = 7.26$, $p < 0.001$. Simple effects showed that only the dyslexic group had significantly lower performances in the speeded condition as compared to the unspeeded one, $F(1,62) = 15.5$, $p < 0.001$ (Figure 2). The remaining groups were not impaired in the speeded condition. There was also a significant group × lexicality interaction, $F(3,62) = 8.80$, $p < 0.001$. The interaction was due to the fact that all groups except for the CA group had better word performance than pseudoword performance. Simple effects showed F-values of 19.9 in the dyslexic group, 32.3 in the normal RA group, and 32.9 in the poor RA group.

Table 2. A′ statistics on the AV matching task

	Normal RA group	Poor RA group	Dyslexic group	CA group
words				
unspeeded	0.98 (0.03)	0.99 (0.03)	0.99 (0.03)	0.99 (0.04)
speeded	0.96 (0.06)	0.97 (0.03)	0.91 (0.11)	0.99 (0.03)
pseudowords				
unspeeded	0.89 (0.05)	0.89 (0.05)	0.91 (0.05)	0.95 (0.09)
speeded	0.87 (0.08)	0.89 (0.05)	0.86 (0.06)	0.98 (0.05)

The numbers within parentheses are standard deviation scores.

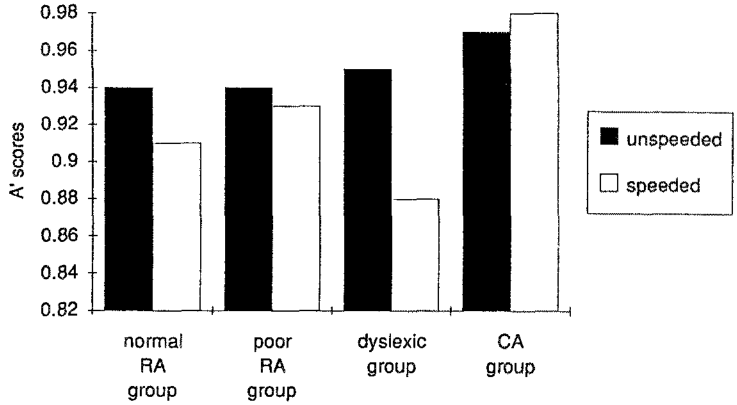

Figure 2. Speeded and unspeeded performances of different groups on the AV matching task.

Discussion. The results on the AV matching task showed that all groups had an almost 100 percent rate of accuracy on their performances in the easiest condition: the unspeeded condition with words. However, group differences occured in the speeded condition with words. Although all the control groups maintained a high rate of accuracy on their performances, the performances of dyslexics dropped significantly below those of the control groups. Unlike that of the control groups, the unspeeded-speeded profile of dyslexics showed impairments in the speeded condition, regardless of whether words or pseudowords were involved. The poor readers, in contrast, resembled the younger and older normal readers on the unspeeded-speeded profile, indicating that normal performances on this task were not disrupted in the speeded condition. The results suggest that dyslexics have an automatization deficit in word processing which is not restricted to decoding. On the word-pseudoword profile, dyslexics did not differ from reading-age controls. Like both reading-age groups, the dyslexic group had better word than pseudoword performances, with pseudoword processing being below the level of the CA group. In normal reading development, the word superiority effect on this task can be expected to disappear by the age of ten, as is indicated by the performances of the chronological-age group. The fact that dyslexics still perform below age level in pseudoword processing indicates that dyslexics have phonological decoding problems but that these problems are not as bad as those encountered in connection with the naming task.

EXPERIMENT III

In experiment III, subjects were given a lexical decision task. This task demands the least with regard to phonological processing because orthographic and semantic features can be useful tools in deciding whether or not a string displayed is a real word. Conversely, in allowing orthographically and semantically based decisions, the lexical decision task gives the subjects more opportunity than other tasks do to compensate for a phonological deficit.

Method. Subjects were instructed to press the 'yes' button if the letter string displayed was a word and the 'no' button if it was a pseudoword. In total, 24 words and 24 pseudowords were presented in a mixed list in random order, and were equally distributed over the unspeeded and speeded conditions. The material consisted of words and pseudowords not presented in the previous two experiments. The words were concrete, high-frequency CVC nouns.

Results. A 4 (group) × 2 (time constraint) × 2 (lexicality) ANOVA was run on A' statistics. In computing A' for words, the proportion of 'yes' responses to words were converted into hit rates and the proportion of 'yes' responses to pseudowords were used for the false alarm rates. Conversely, A′ for pseudowords was computed by converting 'yes' responses to pseudowords into hit rates and 'yes' responses to words into false alarm rates. All main effects were significant, but there were also significant interactions. Where group interactions occurred, planned contrasts were computed between the dyslexic group and each of the control groups, and between the poor readers and the reading-age group of normal readers. Table 3 shows the A′ scores on the lexical decision task. There was a significant group × lexicality interaction, $F(3,61) = 3.87$, $p \leqslant 0.01$. Simple effects showed a significant effect of lexicality in both the normal RA group ($F = 14.8$, $p < 0.001$) and in the dyslexic group ($F = 4.34$, $p < 0.05$), indicating better word than pseudoword discrimination. The poor RA group and the CA group were not sensitive to differences in lexicality. Simple effects also showed significant group differences, but only on pseudoword ($F = 4.09$, $p \leqslant 0.01$) and not on word discrimination. Planned contrasts between groups on pseudoword discrimination demonstrated that both the dyslexic and the poor RA group performed significantly better than the normal RA group ($F = 4.27$, $p < 0.05$ respectively $F = 6.41$, $p \leqslant 0.01$). The dyslexic group did not differ from the poor RA group and the CA group.

The group × time constraint interaction approached significance, $F(3,61) = 2.12$, $p = 0.10$. Simple effects showed a significant effect of time constaint in the RA group ($F = 6.48$, $p \leqslant 0.01$) and in the dyslexic group ($F = 4.89$, $p < 0.05$), revealing better performances in the unspeeded than in the speeded condition. The performances of the poor RA group and the CA group were not affected by time constraint. Simple effects also showed significant group differences, but only in the speeded ($F = 4.00$, $p \leqslant 0.01$) and not in the unspeeded condition. Planned contrasts between groups in the speeded condition demonstrated marginally significant differences between the dyslexic group and the CA group ($F = 3.46$, $p = 0.07$), in favor of the CA group. The dyslexic group matched the normal and the poor RA groups in speeded performances. There was also a significant difference between the normal and the poor RA group ($F = 5.95$, $p < 0.05$), in favor of the poor RA group. There was a significant lexicality × time constraint interaction, $F(1,61) = 5.69$, $p < 0.05$. The interaction demonstrated that lexical decisions were impaired in the speeded condition but only when pseudowords were presented. This was true of all the groups because there was no significant group × time constraint × lexicality interaction.

Discussion. Experiment III showed that dyslexics have no deficits in making lexical decisions. Although the dyslexic group demonstrated a discrepancy between word and pseudoword discrimination, a deficit in phonological processing was not indicated because the normal RA group had a similar word-pseudoword profile. Likewise, dyslexics were impaired in the speeded condition, but a speed deficit is out of the question because the normal RA

Table 3. A′ scores on the lexical decision task

	Normal RA group	Poor RA group	Dyslexic group	CA group
words				
unspeeded	1.0 (0.00)	1.0 (0.02)	1.0 (0.02)	0.99 (0.02)
speeded	0.98 (0.03)	0.98 (0.03)	0.97 (0.03)	0.99 (0.02)
pseudowords				
unspeeded	0.90 (0.11)	0.96 (0.10)	0.95 (0.08)	0.97 (0.06)
speeded	0.79 (0.23)	0.93 (0.07)	0.88 (0.17)	0.96 (0.06)

The numbers within parentheses are standard deviation scores.

group has a similar unspeeded-speeded profile. The results suggest that dyslexics are more affected by time constraint than by phonological processing demand in making lexical decisions. Namely, their word and pseudoword discriminations accord with their age level, but only in the unspeeded condition. In the speeded condition, their performances tended to be behind age level. This indicates that dyslexics have no problems in word processing as long as the task demand allows orthographic and semantic features to be used and the subject is given plenty of time to make a decision. The problem, however, showed up when they have to make rapid decisions. Remarkably, the youngest group (normal RA group) had problems in performing the lexical decision task when pseudowords were presented. Probably, task unfamiliarity and age account for this problem, as the two older groups at the same reading level performed better than the younger group in pseudoword processing. We will return to the subject of task unfamiliarity in the general discussion.

GENERAL DISCUSSION

The aim of the present study was to investigate whether dyslexics have a deficit in automatic phonological decoding skills. For this purpose, the performances of dyslexics were compared to those of different control groups on three different tasks of varying phonological requirements. Phonological decoding and automatic word processing respectively were examined by assessing profiles of word-pseudoword performances and unspeeded-speeded processing respectively.

The following results were obtained for each task. On the explicit phonological task, the naming task, dyslexics showed a deficit in automatic phonological decoding: they were particularly impaired in reading aloud pseudowords in the speeded condition. The poor readers resembled the younger and older normal readers. On the AV matching task, whereby the demand made on phonological processing is lighter and of a more implicit nature, a deficit showed up in general automatic word processing. Dyslexics were particularly impaired in the speeded condition, irrespective of whether words or pseudowords were involved. On this task, we were unable to find any indication of a phonological decoding deficit, as dyslexics had word-pseudoword profiles similar to those of the reading-age groups of normal and poor readers. Their pseudoword performance was, however, still below age level. The poor readers resembled the younger normal readers on the AV matching task. On the lexical decision task, dyslexics showed no signs of a deficit because they resembled the reading-age group of normal readers on both phonological and automatic processing. However, there were still some signs that dyslexics have problems in processing word aspects, as they tended to be behind age level, but only when rapid decisions have to be made.

Combining the results on the three different tasks, the present study provides strong evidence that dyslexics have a deficit in automatic phonological decoding skills. The more demanding the task with regard to phonological processing, the poorer the performance dyslexics showed on pseudowords in the speed condition. Thus, compared to the performances of the control groups, their word-pseudoword discrepancy in the speeded condition was the largest on the naming task. It was smaller, however, on the auditory-visual matching task, and much more so on the lexical decision task. We were unable to find any strong evidence of this kind to support the two alternative hypotheses, namely the mere phonological decoding deficit hypothesis and the general automatic word processing deficit hypothesis. The deficit was really observed in a combination of automatic processing and phonological decoding.

The first alternative hypothesis, that of a mere phonological decoding deficit, can be excluded because dyslexics did not show an unexpectedly large word-pseudoword discrepancy in the unspeeded conditions. However, it is important to note that the easiness of the material (CVC pseudowords) does not demand much of phonological decoding, even when the task involves naming. Therefore, dyslexics may demonstrate a decoding deficit in unspeeded conditions when more complex pseudowords are to be processed. This is what most Decoding-Level-Match studies have found in supporting the phonological deficit hypothesis. Nor do the results of the present study provide any strong evidence in favor of the second alternative hypothesis which claims that dyslexics have a deficit in general automatic word processing not restricted to the decoding process. The most important contra-evidence is that the speed deficit was not demonstrated in the lexical decision task, which demands the least of all tasks of phonological processing. If dyslexics have a deficit in automatic word processing which is not restricted to decoding, dyslexics should have been more disrupted in the speeded condition than the reading-age groups in a task that places minimal demand on decoding, such as the lexical decision task. In fact, dyslexics had an unspeeded-speeded profile similar to that of the youngest normal readers.

However, we feel that the notion of a general automatic word processing deficit in dyslexics should not be completely rejected on the sole basis of the results of the lexical decision task. The fact remains that dyslexics showed a speed deficit when the phonological task demand decreased, as was the case in the AV matching task. It should be further noted that this speed deficit manifested itself regardless of whether words or pseudowords were used. A second point to keep in mind is that the youngest group of readers (the normal RA group) may be confronted with task unfamiliarity on the lexical decision task. Task unfamiliarity may undermine their performances in the speeded condition, particularly when unfamiliar stimuli such as pseudowords are presented. As a matter of fact, younger readers rely heavily on print-sound translations whenever they see a word because this is the way they learn to read at school. For the sake of developing reading automaticity, the reliance on print-sound translations may become mandatory in beginning readers and may operate, for the time being, at the cost of lexical decisions which allow orthographic and semantic processing as well. Dyslexics, on the other hand, may have profited from orthography and semantics because they were older and have been given a great deal of exposure to these aspects of written words. Hence, the performances of the youngest readers on the lexical decision task may be underestimated due to task unfamiliarity. Consequently, their performances are disrupted in the speeded condition, leading to an unspeeded-speeded profile similar to that of dyslexics. Hence, it may be that if the youngest readers were to be equally acquainted with the task demand, their sensitivity to time constraint will disappear. After all, the performances of the more older poor readers and normal readers, who are supposed to be more familiar with the task demand, were not impaired by the speeded condition. The same can be said about the youngest readers' disruption in pseudoword processing as opposed to word processing. Their word-pseudoword profile was equal to that of the dyslexic readers, which leaves the possibility free that dyslexics may show an automaticity as well as a phonological deficit in the lexical decision task. However, the present results also demonstrate that dyslexics tended to perform below age level in the speeded and not in the unspeeded condition. This suggests that dyslexics are more impaired by time constraint than by demand on phonological processing, making the automaticity deficit more likely than the phonological deficit as regards performances in the lexical decision task.

In conclusion, the present study provides strong evidence that dyslexics suffer from a deficit in automatic phonological decoding skills. Consequently, dyslexics not only have qualitatively poor phonological representations, they also have severe problems with rapid, automatic processing of phonological information. The phonological deficit hypothesis does not explicitly cover automatic processing. Therefore, the results fall more in line with the automatization deficit hypothesis as far as phonological decoding is concerned.

There are slight indications that poor automatic processing in dyslexics may extend beyond the domain of phonological decoding, but still fall within the language domain. For one thing, impaired speeded performances remained below reading-age level as phonological task demand decreased, such as in the AV matching task, and occurred regardless of whether words or pseudowords were presented. Moreover, this would probably remain so in a task whereby minimal demand is made on phonological processing, such as in the lexical decision task, that is, given the subjects are familiar with the task requirements. Based on these findings, we would like to advance the cautious suggestion that dyslexics may have an automatization deficit which does not pertain solely to phonological decoding skills.

However, these suggestions are very preliminary and need to be tested in further research. In order to test the general automatization deficit hypothesis, more indexes of automaticity must be used in combination with non-verbal or non-cognitive skills. In the present study, we only used speed of processing as an index of automaticity and left out other characteristics such as the degree of demanding processing capacity, the absence or presence of voluntary control, and the sensitivity to interruption by competing activity. Furthermore, the present tasks were all verbal tasks, though the demand on phonological processing varied. It would be necessary to test nonlinguistic and noncognitive skills as well in order to test the the generality of the automatization deficit hypothesis. Likewise, it is also necessary to demonstrate clearly the relationship between automaticity, speed of processing, and reading.

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