Automatization Aspects of Dyslexia:

Speed Limitations in Word Identification, Sensitivity to Increasing Task Demands, and Orthographic Compensation

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Abstract

A study is presented in which three characteristics of dyslexia were examined: (a) speed limitations in word identification, (b) sensitivity to increasing task demands, and (c) orthographic compensation. Ten students with dyslexia (10 years old) were compared to 10 chronological-age controls and 20 reading-age controls on their performance in reading. Response latencies of the students with dyslexia were slower when familiar words, letter clusters, and nonwords had to be named. A larger word-frequency effect and a larger word-length effect in the these students indicates that they have difficulty with increasing task demands. In addition, a subword-frequency effect was found to be larger in the students with dyslexia. These differences among the three groups of students are interpreted in terms of automatization. Furthermore, it is suggested that students with dyslexia may have a preference for large orthographic units, which is used as a compensatory tool in reading.

Although automaticity as a theoretical concept has been subject to debate and evolution, there seems to be little doubt that it plays an important role in the development of basic skills such as reading. It is fair to state that automaticity is the key feature of skilled reading. As a consequence, learning to read may be interpreted as learning how to automatize word-recognition skills. The reason why it is important was well expressed by Adams (1990): "Human attention is limited. To understand connected text, our attention cannot be directed to the identities of individual words and letters. In reading as in listening, the process of individual word perception must proceed with relative automaticity, and such automaticity is afforded only through learning" (pp. 228–229).

The concepts of automaticity and automatization—the learning process that eventually leads to automaticity—have had considerable influence on the research in reading disabilities, for two obvious reasons. Reading is one of the most important basic skills to be learned, and failure to automatize that skill has strong negative effects on careers in school and work. Furthermore, the core feature of reading disabilities—poor and slow word identification—is suited for interpretation within the theoretical framework of automaticity and automatization. To describe the cognitive characteristics of reading disabilities, it is useful to differentiate between lower order and higher order processing (Spear & Sternberg, 1987). Lower order, or bottom-up, processing is data-driven, as in the case of analyzing incoming stimuli in order to store their features in working memory. Higher order, or top-down, processing is concept-driven, as seen in language activities. Analogously, reading can be subdivided into word-identification skills and reading comprehension. Although mastery of reading skills involves the interaction between a variety of cognitive processes, it is clear that word-identification skills rely heavily on lower level automatization processes. After the first stage of reading acquisition, the development of reading comprehension is decreasingly explained by competence in word-identification skills and increasingly by the influence of higher level language competence (Perfetti, 1985). Indeed, the growing involvement of top-down processes is evident (Aaron, 1991).

The existence of students with specific, lower level deficits in reading is well documented (Rutter, 1978). Traditionally, this type of disability is called "developmental dyslexia" or "specific reading disability." An endogenous factor of genetic origin is indicated as the main cause (Olson, Wise & Rack, 1989). In their review, Spear and Sternberg (1987) concluded that there are two strong indicators of a lower level deficit: (a) poor execution of processes that enable the individual to manipulate the sound structure of speech, and (b) poor automatization of word-identification skills. According to the idea of a "bottleneck" in the verbal efficiency theory of Perfetti (1985), disabilities in lower level decoding processes impede higher level processes, such as comprehension, because decoding consumes too much of the attentional resources.

Phonological Deficit

The hypothesis of the first indicator, a so-called phonological deficit, as the core of developmental dyslexia is nowadays well accepted (Snowling, 1987; Stanovich, 1988). Phonological processing is very important in learning how to read in an alphabetic writing system because essentially the alphabetic system is based on grapheme–phoneme correspondences. A deficit in phonological processing will result in poor word-identification processes in reading. This is most obviously reflected in nonword reading, which demands decoding at the sublexical translation level. In contrast, the recognition of familiar words is less affected in dyslexic readers (Rack, Snowling & Olson, 1992). When written words are considered as lying on a continuum of familiarity, the reading performance of people with dyslexia deteriorates with increasing unfamiliarity—nonwords being the ultimate end—more than the reading performance of nondisabled students of their age (chronological-age controls, from now on referred to as "CA controls"). More important, the difference is also apparent when students with dyslexia are compared with students of the same general reading level (reading-age controls, or "RA controls"). This latter comparison suggests that dyslexia is not associated with slow and backward, but otherwise normal, reading development (developmental lag), but with deviant development (deficit).

Although the phonological deficit hypothesis has received impressive empirical support, the picture may not be complete in several ways. First, the speed element of information processing is neglected therein, although it is clear that differences in performance are strongly related to differences in speed (Seymour, 1986). Second, the phonological deficit hypothesis disregards both the consumption of attentional resources and the competition between top-down and bottom-up processes, although it is clear that people with dyslexia show deviant developmental patterns (Spear & Sternberg, 1987). Moreover, the explanation of characteristics of students with dyslexia outside the area of phonology is beyond its power. It can be argued that the concepts of automaticity and automatization contribute to the understanding of dyslexia because they clarify the element of speed of processing, and are not necessarily restricted to the phonological aspect of reading. Indeed, over the last 3 decades, research in this area has suggested at least three characteristics that relate to dyslexia: (a) speed limitations in word identification, (b) sensitivity to increasing task demands, and (c) orthographic compensation.

Speed Limitations in Word Identification

Inspired by "triple phase acquisition models" (Downing, 1979; LaBerge & Samuels, 1974), the question has been investigated whether good and poor readers vary in accuracy and speed aspects of automatization. In these models, the first part involves a cognitive phase in which the learner attends closely to the functions and techniques of the various tasks he or she must undertake to become a skilled performer. According to the LaBerge and Samuels model of the stages of perceptual learning, time and effort are spent on the discovery of relevant features. In reading, the recognition of letters and association with the phonemes still consume much attention in the beginning. Performance is relatively slow but increasingly accurate. In the next phase, mastery is reached through practice, resulting in (near) perfect accuracy of performance. LaBerge and Samuels call this the stage of *unitization*. Familiar words will be recognized as a whole and read accurately but still somewhat slowly. In the third phase, the learner practices the skill "beyond mastery until he can perform the skill without any conscious concern for it" (Downing, 1979, p. 34). In this phase, full automaticity is reached. At the behavioral level, the three stages can be expressed in terms of accuracy and speed. Accuracy will be mastered at (near) perfect level during Phase 2, and speed will increase in all three phases (but most predominantly in the third phase), until a speed asymptote is reached. As a result, performance is accurate and rapid. The learning process—automatization—is initially reflected in the number of trials required to master accuracy, and, next, in the number of trials required to reach the speed asymptote or previously set mastery criteria for accuracy or speed.

Using the method of repeated practice recommended by Samuels (1985), researches have found differences between good and poor readers when the same set of words is repeatedly presented. For example, in contrast to average readers, less skilled students show smaller familarization effects of repeated practice (Hogaboam & Perfetti, 1978). Students with a more extreme reading disability need more trials than average readers to acquire word-specific knowledge (Reitsma, 1983); moreover, once the accuracy criterion is reached, they still respond with slow latencies even after many extra repetitions of the same material (Van der Leij & Van Daal, 1989). Although these students seem to be able to acquire word-specific knowledge, their *speed limitations in word identification* suggest that, still, a substantial amount of effort is involved. As a consequence of these findings, it seems appropriate to suggest that, to clarify the question of whether individuals with dyslexia can automatize their decoding skills, the speed element in the model of LaBerge and Samuels needs elaboration. We suggest that it does not seem correct to speak of automaticity when familiar words are read accurately time and again but at the cost of more attentional resources, indicated by a speed level that is consistently slower than the age level. In a later section, the speed limitation hypothesis, which predicts that students with dyslexia are able to use word-specific knowledge but at a slower speed than average readers, is put to test again.

Sensitivity to Increasing Task Demands

The decreasing use of attentional resources in the automatization process has already been mentioned. In *attentional resource reduction* models, automaticity has been defined as a mode of processing that is executed rapidly, free from demands on processing capacity, not subject to voluntary control, and not susceptible to interruption by competing activity in the same domain (Shiffrin & Schneider, 1977). During the learning process, automatization eventually leads to reduction of the use of attentional resources, resulting in fast and effortless processing. However, the quality of automaticity may be somewhat overstated with regard to early theorists' claim that no attention at all is involved when this phase is reached (as is expressed by the phrase "without any conscious concern"; Downing, 1979, p. 34). The consequence of this rigid definition could be that very few, if any, individuals ever reach the ultimate stage of automaticity in basic skills. For that reason, Perfetti (1985) preferred to avoid the concept, stating that "it is difficult to say whether any process can really meet this test—certainly not processes as complex as those discussed here" (p. 120). Rayner and Pollatsek (1989), summarizing the evidence on automaticity in skilled word processing, concluded, "While we can't be completely sure that the identification of a word is completely automatic for a skilled reader, it appears to take at most 60 to 70 msec of mental activity" (p. 75). They stated that this amount is far less than the estimated 200 msec or more that is consumed by the identification of the meaning of words in text-comprehension tasks. Still, although skilled reading involves only little attention, it seems best to think of resource costs as a matter of degree and not as an all-or-nothing distinction between attention-free and attention-demanding reading (Perfetti, 1992). This idea is supported by the general view that cognitive processes in basic skills may never become entirely free of attention (Cheng, 1985), as expressed by Adams (1990) in the phrase "*relative* automaticity" (p. 229).

Based on attentional resource reduction models, the role of attention has been studied in two ways. The first way involves demonstrating that students with dyslexia are less susceptible to interference due to the automatic identification of known written words than nondyslexic readers. Typically, pictures of objects with words printed on them are presented to the participants. Good readers have more trouble in avoiding word identification than poor readers (Guttentag, 1979), indicating that the latter have progressed less in automatization. As words become familiar through reading experience, there is an interference effect when children are asked to name the pictures and ignore the words. What the results of this approach indicate is that the skilled reader identifies familiar words even when he or she is asked not to do so (Rayner & Pollatsek, 1989). Although it is clear that poor readers have less trouble in switching their attention from one time-consuming task (word identification) to another (object naming), the evidence does not reveal which components of the reading process explain the difference. With respect to this issue, the second approach in the study of attentional resources seems to be more promising. To investigate whether the word-identification process of dyslexia readers is more costly in terms of attentional resources, task demands within the reading domain have been manipulated. In general, the conclusion can be drawn that individuals with dyslexia suffer more from complicating task conditions within the reading domain than average readers (Seymour, 1986). Students with dyslexia are, possibly at any stage of their reading development, *extremely sensitive to increasing task demands* related to such factors as higher phonological complexity, lower word frequency, longer word length, or the need to process rapidly (Van der Leij, 1993). As an example of the last factor, the use of time constraints ("flashed" presentations) has been demonstrated to trigger certain weaknesses in individuals with dyslexia (Bouma & Legein, 1980). In one of our studies (Yap & Van der Leij, 1993; see also Yap & Van der Leij, 1994), the need to process rapidly was added to the need to segment at the phonemic level by combining the manipulation of word frequency (the word/nonword contrast) and exposure time (the unlimited/200 msec exposure duration contrast). The findings indicated huge differences among 10-year-old students with dyslexia, CA controls, and 7-year-old RA controls. In particular, the demand for fast phonological recoding of flashed nonwords caused a deterioration in the performance of participants with dyslexia far more than was the case in the other groups or in the single conditions of either decreasing word frequency or shortening exposure duration. Strikingly, this automatic decoding deficit—as Yap and Van der Leij labeled it—could be demonstrated even at the simplest level of word structure (CVC). Furthermore, the deficit seemed to be specific to dyslexia because poor readers with a moderate reading backwardness of 6 months did not show the effect to the same extent as the students with dyslexia.

In the experiment that will be described in a later section, the hypothesis of extreme sensitivity to increasing task demands is tested again, this time using decreasing word frequency and increasing word length as conditions.

Orthographic Compensation

Recently attention has shifted from stimulus conditions to the quality of what is processed, that is, models that stress the *quality of representations.* It can be argued that this shift was not triggered by a theory on automaticity or automatization. Instead, it can be regarded as a specification of the model of phonological processing, which forms the basis of the phonological deficit hypothesis. However, for two reasons it seems appropriate to relate the issue of representations to the concepts of automaticity and automatization. First, the concept of quality of phonological representations is directly related to the issue of word-identification skills because in everyday life the importance of phonology is determined primarily by the need to specify phonemes in order to learn grapheme–phoneme correspondences. Furthermore, it is obvious that the associations between orthographic and phonological representations at the lexical and sublexical levels form the heart of automatization. Second, in contrast to models of phonological processing, the quality-of-representations approach defines its object of study at the level of lower order, relatively attention-free processing, which fits well into the theories of automaticity and automatization. This point is elaborated on in the next section.

It has been suggested that the phonological deficits of students with dyslexia may not be due to a lack of phonological analysis skills per se, but instead reflect a lack of quality in the phonological representations of the words they are asked to analyze (Elbro, 1996). According to the present views, in the prereading and early reading phases, phonological representations of lexical items are gradually restructured from wholistic units into increasingly smaller items, and ultimately into phonemes (Fowler, 1991; Metsala & Stanovich, 1995). Individuals with dyslexia fail to complete this process of increasing segmentation. On tasks at different linguistic levels, the problems of individuals with dyslexia have been located at the level of the most fine-grained segmentation, that is, phonemes, which is further proof of their phonological deficits. However, the phonological representation approach emphasizes the specification of the representation of lexical items in more detail (i.e., at the phonetic level) than has been done in studies on phonological awareness (Elbro, 1996). Moreover, the phonological representation approach seems to have a stronger relation to the concepts of automaticity and automatization, because it relates more to a capacity limitation of the phonological system and less to "conscious control," which is inherent in the concept of phonological awareness. This latter point is well demonstrated by the way phonological awareness is operationalized in tasks that give the student the opportunity to use strategic control.

The relation of the representation approach to automatization research with respect to reading can be further clarified when orthographic representations are taken into account. It has been suggested that in normal reading development, a reciprocal relationship exists between specification of phonological representations—especially at the phonemic level—and of orthographic representations (Perfetti, 1992). As a consequence, orthographic representations are developed that are suitable for transfer to new words by mapping. However, reciprocity between the two sources of information may be less balanced in children with dyslexia than in average readers. This suggestion was supported by Swan and Goswami (1997), who found that, in comparison with average readers, dyslexic readers are able to recognize more words that they could not name from pictures, when they had to read them. The authors suggested that those students "were able to use spelling–sound correspondence cues to help them with the accurate specification of phonology" (p. 350). The idea that poor quality of phonological representations may be compensated for by better quality of orthographic representations—at least to some extent—has also been supported by other studies. Indeed, the idea of forced orthographic compensation has been suggested:

> Individuals with dyslexia have to put much effort into the process of learning to read. They have to see the orthographic structure of words over and over again in order to use it, in the long run, as a way of compensating for the phonological deficit. They need more time to reach a particular reading level in development and they need more processing time to read isolated words. (Yap & Van der Leij, 1994, p. 103)

The intriguing question is whether orthographic compensation is restricted to the level of words or also applies to the subword level. As was mentioned before, students with dyslexia are able to recognize familiar words quite accurately (albeit slower than normal) but have greater problems with unfamiliar words in comparison to normal readers. Possibly, this phenomenon reflects a general characteristic in their learning of orthographic entities. According to this view, their learning mechanism is relatively intact at the level of whole units, which are learned by repeated practice, but relatively defective when those units have to be segmented into smaller parts to be decoded. The idea that a whole unit not only may be restricted to the word level but also applies to units at the sublexical level is supported by findings from training studies. Individuals with dyslexia can be taught to perceive multiletter units as a whole and use them to identify words and nonwords when the training conditions involve flashed presentations that enforce fast processing (Das-Smaal, Klapwijk, & Van der

Leij, 1996; Yap & Van der Leij, 1994). If that finding is not restricted to a specific training situation but reflects a more general characteristic of their learning mechanism, the hypothesis may be put forward that they are susceptible to frequency effects at the level of letter clusters and morphemes. Moreover, individuals with dyslexia will show signs of subword frequency effects when they have to read unfamiliar words, because they are inclined to identify large known units to avoid flexible segmenting at a more fine-grained level. This approach is primarily driven by orthographic knowledge and is therefore relatively less flexible than in students who exhibit normal reading development. The latter switch easily back and forth from orthographic to phonological knowledge at different levels of segmenting, smoothly turning to rapid phonological recoding of the smallest orthographic units (graphemes) when they encounter completely unfamiliar words. In general, it is expected that students with dyslexia will show greater frequency effects than average readers at any level of large units, starting with letter clusters. If this "large-orthographic-unit-preference" hypothesis is supported by research findings, it may specify the vehicle of orthographic compensation at the sublexical level, which essentially is forced by the weaknesses of students with dyslexia to process information at the level of the smallest elements.

Study of Automatization Aspects of Dyslexia

In a recently started longitudinal study, the present authors began investigating key issues concerning the automatization process of students with dyslexia. In this article, relevant findings of the first measurement will be described. The general expectations were threefold: (a) According to the speed limitation hypothesis, we expected that, even for accurately read words of high frequency, the students with dyslexia would show slower response latencies than chronological-age (CA) controls. In addition, it was explored whether the slowness of processing is also apparent at the level of sublexical units and when reading nonwords; (b) two effects of increasing task demands were expected: First, the performance of students with dyslexia would suffer from greater losses than the performance of CA and reading-age (RA) controls when word length was increased, and second, students with dyslexia would be comparable in accuracy to CA and RA controls when they were to read high-frequency words but would perform far more poorly with nonwords, not only in accuracy but also in speed, indicating an automatic decoding deficit; and (c) it was expected that, if the large-orthographic-unit-preference hypothesis held, students with dyslexia would be more susceptible to effects of subword frequency than RA controls in reading nonwords. In addition, students with dyslexia would show greater frequency effects when sublexical units like letter clusters and morphemes were presented in isolation (i.e., without the context of a word or nonword).

Method

Participants

Children from Grades 2 and 4, attending either of two schools for primary education, were selected for the present study according to their scores on a standardized reading test (Subtest III of the Drie Minuten Test [DMT]; Verhoeven, 1993). No selected student showed signs of any sensory handicap. The 10 poorest readers from Grade 4 were selected for the dyslexic group (DYS). They read, on average, 43.3 words per minute ($SD = 4.9$). According to traditional criteria, they could be labeled dyslexic, having an average reading backwardness of 2 years and average verbal competence, as measured by the Dutch version of the Peabody Picture Vocabulary Test (PPVT; Dunn & Lloyd, 1965). The 20 selected children from Grade 2 read, on average, 39.5 words within 1 minute ($SD = 12.2$), which reflected reading development within the normal range. Their mean chronological age was 96 months. This group served as the reading-age control group (RA). The chronological-age group (CA) consisted of the 10 best readers from Grade 4 who read, on average, 82.5 words on the same test ($SD = 13.3$). The mean age of the DYS and CA participants from Grade 4 was 120 months.

Design

In a combination of a chronological- and reading-age control group design, the comparison between DYS and CA was used in the analysis to indicate reading backwardness, whereas the comparison between DYS and RA related to the deficit question. The comparison between CA and RA indicated age-related trends in normal development.

Materials and Apparatus

The following reading materials were used: 12 high-frequency single or double letters (e.g., *a, d, aa, ee*); 12 low-frequency single or double letters (e.g., *u, v, ei, uu*); 11 high-frequency morphemes (e.g., *-sel, on-*); 11 low-frequency morphemes (e.g., *-teur, aarts-*); 11 high-frequency letter clusters (e.g., *-ard, ka-*); 11 low-frequency letter clusters (e.g., *-apt, ta-*); 7 high-frequency CVC words (e.g., *jaar* ["year"]); CVC nonwords with high-frequency CV- and -VC parts (e.g., *bem*); CVC nonwords with high-frequency CV- and -VC parts (e.g., *kep*); 7 high-frequency CVCC words (e.g., *land* ["land"]); 7 CVCC nonwords with high-frequency CV- and -VCC parts (e.g., *dant*); 7 CVCC nonwords with low-frequency CV- and -VCC parts (e.g., *falm*); 7 high-frequency CVCVC words (e.g., *vader* ["father"]); 7 CVCVC nonwords with high-frequency CVC- and -CVC parts (e.g., *gader*); 7 CVCVC nonwords with low-frequency CVC- and -CVC parts (e.g., *falem*); 7 high-frequency CVCCVC words (e.g., *mensen* ["people"]); 7 CVCCVC non-words with high-frequency CVC- and -CVC parts (e.g., *zomben*); and 7 CVCCVC nonwords with low-frequency CVC- and -CVC parts (e.g., *bagsum*). Frequency figures are based on frequency counts of reading materials for Dutch youngsters from age 6 to 12 (Staphorsius, Krom, & De Geus, 1988). In the case of letter clusters, positional frequency counts were used. Furthermore, a control task was used: digit naming (the digits from 1 to 9).

The stimuli were presented in the center of the screen of an Apple Macintosh SE/30 computer, which was attached to a Lafayette voice-key device. The font used was Amsterdam-48, which resembles the letter types used in children's reading books. Specially written software controlled the presentation of the stimuli and the registration of the response latencies. A well-trained experimenter recorded, by pressing designated keys, whether a participant's response was correct, incorrect, or invalid, in case the voice-key had closed too soon (because of some noise) or too late (when, e.g., the student did not speak loudly enough).

Procedure

All stimuli were presented twice for each participant in random order within the following blocks: (a) digits, (b) letters, (c) morphemes, (d) letter clusters, (e) CVC words, (f) CVCC words, (g) CVCVC words, and (h) CVCCVC words. The words were presented one by one on a computer screen. Stimuli were presented twice to obtain as many correct responses as possible.

Data Analysis

In the analyses, only the latencies for correct responses to the second presentation of the stimuli were used. Speed was calculated as response latency per phoneme in msec, so that responses across the stimuli blocks could be compared, as there were differences in the number of phonemes within the digit, cluster, and morpheme blocks.

Results

Accuracy

In Table 1, the 95% confidence intervals for the number of reading errors,

TABLE 1

95% Confidence Intervals for Numbers of Reading Errors, *F* Values, and Significance Levels for All Stimuli

Stimuli (max.)	CA controls	With dyslexia	RA controls	*F*(2, 39)	*p*
Digits (9)	0	0	0	—	—
Letters–high frequency (12)	–.10 to .50	.06 to 1.54	.08 to .73	1.63	.208
Letters–low frequency (12)	–.12 to .33	.19 to 1.61	.08 to .73	3.03	.059
Morphemes–high frequency (11)	0	.02 to 1.38	–.04 to .22	6.20	< .005
Morphemes–low frequency (11)	–.10 to .50	.62 to .198	.36 to 1.18	4.28	.021
Clusters–high frequency (14)	–.05 to .64	.02 to 1.38	–.06 to .79	< 1	—
Clusters–low frequency (14)	–.05 to .64	.38 to 2.42	–.04 to .40	8.12	< .001
CVC words (7)	0	–.13 to .33	0	—	—
CVC nonwords with high frequency clusters (7)	–.13 to .33	.32 to 1.67	–.01 to .55	5.48	< .01
CVC nonwords with low frequency clusters (7)	.10 to .33	.14 to 1.46	–.04 to .50	3.54	.040
CVCC words (7)	0	–.10 to .50	0	—	—
CVCC nonwords with high frequency clusters (7)	*0*	*.10 to 1.10*	*.03 to .52*	3.27	.048
CVCC nonwords with low frequency clusters (7)	–.13 to .33	.66 to 2.34	.07 to .47	13.95	< .001
CVCVC words (7)	0	0	–.07 to .34	—	—
CVCVC nonwords with high frequency clusters (7)	–.18 to .78	1.24 to 3.96	1.17 to 2.83	5.23	< .01
CVCVC nonwords with low frequency clusters (7)	–.76 to 1.96	1.43 to 4.77	1.47 to 3.34	3.86	.030
CVCCVC words (8)	0	–.13 to .33	0	—	—
CVCCVC nonwords with high frequency clusters (8)	–.10 to .50	1.42 to 4.18	.48 to 1.34	13.28	< .001
CVCCVC nonwords with low frequency clusters (8)	–.10 to .50	1.08 to 4.11	.45 to 1.73	6.77	< .001

together with *F* statistics and the corresponding significance levels are presented. On all stimuli except digits and high- and low-frequency letters, differences among the three groups were found. Generally, the students with dyslexia made more errors than the CA controls, and nearly half of them made more errors than the RA controls (except on CVCVC words), which can be concluded from the fact that the estimated intervals for these students were twice as large. These words were harder for the RA controls simply because they had not yet seen such words frequently in the reading curriculum.

Latency

In Table 2, the 95% confidence intervals for median response latencies, together with *F* statistics and the corresponding significance levels, are presented. With the exception of letters of both high and low frequency, differences among the three groups were found on all stimuli in favor of the CA group. The finding that the participants with dyslexia performed at the latency level of the RA controls even for high-frequency words gives support to the hypothesis of speed limitations in word identification. Moreover, the findings are not restricted to words and nonwords but seem to reflect a general characteristic of students with dyslexia when it comes to naming speed of orthographic stimuli above the level of single graphemes. The finding that the RA controls were slower on digit naming than the CA controls can be interpreted as a developmental trend.

Word Length Effect: Accuracy

The word length effect was measured by the comparison between CVC and CVCCVC nonwords, both with low-frequency clusters. There was a main effect of group, $F(2, 39) = 8.20$; $p = .001$; $\eta^2 = .30$, and of word length, $F(1, 39) = 14.61$, $p < .001$, $\eta^2 = .27$, and a significant interaction that indicated the expected difference, $F(2, 39) = 3.41$, $p = .043$, $\eta^2 = .15$ (see Figure 1).

Word Frequency and Subword Frequency Effect: Accuracy

The word frequency effect was measured by the comparison between high-frequency words and nonwords with low-frequency clusters. Again, the data confirmed the expectation—a main effect of group, $F(2, 38) = 11.52$,

TABLE 2

95% Confidence Intervals for Median Response Latencies, *F* Values, and Significance Levels for All Stimuli (Latency per Phoneme)

Stimuli	CA controls	With dyslexia	RA controls	*F*(2, 39)	*p*
Digits	.18 to .21	.19 to .23	.22 to .25	5.01	.012
Letters–high frequency	.75 to .97	.82 to 1.08	.84 to 1.07	< 1	
Letters–low frequency	.74 to 1.02	.83 to 1.28	.85 to 1.09	1.10	.343
Morphemes–high frequency	.28 to .34	.35 to .45	.35 to .44	4.03	.026
Morphemes–low frequency	.21 to .30	.29 to .46	.29 to .34	7.33	.002
Clusters–high frequency	.29 to .36	.36 to .50	.36 to .45	4.33	.020
Clusters–low frequency	.28 to .34	.35 to .47	.37 to .45	5.99	< .001
CVC words	.19 to .23	.23 to .27	.24 to .29	5.55	< .001
CVC nonwords with high frequency clusters	.20 to .27	.28 to .42	.27 to .32	7.61	< .001
CVC nonwords with low frequency clusters	.21 to .26	.29 to .40	.26 to .32	8.03	< .001
CVCC words	.14 to .18	.20 to .25	.19 to .24	5.54	< .001
CVCC nonwords with high frequency clusters	.15 to .19	.24 to .34	.21 to .28	7.59	< .001
CVCC nonwords with low frequency clusters	.16 to .21	.27 to .36	.21 to .32	5.02	< .001
CVCVC words	.12 to .15	.17 to .21	.16 to .20	6.10	< .001
CVCVC nonwords with high frequency clusters	.14 to .19	.24 to .46	.21 to .33	5.58	< .001
CVCVC nonwords with low frequency clusters	.11 to .14	.14 to .19	.14 to .17	5.30	< .001
CVCCVC words	.11 to .15	.17 to .26	.16 to .21	6.66	< .001
CVCCVC nonwords with high frequency clusters	.11 to .20	.23 to .52	.17 to .27	7.99	< .001
CVCCVC nonwords with low frequency clusters	.12 to .18	.25 to .63	.21 to .29	10.91	< .001

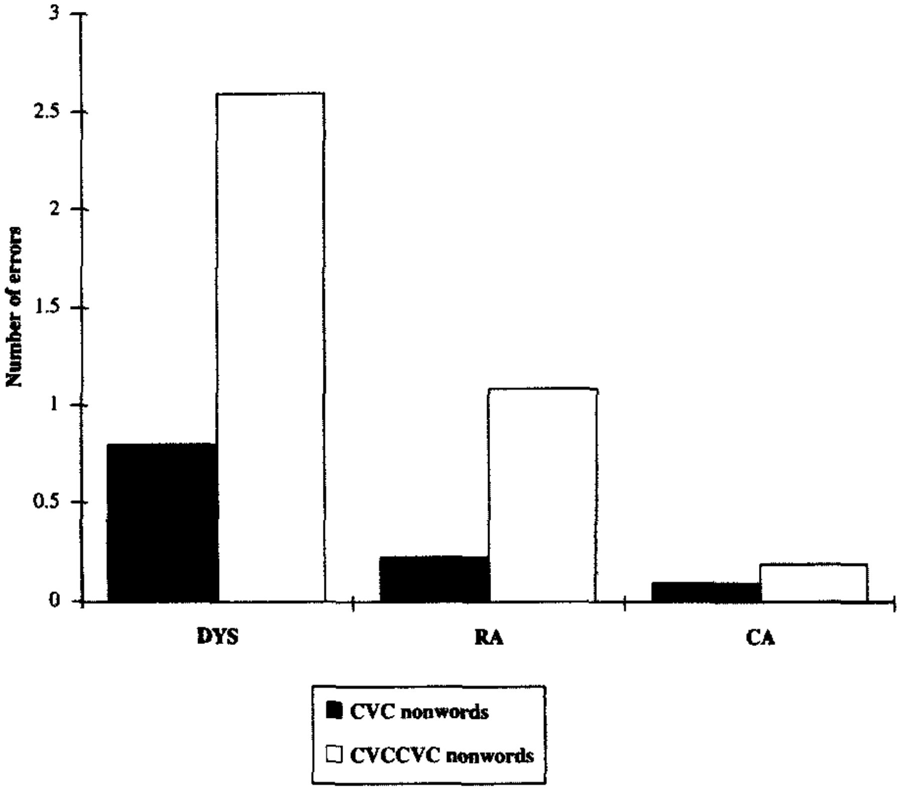

FIGURE 1. Word length effect: Accuracy.

$p < .001$, $\eta^2 = .37$, and of word frequency, $F(1, 38) = 62.81$, $p < .001$, $\eta^2 = .62$; and an interaction, $F(2, 38) = 10.91$, $p < .001$, $\eta^2 = .36$ (see Figure 2). However, the expected subword frequency effect, measured by the comparison of nonwords with high-frequency clusters with nonwords with low-frequency clusters, was not confirmed by a significant interaction in the accuracy data: main effect of group, $F(2, 38) = 13.54$, $p < .001$, $\eta^2 = .41$; a marginally significant effect of subword frequency, $F(1, 38) = 3.29$, $p = .077$, $\eta^2 = .08$; and no interaction, $F(2, 38) < 1$, $\eta^2 = .01$ (see Figure 2).

Word Length Effect: Latency

A word length effect was found in the expected direction (CVC versus CVCCVC nonwords, both with low-frequency clusters: main effect of group, $F(2, 39) = 12.25$, $p < .001$, $\eta^2 = .39$; no effect of word length, $F(1, 39) < 1$; but a significant interaction, $F(2, 39) = 6.94$, $p = .003$, $\eta^2 = .26$. As can be seen in Figure 3, the DYS group slowed down in speed of processing per phoneme with increasing word length, whereas the speed of the CA and RA groups increased.

Word Frequency and Subword Frequency Effect: Latency

The word frequency effect supported the hypothesis of a greater vulnerability of individuals with dyslexia to increasing task demands—real words versus nonwords with low-frequency clusters: main effect of group, $F(2, 38) = 12.05$, $p < .001$, $\eta^2 = .39$; of word frequency, $F(1, 38) = 54.95$, $p < .001$, $\eta^2 = .59$; and an interaction, $F(2, 38) = 8.04$, $p = .001$, $\eta^2 = .30$ (see Figure 4). In contrast to the accuracy findings, the latency data showed the expected subword frequency effect; that is, nonwords with high-frequency clusters versus nonwords with low-frequency clusters: main effect of group, $F(2, 38) = 10.56$, $p < .001$, $\eta^2 = .36$; of subword frequency, $F(1, 38) = 9.95$, $p = .003$, $\eta^2 = .21$; and an interaction, $F(2, 38) = 3.57$, $p = .038$, $\eta^2 = .16$ (see Figure 4).

Discussion

The findings of our study confirmed the hypothesis that speed limitations in word identification are a characteristic of dyslexia. Highly familiar words were processed more slowly by the students with dyslexia than by the nondisabled students of their own age. Moreover, the speed limitation also applied to any other orthographic stimulus, either nonwords or sublexical units, with the exception of single letters. Furthermore, the speed limitation of dyslexic reading performance resulted in response latencies that were, on average, comparable to or worse than the performance at a much younger age. These findings indicate that dyslexic reading performance, even when carried out accurately, does not reach the level of relatively attention-free automaticity that is seen in normal reading development. The finding that there were no differences in the speed of digit naming supports the idea that the deficit of students with dyslexia was specific to orthographic stimuli.

These findings underline the differences between dyslexic readers and the other two groups. The CA participants could be called skilled readers. They read accurately; moreover, the accuracy of their performance was hardly dependent on frequency at the word or subword level, or on word length. The response latencies per phoneme increased only slightly with lower word frequency, and decreased with increasing word length. The results support the view that after more than 3 years of reading practice and experience (the CA group was halfway through Grade 4), students read familiar and unfamiliar words with a

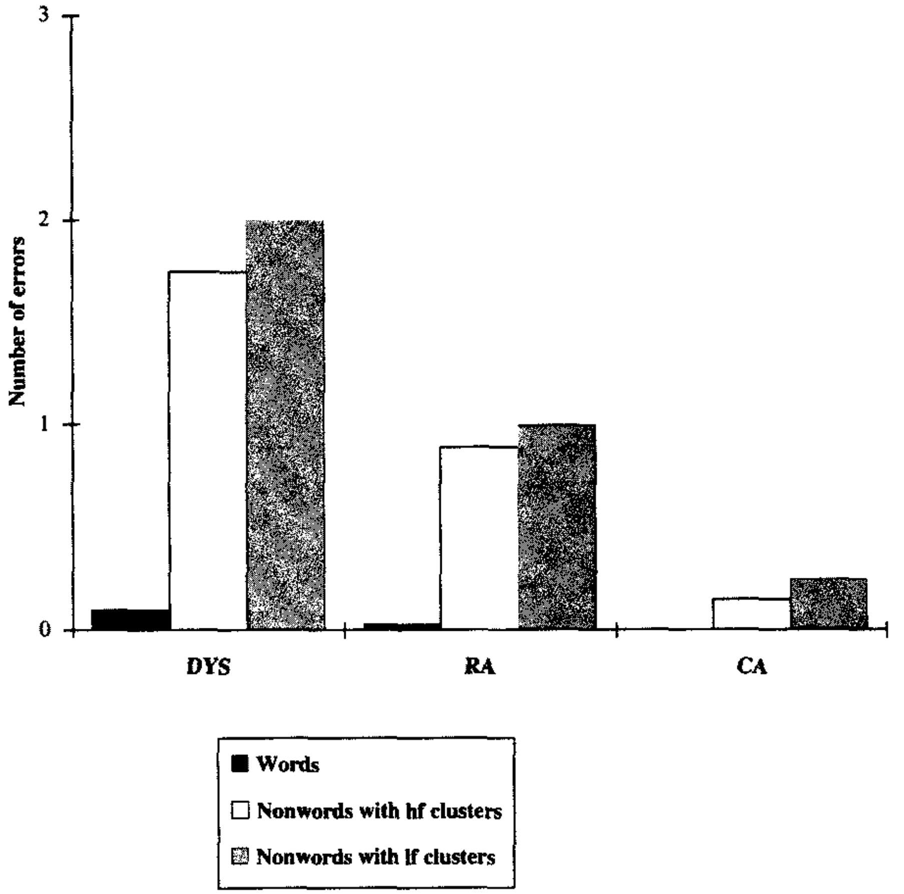

FIGURE 2. Word frequency and subword frequency effect: Accuracy.

high degree of automaticity, indicated by high efficiency and little influence of complicating task demands and, thus, by very reduced use of attentional resources. In terms of the triple-phase-acquisition models (Downing, 1979; LaBerge & Samuels, 1974), the CA group clearly had reached the *third* phase of mastery. In addition to these models, which restrict the third phase to familiar words, the findings support the view that skilled reading is characterized by smooth processing of words across the frequency continuum, even when they are completely unfamiliar. Furthermore, strong readers' skill involves the sublexical level, too. To return to Adams's (1990) quote, *the students read* the various orthographic stimuli at the lexical and sublexicals level with "relative automaticity," that is, without having to attend to the identities of individual letters. Only the individual letters themselves do not give them advantage above less experienced average readers of a younger age, probably because individual letters are less distinct than letter clusters and therefore always *need a relatively larger amount of attention.*

The less experienced RA participants read high-frequency words accurately and fairly rapidly but were still susceptible, to some extent, to frequency effects at the word level. They were also affected by word length, but only in accuracy. In speed, they followed the trend of the CA students: decreasing response latencies per phoneme when words got longer. They did not seem to use subword frequency because it had only a very small influence on their accuracy performance, and did not affect their speed at all. The 95% *confidence intervals indicate* that they read sublexical stimuli nearly as accurately as the CA students, with the exception of morphemes of low frequency, which probably are phonologically quite complicated. In speed, the RA controls still had to gain at the sublexical level. According to triple-phase models, their accuracy when reading sublexical items and short words suggests that their automatization process at that level (halfway through Grade 2) is in Phase 2, heading for Phase 3.

The *students with dyslexia* exhibited deviant profiles of automatization. It is clear that they showed a near perfect accuracy in reading familiar words; however, they did not combine that with mild losses when words were unknown, as was the case with the RA students. Instead, the most striking result was that the performance of the students with dyslexia systematically deteriorated with increasing task demands. This result replicates the findings of earlier studies, but this time with the use of decreasing *frequency and increasing* word length, instead of increasing phonological complexity and decreasing frequency in combination with shortening of exposure duration (Van der Leij, 1993; Yap & Van der Leij, 1993). Although the figures show widening gaps among the three groups in nearly every complicating condition—indicating that the reading-age controls were also affected in comparison to the CA controls—it is clear that the students with dyslexia were more affected than the RA controls. Moreover, their response latency *per phoneme did not* speed up with increasing word length, but slowed down (see Figure 3). Because nonwords with low-frequency clusters were used to analyze the effect of word length, this finding suggests that students with dyslexia were not able to process longer words in a flexible way, using information at the level of grapheme–phoneme correspondences. However, in contrast to the CA and RA controls, subword fre-

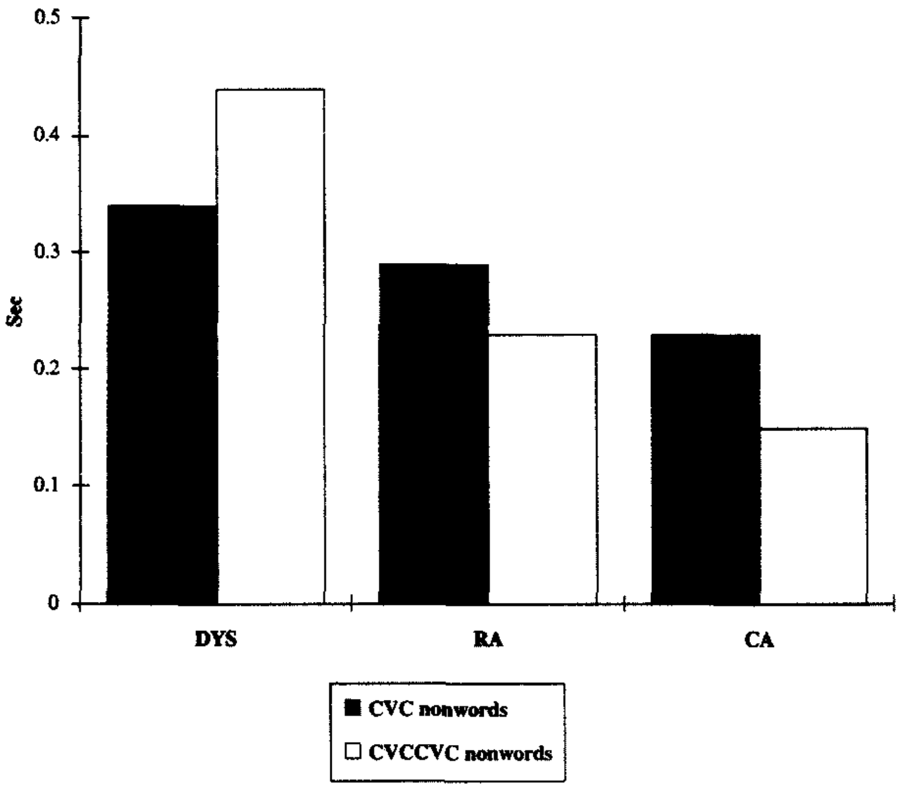

FIGURE 3. Word length effect: Latency.

quency had an effect on their speed performance. (This conclusion will be discussed in more detail below.) In terms of the triple-phase models, students with dyslexia showed mixed results. For familiar words they could be placed in Phase 2, together with their reading-age controls. For unfamiliar words, their accuracy (see Figure 2) was far less. To illustrate this point: They read 11% of the CVC words with low-frequency clusters incorrectly and 37% of the CVCCVC words with low-frequency clusters incorrectly, whereas the RA students missed only 3% and 16%, respectively. In both categories of nonwords, the reading speed of the students with dyslexia was, on average, more than twice as slow as that of the RA. It seems fair to place the dyslexic performance in Phase 1 when it comes to the reading of unfamiliar words. In addition, the fact that with longer words these students' response latency increased instead of decreased, as is the trend in normal reading development, suggests that they were not heading for the third phase of automatization, but were following a deviant path.

From the observation that students with dyslexia showed a near perfect accuracy when reading familiar words, it can be concluded that their large-orthographic-unit preference certainly applied to the whole-word level. With respect to the question of whether units are processed at the sublexical level between whole words and graphemes, the findings suggest that units at the sublexical level may be used by students with dyslexia to identify words, in contrast to chronological- and reading-age controls, who do not show much difference. In comparison, nonwords containing high-frequency clusters were recognized somewhat faster by the students with dyslexia than nonwords with low-frequency clusters (see Figure 4). In combination with the finding that longer nonwords with low-frequency clusters tended to slow down the dyslexic group's processing rate, it can be argued that their performance was helped a little by familiar orthographic units at the sublexical level but was diminished by the need to decode unfamiliar units, at the basis of grapheme–phoneme correspondences. However, the evidence in favor of a large-orthographic-unit preference at the sublexical level is small in comparison to the strong indication at the word level.

At first sight, the findings seem to suggest a parallel with phonological processing. Research in that area indicates that differences with average readers appear when the tasks involve segmentation at the phonemic level (Goswami & Bryant, 1990). In contrast, students with dyslexia are very able learners when they do not have to segment verbal stimuli, as is indicated by their verbal competence. They can acquire considerable semantic knowledge, which means that they possess adequate phonological presentations at the wholistic level of words. In the process of automatization of reading, they seem to "map" these representations to the printed form as one unit, because, although the process of familiarization takes more trials, they gather word-specific knowledge, word by word. However, if this were their only way of learning how to read, it would take them many years to develop a sight vocabulary suitable for reading even simple texts. The participants in our study, who were about 10 years of age, could read simple, familiar texts within error and time limits at the level of Grade 2. Because repeated drill and practice with sets of words up to 20 trials or more is not a part of educational practice in the classroom, it is hard to believe that familiarization at the word level is the only way they acquire orthographic knowledge. Instead, they seem to use segmentation at some level in the automatization process. Obviously, letters seem to help them to define phonemes.

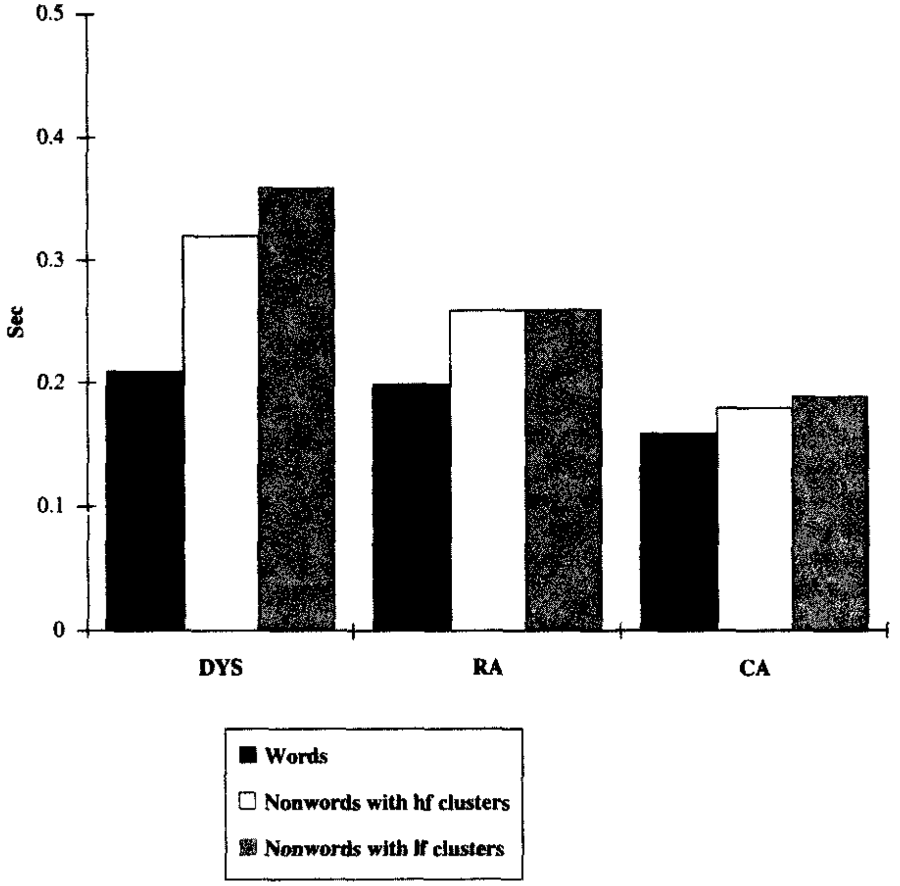

FIGURE 4. Word frequency and subword frequency effect: Latency.

The representation of printed words is physically over-specified and distinctly segmented at the graphemic level and may be used to compensate for segmentation deficits at the phonemic level. Unfortunately, sounding out letters and blending the sounds into words is only a first stage of identification. Besides, as was suggested by Swan and Goswami (1997), this kind of orthographic compensation at the grapheme–phoneme correspondence level may be useful only when regular words are read. The finding that the speed of processing in individuals with dyslexia slows down when they have to read longer nonwords with low-frequency letter clusters (all very pronounceable and regular), suggests a letter-by-letter translation process that consumes more time than is the case in normal reading. However, when high-frequency letter clusters are used in nonwords, students with dyslexia seem to profit. Therefore, it seems reasonable to assume that they can use units of some intermediate size between whole words and letters. Our findings suggest that letter clusters are used. However, the specification of the large-orthographic-unit preference at that level needs further study.

Finally we turn to the concept of orthographic compensation, which has been used throughout the article. It has become clear from the results of training studies (e.g., Kappers, 1997; Van der Leij, 1994) that students with dyslexia exhibit very little ability to become fluent readers. Even when they are taught to use word-specific knowledge and knowledge at the sublexical level, or to apply proper decoding strategies, transfer effects of training over a period of time have been reported to be small. It seems fair to state that no therapy really can remediate an automatic decoding deficit when students suffer from severe dyslexia. Therefore, the concept of compensation must be interpreted with caution. It indicates an intraindividual reading profile with a stronger ability to learn word-specific information and, possibly, sublexical information in comparison with difficulty in identifying unfamiliar orthographic information in a smooth and flexible way. Although it can be useful in treatment, orthographic compensation cannot conceal that students with dyslexia are handicapped in the normal development of automatization.

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