Low Vision Affects the Reading Process Quantitatively But Not Qualitatively

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In this article, the authors compare the reading behavior of students with low vision to that of two groups of students with normal vision (reading-match and age-match students). In Experiment 1, students identified the first letter in words and nonwords and the researchers measured latency and accuracy. No group differences were found for latency, but the reading-match group differed from the other two groups on accuracy. All three groups identified the first letter of words faster than they did for nonwords. In Experiment 2, students named words with typical and atypical letter–sound relationships; the researchers measure latency and accuracy. Both the low-vision and the reading-match groups were slower than the age-match group; only the reading-match group made more errors on typical stimuli than on atypical stimuli. The absence of significant interactions between group and any experimental-word variable justified the conclusion that low vision affects the reading process quantitatively but not qualitatively.

In The Netherlands, children are considered visually impaired, and therefore eligible for institutional support, if their functional vision is less than 3/10 and/or their visual field is less than 30 degrees. If the visual impairment is such that the child is unable to read print and must resort to Braille, he or she is considered to be blind. If, despite a reduced acuity or limited visual field, the visual impairment is such that the child is still able to read print, he or she is considered to have low vision. Children who have low vision but sufficient residual vision to read print are the focus of this study.

A substantial amount of research has indicated that the reading development of children with low vision lags behind that of children with normal vision (e.g., Daugherty, 1977; Fellenius, 1999; Gompel, van Bon, Schreuder, & Adriaansen, 2002). Despite a similar level of intelligence and equal education, children with low vision generally do not succeed in attaining the same reading speed as their peers with normal vision (but see Fridal, Jansen, & Klindt, 1981). Several explanations have been put forward for the relatively slow reading speed of children with low vision. Generally, these explanations pertain to the potential problems that readers with low vision encounter when extracting visual information from a page or a computer screen.

One important explanation for the slow reading speed of children with low vision concerns the ease with which text can be fixated. During reading, the eyes do not slide evenly over the paper, but longer breaks (fixations, varying from 200–250 ms) are alternated with relatively short eye movements (*saccades,* varying from 20–35 ms). The main function of a saccade is to bring a new piece of text into the central visual field. Information from the text can only be extracted during a fixation (Rayner & Pollatsek, 1989). For example, central visual-field loss due to *macular degeneration* (damage to a small area near the center of the retina) or central *scotomas* (regions on the retina that have no or reduced acuity as a result of damage; the retinal field is nonfunctional) will hinder fixation of texts. Individuals with damage to the *fovea* (the region on the retina with maximal visual acuity) tend to develop eccentric viewing behavior; that is, an eccentric part of the retina, rather than the fovea, is used for fixation. This is called the *preferred retinal locus* (see Raasch & Rubin, 1993; Watson, 2000). In people with normal vision, text presented to an eccentric part of the retina is read more slowly than text presented to the fovea, even when the letter size is magnified to compensate for reduced resolution at the eccentric location. According to Raasch and Rubin (1993), this finding suggests that eccentric locations are simply not as fast as the fovea is in recognizing words. At the same time, these authors implied that for people with low vision who have central scotomas, reading rates will be depressed simply by virtue of the fact that they need to read with an eccentric location. In sighted people with artificially created scotomas, the reading rates were reduced when the scotoma was displaced to either the left or the right of the fovea but not when above or below it (Cummins & Rubin, 1991). Reading rates were most depressed when the scotoma was to the right of the fixation. In this condition, it seems that the scotoma leads the eye movements and obscures the word upon which the eye is about to be fixated. There is

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no reason to assume that true scotomas in people with low vision would have a different effect. However, because central visual-field deficits are rare in children, these deficits alone cannot explain slow reading in children with low vision.

A second reason why readers with low vision might read more slowly is related to the process of extracting information from the peripheral visual field. Although exact identification of letters in the peripheral area is not possible for readers with normal vision, information retrieved from the peripheral visual field can guide the reading process. For instance, short words on the right side of the fixated word can sometimes be identified, which in some cases makes fixation on that word unnecessary. The size of the peripheral visual field is restricted when readers suffer from, for example, *tunnel vision* (peripheral vision limited to 10 degrees), which forces the reader to make more fixations. In the case of a short distance between the eyes and the paper—for instance, as a result of text enlargement or the use of a reading aid—the reader is also forced to make more fixations because fewer letters or words can be seen at close distance than at a farther distance, given a fixed size of the visual field. Thus, a short-reading distance might cause lower reading speed as well (Watson, 2000).

Results obtained with the RSVP technique (rapid serial visual presentation) shed some light on the role of saccadic eye movements in people with low vision. With the RSVP technique, in which words are presented sequentially, one at the time, at a uniform rate, and in the same location on a monitor, saccadic eye movements become unnecessary. According to Arditi (1999), people with normal vision appeared to benefit substantially from RSVP, as demonstrated by three to four times faster reading rates, but people with low vision did not. People with central visual-field loss read only 1.5 times faster with RSVP than with conventionally presented text (Rubin & Turano, 1994). This suggests that people with low vision have difficulty with saccadic eye movements. The preceding explanations, except for eccentric fixating, are mainly concerned with the reading of sentences and text and are less applicable to the reading of single words.

A third explanation for the slower reading of readers with low vision is related to text and word reading. It concerns the fact that a restricted visual acuity hampers the identification of letters and thus the reading rate. For instance, West et al. (2002) noted reading disabilities (i.e., reading fewer than 90 words per min) in 50% of their study population with visual acuity worse than 20/30 and in 90% of individuals with acuity worse than 20/40. Note, however, that a restricted visual acuity also negatively affects naming latencies in non-reading tasks, such as naming objects (Gompel, Janssen, van Bon, & Schreuder, 2003; Wurm, Legge, Isenberg, & Luebker, 1993). Although suitably magnified print should solve problems with seeing fine details, it also leads to fewer letters or words that can be fixated in one glance. As a result, more head and eye movements are necessary to read a sentence, which takes time, as does the handling of required optical aids.

As a result of their visual limitations, children with low vision generally read more slowly than children with normal vision, and it is therefore tempting to close the search for explanations of reduced reading levels in children with low vision. However, the question as to whether visual limitations affect cognitive processes in the reading of children with low vision has not yet been adequately answered. Does a visual impairment cause the reader to adjust reading processes qualitatively, or are visual limitations merely affecting the reading process quantitatively? Putting it another way: Does visual impairment cause a different developmental path with respect to reading in children with low vision?

To our knowledge, the first to answer this question experimentally were Corley and Pring (1993a, 1993b). Their comparative study (1993a) on oral-reading errors of students with low vision and students with normal vision showed that reading errors for students with low vision are rather similar to those of younger students with normal vision who had less reading experience. In another study (1993b), in which they used a lexical-decision task, comparable results were obtained in three different experiments. In lexical-decision tasks, students are presented with letter strings and asked to indicate whether the stimulus is a word (e.g., *eye*) or a nonword (e.g., *eke*). In the first experiment, Corley and Pring gave students with low vision and students with normal vision regularly spelled words (words spelled according to standard grapheme–phoneme rules, e.g., *cave*), irregular words (words that are not spelled according to standard grapheme–phoneme rules, e.g., *have*), and nonwords (e.g., *borl, birl*). Although the students with low vision were less accurate than the students with normal vision, both groups erroneously classified irregular words as nonwords more often than regular words. No significant interaction emerged between experimental group and the word variable.

In the second experiment, Corley and Pring presented both groups with a series of words and nonwords in which each word was given twice. In one presentation, the words were shown in the normal orientation (i.e., horizontally); in the other presentation, the words were shown vertically. Students with low vision performed just as well as students with normal vision on this task: Both groups had more correct yes-responses on the words and more correct no-responses on the nonwords in the normal orientation than in the vertical orientation. Again, no significant interaction was found between experimental group and word variable.

In the third and last experiment, half of the words and half of the nonwords were manipulated such that the phonemes were accentuated by alternating the case of the letters analogous to the phoneme boundaries. For example, the word *church* has three phonemes, namely, [ch] [ur] [ch], and was presented as CHurCh. In the other half of the words, there was no correspondence between case alternation and phoneme boundaries (i.e., CHuRCH). Again, students with low vision performed just as well as the students with normal vision:

Both groups had more correct responses to words with analogous case alternation than to words presented with no analogy between phoneme boundaries and case alternation. As in the two previous experiments, no interaction was found between experimental group and word variable, indicating only quantitative differences.

Recently, Douglas, Grimley, McLinden, and Watson (2004) reported a small, qualitative difference between the reading behavior of children with low vision and that of children with normal vision. Douglas et al. matched a group of children with low vision with a group of children with normal vision on the *Neale Analysis of Reading Ability Test* (NARA, a standardized reading test for children ages 6–12 years). It appeared that children with low vision were more prone to making substitution errors rather than mispronunciation errors, whereas children with normal vision displayed the opposite pattern. This result with regard to a qualitative difference between readers with low vision and those with normal vision hints at the possibility of a different developmental path for children with low vision. Perhaps these children rely more on a guessing strategy when reading words that are difficult to perceive, and this strategy may involve the use of different reading processes.

Although the finding by Douglas et al. (2004) does not coincide with the work of Corley and Pring (1993a, 1993b), who only found quantitative differences, some caution is in order, because the dependent variable (i.e., error percentage) in Corley and Pring (1993b) may not have been sufficiently sensitive to discriminate between students with low vision and students with normal vision. Reading errors are the outcome of a process; perhaps it is the process underlying reading that distinguishes between readers with low vision and those with normal vision. In many experimental and psycholinguistic studies, researchers use a more sensitive measure, namely, response times. Response latencies based on correct responses may provide more detailed information on the cognitive process under investigation.

Apart from using an additional measure to study reading processes in students with low vision, we also took two additional measures to enhance the possibility of finding distinct qualitative differences between students with low vision and children with normal vision. First, we attempted to improve the power of our experimental manipulations by using a larger sample size. Corley and Pring's (1993a, 1993b) sample sizes were relatively small, 9 and 10, respectively. In our study, the sample of students with low vision was doubled. Second, answering the question as to whether there are qualitative differences between students with low vision and students with normal vision requires carefully matched groups. The 10 students with low vision in Corley and Pring's (1993b) study had statistically similar age and reading levels as the 20 students with normal vision. If reading levels of students with low vision are more or less on par with those of students with normal vision, qualitatively more subtle differences might be difficult to obtain. We therefore decided to use an experimental design common in research on dyslexia, in which the behavior of the (experimental) group that constitutes the focus of the investigation (here, the students with low vision) is compared with that of two control groups (i.e., students with normal vision). In the studies we report on here, we compared the reading behavior of students with low vision to that of (a) students with normal vision whose reading level matched that of the students with low vision but who were significantly younger, and (b) students with normal vision whose age matched that of the students with low vision but had a significantly higher reading level.

When the reading behavior of students with low vision deviated from the reading behaviors of both the reading-match and age-match groups with normal vision, we took it as an indication of qualitative differences. When the reading behavior of students with low vision was similar to that of the reading-match group but different from that of the age-match group, we believe it indicated quantitative differences. To investigate this issue, we developed two tasks for the present study. In Experiment 1, the emphasis was on the role of phonology in the reading of single words by students with low vision. In Experiment 2, the main issue was the effect of atypical letter–sound relationships on decoding single words.

STUDY 1

In this experiment, we investigated the role of phonology in students with low vision. An overwhelming amount of evidence for the fundamental role of phonology in reading now exists (see, e.g., Frost, 1998; Van Orden, Pennington, & Stone, 1990). Reading without activating the phonology of the word appears impossible. An example of a task that provides evidence for the role of phonology in reading is first-letter naming. In this task, study participants are presented with a letter string and asked to name the first letter of that string as quickly and as accurately as possible. Participants are presented with a set of words (e.g., *book*) and a set of orthographically illegal nonwords (e.g., *bkoo*). Previous experiments (Bosman & de Groot, 1995) have shown that participants across a range of reading experience name the first letter of words more quickly than the first letter of (orthographically illegal) nonwords. This effect has been explained in terms of an inhibition process; that is, being exposed to a letter string involves mandatory phonological processing of the entire letter string, irrespective of the instruction of merely naming its first letter. Phonological activation of the entire letter string inhibits the first-letter naming process, but this inhibition process is resolved more quickly for a word than for an orthographically illegal nonword. Bosman and colleagues (Bosman & de Groot,1995; Bosman, van Leerdam, & de Gelder, 2000); van Leerdam, 1995) concluded that the individuals in their studies were unable to avoid phonological activation of the entire letter string, which hindered the task at hand, naming the first letter of the letter string.

The question here is whether the naming performance of children with low vision is equally affected by the task of first-letter naming as that of children with normal vision. Or, is it possible that they rely even more on phonology than do sighted peers; that is, is the sound of words more important in people with low vision than in people with normal vision? People with low vision who are otherwise unaffected may use the sound of words more explicitly to aid the reading process than people with normal vision because, more than anyone else, they have experienced that auditory information is a better guide to memory and comprehension than is visual information. If so, we expected that a larger difference between the naming latencies of nonwords and words in students with low vision than in students with normal vision. Similarly, for the number of errors, we expected that the difference in errors between nonwords and words would be larger in students with low vision than in students with normal vision.

Method

Participants

Fifty-four Dutch-speaking primary school students participated: 18 students with low vision, 18 students with normal vision who had the same reading level as the students with low vision (reading-match group) and 18 students with normal vision of the same age as the students with low vision (age-match group). Table 1 presents the mean scores and standard deviations of the relevant matching variables for all three groups.

The students with low vision all came from the Comeniusschool, a special school for students with low vision and blindness in Amsterdam, The Netherlands. With a few exceptions, only students with a visual acuity below 20/60 or a visual field less than 30 degrees are admitted to the Comeniusschool. Students with a visual acuity above 20/60 are referred to mainstream education schools. Ophthalmological characteristics of the participants with low vision are presented in Table 2. (A detailed description of eye diseases can be found in Taylor, 1997.) Visual acuity was determined after the best possible correction for refractional errors and ranged from 20/50 to 20/250. All students with low vision wore glasses or contact lenses and had sufficient vision for reading print; none of them read Braille. Seven participants had restricted visual fields: Four of them fixated primarily with one eye, which left them with a visual field of approximately 150 degrees of arc. Only two participants had central visual field defects. *Nystagmus,* characterized by rhythmic involuntary movement of the eyes, was present in all but five participants. *Strabismus* (squint), in one or both eyes was present in 11 participants.

TABLE 1. Mean Age in Months and Reading Scores of the Experimental Groups

Participant group	Age	Reading score	*n*
Low vision	126 (15)	44 (19)	18
Reading match	108 (18)	44 (18)	18
Age match	125 (14)	67 (18)	18

Note. Standard deviations in parentheses. The reading score refers to the number of words read correctly in 1 minute on the *One-Minute Test* (Brus & Voeten, 1973).

The students who constituted the reading-match and the age-match groups all attended a school for general education in The Netherlands. They were all regularly screened for visual acuity problems at school. None of these children had visual acuity in the better eye below normal limits. The mean reading level of the students in the reading-match group did not differ statistically from that of the students with low vision ($F < 1$), but their mean age was significantly lower (18 months) than that of the students with low vision, $F(1, 35) = 10.44$, $p < .01$. The mean age of the students in the age-match group was not statistically different from that of the students with low vision ($F < 1$), but their reading level was significantly higher than that of the students with low vision, $F(1, 35) = 14.54$, $p < .01$.

We measured reading level using a standardized reading-decoding test that is the most widely used word-decoding test for both educational and scientific purposes in The Netherlands (Brus & Voeten, 1973). This test assesses predominantly the speed of word decoding but does take into account errors. Readers are asked to read a list of single words as quickly and as accurately as they can in 1 min. The score is the number of words read correctly in that time. Errors are generally very small, because the Dutch language is relatively transparent, and for most readers, except people with dyslexia, decoding is a relatively straightforward task once the basic grapheme–phoneme relationships are mastered. The correlation between the number of words read correctly and the number of words read thus is almost perfect (Verhoeven & van Leeuwe, 2003).

The use of a standardized reading test developed for students with normal vision is justified, given the results of the research conducted by Ahn and Legge (1995). They showed that reading performance on a regular reading test of students with low vision who did not use a reading aid explained about 80% of the variance of performance on texts when they used favorite reading aid. In our study, all students, except the students who wore spectacles, read without a reading aid. (None of the participants used magnifiers.) We did not know how many used magnifiers in regular reading practice, but there must have been some children who did. Finally, only students whose mother tongue was Dutch were considered eligible for participation in our study.

Materials

We used 48 four-letter stimuli from Bosman and de Groot (1995): 24 consonant–vowel–vowel–consonant (CVVC) words and 24 consonant–consonant–vowel–vowel (CCVV) nonwords. The two vowels in both stimuli always constituted one

TABLE 2. Ophthalmologic Characteristics of the Participants With Low Vision

Case	Gender	Etiology	Visual acuity	Visual field	Nystagmus	Strabismus
1	Girl	Cataract: right eye more than left eye	20/100	Restricted to the right due to cataract in right eye	Yes	Convergent right eye
2	Girl	Persistent papillary membranes	20/80	Restricted to the right due to amlyopia in right eye	Yes	Divergent right eye
3	Girl	Juvenile macular degeneration	20/250	Central scotoma, left eye	—	—
4	Boy	Myopia gravior	20/140	—	—	—
5	Girl	Vitreoretinal degeneration with high myopia	20/100	—	Yes, latent	Divergent left eye
6	Girl	Aniridia	20/250	—	Yes	Divergent right eye
7	Girl	Unilateral cataract and myopia	20/75	Restricted to right due to cataract in right eye	Yes	Convergent right eye
8	Boy	Cornea plana with hypermetropia	20/100	—		—
9	Girl	Opsoclonus	20/100	—	Irregular, rapid eye movements	Alternating divergent
10	Girl	Astrocytoma, third ventricle	20/250	Bitemporal hemianopsia	Yes	Divergent left eye
11	Girl	Congenital cataract	20/125	—	yes	Convergent left eye
12	Boy	Ocular albinism	20/140	—	yes	—
13	Girl	Tapetoretinal degeneration	20/80	Small concentric restriction	—	—
14	Boy	Vitelliform macular degeneration	20/50	Central scotoma	—	Alternating convergent
15	Girl	Nervus opticus atrophy	20/140	—	—	—
16	Boy	Oculocutaneous albinism	20/140	—	yes	—
17	Girl	Congenital cataract	20/125	—	yes	Convergent right eye
18	Boy	Oculocutaneous albinism	20/140	—	yes	Alternating divergent

Note. *Aniridia* is congenital or traumatically induced absence or defect of the iris; *cataract* is lens opacities; *cornea plana* is flat cornea and *hypermetropia* is farsightedness; *juvenile macular degeneration* is degeneration starting in childhood of the retinal area lying slightly lateral to the center of the retina that constitutes the region of maximum visual acuity and is made up almost wholly of retinal cones; *myopia* is nearsightedness; *nervus opticus atrophy* is atrophy of the nerve coming from the eye; *opsoclonus* is eye motility disorders in which irregular, rapid eye movements are present; *persistent papillary membranes* are strands of tissue in the eye that are remnants of blood vessels that supplied nutrients to the developing lens of the eye before birth; *strabismus* is crossed eyes or squint, a vision condition in which a person can not align both eyes simultaneously under normal conditions; *vitreoretinal degeneration* is degeneration of the vitreous, including the presence of filaments or cord-like structures or avascular bands and a condensation of the peripheral vitreous. The central vitreous cavity appears empty, and the peripheral retina may be progressively affected by pigmentary changes and chorioretinal degeneration.

phoneme. The words (e.g., *boek* [*book*], *maan* [*moon*], weeg [*weigh*]) were drawn from the first three reading-instruction books in *Veilig Leren Lezen* (*Learning to Read Safely;* Caesar, 1979), the most widely used curriculum in The Netherlands. This curriculum stresses the importance of phonics instruction. The nonwords were derived from the words and constructed such that orthographically illegal nonwords emerged (e.g., *bkoe, mnaa, wgee*).

Procedure

The experimenter told the students that words would appear on the screen and they should name the first letter of each stimulus. All students used letter names to identify the first letter of each word. The experimenter explained that some of the words were not real words but that the students were not to take note of this.

The research was conducted on a Macintosh Classic computer. Each stimulus appeared on the same place in the middle of the screen in 14-point Helvetica black letters on a white background. The students with low vision were seated approximately 20 cm from the computer screen, whereas the two groups of students with normal vision were about 50 cm from the screen. The angular size of the letters was 4.3° × 11.3° (height × width) at 20 cm and 1.7° × 4.6° at 50 cm. Angular size was within the visual fields and above the acuity threshold of all the children with low vision. We did not consider testing the children with low vision and those with normal vision at 20 cm so that viewing distance would be identical because we were interested in an ecologically valid situation for all groups, and a viewing distance of 20 cm for children with normal vision is too short. An Authorware software program controlled stimulus presentation, stimulus randomization, and response registration.

Each trial started with an auditory warning signal 500 ms prior to stimulus presentation. The stimulus remained on the screen until the student responded. Response latencies were registered in ms by a voice key. Response latency was the time between presentation of the stimulus and the voice onset (i.e., the beginning of the pronunciation of the letter). The experimenter evaluated each response through pressing the appropriate key (1 = correct, 3 = incorrect, 2 = invalid response) on the computer keyboard. Each experimental session was preceded by a set of five practice trials to familiarize the student with the task and to ensure the stimuli were easily readable for the children with low vision.

Results

Although the actual number of participants in the experiments appears modest, previous experiments with the first-letter naming paradigm have indicated that 20 participants are more than sufficient to obtain reliable and robust effects (Bosman & de Groot, 1995; Bosman et al., 2000).

Error Analysis

We performed a 3 (group: low vision vs. reading-match vs. age-match) × 2 (stimulus: words vs. nonwords) ANOVA on the mean number of errors for the participants. We treated group as a between-participants variable and stimulus as a within-participants variable. The means are presented in Table 3. The main effect of group, $F(2, 51) = 1.75$, $p = .18$, and the main effect of stimulus, $F(1, 51) = 2.30$, $p = .14$, were not significant, but the interaction effect between group and stimulus was, $F(2, 51) = 3.40$, $p < .05$.

To further investigate the overall interaction effect, we performed two separate ANOVAs on the error data. In the analysis in which we compared the error scores (on words and nonwords) of the low-vision group with the reading-match group, no significant interaction effect between group and stimulus emerged, $F(1, 34) = 2.16$, $p = .15$. Similarly, when comparing the error scores of the low-vision group with the age-match group, the interaction effect between group and stimulus did not reach a significant level, $F(1, 34) = 1.22$, $p = .28$.

The most detailed analysis in which the source of the overall interaction could be revealed was testing the effect of stimulus for each group separately. It appeared that the dif-

TABLE 3. Errors and Response Latencies in Experiment 1

	Low-vision group		Reading-match group		Age-match group	
Stimulus	% errors	Latency (in ms)	% errors	Latency (in ms)	% errors	Latency (in ms)
Words						
M	5.6	870	7.9	923	2.8	790
SD	4.3	227	7.4	316	3.8	195
Nonwords						
M	4.6	910	4.2	944	4.0	821
SD	5.3	244	4.3	281	5.0	177
First-letter effect	1.0	40	3.7	12	–1.2	31

ference in error scores was only significant in the reading-match group students, indicating that they made more errors in first-letter naming on words than on nonwords, $F(1, 17) = 8.12$, $p < .01$. The F-values for the students with low vision and the age-match group were $F(1, 17) = .46$, $p = .51$, and $F(1, 17) = .80$, $p = .38$, respectively.

Latency Analysis

We performed a 3 (group: low vision vs. reading-match vs. age-match) × 2 (stimulus: words vs. nonwords) ANOVA on the mean correct first-letter-naming latencies of the participants. Group was treated as a between-participants variable and stimulus as a within-participants variable. The means are presented in Table 3.

The interaction effect between group and stimulus ($F < 1$) and the main effect of group, $F(2, 51) = 1.39$, $p = .26$, were not significant. Thus, overall times for first-letter naming were statistically the same for all three groups. The main effect of stimulus, however, was significant, $F(1, 51) = 7.57$, $p < .01$. The first letter of words ($M = 864$, $SD = 253$) was named faster than the first letter of orthographically illegal nonwords ($M = 892$, $SD = 238$).

Discussion

The error analysis showed that first-letter naming of students with low vision was similar to that of the age-match students and that first-letter naming for both groups differed from that of the reading-match group. The reading-match group committed more errors in first-letter naming on words than on nonwords, whereas students in the age-match group and those in the low-vision group had equal numbers of errors. The latency analysis showed that first-letter naming behavior of students with low vision was similar to that of the age-match and reading-match students. That is, not only did mean naming times not differ statistically, all three groups showed the so-called first-letter effect, indicating that the first letters of words were named more quickly than the first letters of nonwords.

STUDY 2

Results of ample eye-movement research have shown that readers with normal vision fixate one position in a single word (e.g., Rayner & Pollatsek, 1989). Sufficient peripheral vision to the left and to the right of the fixation point enables them to correctly identify the word. This issue has been investigated in detail by Legge, Mansfield, and Chung (2001), who showed that a limited visual span in readers with normal vision resulted in slower reading in peripheral vision. Readers with normal vision appeared to be able to process letters in a word in parallel. The question is whether people with low vision are also capable of parallel processing of letters, albeit to a lower degree. After all, if peripheral vision is limited, it may well be that readers with low vision are forced to read words letter by letter from left to right.

To address this question, we selected two types of word stimuli: words that consisted of typical letter–sound relationships and words that consisted of atypical letter–sound relationships. Decoding letters in words with typical letter–sound relationships is almost independent of the word context in which the letters are embedded. A Dutch example is *minst* (*fewest*) and an English example is *tramp*. Decoding letters in words with atypical letter–sound relationships, however, depends to a large extent on the word context in which the letters are embedded. A Dutch example is the word *moeite* (*effort*). English examples are *choir* or *through*. Words with typical letter–sound relationships can be read through successive decoding from left to right, whereas the reading of words with atypical letter–sound relationships is largely determined and often dramatically changed by preceding and following letters. If students with low vision rely more on successive decoding of letters, we expected that the difference in errors and in latencies between words with atypical and words with typical letter–sound relationships would be larger in students with low vision than in students with normal vision.

A second variable of interest we investigated was word frequency. Ample evidence in the visual-word perception literature has indicated that words that occur often in written language are processed more quickly and more accurately than words that only occur sporadically (e.g., Monsell, 1991). We thus expected that students with low vision as well as students with normal vision would display the so-called frequency effect because word frequency affects the reading process early in the development of beginning readers (Ducrot, Lété, Sprenger-Charolles, Pynte, & Billard, 2003). All participants in this study, including the group with low vision, had sufficient reading experience to show a frequency effect.

Method

Participants

The students from Experiment 1 also took part in Experiment 2.

Materials

We selected a set of 30 words from a word-frequency list from Staphorsius, Krom, and de Geus (1988), a corpus of 202,526 words containing the frequency count of occurrence in youth literature. From this list, we chose 15 words with atypical letter–sound relationships. Words with typical letter–sound relationships predominantly contain letters that are pronounced according to their letter sounds, the so-called prototypical letter–sound correspondences. Prototypical letter–sound relationships are taught in first grade in The Netherlands. English examples are used to clarify the issue. In the English word *mat,* all three letters are pronounced according to the English letter sounds, whereas two of the four letters in the word *call* (c, a) are not pronounced according to the English letter sounds. In terms of letter–sound typicality, *mat* would be perfectly typical, whereas *call* would be rather atypical, having two letters that do not follow prototypical letter–sound correspondences. In this experiment, we quantified letter–sound typicality for the Dutch stimuli as follows: Words with 0 or 1 atypical letter–sound relationships were considered to be typical, whereas words with 2, 3, or 4 atypical letter–sound relationships were considered atypical. The mean number of typical letters in the set of words designated as typical (M = 0.4, SD = .5) deviated significantly from the mean for the set of words designated atypical (M = 2.8, SD = .9), $F(1, 28) = 75.6$, $p < .0001$.

The second variable of interest was frequency. The set of experimental stimuli contained 14 high-frequency words and 16 low-frequency words. High-frequency words were words that occurred more than 17 times but less than 96 in the corpus of 202,526 words. Low-frequency words were words that occurred less than 14 in the same corpus. The mean number of typical letters in the high-frequency condition (M = 1.6, SD = 1.4) was almost identical to the mean for the low-frequency condition (M = 1.6, SD = 1.5), $F < 1$. The mean length in letters was 5.7 (SD = 1.0) and varied between 4 and 7 letters. The mean length of the high-frequency words and of the low-frequency words was statistically equal ($F < 1$), and the mean length of words with typical and atypical letter–sound relationships was identical ($F = 0$).

Procedure

We used the same process in this experiment as in Experiment 1. The stimuli were presented on the screen one by one, and the students were asked to read the presented word as quickly and as accurately as possible. Stimulus presentation and response registration was identical to Experiment 1. Prior to the experimental session, each participant was given five practice trials.

Results

Previous word-naming experiments with Dutch beginning readers have shown that 20 participants are more than sufficient to reliably distinguish between experimental conditions (e.g., Bosman & de Groot, 1991, 1996).

Error Analysis

We performed a 3 (group: low vision vs. reading-match vs. age-match) × 2 (frequency: high vs. low) × 2 (stimulus: typical vs. atypical) ANOVA on the mean number of errors of the participants. Group was treated as a between-participants variable and frequency and stimulus as within-participants variables. The means are presented in Table 4.

The error analysis yielded significant main effects for group, $F(2, 51) = 4.23$, $p < .05$; stimulus, $F(1, 51) = 4.32$, $p < .05$; and frequency, $F(1, 51) = 16.82$, $p < .0001$. All main effects had to be qualified because of significant interactions.

TABLE 4. Errors and Response Latencies in Experiment 2

Stimulus	Low-vision group		Reading-match group		Age-match group	
	% errors	Latency (in ms)	% errors	Latency (in ms)	% errors	Latency (in ms)
High-frequency words						
Typical						
M	7.1	1,217	4.7	1,014	0.8	661
SD	8.8	697	8.5	421	3.3	102
Atypical						
M	7.9	1,273	4.0	1,054	1.6	659
SD	10.1	862	8.2	466	4.6	133
Low-frequency words						
Typical						
M	11.1	1,449	18.1	1,353	5.6	734
SD	12.8	956	13.7	863	7.7	276
Atypical						
M	9.0	1,350	6.9	1,174	5.6	744
SD	14.1	952	8.8	621	9.8	250
Stimulus effect	0.6	21	5.9	70	−0.4	−4
Frequency effect	2.5	155	8.1	230	4.4	79

The significant interaction effect between group and stimulus, $F(2, 51) = 3.91$, $p < .05$, necessitated using two separate ANOVAs on the error scores.

In the first analysis, we compared the low-vision group with the reading-match group on the error scores of the typical and atypical stimuli. A significant interaction effect between group and stimulus emerged, $F(1, 34) = 3.67$, $p = .06$. Subsequent analyses indicated that in the low-vision group, the error scores between typical ($M = 9.1$, $SD = 9.0$) and atypical stimuli ($M = 8.5$, $SD = 8.3$) did not differ statistically ($F < 1$), whereas in the reading-match group, significantly more errors were made on typical stimuli ($M = 11.4$, $SD = 9.1$) than on atypical stimuli ($M = 5.5$, $SD = 5.2$), $F(1, 17) = 9.33$, $p < .01$. Mean numbers of overall errors between the low-vision and the reading-match groups were not statistically different either, $F < 1$.

In the second analysis, we compared the low-vision group with the age-match group on the error scores of the typical and atypical stimuli. The interaction between group and stimulus was not statistically significant, $F < 1$. Both groups made equal number of errors on the typical and atypical stimuli, $F < 1$. The only significant difference between groups emerged on the overall numbers of errors, $F(1, 34) = 6.65$, $p < .01$: Students with low vision ($M = 8.8$, $SD = 7.6$) made more errors than age-match students ($M = 3.4$, $SD = 4.7$).

The final error analysis pertains to the significant interaction between frequency and stimulus, $F(1, 53) = 3.32$, $p = .07$. Subsequent analyses indicated that in the low-frequency condition, no significant difference was found between typical ($M = 4.2$, $SD = 7.7$) and atypical stimuli ($M = 4.5$, $SD = 8.2$), $F < 1$. In the high-frequency condition, however, more errors were committed on the typical stimuli ($M = 11.6$, $SD = 12.6$) than on the atypical stimuli ($M = 7.2$, $SD = 11.0$), $F(1, 53) = 5.69$, $p < .05$.

Latency Analysis

We performed a 3 (group: low vision vs. reading-match vs. age-match) × 2 (frequency: high vs. low) × 2 (stimulus: typical vs. atypical) ANOVA on the mean correct response latencies of the participants. Group was treated as a between-participants variable and frequency and letter context as within-participants variables. The means are presented in Table 4.

Neither the interaction effect between group and frequency, $F(2, 51) = 1.32$, $p = .28$, nor the one between group and stimulus ($F < 1$) reached significant levels, but the main effect of group was significant, $F(2, 51) = 5.17$, $p < .01$. Subsequent analyses (Fisher's *PLSD*, critical value = 401 ms) revealed that the difference in naming latencies between the low-vision group and the reading-match group (173 ms, $p = .40$) was insignificant, whereas the difference between the low-vision group and the age-match group was (623 ms, $p < .01$), with the low-vision group being slower than the age-match group. The difference between the reading-match and the age-match groups was also significant (449 ms, $p < .05$), with the reading-match group being slower than the age-match group.

The main effect of frequency was significant, $F(1, 51) = 16.48$, $p < .001$, whereas the main effect of stimulus was not, $F(1, 51) = 1.17$, $p = .29$. The significant interaction between frequency and stimulus, $F(1, 51) = 7.44$, $p < .01$, required further investigation of the differential effects of frequency and stimulus. In the low-frequency condition, all groups read atypical stimuli (M = 1,090 ms, $SD = 708$) faster than typical stimuli (M = 1,179 ms, $SD = 812$), $F(1, 53) = 4.67$, $p < .05$; whereas in the high-frequency condition, no such difference emerged (typical stimuli: M = 964 ms, $SD = 520$; atypical stimuli: M = 995 ms, $SD = 616$), $F(1, 53) = 1.29$, $p = .26$.

Discussion

The error analysis revealed that with respect to the overall number of errors, the reading behavior of the low-vision group was similar to that of the reading-match group but differed from the age-match group. With respect to the number of differential errors on typical and atypical stimuli, the low-vision group was similar to the age-match group but differed from the reading-match group. Only the reading-match group made more errors on typical stimuli than on atypical stimuli; no such difference was found in the low-vision and in the age-match group. Moreover, all three groups made more errors on high-frequency typical stimuli than on high-frequency atypical stimuli, and they made equal numbers of errors on low-frequency typical stimuli and low-frequency atypical stimuli. The latency analysis showed no significant interactions between group and any of the experimental variables. The overall naming speed of the low-vision group was equal to that of the reading-match group, which in turn were both slower than the age-match group. Moreover, all three groups read low-frequency atypical stimuli faster than low-frequency typical stimuli, but no such difference emerged between typical and atypical stimuli in the high-frequency condition.

The error and the latency results indicated that the reading behavior of students with low vision mimicked the reading behavior of the age-match students qualitatively and the reading behavior of the reading-match group quantitatively. The fact that the students with low vision made more errors and were slower in reading words than the age-match students but were equally accurate and fast as the reading-match students affirms the validity of the matching procedure.

We need to address an unexpected but interesting finding, namely, the effect of stimulus and the interaction between stimulus and frequency. We had hypothesized that words with typical letter–sound relationships are read more accurately and more quickly than words with atypical letter–sound relationships. With respect to accuracy, the results showed that all groups made *more* errors on typical stimuli than on atypical stimuli in the high-frequency condition and were equally accurate on both types of stimuli in the low-frequency condition. With respect to speed, the results showed that all groups took *longer* to name typical stimuli than atypical stimuli in the low-frequency condition and were equally fast on both types of stimuli in the high-frequency condition. Thus, contrary to our hypothesis, typical stimuli were not processed faster or more accurately. If anything, they were processed more slowly and less accurately. A possible explanation is that the reading of words with atypical letter–sound relationships is more constrained than of words with typical letter–sound relationships. This enables the reader to guess the identity of words with atypical letter–sound relationships with a little more confidence and success, as was the case with words in which the uniqueness point was closer to the beginning of words.

GENERAL DISCUSSION

The central question of this study was whether the reading process of students with low vision is qualitatively different from that of students with normal vision (age-match and reading-match students). We tested this question in two studies. When the reading behavior of students with low vision deviated from that of the reading-match and age-match students with normal vision, it was taken to indicate qualitative differences. When the reading behavior of students with low vision was similar to that of the reading-match students but differed from that of age-match students, it is taken to indicate quantitative differences.

In the first study, the error and latency results of the first-letter naming task indicated that the reading behavior of students with low vision closely mimicked the reading behavior of the age-match students both quantitatively and qualitatively; that is, the number of first-letter errors and first-letter naming speed were similar in the two groups. The comparison between the students with low vision and those from the reading-match group indicated superior performance for the students with low vision with respect to accuracy and equal performance with respect to speed. The fact that all three groups of students named the first letter of words more quickly than the first letter of illegal nonwords agrees with earlier research by Bosman et al. (2000), who interpreted this effect in terms of the activation of phonology, a well-established phenomenon in the reading of beginning and highly experienced readers with normal vision. The present findings indicate that the reading process of students with low vision is also phonologically mediated, which agrees with the results of Pick, Thomas, and Pick (1966) and Pring (1982), who found phonological effects in the reading of blind people who use Braille. The fact that children with low vision clearly rely on phonology when reading contributes in an interesting way to the ongoing discussion with respect to the underlying cause of developmental dyslexia. Whether a distinct visual factor (a magnocellular deficit; e.g., Stein & Talcott, 1999) contributes to the problem of dyslexia in some people, it is obvious to almost all researchers in this area that phonology is the key problem. Even if this group of readers differs on some visual processing measure, those differences do not necessarily contribute to the reading problems of students with reading disabilities, which seems to parallel the conclusion that the reading process of students with low vision is similar to that of students with normal vision who have the same reading abilities.

In the second study, we presented all three groups of students with high- and low-frequency typical letter–sound relationships and atypical letter–sound relationships. It was argued that the reading process of students with low vision was best characterized as a serial, letter-by-letter, left-to-right process; therefore, they should have more trouble reading words in which the correct reading of letters largely depends on the other letters in the word (i.e., words with atypical letter–sound relationships) than words containing letters that are relatively independent of the other letters in the word (i.e., words with typical letter–sound relationships). Our results provided no evidence for this hypothesis, because the students with low vision read words with atypical letter–sound relationships and words with typical letter–sound relationships equally fast, exhibiting the same effect as the two groups of students with normal vision. These results therefore did not indicate a qualitatively different reading behavior for the students with low vision. The finding that all three groups exhibited a frequency effect substantiates this conclusion. There was, however, a quantitative difference among the groups. Unlike in the first study, the students with low vision did not name the words as fast as their age-matched peers, but they were equally as fast as the students in the reading-match group.

The picture that emerges suggests that the process of students with low vision involved in the reading of single words only deviates quantitatively, not qualitatively, from that of students with normal vision. We are well aware that this general conclusion is partly based on a series of null effects, but every effort has been made to ensure that potential effects *could* emerge. Both studies included experimental manipulations (i.e., Study 1: first-letter effect, Study 2: frequency effect) showing sufficient sensitivity for revealing immanent effects. The absence of qualitative differences is also in accordance with earlier research in which no evidence was obtained for the assumption that children with low vision adopt a different cognitive-reading strategy to compensate for their limited vision. Based on previous and our present findings, the conclusion that the reading of single words, provided sufficient practice, is a relatively modular process in readers with normal vision as well as in those with low vision seems warranted.

Because the physical aspects of print might have affected reading rate, the mechanisms explaining why the reading-matched children and the children with low vision read more slowly than the age-matched children is probably different for the two groups. In theory, the reading rate in children with low vision may be hampered by physical constraints on the visual input; in younger sighted children with less reading experience, reading rate may be mostly affected by aspects related to the reading process itself, such as automation, semantic knowledge, and phonological awareness. A positive finding with respect to the reading behavior of students with low vision was presented by Gompel et al. (2002), who showed that reading comprehension and spelling ability in a group of children with low vision in The Netherlands did not deviate significantly from that of their peers with normal vision.

Although physical factors probably contribute to the relatively slow reading of readers with low vision, there certainly are also psychological explanations. First, like all other skills, reading improves through practice, but when perception is difficult, as it is for students with low vision, it may affect the children's motivation to read. Students with little reading motivation are not likely to read often and thus have limited amounts of practice. The "practice makes perfect" explanation is supported by Fellenius (1996), who found that the reading achievement of students with low vision was affected by such factors as motivation, reading habits, and verbal cognitive ability but not by visual acuity. More important, Daugherty (1977) and Fridal, Jansen, and Klindt (1981) showed that the decoding skills of students with low vision can be improved in a fairly short time by means of remedial reading programs. Second, children with normal vision experience ample opportunity for *incidental learning* (i.e., learning that happens outside of the instructional context). Children with normal vision encounter writing on walls, labels on food packages, directional road signs, and so forth. Because these opportunities are out of the scope of children with low vision, they necessarily have less experience with written materials. After Stanovich and West's (1989) seminal paper on print exposure, we know that reading performance is largely determined by the degree of reading experience, which is directly related to the amount of print exposure. These factors suggest that the visual aspect does not necessarily have to be the only factor that could account for the limited reading speed of students with low vision.

With respect to practical and educational implications, our work indicates that teaching children with low vision is not very different from teaching children with normal vision. For example, the suggestion from the Committee on the Prevention of Reading Difficulties in Young Children of the U.S. National Research Council that teaching reading should be based on phonics rather than on a whole-word approach is as true for students with low vision as it is for students with normal vision (Snow, Burns, & Griffin, 1998). Moreover, the fact that reading, like any other skill, improves with practice emphasizes the importance of practice even more in children with low vision, who experience less incidental reading opportunities than children with normal vision. Finally, teachers have to be knowledgeable about the physical factors that need to be addressed to optimize the visual aspect of the process, but they should also be aware of the psychological aspects that may interfere with or hamper the development of reading skill in children with low vision.

AUTHORS' NOTES

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