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# Word Reading and Processing of the Identity and Order of Letters by Children with Low Vision and Sighted Children

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***Abstract:*** Two aspects of word reading were investigated in two word-naming experiments: the identification of the constituent letters of a word and the processing of letter-order information. Both experiments showed qualitative differences between children with low vision and sighted children, but no quantitative or qualitative differences within the group of children with low vision.

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Generally, children with low vision read more slowly than do sighted children (Corley & Pring, 1993a, 1993b; Daugherty & Moran, 1982; Fellenius, 1999; Gompel, van Bon, Schreuder, & Adriaansen, 2002; Tobin, 1985; van Bon, Adriaansen, Gompel, & Kouwenberg, 2000). A previous study showed that this difference in reading speed should not be attributed to a difference in orthographic knowledge between children with low vision and sighted children (Gompel, Janssen, van Bon, & Schreuder, 2003). A conclusion of that study was that only visual processing constrains the reading speed of children with low vision.

When reading texts, a restricted visual field (caused by eye anomalies or by a short reading distance) and, consequently, the restricted use of information from the periphery can explain the slower reading rate of children with low vision. However, children with low vision do not have slower reading rates only when reading texts; they also have them when reading isolated words (Gompel, van Bon, & Schreuder, 2004). This finding suggests that the reading of these children is hampered not just at the text or sentence level but at the word level. Therefore, in the study presented here, we investigated some relevant aspects of word decoding.

We compared the word-recognition process of children with low vision with that of sighted children, but also investigated whether this process is different for children with low vision with and without visual field restrictions. Previous research has indicated that of all visual impairments, central visual field defects have the highest adverse effect on decoding skills (Legge, Rubin, Pelli, & Schleske, 1985; van Bon et al., 2000). Gompel et al. (2002) also found that children with visual field restrictions were poorer decoders than children with other visual impairments, but no difference in decoding skills was found between children with central field defects and children with peripheral field defects. It is possible, however, that despite equality on global outcome measures, decoding processes are different in these groups of children with low vision. For children with central scotomas (blind spots), parts of words can fall on the retina just at the location of a scotoma (Legge, Klitz, & Tjan, 1997), so that some of the constituent letters of a word may not be seen. This finding is in line with the finding of Bullimore and Bailey (1995) that readers with central scotomas need to make more regressions than do readers without central scotomas. A peripheral field restriction, however, narrows the field of view; depending on the width of the visual field, more or fewer characters can be recognized within one fixation. A narrow visual field could affect not only the reading of sentences (Koenen, Bosman, & Gompel, 2000), but the identification of isolated words, especially long words.

We studied two aspects of visual word recognition: the identification of the constituent letters of a word and the processing of letter-order information in words. The recognition and identification of the letters may be difficult for children with low vision because some letters (such as “i” versus “l”) differ only in a single feature. It is conceivable that when vision is not sharp, single features are hard to perceive or distinguish. In addition, when the visual field is restricted, it is possible to miss one or more letters or parts of letters. The perception and identification of letters are essential, however, for the correct reading of words. A slight change can make all the difference in meaning as well as in pronunciation (for example, *cure* versus *core*).

The order of the constituent letters is also essential in determining the pronunciation and meaning of a word (such as *rose* versus *sore*). Thus, the identification of the constituent letters is not enough to identify a word; information about the order of the letters also needs to be processed. The processing of letter-order information may be more difficult for children with low vision than for sighted children because they require more time to identify the single letters and hence have to keep the identified letters longer in working memory, which may interfere with their keeping track of the position of the letters.

Children with central visual field restrictions may have an additional disadvantage in processing letter-order information. Legge et al. (1997) showed that people with central scotomas make more regressions while reading because some letters of a word fall on a scotoma on the retina and are thus not visible. These regressions may cause people with scotomas to perceive the letters of a word in a different order than do people without scotomas and may slow down their reading rates. In the case of words in which the constituent letters can form two or more different words, these regressions may also cause letter-order errors, especially when words are not presented in a context.

In this article, we describe word recognition in terms of connectionist (network) models (see, for example, McClelland & Rummelhart, 1981). A property of this type of word-recognition model is that the frequency of words determines the base level of activation of a word representation in the mental lexicon. Thus, for high-frequency words, less information is needed to reach a threshold than for low-frequency words.

Nonwords have no representations on the word level, yet adults and even children are able to read nonwords. Rayner and Pollatsek (1989) explained the reading (pronunciation) of nonwords either by the use of grapheme or phoneme conversion rules or by the analogy that these nonwords may have with existing words. When a word is presented, both its specific representation and representations of orthographically similar words, specifically orthographic neighbors (words that differ in only one letter from the target word), are activated. Nonwords may therefore activate the representations of words that are orthographically similar to the nonword. Reasoning along these lines, we predicted that the naming of nonwords will be facilitated by the activation of high-frequency neighbors because they provide the analogy on which to base the pronunciation.

Grainger (1990) found a facilitating effect of neighbor frequency in word-naming tasks. Words with at least one higher-frequency neighbor had shorter naming latencies than did words with no higher-frequency neighbors. Laxon, Coltheart, and Keating (1988) found a facilitating effect of neighborhood size on the accuracy in word naming. We expected to find such a facilitating effect of high-frequency neighbors on the naming of nonwords by children with low vision as well as by sighted children. We also expected this effect to be stronger in children with low vision because their restricted visual input forces them to use all possible resources for recognizing words, such as knowledge of similar words.

Nonwords can also be informative about the reading accuracy of the different groups of children. In a previous study, we did not find that children with low vision made more reading errors than did sighted children (Gompel et al., 2003). Such errors would have been an indication of an inaccurate reading strategy involving guessing, for instance. This result, however, was based on the reading of existing words, in which a guessing strategy probably leads to correct responses most of the time, but with nonwords, a guessing strategy is not likely to result in correct responses. If children with low vision apply a guessing strategy more often than do sighted children, then the naming of nonwords would result in more errors for them. Thus, when presented with nonwords, children with low vision would have not only longer response latencies and more errors than would sighted children of the same age, but longer response latencies and more errors than sighted children of the same reading level.

The two experiments described here investigated the two aspects of word recognition in children with low vision and sighted children. In the first experiment, we assessed the letter-recognition process in word naming by studying the effects of orthographic neighbors on nonword naming. Since we expected that the identification of letters is more difficult for children with low vision, we predicted that an effect of neighbor frequency would be larger for children with low vision than for sighted children.

In the second experiment, we investigated the role of letter-order information by studying the reading of anagrams, that is, words whose letters can be rearranged to form one or more other words; for example, *kerst* (Christmas) is an anagram of *sterk* (strong) and of *strek* (stretch). We predicted that the processing of letter-order information would be more difficult for children with low vision than for sighted children and especially for children with visual field restrictions, as evidenced by the errors made and the time needed when reading anagrams.

## Experiment 1

In this first experiment, we studied the letter-recognition process by presenting children with nonwords. Apart from neighbor frequency, three visual aspects of the nonwords were manipulated. The first aspect involves the visual features of individual letters. Some letters are more visually similar to each other than others (for instance, “f” and “t” are more alike than are “p” and “w”). In half the nonwords, a letter of an existing word is substituted with a visually similar letter; in the other half, a letter is substituted with a visually nonsimilar letter.

The second aspect is word length. Because of a peripheral field restriction or a short reading distance, children with low vision may not be able to retrieve information from the same range of letter positions as may sighted children within one eye fixation. As a result, with long words, children with low vision would need to make more fixations than would sighted children, which could increase their reading time. For short words, one fixation could be sufficient for both groups of children.

The third aspect is the position of the substitution. In half the nonwords, a letter of an existing word is substituted in the first part of the word, and in the other half, the substitution was in the last part of the word.

Since the Dutch reading system, like that of many other languages, operates from left to right, it is possible that children with peripheral field restrictions process the first part of a word and respond on the basis of that information even before they process the latter part of a word. If this surmise is true, then nonwords with the substitution in the final part are likely to cause more activation of the orthographic neighbor than are nonwords with the substitution in the first part.

The first research question in this experiment was whether children with low vision are more inclined to apply an inaccurate strategy in decoding words than are sighted children. The use of nonwords in this experiment made it possible to investigate this question. In nonwords. a guessing strategy is not likely to result in the correct response. If children with low vision are inclined to guess, we predicted that they will make more errors in the naming of nonwords than will sighted children of the same word-reading level.

The second research question was whether the effects of neighbor frequency are larger for children with low vision than for sighted children. If such a difference in effect size is found, it can indicate an analogy-based reading strategy instead of a grapheme or phoneme conversion strategy. Because the visual input of children with low vision is of a low quality, we expected these children to compensate for it by using analogy (similar words). To investigate this possibility, we derived the presented nonwords from existing words by changing one letter in the existing words, so that the existing word was an orthographic neighbor of the presented nonword. Half the presented nonwords had a high-frequency neighbor, and half had a low-frequency neighbor.

The third research question concerned the effects of three visual aspects of nonwords (word length, the visual similarity of substituted letters, and the position of the substitution) and their interaction with neighbor frequency. In this study, we explored whether these visual factors differentiate among the different groups of readers, which would indicate qualitatively different word-recognition processes. The fourth research question was whether any of the effects we found would be different in children with visual field defects than in other children with low vision.

## Method

### *Participants*

In Experiment 1, 120 children (all native speakers of Dutch) participated: 40 children with low vision, 40 age-matched sighted children, and 40 reading level-matched sighted children. The sighted children were selected from a neighborhood primary school. At the time of the study, all the children with low vision had received 40 to 60 months of literacy education. The children in the reading-level control group had a word-reading score, determined by the Drie Minuten Toets, (DMT), or Three Minutes Test (Verhoe- ven, 1995) that was equal to that of the children with low vision ($F < 1$), but their educational age was significantly lower than that of the children with low vision ($F(1,78) = 79.8$, $p < .01$). The children in the age-level control group were matched on educational age but had a significantly higher word-reading score ($F(1,78) = 8.8$, $p < .01$).

The children with low vision were selected from a larger sample of children with low vision who had participated in an earlier study (Gompel et al., 2002). We selected the children on the basis of their visual diagnoses, such that half the children had some form of a visual field restriction and half had intact visual fields. Before the study was conducted, the parents or caretakers of all the participating children were informed about its purposes and procedures, and we obtained their written consent for the children to participate.

***Materials and procedure***

To be able to study the effects of different visual field restrictions on the naming of words, we required all the children with low vision to have visual field examinations, conducted by optometrists at two institutes for children with low vision. The peripheral visual field was determined by means of a Goldmann visual field examination or the Tübinger perimeter.

The central visual field was determined with the Friedmann Visual Field Analyzer. The results of these visual field examinations and the diagnoses of the children with low vision are summarized in Table 1.

The children's reading levels were determined by means of the second card of the DMT. The DMT is a standardized word-decoding test, consisting of three cards. The DMT was administered according to standard procedures, which means that children were presented with a card with isolated words and were instructed to read the words as fast and as accurately as possible. The reading score is the number of correctly read words per card within a minute.

The orthographic neighbor experiment was a computerized word-naming task that used 80 nonwords. All nonwords were derived from existing words by substituting one letter for another one. In half the nonwords, the substituted letter was replaced by a visually similar letter, and in the other half, the replaced letter was not visually similar. The similarity of letters was based on a study by Geyser (1977). The substitution was either in the first half or the last half of the word. Half the nonwords were long strings of letters (8–10 letters; mean = 8, *SD* = 1), and half were short letter strings (4–6 letters; mean = 5, *SD* = 1). Half the nonwords were derived from high-frequency words (more than 3,000 per 42 million), and half were derived from low-frequency words (100–400 per 42 million). Word frequencies were determined on the basis of the CELEX lexical database (Baayen, Piepenbrock, & Gulikers, 1995). Every possible combination of the four factors was represented by five instances. For example, there were five long nonwords that were derived from a high-frequency word, with a highly similar substituted letter in the first half of the letter string. To illustrate the distribution of the nonwords over the different conditions, Table 2 presents an example of a nonword for each condition.

The experiment was conducted on an Apple MacIntosh Powerbook computer, with a screen resolution of 1024 × 768 and a screen diagonal of 35 centimeters (13.78 inches). The children were free to use the viewing distance that was the most comfortable for them. Words were displayed in a 40-point font; for example, the letter "o" had a width of 5 millimeters (0.20 inches) and a height of 6 millimeters (0.24 inches). The font type of the presented words was Monaco. The children were told that the words they were going to see were words that do not exist and that they had to try to read them as quickly and accurately as possible. Naming latencies and errors were recorded.

Naming latencies were recorded in milliseconds by means of a voice key. The experimenter evaluated the responses by means of a button box. Responses could be correct, incorrect, or a voice-key error (if the voice key did not respond or was triggered by a sound other than the onset of the pronunciation of the target).

## Results

Because of a computer failure, the data for one child with low vision were not recorded. The data for the corresponding child in the reading-matched and the corresponding child in the age-matched group were also discarded. Thus, the analyses of Experiment 1 are based on the data of the remaining 137 children.

A 3 (group: low vision versus age matched versus reading matched) by 2 (neighbor frequency: high versus low) by 2 (position of substitution: the beginning versus the end of a word) by 2 (similarity of substitute: high versus low) by 2 (length: long versus short) analysis of variance (ANOVA) was conducted on the median response latencies and mean error proportions of all the children. For the sake of brevity, we discuss only the results that pertain to the research questions. Table 3 shows all the mean naming latencies and mean error proportions.

The first research question was whether children with low vision use a more inaccurate word-reading strategy than do sighted children. The ANOVA revealed no significant main effect for group on error proportions, $F(2,113) = 1.4$, $p = .26$. This result indicates that children with low vision do not have relatively more problems with nonwords than do sighted children of the same reading level and supports a previous finding that children with low vision do not apply guessing strategies in reading more often than do sighted children (Gompel et al., 2003).

The second research question was whether the effect of neighbor frequency is larger for children with low vision than for sighted children. We found no significant main effect of neighbor frequency on response latencies, $F(1,107) = 1.9$, $p = .17$. The interaction between group and frequency was significant, $F(2,107) = 9.2$, $p < .0001$, however. The children with low vision had significantly shorter response latencies on nonwords with a high-frequency neighbor than on nonwords with a low-frequency neighbor, $F(1,37) = 15.8$. $p < .001$. No significant effect of frequency on response latencies was found in the groups of age-matched ($F < 1$) and reading-matched, [$F(1,35) = 3.3$, $p = .08$] children. There was a significant main effect of frequency on the error proportions, $F(1,113) = 15.9$, $p < .0001$. More errors were made in nonwords with a low-frequency neighbor than in nonwords with a high-frequency neighbor. No significant interaction on the error proportions was found between group and frequency, $F(2,113) = 1.4$, $p = .91$, indicating a similar effect of frequency on the error proportions for all three groups. These results show that for the children with low vision, a high-frequency neighbor had a facilitating effect for reading speed as well as for accuracy. For the sighted children, the data show a facilitating effect only for accuracy.

The third research question concerned the effects of three visual aspects of nonwords (word length, the visual similarity of substituted letters, and the position of the substitution) and their interaction with neighbor frequency. None of the visual aspects showed a significant interaction with group on naming latencies or error rates, except for word length on naming latencies, $F(2,107) = 7.4$, $p < .001$. The effect of word length on naming latency was significantly larger in both the low vision group and the reading-matched group than in the age-matched group, $F(1,72) = 4.1$, $p < .05$; $F(1,70) = 16.9$, $p < .0001$, respectively. The difference between the effect in the low vision group and the reading-matched group was not significant, $F(1,72) = 3.2$, $p = .08$. For the naming latencies, the interaction among group, neighbor frequency, and word length was not significant ($F < 1$). The interaction effect of frequency and word length was significant, $F(1,107) = 8.2$, $p <.01$, with larger frequency effects on long words than on short words, but the absence of an interaction with group indicates that this effect is not different for children with low vision than for sighted children. For the error rates, the interaction among group, frequency, and word length was also not significant ($F < 1$).

For the naming latencies and the error rates, the interactions among group, frequency, and position of substitution were not significant, $F(2,107) = 1.1$, $p = .33$, and $F(2,113) = 1.5$, $p = .22$, respectively. For the naming latencies and the error rates, the interactions among group, frequency, and visual similarity were not significant (both $Fs < 1$). Although all manipulations did affect the effect of neighbor frequency, this effect was not different for the different groups.

To examine possible differences between the children with different visual field defects and the children without visual field defects (our fourth research question), we repeated all the analyses with the following between-groups contrasts: children with visual field defects versus those with intact visual fields, children with central field restrictions versus those without central field restrictions, children with peripheral field restrictions versus those without peripheral field restrictions, and children with absolute field defects versus those with relative field defects. None of the ANOVAs revealed any significant main effect for group (all *Fs* < 1). No significant interactions were found between group and type of word (all *Fs* < 1). This finding indicates that the effects of the characteristics of words (neighbor frequency, length, similarity, and place of substitution) are the same for all children with low vision, independent of the absence or presence of any kind of visual field restriction.

The results of this experiment show that the effect of neighbor frequency is larger for children with low vision than for sighted children. Neighbor frequency has no effect on the response latencies of sighted children, but it does affect the response latencies of children with low vision; a high-frequency neighbor facilitates the reading of nonwords in this latter group.

Contrary to our expectations, the effects of word length, position, and visual similarity of the substituted letter on the reading speed or accuracy was not different for the children with low vision than for the sighted children or for the children with low vision with and without visual field restrictions.

## Discussion

The results of the first experiment show that several visual letter or word features (word length, visual similarity, and position of substitution) do not specifically facilitate or hinder the word reading of children with low vision. However, the effect of neighbor frequency is different for children with low vision than for sighted children. Furthermore, the effect of neighbor frequency is larger in long words than in short words for children with low vision. The fact that children with low vision read nonwords with a high-frequency neighbor faster than they do nonwords with a low-frequency neighbor is in line with the idea that these children rely more on an analogy-based reading strategy than on a rule-based reading strategy. This is a qualitative difference between children with low vision and sighted children, not just a developmental lag, because this difference is found not only between children with low vision and sighted children of the same age, but between children with low vision and sighted children of the same reading level.

The finding that children with low vision do not make more errors than do sighted children in nonwords confirms the results of a previous study (Gompel et al., 2003) that children with low vision do not apply a guessing strategy in word reading more often than do sighted children. If they did, they would have had higher error rates in this experiment than the sighted children because a word-based guessing strategy cannot lead to a correct response in reading nonwords as it can in reading existing words.

## Experiment 2

In this word-naming experiment, we investigated the role of the order of letters by presenting two kinds of words: anagrams and unique words. As was mentioned earlier, the letters of an anagram can be rearranged to form one or more other words, whereas the letters of a unique word cannot; for example, with the letters of the word *zalm* (salmon), no other Dutch word can be formed. We expected that for all the children, anagrams would take more time to read than unique words because both words are activated and are candidates for lexical access. The competition between both the word and its anagram or anagrams will increase the time needed for lexical access. In the case of unique words, no such competition has to be resolved. We also expected that this effect of anagrams would be larger in children with low vision than in sighted children and specifically in children with visual field defects because of the difficulties that they may have in processing letter-order information. The same

120 children who participated in Experiment 1 participated in Experiment 2.

## Method

### *Materials and procedures*

The stimuli in this word-naming experiment were 40 words. Half the words were anagrams, and the other 20 words were unique words. Of an anagram set, the anagram with the lowest frequency was presented. The selected (least-frequent) anagrams and unique words were matched on frequency and word length. Word frequencies were determined on the basis of the CELEX lexical database (Baayen et al., 1995). The mean frequency of the presented words of the anagram sets was 104.2, the mean frequency of the remaining words of an anagram set was 7,405.3, and the mean frequency of the unique words was 109.8. The equipment and procedure of this word-naming task were the same as those of Experiment 1.

## Results

A 3 (group: low vision versus reading matched versus age matched) by 2 (word type: anagram versus unique) ANOVA was performed on the median latencies of the correct responses. The variable group was treated as a between-subjects variable and word type as a within-subjects variable. Figure 1 shows the results.

The main effect of the variable group was significant, *F*

(2,117) = 4.7, $p < .05$. Both the children with low vision and the children in the reading-matched group had significantly longer median response latencies than did the children in the age-matched group (Fisher's PLSD, both $p < .001$). No difference was found between the median response latencies of the children with low vision and those of the children in the reading-matched group (Fisher's PLSD, $p = .56$).

The main effect of word type was not significant ($F < 1$), indicating that there was no difference in the median response latencies on unique words and anagrams. The interaction effect, however, was significant, $F(2,117) = 12.5$, $p < .0001$, indicating that the effect of word type was different for the different groups of participants. The children with low vision had significantly longer median response latencies on anagrams than on unique words, $F(1,39) = 6.4$, $p < .05$. Both the children in the age-matched and in the reading-matched group had significantly longer naming latencies on the unique words than on the anagrams, [$F(1,39) = 4.2$, $p < .05$; $F(1,39) = 19$, $p < .0001$, respectively]. Within the group of sighted children, a significant interaction effect of group by word type was found, $F(1,78) = 6.4$, $p < .05$. The effect of word type was larger for the younger children in the reading-matched group than for the children in the age-matched group.

Another 3 (group: low vision versus reading matched versus age matched) by 2 (word type: anagram versus unique) ANOVA was performed on the mean error rates of each participant. Group was treated as a between-subjects variable and word type as a within-subjects variable. The main effect of group was not significant [$F(2,117) = 2.0$, $p = .14$], indicating that there was no difference in error rates between the groups. The main effect of word type was significant, $F(1,117) = 126.2$, $p < .05$. All the groups made more errors on anagrams than on unique words. The interaction between group and word type was not significant, $F(2,117) = 2.2$, $p = .12$.

To examine possible differences between children with different visual field defects and children without visual field defects, we repeated all the analyses with the same between-groups contrasts as those in Experiment 1. None of the ANOVAs revealed any significant main effect for group (all *Fs* < 1). Nor were any significant interactions found between group and word type (all *Fs* < 1). This finding indicates that the effect of word type is the same for all children with low vision, independent of the absence or presence of any kind of visual field restriction.

The aim of this experiment was to investigate whether the processing of letter-order information is affected by visual impairments. If this is the case, then anagrams would be relatively harder to read for children with low vision than for sighted children. The results of this experiment show that children with low vision need more time to read anagrams than to read unique words, whereas sighted children need more time to read unique words than to read anagrams. This difference between children with low vision and sighted children applies not only to sighted children of the same age, but to younger sighted children of the same reading level as the children with low vision. It indicates a qualitative difference between children with low vision and sighted children, not just a developmental lag.

## General discussion

In this study, two aspects of visual word recognition were investigated: letter identification and letter-order information. In the first experiment, the effects of the frequency of orthographic neighbors were studied. The results showed a qualitative difference between children with low vision and sighted children. The children with low vision read nonwords with high-frequency neighbors faster than they did nonwords with low-frequency neighbors, whereas for the sighted children, no such difference was found. In terms of a connectionist model of word recognition (see McClelland & Rummelhart, 1981), this finding indicates that for children with low vision, the activation of the representation of a relatively well-known word facilitates the reading of a similar target nonword. In sighted children, this facilitating effect was not found.

This finding confirms our hypothesis that the low quality of the input of children with low vision is partially compensated for by the use of analogy, as evidenced by the effect of neighbor frequency. We did not expect, however, an absence of an effect of neighbor frequency in sighted children. It is possible that this was a ceiling effect. The nonwords of the experiment may have been too easy for these sighted children to differentiate between high- and low-frequency neighbors. Although this possibility can explain the absence of an effect of neighbor frequency in the age-matched group, it does not explain the absence of an effect in the reading-matched group because the latter group had the same reading level as the children with low vision.

An explanation for the difference between children with low vision and sighted children of the same reading level may be the difference in the two groups' reading experience. The children in the reading-matched group were, on average, younger than the children with low vision. Younger children generally have fewer occasions to read and read fewer words per occasion than do older children. Therefore, they encounter fewer words in their written form. It is possible that the words that the nonwords were derived from were all less well known by the younger children of the reading-matched group then by the children with low vision. If that was the case, the orthographic neighbors of all nonwords would have been of low frequency for the children in the reading-matched group. Whereas the absence of a frequency effect in the age-matched group could have been a ceiling effect, the absence of a frequency effect in the reading matched group might have been the result of a floor effect.

Of the other conditions (visual similarity, position of substitution, and word length), only the last factor increased the facilitating effect of neighbor frequency in the reading of children with low vision: The effect was larger in long words. A surprising finding was that the effect of the visual similarity of the substituted letter was the same for all groups of children—facilitating response latency and interfering with accuracy. The children with low vision were not any more confused by visual similarity then were the sighted children.

Together with the finding that children with low vision do not make more errors in general, this finding indicates that children with low vision do not trade accuracy for speed. When reading, they seem to take into account their deficiency in recognizing visual patterns and deal with this deficiency by not relying on a first impression, but analyze the visual patterns cautiously.

The second experiment investigated the role of the order of letters in the word reading of children with low vision. Legge et al.'s (1997) model predicts that people with central scotomas need to make more regressions while reading. Therefore, we expected that children with central visual field restrictions would need more time than other children with low vision and than sighted children. We also expected that the regressions would cause letter-order errors in the reading of children with central visual field restrictions.

Our data indicate that all the children with low vision, not only those with central field restrictions, had more problems with letter order than did the sighted children. This result may be explained by the burden that reading places on the working memory of children with low vision. As was indicated by the main effect of this experiment, children with low vision need more time to perceive and identify letters within words. This finding suggests that they have to keep the individual letters of a word longer in working memory, which may interfere with their keeping track of the order of the letters. If the letters can constitute different words, as in the anagrams of the experiment, children with low vision may be forced to reconsider all alternatives.

Another explanation is that many children with low vision (with and without visual field restrictions) also have nystagmus (an involuntary, rapid movement of the eyes). This condition could cause them to make more- and less-efficient fixations that interfere with the processing of the correct order of letters. Furthermore, the finding that children with low vision do not make more errors in either of the two types of words than do sighted children is in line with previous findings (Gompel et al., 2003) and the results of the first experiment, that children with low vision do not seem to trade accuracy for speed.

The overall conclusion of this study is that children with low vision seem to adapt to their typical visual functioning fairly well. Although they need more time for reading than sighted children do, children with low vision read accurately and are not easily confused by visual similarity.

We found no qualitative differences in word reading between the children with low vision who had and did not have visual field restrictions. Although the instrument used to determine the visual field, the Friedman Visual Field Analyzer, has its limitations in detecting minimal central scotomas, we do not believe that the detection of such small scotomas would have altered the results. When more sophisticated techniques are available, it would be worthwhile to study the latter hypothesis. Until then, we consider our results to be an indication that children with low vision have learned to acknowledge their specific visual deficiencies and have found ways to compensate for them.

## Practical implications

In general, children with low vision are accurate readers. Even if they are distracted by visually similar letters, they do not trade accuracy for speed. They may be aware of their visual limitations and compensate for them with an extra investment in time. For classroom practice, the implication is that when children with low vision are given sufficient time for reading assignments, they can read as accurately as can sighted children.

The first qualitative difference we found between children with low vision and sighted children is in the strategy each group seems to apply when reading isolated words. Whereas sighted children are more likely to apply a rule-based reading strategy, children with low vision seem to apply an analogy-based reading strategy. The analogy with well-known words facilitates the reading of unknown words. Teachers of children with low vision should use this information and explicitly point out the similarities with familiar words when teaching new words to these children.

The second qualitative difference we found is that children with low vision have more problems with the order of letters than do sighted children. Making children with low vision more aware of the importance of the order of letters in reading may encourage them to apply reading strategies that help them in keeping track of the order of letters, such as following the words with a finger or a ruler.

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