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Visuo-Attentional Processing by Dyslexic Readers on the Reicher-Wheeler Task

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Running head: visuo-attentional deficits in dyslexic readers

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Abstract

A two-group, reading-level design was used to investigate the perception of letters in words by dyslexics compared to reading-level-control children (RL-controls). Two paradigms were used: the Reicher-Wheeler paradigm with a forced-choice procedure to elicit a word-superiority effect (WSE, difference between performance on pseudoword targets and word targets) and a pseudoword-superiority effect (PSE, difference between performance on nonword targets and pseudoword targets), and the visual-field paradigm to evaluate processing in the fovea (between 0° and 2° of visual angle) and parafovea (more than 3° of visual angle in the left visual field -LVF- and the right visual field -RVF). Performance was analyzed in terms of the percentage of correct responses (correct letters given). Adults were tested first. Their results indicated a WSE and a PSE for all target locations in the visual field. Unlike adults, children exhibited only a PSE but no WSE, a result that is congruent with Grainger et al.'s (2003) study. The PSE was located in the fovea for dyslexics and in the LVF for RL-controls. RL-controls also exhibited a word-inferiority effect in the LVF.

Résumé

Le travail étudie les traitements visuo-attentionnels engagés dans la perception du mot écrit chez des enfants dyslexiques qui sont comparés à un groupe contrôle de même âge lexique (niveau CP avril). Un groupe d'adultes a également été testé. Deux paradigmes sont utilisés. Le paradigme de Reicher-Wheeler vise à rechercher les effets de supériorité de mot (ESM) et de pseudo-mot (ESP) pour évaluer l'influence des processus top-down dans le traitement des mots écrits. Le paradigme du champ visuel divisé mesure cette influence en fovéa entre 0° to 2° d'angle visuel et en parafovéa au-delà de 3° d'angle visuel dans le champ visuel droit (CVD) et dans le champ visuel gauche (CVG). Les performances sont analysées sur le pourcentage de lettres correctement perçues. Les adultes montrent un ESM et un ESP dans les trois zones. Les dyslexiques et les contrôles en âge lexique révèlent un ESP en l'absence d'un ESM. L'ESP est situé en fovéa chez les dyslexiques et en CVG chez les contrôles. Ces derniers révèlent également un effet d'infériorité du mot en CVG.

Mots-clés: dyslexie – traitements visuo-attentionnels – effet de supériorité du mot – paradigme Reicher-Wheeler – paradigme du champ visuel divisé

Introduction

Reading is generally viewed as a complex cognitive task that requires the coordination of two major cognitive processes: visuo-attentional processes such as analyzing features, letters, and letter clusters (graphemes), and language processes such as phonological decoding, and syntactic and semantic coding. In a normal reader, processing occurs completely in parallel, and word knowledge works together with sensory information to enable word recognition. Both types of processes must therefore be taken into account in investigating reading disabilities. This is precisely the aim of the present study, where two paradigms were used to examine word processing in dyslexics: the visual field paradigm to evaluate their foveal and parafoveal word processing, and the Reicher-Wheeler paradigm to evaluate the benefit of contextual information in letter perception.

Language vs. Visuo-Attentional Deficits in Dyslexia

Developmental dyslexia refers to difficulty learning to read that is not due to inadequate schooling, peripheral sensory handicaps, acquired brain damage, or low overall IQ. Current research suggests that developmental dyslexia is caused largely by language deficits, particularly in the use and coding of phonological information (for review, see Sprenger-Charolles, Colé, & Serniclaes, 2006). According to the dual-route theory of reading (Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), correct reading of pseudowords (or unknown words) necessitates the proper use and knowledge of rules specifying grapheme-phoneme correspondences. However, if such rules are used to read irregular words (e.g. yacht), then pseudowords would be read incorrectly (i.e., regularized). Correct reading of irregular words would thus require direct access to their lexical representations. Skilled readers are thought to be

proficient at both of these routes for processing letter strings, and if a child is to become a skilled reader, he/she must acquire both of these skills. According to this view, difficulty acquiring the lexical procedure, called developmental surface dyslexia, is revealed by poor performance on exception-word reading. Difficulty acquiring the nonlexical procedure, called developmental phonological dyslexia, is revealed by poor performance on pseudoword reading. This dual-route analysis of learning to read and developmental dyslexia is not the only possible one, however. For example, Plaut, McClelland, Seidenberg, and Patterson (1996) provided an alternative account that extends Seidenberg and McClelland's (1989) connectionist model. The extended model posits a single mechanism that maps orthography to phonology using weighted connections between units that encode distributed representations, rather than pronunciation rules or lexical lookup. This model provides a natural account of both surface dyslexia and phonological dyslexia (Patterson, Seidenberg, & McClelland, 1989; Plaut et al., 1996).

In the above description, dyslexia is viewed as a language-related deficit, that is, the deficit arises because of problems acquiring particular components of the language-processing system. However, some researchers consider dyslexia to be a visuo-attentional deficit rather than a language deficit (e.g., Bosse, Tainturier, & Valdois, 2007; Prado, Dubois, & Valdois, 2007; for a thorough review in this field, see Everatt et al., 1999). Visuo-attentional processing may serve to correctly extract graphemes from words and match them to abstract categories stored in lexical memory. Beginning readers, for example, cannot process a word as a single unit. Instead, they need to correctly discriminate and group letters into graphemes in order to read the word aloud. If these units are not correctly identified, memory

associations between graphemes and phonemes will be weak, impairing the ability to read novel words.

Visuo-attentional processing has mainly been studied in eye-movement research. When a reader makes an eye fixation, the eye has access to three areas for analyzing information: the fovea, the parafovea, and the periphery. The foveal area includes two degrees of visual angle around the point of fixation, where one degree is approximately equal to three letters (so six letters are in focus). The parafoveal area is beyond three degrees of visual angle on either side of the fixation point and encompass about 15 letters. The peripheral area includes everything in the visual field beyond the parafoveal area. The fovea processes details, and anything beyond the fovea is subject to a marked drop in acuity due to the decreasing concentration of cones in that part of the retina. Information from the retina is sent by the optic nerve fibers to the chiasma, where crossing-over takes place. The visual cortex in the right hemisphere receives information from the right side of each eye (the left side of the visual field), and the left hemisphere receives information from the left side of each eye (the right side of the visual field).

During left-to-right text reading, word identification is dependent on the high visual acuity afforded by foveal vision. Simultaneously, an attentional window which extends asymmetrically into right parafoveal vision provides partial word identification, as well as assisting in the planning of reading saccades to the next viewing point. Many experiments using the moving-window paradigm (for an overview, see Rayner, 1998) have demonstrated that when readers have the necessary text information, i.e., up to 14-15 letter spaces to the right of the fixation point and up to the beginning of the currently fixated word or 3-4 letters to the left of that point, reading proceeds as if there were no window. During reading, then, most

words are processed in both foveal and parafoveal vision, and there is a reading-time advantage if a word is processed first in the parafovea and then in the fovea: this is referred to as the parafoveal preview effect (Rayner, McConkie, & Ehrlich, 1978; Rayner, McConkie, & Zola, 1980).

Regarding reading difficulties, it has been shown that dyslexic readers process less parafoveal information on each fixation than do normal readers (Rayner, 1998). Rayner, Murphy, Henderson, and Pollatsek (1989) used a moving-window paradigm and found that the perceptual span was smaller for dyslexic readers than for normal ones. They also described a dyslexic reader who identified parafoveal words better than normal readers did. In the moving-window paradigm, he read better with a small window than with a larger one. Rayner et al. argued that this reader had a selective attention deficit, which made it difficult for him to focus attention on the fixated word. However, they considered him to be atypical of dyslexic readers. Rayner (1998) pointed out that if the perceptual span is somewhat smaller for dyslexic readers, it is probably because they have trouble processing the fixated word, as shown for normal readers who obtain less parafoveal information when the fixated word is difficult to process (Henderson & Ferreira, 1990; Rayner, 1986).

Gathering eye movements to study visuo-attentional processing is a very costly undertaking. Another paradigm that appears to be easier to implement, has been used to evaluate foveal word processing in both normal readers and dyslexics, the Reicher-Wheeler paradigm. Using this paradigm, the benefit of contextual information in letter perception has been evaluated in the fovea (e.g., Chase & Tallal, 1990; Grainger et al., 2003). Here, we used this same paradigm, but also in the parafovea, by combining it with a visual-field paradigm.

The Reicher-Wheeler Task and the Study of Reading Deficits

In the Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970), a string of letters that does or does not form a real English word (e.g., READ or WCXD) is presented, followed by a postexposure mask containing two letter choices for one of the positions in the string. If the string forms a real word, the letter choices are such that either can be integrated with the others to produce a word (READ versus ROAD). The use of a forced-choice task eliminates the possibility of using a word-level guessing strategy, since both letters (E and O) are valid word completions. Comparing 4-letter words and derived nonwords, Reicher discovered that there was a reporting advantage of single letters from words over ones from nonwords. This advantage came to be called the word superiority effect (WSE).

The Interactive Activation Model (IAM) of letter perception (McClelland & Rumelhart, 1981, 1988; Rumelhart & McClelland, 1982) was developed to explain such contextual influences on letter perception. IAM assumes that word perception takes place in a multilevel processing system with at least three levels of representation, i.e., the visual-feature level, the letter level, and the word level. The WSE is due by the fact that words require both bottom-up and top-down processes. People use their (top-down) knowledge of words to help identify letter sequences from (bottom-up) visual input. Activation of word units reinforces the activation of their component letter representations, thus allowing for more accurate letter perception in words than in nonwords. A notable finding is that the perceptual advantage of letters in words compared to letters in nonwords also holds for letters in pseudowords (McClelland & Johnston, 1977; Rumelhart & McClelland, 1982; Spoehr & Smith, 1975). For example, people are better at perceiving the letter G in a pseudoword context such as POG than in a nonword context (e.g., BNG), since POG partially

overlaps with a number of other words (e.g., FOG and DOG). In IAM, the letter sequence OG is sufficient to partially activate FOG and DOG, and thereby provides additional top-down activation of the letter G in the third position. In an unpronounceable nonword, top-down activation of the letter G in the third position would be absent or significantly reduced.

Another possible account of the WSE was given by Grainger and Jacobs (1994, 1996) in their dual read-out model of word context effects on letter perception. Performances on a two-alternative forced-choice task is generated by a process of letter identification. Letters can be identified either directly on the basis of activation at the letter level (letter-read-out mechanism) or they can be inferred from word identification (word-read-out mechanism). If a letter is not identified by either of these processes, then a guess strategy is applied. The WSE is explained by the advantage gained from having an additional word-read-out mechanism that can be used when individual letter identification fails.

Some studies have investigated letter perception in dyslexics using the Reicher-Wheeler task. In most cases, target items are presented in the fovea and correct response scores are analyzed. Chase and Tallal (1990) used the Reicher paradigm to examine the effects of orthographic context on the letter-recognition skills of dyslexic children, and compared their performance to adults and to chronological- and reading-level matched groups (CA-control and RL-control groups, respectively). They showed that adults were better able to identify letters in words and pseudowords than in random letter strings. The young normal readers exhibited the WSE (over nonwords), but their PSE (over nonwords) was not as great as in the adults. The dyslexic children showed no WSE or PSE, and they appeared to process nonwords in the same way as words. PDP computer simulations on the experimental

data using IAM suggested that the orthographic components of the lexical system of normal children were interactive and distributed, as they are in adults but with less bottom-up activation. In addition, simulations showed that top-down processing increased with age and reading skill, but may have been absent in dyslexic readers.

Hildebrandt, Caplan, Sokol, and Torreano (1995) used a Reicher-Wheeler paradigm to look at whether fluent and adult dyslexics readers can identify letters better when they appear in a word than when they appear in either a pronounceable pseudoword (a potential WSE over pseudowords) or a single letter (a potential WSE over letters, i.e., a WLE). They predicted that if both of these effects involve a lexical factor, then dyslexic subjects whose deficit prevents access to visual word forms should show disruptions of the normal effects on the Reicher-Wheeler task. The results were that dyslexic subjects as well as chronological-age controls showed a WSE over pseudowords; however, while the control subjects showed a normal WLE, the dyslexics exhibited the opposite effect. Hildebrandt et al. suggested that there is a lexical factor underlying both effects, and proposed that the abnormal letter-superiority effect in dyslexics can be accounted for as the manifestation of other competing factors.

Grainger et al. (2003) tested children diagnosed as dyslexic and exhibiting a clear disadvantage in recognizing and reading aloud words and pseudowords, and compared them with CA- and RL-controls. The aim of Grainger et al.'s study was to determine whether word and pseudoword superiority effects were due to phonological fluency processes (pronounceability of the string), orthographic regularities (orthotactic constraints), or lexical feedback (IAM's activation-inhibition mechanisms). They stated that if the WSE and the PSE are based on phonological fluency, then dyslexic children should show a reduced PSE because of their

phonological deficit in pseudoword reading. If, on the other hand, the effects are based on the use of orthographic regularities in the letter string, dyslexic children should show a PSE similar to that of a control group.

Forced choices were given for either the 2nd or 4th position in a string of 5 letters. They analyzed correct response percentages for the WSE over pseudowords and the PSE. The result pattern of dyslexics was qualitatively identical to both control groups. Only a PSE was obtained in all three groups of children, whereas a group of adult participants tested with the same materials showed a WSE as well as a PSE. Grainger et al. concluded that the observed dissociation — pseudoword superiority (PSE) in the absence of word superiority (WSE) — could not be explained by lexical feedback as in IAM, because words always provide more feedback than pseudowords in this type of model. So, in the presence of a PSE, a WSE should be found. Furthermore, given that dyslexics exhibited a PSE like that of RL-controls, despite the fact that their pseudoword reading was clearly worse, Grainger et al. considered that the PSE was subtended by regularities operating at the level of sublexical orthographic representations.

The Present Study

Few studies have attempted to study reading disabilities and the perception of letters in single words in a divided-visual-field paradigm. In the present study, we tried to tie these lines of research together by examining dyslexics' performance in a Reicher-Wheeler task where targets were displayed in the fovea (within 2° of visual angle) and the parafovea (beyond 3° of visual angle to the left or right of the fixation point; hereafter LVF and RVF, respectively). As in Grainger et al.'s (2003) study, the WSE effect was calculated with pseudoword performance as the baseline condition,

and the PSE effect was calculated with nonword performance as the baseline condition.

The main effect of the visual-field factor can be used as a measure of visuo-attentional processing: better performance is expected for foveal display than for parafoveal display (LVF and RVF), and for RVF display than for LVF display. The main effect of target type can be used as a measure of language processing: better performance is expected for word targets than for pseudoword targets, and for pseudoword targets than for nonword targets. Finally, the interaction of these two factors can be used as a measure of visuo-attentional and language processing combined. If the dyslexics suffered from deficient language processing, words and pseudowords could be expected to produce different patterns of altered activation, leading to a decrease in *one or both* effects. Alternatively, if the dyslexics suffered from deficient visuo-attentional processing, words and pseudowords could be expected to produce similar patterns of altered activation, leading to a decrease in, or the absence of, *both* WSE and PSE, particularly in the parafovea where attentional processes are engaged during normal reading.

The performance of dyslexic children (Experiment 2) was compared to that of a control group matched on reading level (RL-controls) (Experiment 3). A reading-level match is important to rule out the possibility that a given deficit is simply a consequence of less reading experience among dyslexic children. The material was tested in advance on an adult group (Experiment 1) to analyze the normal overall pattern of effects in experienced readers.

Experiment 1. Adults

Method

Participants. Forty second-year psychology students at the University of Lyon took part in the experiment. They were between 19 and 23 years of age (mean age = 20 years 4 months). All were native speakers of French.

Materials. A set of 15 pairs of 5-letter words was selected from *Manulex* (Lété, Sprenger-Charolles, & Colé, 2004). *Manulex* is a computerized lexical database which provides frequency-based lists of non-lemmatized and lemmatized words compiled from the 1.9 million words found in the main French primary school reading books. Frequency is given for four levels: 1st grade, 2nd grade, 3rd to 5th grades, and all grades combined. The words for this study were taken from the first-grade lemma lexicon to ensure that they would be known and read by beginning readers. The mean frequency was 136 occurrences per million words. There were 26 nouns, 3 verbs, and 1 adjective. All pairs were selected such that anyone of the five letters could be changed to form another 5-letter word. There were 3 pairs in each position (e.g., *bague-vague*, *bille-bulle*, *litre-livre*, *corde-corne*, *radio-radis*). The word pairs determined the critical letters given in the two-alternative forced-choice procedure. A set of 15 pairs of 5-letter pseudowords and a set of 15 pairs of 5-letter nonwords were constructed by keeping the 15 pairs of critical letters (e.g., *b-v*, *i-u*, *t-v*, *d-n*, *o-s*) in their respective positions in the word. Pseudowords were constructed using pronounceable, orthographically legal letter strings. Nonwords were generated by randomly adding consonants to the critical letters. See Appendix for a detailed list of the targets.

Each participant saw the entire set of 90 stimuli. He/she saw each stimulus pair in the same visual field (e.g., *bague* and *vague* were presented in the fovea, as were

bonge-yonge and *bxgrt-yxgrt*, with *b-y* as letter choices). All participants saw each pair in all three visual fields.

Procedure and apparatus. Tests were carried out in a dimly lit room. Participants were seated at a fixed distance of 60 cm in front of a 17" color monitor connected to a Pentium III laptop computer running on DMDX software (Forster & Forster, 2001, version 2.9.01). The stimuli were displayed in lowercase in 24-point Courier font with a 640 X 480 resolution. One letter sustained 1° of visual angle.

Each trial consisted of the following sequence of events. Participants were first instructed to look at a fixation point ("+") at the beginning of each trial, and not to move their eyes. After 1000 ms, the fixation point was replaced by a target that was displayed on the screen for 100 ms. The duration used was brief enough to discourage eye movements (Rayner, 1998). In the fovea condition, the target was centered on the screen (2° of visual angle). In the left-visual-field condition (LVF condition), the target began at 7° of visual angle to the left of the fixation point and finished at 3°. In the right-visual-field condition (RVF condition), the target began at 3° of visual angle to the right of the fixation point and finished at 7°. Then the target was replaced by a string of hashes accompanied by two letters located above and below first, second, third, fourth, or fifth position of the string. The hashes and the two letters remained on the screen until the participant responded by selecting the upper letter (left shift key on the keyboard) or the lower letter (right shift key).

The targets were presented in a different random order to each participant. There were 27 practice trials (3 trials per experimental condition) followed by 3 blocks of 30 experimental trials.

Results and Discussion

Mean percentage of correct responses was calculated for each participant in each experimental cell. In each group, a 3 (Target Type: word, pseudoword, nonword) x 3 (Visual Field: LVF, fovea, RVF) ANOVA was conducted with participants as random factors and Target Type and Visual Field as between factors. In each visual field, WSE and PSE were tested by restricted ANOVAs between word and nonword targets for the WSE, and between pseudoword and nonword targets for the PSE. The mean correct response percentages are shown in Table 1.

Table 1. Mean correct response percentages and standard deviations (in parentheses) for adults in Experiment 1.

	LVF	Fovea	RVF
Words	78 (13)	86 (12)	82 (12)
Pseudowords	71 (13)	80 (16)	76 (15)
Nonwords	65 (15)	71 (13)	66 (15)
WSE	<u>+7</u>	<u>+6</u>	<u>+6</u>
PSE	<u>+6</u>	<u>+9</u>	<u>+10</u>

Note: significant WSE and PSE effects in planned comparisons ($p < .05$) are underlined.

Overall analysis of correct responses. The analysis on the correct responses yielded a main effect of target type: there were fewer correct responses for letters in nonwords (67%) than for letters in pseudowords (75%) or words (82%), $F(2,78) = 46.49, p < .001$. There was also a main effect of visual field: 79% of the letters were correctly recognized in the fovea, 75% in the RVF, and 71% in the LVF, $F(2,78) = 11.92, p < .01$. Pairwise contrasts (Tukey's Honestly Significant Difference Tests) were performed for the two factors. All pairwise contrasts were significant at

the .05 level. Word targets obtained significantly higher accuracy scores than pseudoword or nonword targets, and pseudoword targets enhanced performance compared to nonword targets. Moreover, the accuracy scores were higher in the fovea than in the RVF, and in the fovea than in the LVF. Finally, there was a significant RVF advantage compared to the LVF.

WSE and PSE. Restricted ANOVAs indicated significant WSE effects in all three visual fields: there was a +7% effect in the LVF ($F(1,39) = 5.94, p < .05$), a +6% effect in the fovea ($F(1,39) = 4.83, p < .05$), and a +6% effect in the RVF ($F(1,39) = 5.28, p < .05$). Similarly for the WSE, comparisons yielded significant PSE effects in all three visual fields: there was a +6% effect in the LVF ($F(1,39) = 4.08, p < .05$), a +9% effect in the fovea ($F(1,39) = 14.65, p < .001$), and a +10% effect in the RVF ($F(1,39) = 11.19, p < .01$).

As predicted, the results indicated optimal activation of orthographic-lexical codes during task performance. Whatever the side of fixation, the adults benefited from the lexical status of the string as well as from its orthographic regularities. The results of the response analysis for the fovea are in line with those found by Grainger et al. (2003) in their adult group.

EXPERIMENT 2. Dyslexics

Method

Participants. Eighteen dyslexics (14 boys, 4 girls) were tested (mean age 11 years 7 months). They came from two neurological rehabilitation wards situated in France (*Kremlin-Bicêtre Hospital* in Paris, and *Airelles* in Gap). The children were selected on the basis of their reading level (6 years 11 months, i.e. 1st grade), which was assessed on the *Alouette* standardized reading test (Lefavrais, 1965). They were

diagnosed as phonological dyslexics in reading aloud (Sprenger-Charolles, Colé, Béchenec, & Kipffer-Piquard, 2005), with pseudoword scores more than 1.65 standard deviations below those of same-age average readers.

Materials, procedure, and apparatus. The materials, the procedure, and the apparatus were the same as in Experiment 1. Fixation on the central cross was emphasized in the instructions to the children. The target duration was 250 ms. This value was chosen in reference to previous work using the OVP paradigm (Ducrot et al., 2003; Ducrot & Lété, 2005; Lété & Ducrot, 2007). In these studies, target exposure time was determined individually for each participant in a perception-threshold session during which the target duration was incremented until a correct identification score between 50 and 75% was reached. Across all studies, participants with a lexical age of about 6 years 8 months showed a mean target-duration of 250 ms, so it was taken as the baseline target duration for the child groups.

Results and Discussion

The results were analyzed as in Experiment 1. The mean correct response percentages are shown in Table 2.

Overall analysis of correct responses. There was a main effect of target type on the correct response scores of dyslexics: they responded more accurately for letters in words (61%) and pseudowords (59%) than for letters embedded in nonwords (54%), $F(2,34) = 3.53, p < .05$. Pairwise contrasts revealed a significant difference only between word and nonword targets. There was a marginally significant difference between pseudoword and nonword targets ($p=.055$) but word and pseudoword targets did not differ significantly. There was no main effect of visual field: the correct response percentage was 59% in the fovea, 58% in the LVF, and

57% in the RVF, $F < 1$. The pairwise contrasts did not yield significant differences between the mean correct response percentages: unlike adults, the dyslexics did not benefit from the foveal presentation of the target compared to the LVF or RVF, and there was no RVF advantage over the LVF.

Table 2. Mean correct response percentages and standard deviations (in parentheses) for dyslexic and RL-control children (first graders) in Experiment 2.

	LVF	Fovea	RVF
Words	63 (16)	63 (14)	56 (17)
Pseudowords	56 (17)	62 (13)	60 (18)
Nonwords	54 (14)	52 (13)	56 (15)
WSE	+7	+1	-4
PSE	+1	<u>+11</u>	+4

Note: significant WSE and PSE effects in planned comparisons ($p < .05$) are underlined.

WSE and PSE. Restricted ANOVAs showed no significant WSE effects in the fovea or RVF, all $F_s < 1$. The +7% effect observed in the LVF did not reach significance, $F(1,17) = 1.58, p > .10$. A significant PSE was found only in the fovea (+11%), $F(1,17) = 8.35, p < .01$. There was a +1% effect in the LVF and a +4% effect in the RVF, but these differences did not reach the significance level in the comparisons (all $F_s < 1$).

Experiment 2 revealed that dyslexic children showed a context effect only in the fovea: they were significantly more accurate at giving correct letters when the letters were embedded in a legal consonant string than when they were embedded in an

illegal consonant string (a PSE). In the LVF and RVF, there were no significant context effects.

EXPERIMENT 3. Reading-Level Controls

While differences between dyslexics and chronological age controls could be due to a developmental delay, differences between dyslexics and RL-controls most likely reflect a fundamental deviation from the normal reading process. So, if the dyslexic group performs more poorly than the RL-control group on a given measure, it can be argued that their difficulties are not simply a byproduct of low reading achievement.

Method

Subjects. Twenty-eight first-grade children were tested, eighteen of whom were selected for the RL-control group. Their mean age was 7 years. They were matched to dyslexic children on reading level assessed on the *Alouette* (mean reading age 7 years 1 month vs. 6 years 11 months for dyslexic children).

Materials, procedure, and apparatus. The materials, procedure, and apparatus were the same as in Experiment 1, with a target presentation of 250 ms.

Results and Discussion

The results were analyzed as in Experiment 1. The mean correct response percentages are shown in Table 3.

Overall analysis of correct responses. In the overall analysis, the RL-control group exhibited a performance pattern similar to that of the adult group. There was a main effect of target type, with fewer correct responses for letters in nonwords (57%) than for letters in pseudowords (64%) or words (65%), $F(2,34) = 6.45, p < .01$. Visual field also had a main effect: 64% of the letters were correctly recognized in the fovea,

65% in the RVF, and 57% in the LVF, $F(2,34) = 4.10$, $p < .05$. Pairwise contrasts revealed significant differences between word and nonword targets, and between pseudoword and nonword targets. As in the dyslexic group, there was no significant difference between word and pseudoword targets. For the visual field factor, as in the adult group, there were a significant advantage of the RVF over the LVF, and of the fovea over the LVF. However, contrary to the adult group, there was no advantage of the fovea over the RVF.

Table 3. Mean correct response percentages and standard deviations (in parentheses) for RL-control children (first graders) in Experiment 3.

	LVF	Fovea	RVF
Words	54 (15)	70 (14)	69 (19)
Pseudowords	65 (13)	63 (16)	63 (20)
Nonwords	51 (15)	59 (17)	62 (9)
WSE	<u>-11</u>	+7	+6
PSE	<u>+14</u>	+5	+1

Note: significant WSE and PSE effects in planned comparisons ($p < .05$) are underlined.

WSE and PSE. None context effect was significant in the fovea or in the RVF. In the LVF, there were a significant word inferiority effect (WIE) (-11%), $F(1,17) = 5.74$, $p < .05$, and a significant PSE (+14%), $F(1,17) = 22.34$, $p < .001$, which was greater than the one found for adults (+6%). In fact, RL-controls had difficulty performing the task for words and nonwords in the LVF compared to pseudowords, leading to the emergence of a word-inferiority effect. We will return to this outcome in the discussion.

Dyslexic vs. RL-control comparison. To compare the child groups, a 2 (Group: dyslexics vs. RL-controls) x 3 (Target Type: word, pseudoword, and nonword) x 3 Visual Field (LVF, fovea, and RVF) ANOVA was carried out. The main effect of group did not reach significance (58% correct scores for dyslexics vs. 62% for RL-controls), $F(1,34)= 2.52, p > .10$. The Group x Visual Field interaction was not significant, $F(1,68)= 2.06, p > .10$, despite the fact that RL-controls performed better than dyslexics in the fovea (+5% correct scores) and in the RVF (+8%), and slightly worse in the LVF (-1%). The Group x Target Type interaction was also nonsignificant, $F(1,68)= 2.06, p > .10$, despite the fact that RL-controls performed better on words (+4% correct scores), pseudowords (+5%), and nonwords (+3%). However, the critical three-way interaction was significant, $F(4,136)= 2.52, p < .05$, showing that visual-field asymmetries in the context effects were significantly different across groups.

To determine where the WSE and PSE differed between the two groups, separate 2 (Group: dyslexics vs. RL-controls) x 2 (Target Type: word and nonword for WSE; pseudoword and nonword for PSE) ANOVAs were carried out in the three visual fields. The analyses showed that the context effects were significantly different only in the LVF, $F(1,34)= 3.88, p = .05$ for PSE (+14% for RL-controls vs. +1% for dyslexics), and $F(1,34)= 5.98, p < .05$ for WSE (-11% for RL-controls vs. +7% for dyslexics).

Finally, the means of the two groups were compared to each other in pairwise comparisons. There were two comparisons that reached the significance level: RL-controls performed significantly better on word targets in the RVF (69% vs. 56%), $F(1,34)= 5.10, p < .05$, and on pseudoword targets in the LVF (65% vs. 56%), $F(1,34)= 3.97, p < .05$.

GENERAL DISCUSSION

The aim of the present study was twofold. First, we wanted to evaluate foveal and parafoveal processing in dyslexic children. Secondly, we wanted to find out how their lexical knowledge interacts with visual information intake, and to what extent this interaction facilitates perceptual processing. The roles of top-down and bottom-up processing in letter perception were examined by studying the degree to which visual perception can be affected by manipulations of the visual field (fovea and beyond 3° of visual angle) and by the amount of experience with print (dyslexics, first grade children, adults).

The results can be summarized as follows. The adults showed high processing capabilities in the parafovea, where proficient activation of their infra-lexical and lexical knowledge helped them recognize letters embedded in legal strings. They performed significantly better in the fovea than in the parafovea (LVF and RVF), and they also performed better on words than on pseudowords, and on pseudowords than on nonwords. Finally, they showed a WSE and a PSE in all target locations. RL-controls and dyslexics had difficulty processing letter strings in the parafovea. Contrary to the adult group, neither child group performed better in the fovea than in the RVF, and only RL-controls performed better in the fovea than in the LVF. Moreover, both groups performed equally on words and pseudowords, and better on pseudowords than on nonwords. Finally, in both groups, a PSE was found, but no WSE. Taken together, the context-effect patterns showed that the children had less proficient lexical knowledge than infra-lexical knowledge. The PSE was located in the fovea for dyslexics and in the LVF for RL-controls. A word-inferiority effect was also found for RL-controls in the LVF. Comparisons between the two child groups indicated differing context effects only in the LVF. Moreover, RL-controls were shown

to outperform the dyslexics on both words and pseudowords but at different locations: in the RVF for words, and in the LVF for pseudowords.

In both groups of children, a substantial PSE was found in the absence of a WSE, whereas the adults exhibited both effects. This pattern of results allows us to interpret the PSE as Grainger et al. (2003) did. First, a lexically-based account of the PSE can be ruled out because it would predict an advantage of word contexts over pseudoword contexts, as observed in adults. The fact that this was not found in the present experiment suggests that, at least for the children tested here, the PSE was generated by sublexical regularity differences between the pseudoword and nonword contexts. The fact that the dyslexic children had obtained the same PSE as the reading-age control children but in a different location –even though they suffer from a deficit in reading pseudowords aloud– suggests that the sublexical regularities responsible for the PSE are different from the sublexical regularities involved in spelling-to-sound conversion.

Clearly, the dyslexic children produced a pattern of results that strongly resembled that of the RL-controls. Both groups performed at their expected lexical level: their poorer lexical representation produced only a PSE (supported by infra-lexical knowledge) but no WSE (supported by lexical knowledge). There were differences, however, in the location of the PSE effects, and more subtle differences between target types in the parafovea: RL-controls were more proficient at processing words in the RVF and at processing pseudowords in the LVF. The difference between the two groups lies in their LVF processing. We stated above that if the dyslexic children suffered from deficient visuo-attentional processing, words and pseudowords could be expected to produce similar patterns of altered activation, leading to a decrease in, or an absence of, *both* WSE and PSE, particularly in the

parafovea where attentional processes are engaged during normal reading. Alternatively, we hypothesized that if dyslexics suffered from deficient language processing, words and pseudowords could be expected to produce different patterns of altered activation, leading to a decrease in *one or both* effects. The latter pattern fits with our study results, because a PSE was found without a WSE, indicating poor lexical representation in both groups of children. Given that no phonologically-based processing is needed to produce the PSE (it comes from orthographic redundancy, as stated by Grainger et al., 2003), the dyslexics were not affected more than the RL-controls, and they did not show an atypical language-processing pattern. The same conclusion can be drawn for visuo-attentional processing, because even though the dyslexics were poorer at visuo-attentional processing in the LVF, no atypical pattern emerged from the results. In conclusion, both groups of children performed the Reicher-Wheeler task at their lexical-age level.

The PSE and the word-inferiority effect found in the LVF for RL-controls may seem surprising but it can be explained by examining performance on the three target types. Pseudoword targets were processed equally well in the LVF (65% correct identifications) as in the fovea or RVF (63% correct identifications in each condition). As previously noted, RL-controls were less affected by the left parafoveal display when the targets were pseudowords. The PSE originated in a very low performance level on nonwords (chance level), and the word-inferiority effect originated in a very low performance level on words (also chance level). There is no reason why the RL-controls failed to process words when they succeeded on pseudowords. They should have processed words at least as well as pseudowords, therefore obtaining equal scores. The fact that RL-controls performed better on pseudowords than on words led us to suspect a misperception account of the word-

inferiority effect, whereby a given word (e.g., POIRE) might be misperceived as the neighboring word on some trials (e.g., FOIRE), thus decreasing forced-choice accuracy. A similar interpretation was proposed by Hooper and Paap (1997) to explain a pseudoword-inferiority effect (for a discussion, see Grainger et al., 2003).

To our knowledge, our study is the first to use the Reicher-Wheeler task in a divided-visual-field paradigm to evaluate visuo-attentional and language-processing capabilities in dyslexics (for a lateralized word-recognition study with adults, see Jordan, Patching, & Milner, 2000). Our main goal in the present work was to find out whether the two paradigms are well suited to studying top-down effects of infra-lexical and lexical knowledge in the fovea and parafovea. The results obtained here are promising because a dissociation between infra-lexical (orthographic) knowledge and lexical knowledge was found in unexperienced readers. Future research should highlight the contribution of hemispheric specialization in the crossed pattern of specialized processing found in beginning readers, that is, a word specialization for the RVF (left hemisphere) and pseudoword specialization for the LVF (right hemisphere). Moreover, visuo-attentional processing needs to be clearly separated from perceptual processing if we want to validate its specific contribution to reading disabilities. This could turn out to be difficult, because the two-postulated processes, if they exist, seem to be intricately linked when a word is being recognized.

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Appendix. Material used in Experiments.

Position of the critical letter	Target 1	Target 2
Words		
1	<u>b</u> ague	<u>v</u> ague
1	<u>c</u> oupe	<u>s</u> oupe
1	<u>m</u> erle	<u>p</u> erle
2	b <u>i</u> lle	b <u>u</u> lle
2	f <u>r</u> ite	f <u>u</u> ite
2	<u>j</u> aune	<u>j</u> eune
3	l <u>i</u> tre	l <u>y</u> re
3	s <u>a</u> lon	s <u>a</u> yon
3	v <u>i</u> der	v <u>i</u> ser
4	cor <u>d</u> e	cor <u>n</u> e
4	crab <u>e</u>	cra <u>j</u> e
4	plac <u>e</u>	plag <u>e</u>
5	radi <u>o</u>	radi <u>s</u>
5	vill <u>a</u>	vill <u>e</u>
5	vol <u>e</u> r	vol <u>e</u> t
Pseudowords		
1	<u>b</u> onge	<u>v</u> onge
1	<u>c</u> onto	<u>s</u> onto
1	<u>m</u> erge	<u>p</u> erge
2	t <u>i</u> lba	t <u>u</u> lba
2	f <u>r</u> ile	f <u>u</u> ile
2	ba <u>n</u> e	be <u>n</u> e
3	pa <u>t</u> ol	pa <u>y</u> ol
3	pu <u>l</u> on	pu <u>y</u> on
3	an <u>d</u> au	an <u>s</u> au
4	par <u>d</u> u	par <u>n</u> u
4	tor <u>b</u> e	tor <u>i</u> e
4	plac <u>o</u>	plag <u>o</u>
5	rap <u>i</u> o	rap <u>i</u> s
5	bal <u>t</u> a	bal <u>t</u> e
5	bod <u>e</u> r	bolet
Nonwords		
1	<u>b</u> xgrt	<u>v</u> xgrt
1	<u>c</u> zxpq	<u>s</u> zxpq
1	<u>m</u> ghxq	<u>p</u> ghxq
2	b <u>i</u> xdz	b <u>u</u> xdz
2	pr <u>t</u> gb	pu <u>t</u> gb
2	x <u>a</u> kcd	x <u>e</u> kcd
3	lz <u>t</u> rp	lz <u>y</u> rp
3	sd <u>l</u> hn	sd <u>y</u> hn
3	vp <u>d</u> wr	vp <u>s</u> wr
4	cnr <u>d</u> x	cnr <u>n</u> x
4	crs <u>b</u> j	crs <u>i</u> j
4	pld <u>c</u> k	pld <u>g</u> k
5	rp <u>d</u> wq	rp <u>d</u> wg
5	vfl <u>x</u> a	vfl <u>x</u> e
5	vh <u>l</u> sr	vh <u>l</u> st

Note. The critical letters are underlined. The same critical letters appeared in the three target types (words, pseudowords, nonwords). Participants were tested on both targets.

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