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# The inhibitory effect of word neighborhood size when reading with central field loss is modulated by word predictability and reading proficiency

Lauren Sauvan, Natacha Stolowy, Carlos Aguilar, Thomas François, Nuria Gala, Frederic Matonti, Eric Castet, Aurelie Calabrese

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1 **The inhibitory effect of word neighborhood size when reading with central field**  
2 **loss is modulated by word predictability and reading proficiency**

3

4 **Authors:** Lauren Sauvan<sup>1</sup>, Natacha Stolowy<sup>1</sup>, Carlos Aguilar<sup>2</sup>, Thomas François<sup>3</sup>,  
5 Núria Gala<sup>4</sup>, Frédéric Matonti<sup>5</sup>, Eric Castet<sup>6</sup>, Aurélie Calabrèse<sup>6,7\*</sup>

6

7 **Affiliations:**

8 <sup>1</sup>North Hospital, Marseille France

9 <sup>2</sup>Mantu Lab, Amaris Research Unit, Sophia Antipolis, France

10 <sup>3</sup>UCLouvain, CENTAL (IL&C), Louvain-la-Neuve, Belgique

11 <sup>4</sup>Aix-Marseille Univ., CNRS UMR 7309, Aix-en-Provence, France

12 <sup>5</sup>Centre Paradis Monticelli, Marseille, France

13 <sup>6</sup>Aix-Marseille Univ., CNRS UMR 7290, Marseille, France

14 <sup>7</sup>Université Côte d'Azur, Inria, France

15

16 **Corresponding author:**

17 Aurélie Calabrèse (AC)

18 aurelie.calabrese@inria.fr

19 2004 Route des Lucioles, 06902 Valbonne, France

20

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25 None

26 ABSTRACT

27 **Background:** For normally sighted readers, word neighborhood size (i.e., the total  
28 number of words that can be formed from a single word by changing only one letter)  
29 has a facilitator effect on word recognition. When reading with central field loss  
30 (CFL), however, individual letters may not be correctly identified, leading to possible  
31 misidentifications and a reverse neighborhood size effect. Here we investigate this  
32 inhibitory effect of word neighborhood size on reading performance and whether it is  
33 modulated by word predictability and reading proficiency.

34 **Methods:** Nineteen patients with binocular CFL from 32 to 89 years old (mean  $\pm$  SD  
35 =  $75 \pm 15$ ) read short sentences presented with the self-paced reading paradigm.  
36 Accuracy and reading time were measured for each target word read, along with its  
37 predictability, i.e., its probability of occurrence following the two preceding words in  
38 the sentence using a trigram analysis. Linear mixed effects models were then fit to  
39 estimate the individual contributions of word neighborhood size, predictability,  
40 frequency and length on accuracy and reading time, while taking patients' reading  
41 proficiency into account.

42 **Results:** For the less proficient readers, who have given up daily reading as a  
43 consequence of their visual impairment, we found that the effect of neighborhood size  
44 was reversed compared to normally sighted readers and of higher amplitude than the  
45 effect of frequency. Furthermore, this inhibitory effect is of greater amplitude (up to  
46 50% decrease in reading speed) when a word is not easily predictable because its  
47 chances to occur after the two preceding words in a specific sentence are rather low.

48 **Conclusion:** Severely impaired patients with CFL often quit reading on a daily basis  
49 because this task becomes simply too exhausting. Based on our results, we envision

50 lexical text simplification as a new alternative to promote effective rehabilitation in  
51 these patients. By increasing reading accessibility for those who struggle the most,  
52 text simplification might be used as an efficient rehabilitation tool and daily reading  
53 assistive technology, fostering overall reading ability and fluency through increased  
54 practice.

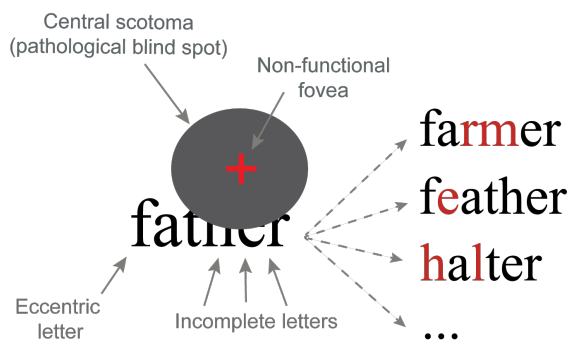
## 55 INTRODUCTION

56

57 Individuals with Central Field Loss (CFL) induced by maculopathy experience  
58 severely impaired functional vision, leading to major incapacitating reading deficits  
59 [1,2,3]. Reading speed being a strong determinant of overall quality of life in low-  
60 vision patients of all ages, there is a real societal need to help promote their reading  
61 performance through rehabilitation and assistive reading technology [4,5]. Such  
62 initiative requires a better characterization of the underlying factors involved in their  
63 overall reading deficit, which remain poorly understood. The influence of  
64 psycholinguistic factors, for instance, have been generally overlooked in the context  
65 of low vision. In 2016, Calabrèse et al. investigated eye movement characteristics  
66 when low-vision patients with CFL read short sentences and showed that specific  
67 disruptions in fixation patterns occurred in the presence of low-frequency words [6].  
68 This result alone suggests that psycholinguistic factors may be an important  
69 determinant of reading performance for low vision, opening the way for further  
70 investigations and potential use of text simplification for the visually impaired.

71 Word frequency and word neighborhood size are some of the most important lexical  
72 factors known to affect reading in normal vision [7,8]. However, whether findings  
73 from normally sighted readers can be applied to low-vision individuals is not obvious.  
74 In the case of CFL, visual input is deteriorated because of blur, distortion and/or  
75 occluded letters, and access to text is only partial (Fig. 1) [9]. For instance, when  
76 reading the word “father” with a central blind spot, some letters are totally or partially  
77 occluded by the scotoma. In addition, complete letters that fall out of the scotoma  
78 must be identified with eccentric portions of the retina, yielding degraded letter  
79 identification due to low acuity and strong crowding [10]. Therefore, incomplete

80 and/or eccentric letters may not be correctly identified, leading to many possible  
81 misidentifications (“farmer”, “feather”, “halter”, etc.). Since bottom-up visual input is  
82 not reliable, patients must rely much more on top-down linguistic inference than  
83 normally sighted readers [11,12,13]. For this reason, the effect of lexical factors on  
84 reading performance should be rather different in visually impaired readers than  
85 reported before with normally sighted individuals.



86  
87 **Figure 1: The presence of a central scotoma occludes part of the word “father”, leading to**  
88 **possible misidentifications, potentially due to: (1) incomplete letters (e.g., farmer); (b) eccentric**  
89 **letters, for which low acuity and increased crowding decrease identification performance (e.g.,**  
90 **feather) or (c) both (e.g., halter). The overall lack of identification accuracy yields a greater need**  
91 **for linguistic inference.**

92 A first attempt to characterize this effect has been made recently by Stolowy et al.  
93 who inspected the effect of word frequency on the reading performance of CFL  
94 individuals reading sentences in French [14]. The clear-cut frequency effects they  
95 reported on word reading time validated the hypothesis that, as for normally sighted  
96 readers, low-frequency words tend to decrease reading speed with CFL patients.  
97 However, the amplitude of this effect was much larger (differences in the range of  
98 seconds) than it had been reported before with normal vision (range of milliseconds).  
99 More interestingly, the same effect of frequency was not observed for all pairs of  
100 synonyms. For instance, the high-frequency word “*utiliser*” [*use* in English] was read

101 on average more slowly than its lower frequency synonym “*employer*” [*employ*].  
102 Such observation suggests that frequency cannot be the only predictive linguistic  
103 factor of reading speed with CFL. This reasoning was a cornerstone for the present  
104 work that aims at investigating two other psycholinguistic factors extensively studied  
105 in normal reading: orthographic similarity and word predictability.

106 The most common measure of orthographic similarity in the psychological literature  
107 is Coltheart’s orthographic neighborhood size metric ‘N’ [15]. N measures the  
108 number of close orthographical neighbors of a stimulus word and is defined as the  
109 total number of words that can be formed by changing one letter, while preserving  
110 letter positions. For example, “shore” has many neighbors, including chore, score and  
111 share, while “neighbor” has 0 neighbors. For skilled readers with normal vision, N  
112 (i.e., word neighborhood size) seems to have a facilitator effect on word recognition:  
113 the more neighbors, the faster a word is identified - although this effect is now often  
114 assumed to be task dependent and language dependent (see [16,17] for reviews). It is  
115 possible that the visual constraint imposed by the presence of a central scotoma,  
116 hiding portions of the text (*i.e.*, letters) and forcing to use eccentric vision (low  
117 resolution), may lead to a reverse effect of neighborhood size. The lack of high  
118 resolution coupled with missing visual information, would lead CFL readers to  
119 confuse one word with its orthographic neighbors, creating even more uncertainty for  
120 words with large neighborhood size. Therefore, we hypothesize that, unlike normal  
121 vision, word neighborhood size has a negative effect on reading speed with CFL  
122 (Hypothesis 1). This first hypothesis has recently received support through some  
123 preliminary work of ours [18].

124 In addition to frequency and orthographic similarity, word predictability counts as one

125 of the most influential processing factors during word recognition with normal vision  
126 [19]. The predictability of a given word in a sentence (based on the context induced  
127 by the preceding words) has been shown to influence processing speed by enabling  
128 readers to make forward inferences (i.e. predictions about the probable upcoming  
129 word). Thus, as shown by eye movement studies, highly predictable words: (1) are  
130 skipped more often, (2) are more likely to be identified within a single fixation and (3)  
131 yield overall shorter fixations during sentence reading [20,21]. In the context of CFL,  
132 word predictability should also play an additional role by reducing uncertainty when  
133 identifying a word with many confusable neighbors. In the sentence “You should go  
134 for a walk along the shore” for instance, even if the word “shore” has many  
135 potentially confusable neighbors, most of them (such as chore, score and share) may  
136 be easily ruled out based on semantic context and forward inferences. Therefore, we  
137 hypothesize that the amplitude of the neighborhood size effect is influenced by word  
138 predictability: the more predictable a word is (thanks to sentence context), the smaller  
139 the effect of neighborhood size should be (Hypothesis 2).

140 Finally, for normally sighted adult readers, word predictability does influence reading  
141 processing differently depending on individual reading skills [21,22]. Simply put, less  
142 skilled readers rely more on context for word identification than highly skilled readers  
143 do. Based on this result, we assume that results of CFL individuals should also be  
144 influenced by their reading proficiency. Therefore, we hypothesize that the interaction  
145 between neighborhood size and word predictability (see Hypothesis 2) depends on  
146 patients’ reading proficiency. Our prediction is that this interaction will be more  
147 pronounced for less proficient readers than for proficient ones (Hypothesis 3).

148 In short, the purpose of this work is two-fold: (1) to test the hypothesis that word



149 neighborhood size exerts an inhibitory effect on reading performance with CFL  
150 (Hypothesis 1; Analyses 1 & 2) and (2) to test whether this effect is modulated by  
151 word predictability and reading proficiency (Hypothesis 2 & 3; Analysis 3).

## 152 **METHODS**

153

### 154 **Participants**

155 19 patients (13 females) were recruited from the Low-Vision Clinic of the La Timone  
156 Hospital (Marseille, France) between March and June 2017. All presented a bilateral  
157 central scotoma with a monocular acuity of 0.4 logMAR (i.e., 20/50 or 4/10) or worse  
158 in their better eye. Patients with ophthalmologic disorders other than maculopathy  
159 (e.g. glaucoma), cognitive disorders or reading disorders present before their visual  
160 impairment were not included. The following information was collected for each  
161 participant: age, etiology, lens status, disease onset (duration of maculopathy in  
162 years), field loss (central only vs. central + peripheral), low-vision rehabilitation  
163 history. Additional information was collected regarding their reading habits,  
164 including: current daily reading time (in minutes), current / former profession,  
165 whether they considered themselves heavy readers before their impairment. Recruited  
166 participants ranged in age from 32 to 89 years (mean  $\pm$  SD = 75  $\pm$  15). Mean best-  
167 corrected visual acuity was 0.81  $\pm$  0.28 logMAR. Details of the participants'  
168 demographic, visual and reading characteristics are given in Table 1. The research  
169 was approved by the Ethics Committee of the French Society of Ophthalmology (IRB  
170 00008855 Société Française d'Ophthalmologie IRB#1) and carried out in accordance  
171 with the Code of Ethics of the World Medical Association (Declaration of Helsinki).  
172 Informed consent was obtained from all participants after complete explanation of the  
173 nature and possible consequences of the study.

Participants	Gender	Age (years)	Etiology	Disease onset (years)	Low-vision rehabilitation	Visual acuity (logMAR)	Lens status	Daily reading time (min/day)	Former heavy reader	Current/former profession
1	M	76	Atrophic AMD	2	Yes	1	Phakic	0	No	Bus driver
2	F	77	Atrophic AMD	7	No	0.4	Pseudophakic	45	Yes	Housewife
3	F	80	Atrophic AMD	7	Yes	1	Pseudophakic	0	Yes	Cook
4	F	80	Atrophic AMD	5	Yes	0.8	Phakic	0	No	Daycare provider
5	F	83	Atrophic AMD	12	Yes	0.5	Phakic	60	Yes	Nurse
6	F	83	Atrophic AMD	2	Yes	0.5	Pseudophakic	0	Yes	Secretary
7	F	85	Atrophic AMD	15	No	0.7	Pseudophakic	60	Yes	Seamstress
8	M	86	Atrophic AMD	8	Yes	0.7	Pseudophakic	60	No	Driving instructor
9	M	88	Atrophic AMD	20	Yes	0.7	Phakic	60	No	Teacher
10	F	78	Exudative AMD	3	No	1.1	Pseudophakic	0	No	Postwoman
11	F	87	Exudative AMD	2	Yes	0.5	Pseudophakic	10	Yes	Secretary
12	M	89	Exudative AMD	3	Yes	0.4	Pseudophakic	30	Yes	Clerical worker
<b>13</b>	<b>F</b>	<b>48</b>	<b>Stargardt's disease</b>	<b>35</b>	<b>Yes</b>	<b>1.3</b>	<b>Phakic</b>	<b>25</b>	<b>Yes</b>	<b>Educator</b>
14	F	72	Stargardt's disease	16	No	1	Phakic	120	No	Housewife
<b>15</b>	<b>F</b>	<b>32</b>	<b>Cone dystrophy</b>	<b>30</b>	<b>No</b>	<b>1</b>	<b>Phakic</b>	<b>120</b>	<b>No</b>	<b>Physiotherapist</b>
16	M	73	Diabetic retinopathy	10	No	0.7	Pseudophakic	0	Yes	Company director
<b>17</b>	<b>M</b>	<b>59</b>	<b>Myopic retinopathy</b>	<b>15</b>	<b>Yes</b>	<b>1</b>	<b>Phakic</b>	<b>0</b>	<b>Yes</b>	<b>Computer specialist</b>
18	F	70	Myopic retinopathy	20	Yes	1.3	Pseudophakic	120	Yes	Art teacher
19	F	70	Myopic retinopathy	62	Yes	0.8	Pseudophakic	30	Yes	Teacher

174

175 **Table 1: Participants' demographic, visual and reading characteristics.**

176 **Visual acuity and lens status are given for the tested eye only. Participants with central scotoma**  
177 **only are highlighted in red. Participants with central scotoma and peripheral lesions are**  
178 **highlighted in blue. Participants who are still active workers are highlighted in bold font.**

179

## 180 **Apparatus and stimuli**

181 Experiments were run at 60 Hz with an LCD HP LE2201W monitor (full display area:  
182 1680 x 1050 pixels; 47.4 x 29.6 cm). Stimuli (i.e. sentences) were generated with the  
183 PsychoPy library [23,24] and presented on a 1400 x 1050 pixel window that  
184 subtended 56° x 42° at 40 cm. Sentences were aligned to the left and displayed in  
185 Courier (non-proportional font) in black on a white background. Print size was chosen  
186 optimally for each participant as the value of his/her critical print size, measured  
187 before testing with a French computerized version of MNREAD [25,26]. Reading was  
188 monocular (eye with better visual acuity) with an appropriate correction for near  
189 vision (wide-field Metrovision lenses). Monocular vision allows to better control for  
190 individual eye characteristics and was shown to yield similar reading performance  
191 compared to binocular vision in patients with binocular AMD [27]

192

## 193 **Reading material**

194 Reading material was created in French using ReSyf, a French lexicon with  
195 disambiguated and graded synonyms [28] and Lexique3, a lexical database with word  
196 frequencies of standard written and oral French [29]. First, we created a pool of target  
197 words (Figure 2 – Step 1), by selecting 32 pairs of synonyms matching the following  
198 criteria: (1) equal length within a pair (from 3 to 8 characters); (2) difference in  
199 number of orthographic neighbors (N) comprised between 5 and 10 within a pair; (3)  
200 frequency ratio between a large neighborhood word and a its small neighborhood  
201 synonym could be either <1 or >1. Second, 32 pairs of matching sentences were

202 created so that each word from a pair could fit within either sentence of the  
203 corresponding sentence pair (Figure 2 – Step 2). Three criteria were used: (1) all  
204 sentences had similar length (42 to 65 characters; mean  $\pm$  SD = 54  $\pm$  6), with a  
205 maximum difference of 5 characters within a pair; (2) pairs of sentences were  
206 specifically designed to fit the single and most frequent common sense of a synonym  
207 pair; (3) within each sentence, comprised of ‘n’ words, the target word could be  
208 located in any of these three locations: ‘n-1’, ‘n-2’, or ‘n-3’. Target words were never  
209 presented in position ‘n’ to avoid any interference from a possible wrap-up effect  
210 [14,30]. At last, we created our final reading material by combining sentence pairs  
211 with their matching synonym pairs (Figure 2 - Step 3). In Condition 1, the first word  
212 of a pair was assigned to the first sentence of the corresponding pair, while the second  
213 word was assigned to the second sentence, thus creating 64 full sentences. In  
214 Condition 2, the “sentence – word” pairing was reversed to create a different set of 64  
215 full sentences. These two experimental conditions allowed us to counterbalance any  
216 potential effect of the sentence structure and complexity (by randomly assigning  
217 participants to Condition 1 or 2), while providing two different measures of  
218 predictability for a single target word.

### Step 1: Selection of 32 pairs of synonyms

#### Synonym 1

*shore* - 13 neighbors (share, score, short, ...)

#### Synonym 2

*coast* - 3 neighbors (roast, toast, boast)

Length = 5 characters  
Diff. = 10 neighbors

Selection criteria within a pair

- 1- Equal length - 3 to 8 characters
- 2- Difference in neighbors number - 5 to 10
- 3- No restriction on the frequency ratio

### Step 2: Creation of 32 matching pairs of sentences

#### Sentence A

*You should go for a walk along the [...] to relax*  
(44 characters / synonym position = n-2)

#### Sentence B

*My parents have worked by the [...] for many years*  
(45 characters / synonym position = n-3)

Creation criteria within a pair

- 1- Equivalent length - 5 characters difference max.
- 2- Must fit the **same sense** with both synonyms
- 3- Must include synonym in position n-1, n-2 or n-3

Length diff. = 1 character  
Unique sense = 'seaboard'

### Step 3: Creation of the final corpus of sentences

#### Condition 1 - 64 sentences

Sentence A + **Synonym 1**  
*You should go for a walk along the **shore** to relax.*

Sentence B + **Synonym 2**  
*My parents have worked by the **coast** for many years*

#### Condition 2 - 64 sentences

Sentence A + **Synonym 2**  
*You should go for a walk along the **coast** to relax*

Sentence B + **Synonym 1**  
*My parents have worked by the **shore** for many years*

219

### 220 Figure 2: Creation of the reading material.

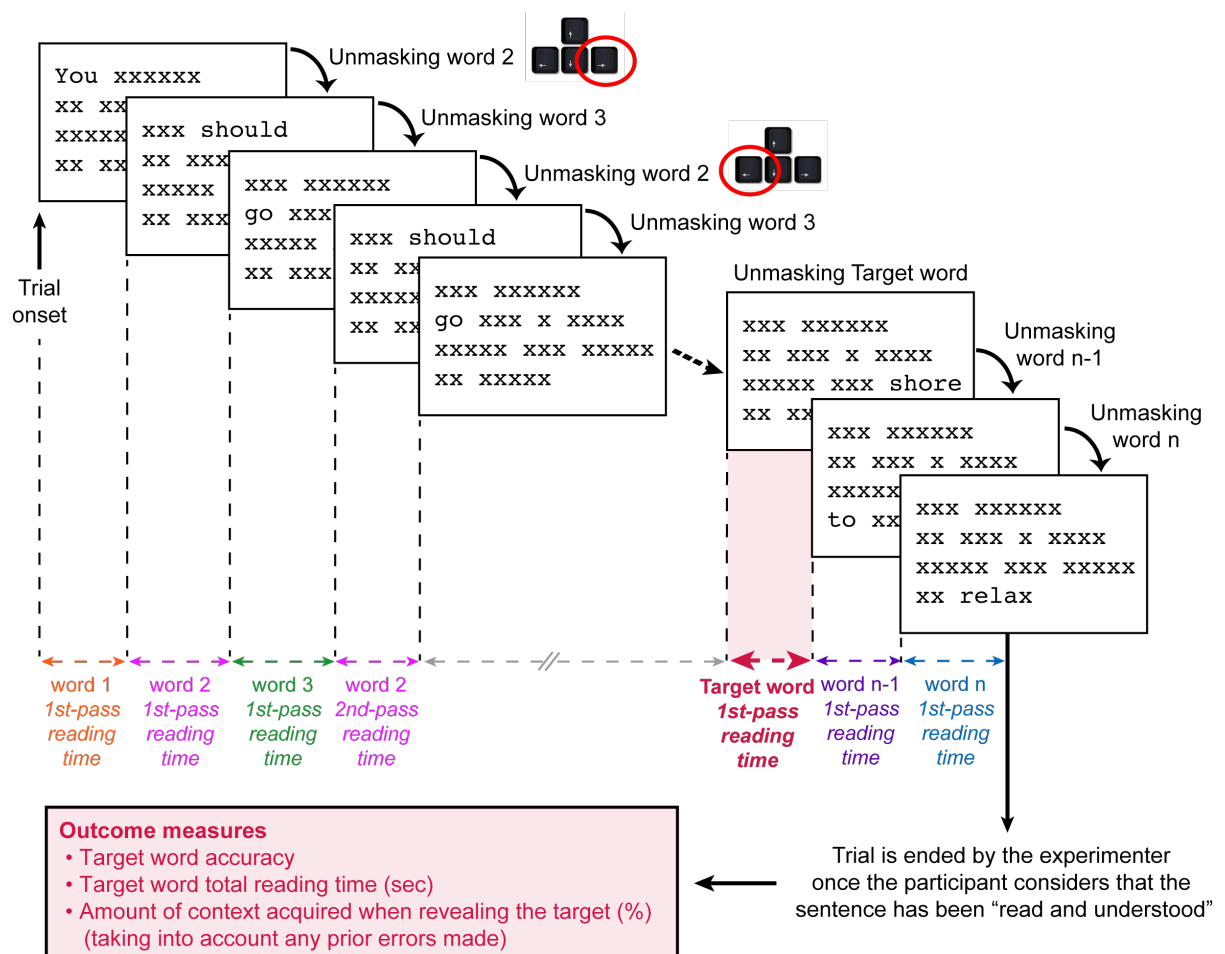
221 **Illustration of the reading material creation, using the synonym pair “shore / coast”. Both words**  
222 **in this example contain 5 characters. Their difference in number of neighbors is 10. Sentences A**  
223 **and B were created so either word of this synonym pair can fit in both sentences. In Condition 1,**  
224 **sentence A contains the target word 1 (‘shore’) and sentence B contains the target word 2**  
225 **(‘coast’). In Condition 2, the pairing is reversed. Note that this example is given in English to ease**  
226 **understanding. See Supplementary Material for the complete set of French sentences created.**

227

### 228 **Reading procedure and experimental design**

229 Sentences were presented within 4 blocks of 16 trials (8 pairs of sentences) each.  
230 Participants were randomly assigned to Condition 1 or 2 and read between two to four  
231 blocks, depending on their reading speed and level of fatigue. Sentences were  
232 displayed randomly within each block with non-cumulative self-paced reading, where  
233 sentences appear as a whole but with all words masked by strings of “x” [31,32,33]  
234 (Figure 3). As opposed to other reading paradigms specifically designed for low  
235 vision, such as “word mode” [34], self-paced reading allows to present words

236 individually while still maintaining a whole sentence view and therefore to remain  
 237 closer to the visual constraints of natural reading (e.g., crowding). Participants were  
 238 instructed to read each sentence aloud as quickly and accurately as possible while  
 239 revealing each word one at a time using keyboard presses, with the possibility to  
 240 unmask backward as many times as they wanted. When participants considered they  
 241 had finished reading the sentence accurately (no matter which word was unmasked at  
 242 that moment), they said the word “stop” and the experimenter stopped the trial. Prior  
 243 testing, a training phase with short French proverbs was performed to familiarize the  
 244 participant with the task and protocol. Reading accuracy (correct vs. incorrect) and  
 245 total reading time (in seconds) were recorded for each target word. For words  
 246 unmasked several times, reading time was obtained by summing the duration of all  
 247 the unmasked periods.



248

249 **Figure 3: Self-paced Reading paradigm.**

250 Words are revealed one at a time by the participant, using keyboard presses. A press on the right  
251 arrow key will unmask the upcoming word (while masking the currently visible word) and a  
252 press on the left arrow key will unmask the previous word (while masking the currently visible  
253 word). For words unmasked only once (e.g. word 1), the total reading time equals the 1<sup>st</sup>-pass  
254 reading time. For words unmasked more than once (e.g. word 2), the total reading time is the  
255 sum of each individual reading time pass.

256

257 **Measure of word predictability**

258 For each target word, we estimated its percentage of occurrence following the two  
259 preceding words in the sentence based on a large corpus of French texts. To do so, we  
260 selected all series of three consecutive words (i.e., 3-grams or trigrams) in our reading  
261 material that ended with a target word. Using the Google Books Ngram Viewer  
262 resource [35], we extracted for each of these 128 trigrams (64 sentences x 2  
263 conditions) its percentage of occurrence in the ‘French 2012’ corpus, a corpus of 792  
264 118 digitized books published in French between 1800 and 2008. This measure will  
265 be referred to as the ‘trigram occurrence’.

266

267 **Measures of reading proficiency**

268 Prior to testing, each patient was asked to report the total duration of reading they  
269 performed on a typical day (in minutes per day; cf. Table 1). This value would include  
270 reading for both work and leisure, with or without visual aid systems, on all types of  
271 display (i.e., print, screen) and any kind of reading material (e.g., book, magazine, tag  
272 label, mail, recipe). Because of the large proportion of patients who reported to read 0  
273 min/day (37%), this variable’s distribution was highly skewed and not suited to be  
274 used as a continuous variable. Therefore, we transformed it into the binary variable

275 “Daily reading” (*yes or no*). Patients who reported to read at least a few minutes each  
276 day were categorized as Daily reading – *yes*; The other patients who reported to read  
277 0 minutes daily were categorized as Daily reading – *no*. In addition to this measure of  
278 current reading proficiency, patients were also grouped based on their self-reported  
279 literacy level prior impairment through the variable “Former heavy reader” (*yes or*  
280 *no*).

281

## 282 **Statistical analysis**

283 Statistical analyses were carried out using R, a free software environment for  
284 statistical computing and graphics [36]. Reading accuracy (i.e. binary variable) was  
285 analyzed by fitting a generalized linear mixed-effects model (GLME; Analysis 1),  
286 while reading time (i.e. continuous variable) was analyzed with linear mixed-effects  
287 models (LME; Analyses 2 & 3), both allowing the modeling of experimental designs  
288 with unbalanced repeated measures [37,38]. Models were constructed with either  
289 target word accuracy or target word reading time as the dependent variable. Several  
290 factors of interest (Table 2) were included as independent variables to inspect their  
291 effect on accuracy and reading time, as well as their potential interaction with each  
292 other. The random structure of all models included a random intercept for  
293 participants, assuming a different “baseline” performance level for each individual, as  
294 well as random intercept for each target word. Before analysis, variables of interest  
295 were inspected and transformed as follow to satisfy the assumptions of parametric  
296 statistical tests [39,40]: reading time and word frequency were transformed in natural  
297 logarithm (ln) units, trigram occurrence was transformed with the ordered quantile  
298 normalization and context amount was square-root transformed. Word frequency and  
299 word length were centered around their mean. Optimal model structures were



300 assessed using the Akaike Information Criterion (AIC) and likelihood-ratio tests [41].  
 301 Significance of the fixed effects was estimated using z-values for the GLME model  
 302 and t-values for the LME models. Z- and t- values larger than 2 were considered  
 303 significant, corresponding to a 5% significance level in a two-tailed test [42,43]. In  
 304 the Results section fixed-effects estimates are reported along with their z- and t-values  
 305 and 95% confidence intervals [44].

306

Variable name	Unit / Transformation	Centered	Description
<b>Target word characteristics</b>			
Neighborhood size (N)	--	--	Number of neighbors
Frequency (ln)	Natural log	Yes	Occurrences/million
Length	--	Yes	Number of characters
<b>Sentence characteristics</b>			
Trigram occurrence	Ordered quantile normalization	--	Percentage of occurrence for each trigram ending with a target word
<b>Participant's individual characteristics</b>			
Age	Years	--	--
Disease onset	Years	--	--
Visual Acuity	LogMAR	--	--
Type of field loss	<ul style="list-style-type: none"> <li>• Central only</li> <li>• Central + peripheral</li> </ul>	--	--
Still reading daily	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> </ul>	--	--
Former heavy reader	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> </ul>	--	--

307

308 **Table 2: Description of the different factors included as independent variables in the linear**  
 309 **mixed-effects models.**

310

311 **RESULTS**

312

313 **Analysis 1 – Effect of neighborhood size on reading accuracy**

314 On average, target words were read accurately 94% of the time, with individual  
 315 variations ranging from 62 to 100% depending on patients. When all implemented in  
 316 a GLME model, N, word frequency, word length and word predictability (expressed  
 317 as trigram occurrence) showed no significant effect on accuracy (Table 3). As  
 318 estimated by the model, percentage of accuracy for patients who continue reading on  
 319 a daily basis was 99.1% ( $\exp(4.716) / (1 + \exp(4.716)) * 100$ ) ( $z = 7.694$ ;  $p < 0.001$ ;  
 320 95%CI = [3.65; 6.17]). For patients who quit daily reading activities, percentage of  
 321 accuracy was 97.3% ( $\exp(4.716-1.126) / (1 + \exp(4.716-1.126)) * 100$ ). This 1.8%  
 322 difference barely reached significance ( $z = -2.064$ ;  $p = 0.039$ ; 95%CI = [-2.31; -  
 323 0.03]). Figure 4 shows the null effect of N on accuracy, for these two groups of  
 324 participants.

	Estimate	Standard Error	z-value	p-value	95% Confidence Interval
Intercept	4.716	0.613	7.694	<0.001	[3.65; 6.17]
Word neighborhood size (N)	-0.058	0.054	-1.069	0.285	[-0.17; 0.05]
Word frequency (ln)	0.147	0.147	1.003	0.316	[-0.15; 0.46]
Word length	-0.028	0.213	-0.13	0.897	[-0.47; 0.41]
<b>Trigram occurrence</b>	0.361	0.292	1.236	0.216	[-0.21; 0.98]
<b>Daily reading No</b>	<b>-1.126</b>	<b>0.545</b>	<b>-2.064</b>	<b>0.039</b>	<b>[-2.31; -0.03]</b>

325

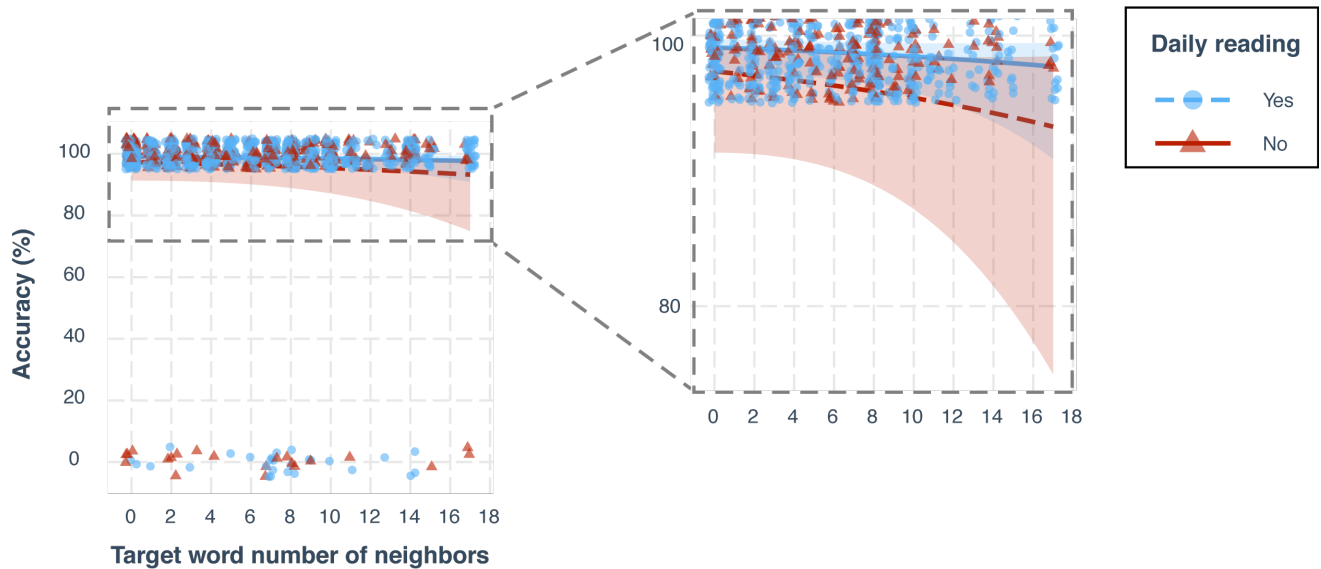
326 **Table 3: Fixed-effects estimates from the GLME model (Analysis 1).**

327 The dependent variable is ‘Target word reading accuracy’. The intercept estimate is the  
 328 predicted value of the dependent variable when all independent variables are at 0 (continuous

329 variables) or at their reference level (categorical variable). Reference level for the binary factor  
330 "Daily reading" (representing reading proficiency) is 'yes'. Factors showing a significant effect  
331 on reading accuracy are in bold font and highlighted in grey.

332

333



336 **Figure 4: Effect of the neighborhood size (N) on word reading accuracy.**

337 Each data point represents a target word. Raw data points and fitted curves estimated by the  
338 GLME model are grouped according to reading proficiency: blue for participants reading daily,  
339 red for participants who quit daily reading activities. The right-side panel shows a zoomed view  
340 of the left plot between 70 and 100% accuracy.

341

## 342 **Analysis 2 – Effect of neighborhood size on reading time**

343 In this first LME model (Table 4), the respective effects of neighborhood size, word  
344 predictability and reading proficiency are estimated individually, without any  
345 interaction term, to test our Hypothesis 1. According to this simple model, words with  
346 zero neighbors were read on average in 2.3 seconds ( $\exp(0.841)$ ). Increasing the  
347 number of neighbors by 1 did increase reading time significantly, but moderately, by  
348 a factor of 1.01 ( $\exp(0.013)$ ;  $t = 2.507$ ,  $p = 0.013$ ,  $95\%CI = [0.003; 0.023]$ ; Figure 5).

349 In other words, increasing neighborhood size from 0 to 6 (the mean value in our pool  
 350 of target words), increases reading time by a factor of 1.08 ( $\exp(0.013)^6$ ), i.e. an 8%  
 351 increase. Similarly, increasing neighborhood size from 0 to 10 (where most of our  
 352 values lie), increases reading time by a factor of 1.14 ( $\exp(0.013)^{10}$ ), i.e. a 14%  
 353 increase. Word predictability (expressed as trigram occurrence) also showed a  
 354 significant effect on reading time ( $t = -4.129$ ,  $p < 0.001$ ,  $[-0.17; -0.06]$ ). Age, acuity,  
 355 disease onset, type of field loss and former heavy reader (which were dropped from  
 356 the final model) showed no significant effect on reading time and no significant  
 357 interaction with word neighborhood size.

358

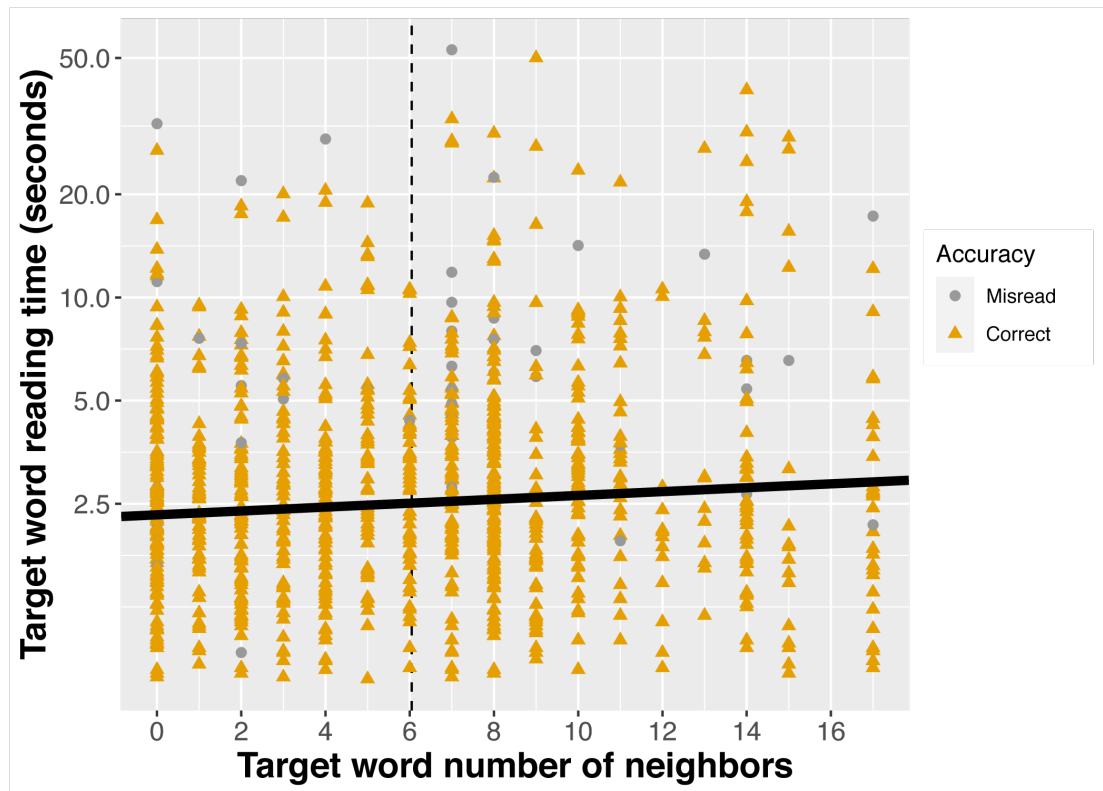
	Estimate	Standard Error	t-value	p-value	95% Confidence Interval
Intercept	0.841	0.143	5.855	<0.001	[0.55; 1.13]
<b>Word neighborhood size (N)</b>	<b>0.013</b>	<b>0.005</b>	<b>2.507</b>	<b>0.013</b>	<b>[0.003; 0.023]</b>
<b>Word frequency (ln)</b>	<b>-0.047</b>	<b>0.013</b>	<b>-3.419</b>	<b>&lt;0.001</b>	<b>[-0.07; -0.021]</b>
Word length	0.016	0.030	0.546	0.589	[-0.04; 0.08]
<b>Trigram occurrence</b>	<b>-0.115</b>	<b>0.027</b>	<b>-4.129</b>	<b>&lt;0.001</b>	<b>[-0.17; -0.06]</b>
Daily reading <i>No</i>	0.392	0.217	1.809	0.087	[-0.09; 0.87]

359

360 **Table 4: Fixed-effects estimates from the simple LME model (Analysis 2).**

361 **The dependent variable is log-transformed target word total reading time. The intercept estimate**  
 362 **represents the log-transformed reading time when all factors included in the model are at their**  
 363 **reference level (categorical variable) or at 0 (continuous variables). Reference level for the binary**  
 364 **factor "Daily reading" is 'yes'. Factors showing a significant effect on reading time are in bold**  
 365 **font and highlighted in grey.**

366



367

368 **Figure 5: Effect of neighborhood size (N) on word reading time.**

369 Data for both well-read words (yellow triangles) and misread words (grey circles) are plotted but  
 370 the fitted line extracted from the LME model (solid black) only considers the words correctly  
 371 read. The black dotted line marks N mean value.

372

373 **Analysis 3 – Effect of the interaction between neighborhood size, word**  
 374 **predictability and reading proficiency on reading time**

375 In this second LME model (Table 5), a 3-way interaction between neighborhood size,  
 376 word predictability and reading proficiency was added to test our Hypotheses 2 and 3.  
 377 According to this complex model, when trigram occurrence is at 0 (implying a highly  
 378 infrequent trigram and low predictability; Figure 6A), words with zero neighbors were  
 379 read on average in 3.0 seconds ( $\exp(1.099)$ ) by patients who practice reading daily  
 380 (Figure 6A – blue dashed line). For this same group of readers, increasing the number  
 381 of neighbors did not have a significant effect on reading time ( $t = -1.043$ ,  $p = 0.298$ ;  
 382  $95\%CI = [-0.02; 0.01]$ ; Figure 6A – blue dashed line). For patients who quit daily

383 reading activities, average reading time of words with zero neighbors was 3.14  
384 seconds ( $\exp(1.099+0.044)$ ) and was not significantly different from the ‘daily  
385 reading’ group estimate ( $t = 0.188$ ,  $p = 0.853$ ,  $95\%CI = [-0.42; 0.52]$ ; Figure 6A – red  
386 solid line). However, for these participants who stopped reading on a daily basis,  
387 increasing the number of neighbors by 1 did increase reading time significantly by a  
388 factor of 1.07 ( $\exp(0.07)$ ;  $t = 5.22$ ,  $p < 0.001$ ,  $95\%CI = [0.04; 0.10]$ ; Figure 6A – red  
389 solid line). In other words, for low predictability, increasing neighborhood size from 0  
390 to 6 (the mean value in our pool of target words), increases reading time by a factor of  
391 1.52 ( $\exp(0.07)^6$ ), i.e. a 52% increase. Similarly, increasing neighborhood size from 0  
392 to 10 (where most of our values lie), increases reading time by a factor of 2.01  
393 ( $\exp(0.07)^{10}$ ), i.e. a 101% increase.

394

	Estimate	Standard Error	t-value	p-value	95% Confidence Interval
Intercept	1.099	0.136	8.09	<0.001	[0.84; 1.37]
Word neighborhood size (N)	-0.009	0.008	-1.043	0.298	[-0.02; 0.01]
<b>Word frequency (ln)</b>	<b>-0.046</b>	<b>0.014</b>	<b>-3.39</b>	<b>&lt;0.001</b>	<b>[-0.07; -0.02]</b>
Word length	0.013	0.028	0.48	0.633	[-0.04; 0.07]
<b>Trigram occurrence</b>	<b>-0.162</b>	<b>0.049</b>	<b>-3.24</b>	<b>0.002</b>	<b>[-0.26; -0.07]</b>
Daily reading <i>No</i>	0.044	0.234	0.188	0.853	[-0.42; 0.52]
<b>N:Daily reading <i>No</i></b>	<b>0.07</b>	<b>0.013</b>	<b>5.22</b>	<b>&lt;0.001</b>	<b>[0.04; 0.10]</b>
Trigram occurrence:Daily reading <i>No</i>	0.093	0.081	1.15	0.248	[-0.06; 0.25]
N:Trigram occurrence:Daily reading <i>Yes</i>	0.011	0.006	1.85	0.066	[-4e-04; 0.02]
<b>N:Trigram occurrence:Daily reading <i>No</i></b>	<b>-0.017</b>	<b>0.008</b>	<b>-2.03</b>	<b>0.043</b>	<b>[-0.03; -8e-04]</b>

395

396 **Table 5: Fixed-effects estimates from the complex LME model (Analysis 3).**

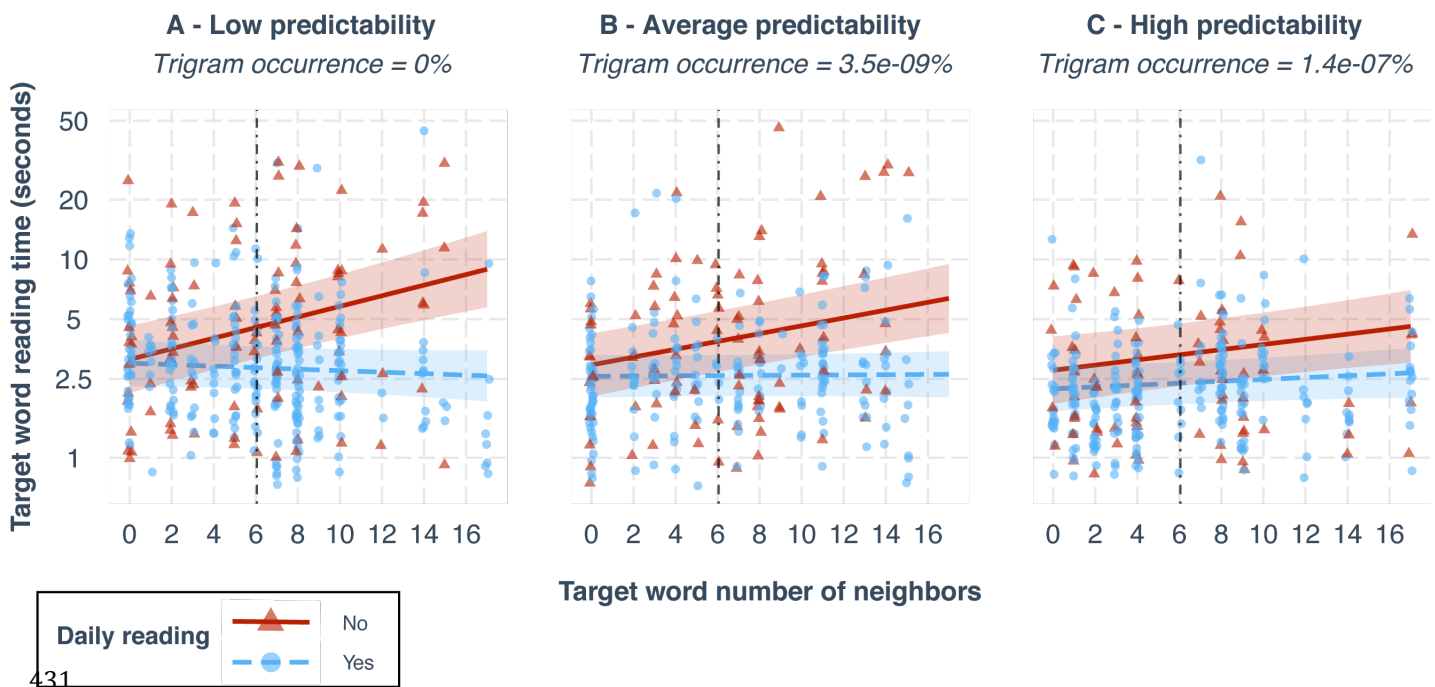
397 **The dependent variable is log-transformed target word total reading time. The intercept estimate**  
398 **represents the log-transformed reading time when all factors included in the model are at their**  
399 **reference level (categorical variable) or at 0 (continuous variable). Reference level for the binary**  
400 **factor "Daily reading" is 'yes'. Interactions are represented by the symbol ":". Factors showing a**  
401 **significant effect on reading time are in bold font and highlighted in grey.**

402

403 As trigram occurrence increases to an average value (Figure 6B) and a high value  
404 (Figure 6C), the effect of neighborhood size remains null for the 'daily reading' group  
405 ( $t = 1.85$ ;  $p = 0.066$ ;  $95\%CI = [-4e-04; 0.02]$ ; blue dashed lines). However, for the  
406 other group of patients who stopped practicing reading daily (red solid lines), the  
407 amplitude of the neighborhood size effect is significantly reduced by a factor of 1.02  
408 ( $\exp(0.017)$ ;  $t = -2.03$ ;  $p = 0.043$ ;  $95\%CI = [-0.03; -8e-04]$ ) every time trigram  
409 occurrence increases by one unit. As given by a slopes post-hoc analysis, the  
410 amplitude of the effect for the group who quit daily reading (red solid line) was of  
411 1.05 ( $\exp(0.05)$ ;  $t = 5.39$ ,  $p < 0.001$ ) for average trigram occurrence values (Figure  
412 6B) and of 1.03 ( $\exp(0.03)$ ;  $t = 2.77$ ,  $p = 0.01$ ) for highly frequent trigrams (Figure  
413 6C). In other words, for fairly frequent trigrams yielding average predictability,  
414 increasing neighborhood size from 0 to 10, increases reading time significantly by a  
415 factor of 1.65 ( $\exp(0.05)^{10}$ ), i.e. a 65% increase, while the same increase in  
416 neighborhood size for highly frequent trigrams yielding high predictability, increases  
417 reading time significantly by a factor of only 1.35 ( $\exp(0.03)^{10}$ ), i.e. a 35% increase.

418 Besides this significant 3-way interaction, word frequency also had a significant effect  
419 on reading time with a regression coefficient estimate of -0.046 ( $t = -3.39$ ,  $p < 0.001$ ,  
420  $95\%CI = [-0.07; -0.02]$ ). As both reading time and frequency are expressed in natural  
421 log units, multiplying frequency (in original units) by 10 multiplies reading time (in

422 original units) by 0.90 ( $10^{-0.046}$ ), i.e. a 10% decrease. We found no significant  
 423 interaction between frequency and the ‘daily reading’ factor, nor between frequency  
 424 and the number of neighbors. Word length had no significant effect on reading time ( $t$   
 425 = 0.48,  $p = 0.633$ , 95%CI = [-0.04; 0.07]). Similarly, age, acuity, disease onset, type  
 426 of field loss and former heavy reader (all dropped from the final model) showed no  
 427 significant effect on reading time and no significant interaction with word  
 428 neighborhood size.  
 429  
 430



431  
 432 **Figure 6: Effect of neighborhood size (N) on reading time, depending on word predictability and**  
 433 **reading proficiency.**

434 Raw data points and fitted lines estimated by the LME model are grouped by reading  
 435 proficiency: red for participants who quit reading on a daily basis, blue for participants still  
 436 reading daily. Each subplot represents the effect of N for a different value of the trigram  
 437 occurrence distribution, split into three equal-sized groups (i.e., terciles): (A) median of the lower  
 438 tercile, (B) median of the middle tercile, (C) median of the upper tercile (C).  
 439



## DISCUSSION

The first goal of the present work was to test the hypothesis that the visual constraint imposed by the presence of a central scotoma leads to an inhibitory effect of neighborhood size during sentence reading. Therefore, we assessed the effect of word neighborhood size (N) on the reading performance of 19 patients with CFL, namely reading accuracy (Analysis 1) and reading time (Analysis 2). Our results show that N has no significant effect on accuracy, which ceils around 94% overall. On the other hand, we found a moderate inhibitory effect of N on reading time, with a 14% increase in word reading time (i.e., a 12% decrease in reading speed) when N goes from 0 to 10 neighbors (i.e., the range where most of our values lie). This result confirms our first hypothesis and builds up the recent report of a reversed neighborhood size effect for visually impaired individuals compared to normally sighted readers [18].

Effects of orthographic neighbors on word identification have been extensively explored in readers with normal vision. Despite the many contradictory findings accumulated over the years, it is now accepted that the neighborhood size effect depends on the task and is modulated by the frequency of the neighbors themselves (i.e. the neighborhood frequency effect). Indeed, large neighborhood has consistently been reported to facilitate responses in a variety of tasks such as word naming [45] and lexical decision [46,47], but this facilitative effect seems to be restricted to low-frequency neighbors [48]. Despite their great interest to help understand the underlying mechanisms of lexical processing, these results are difficult to interpret in the context of our work with natural reading since they are restrained to isolated word identification.

465 Because semantic context may help decide between visually similar words, it is  
466 necessary to examine the effects of neighborhood (i.e., size and frequency) during  
467 natural reading in context to assess their influence on reading performance. To this  
468 end, Pollatsek et al. examined eye movement patterns of normally sighted readers  
469 during both a lexical decision task and silent reading, when target words varying in  
470 neighborhood size were embedded in neutral sentences [49]. Their overall conclusion  
471 was that, for silent reading, increasing the number of higher frequency neighbors had  
472 a clear inhibitory effect on word identification, whereas increasing the number of  
473 lower frequency neighbors may have a weak facilitative effect. In the present work,  
474 reading material was created without controlling for neighborhood frequency, but a  
475 post-hoc analysis revealed that most of our target words (82%) had a majority of low-  
476 frequency neighbors (from 60% to 100%; mean =  $83 \pm 14\%$ ). Based on this  
477 distribution, results from normal vision would predict a weak facilitative effect of  
478 neighborhood size on reading performance [49]. On the contrary, we found a reverse  
479 effect of neighborhood size, with a weak inhibitory effect. This result confirms our  
480 assumption that under degraded visual conditions, the lack of complete stimulus  
481 information will have more of an effect on words that are visually similar to many  
482 others than on words with few neighbors. It is likely that in the interest of time  
483 performance, readers may infer a word by guessing one of its high-frequency  
484 neighbors. However, because of the incongruousness between this guess and the  
485 overall sentence meaning, processing would persist until a better match, that fits both  
486 the visually identified letters and the meaning, is found. This would explain why  
487 reading accuracy remained very high among our participants, at the expense of  
488 reading time.

489 The second goal of the present work was to test the hypotheses that, with CFL, the  
490 effect of neighborhood size is modulated by both word predictability and reading  
491 proficiency. Therefore, we assessed the word neighborhood size effect through a 3-  
492 way interaction, including a measure of predictability (trigram occurrence) and  
493 proficiency (daily reading - *yes or no*) (Analysis 3). First, we found that the inhibitory  
494 effect of N is modulated by word predictability: the more familiar a sequence of  
495 words is, the weaker the effect of neighborhood size on the last word identification  
496 time. This result confirms our second hypothesis that the amplitude of the  
497 neighborhood size effect is influenced by word predictability.

498 However, we found that this is only true for the less proficient readers, who have  
499 stopped reading on a daily basis, confirming our third hypothesis that the interaction  
500 between neighborhood size and word predictability depends on patients' reading  
501 proficiency. In short, we found that for the less proficient readers reaching a low-  
502 predictable word in a sentence, reading speed decreases by up to 50% (101% increase  
503 in reading time) when the number of neighbors goes from 0 to 10. As predictability  
504 increases, the amplitude of this effect lessens gradually, with 39% decrease in reading  
505 speed for average predictability (65% increase in reading time) and 26% decrease in  
506 reading speed for high predictability (35% increase in reading time). For proficient  
507 readers who reported to retain a daily leisure activity of reading however, even for a  
508 few minutes each day, the effect of N remains null, regardless of the word  
509 predictability. This result, close to what has been reported with normally sighted  
510 readers [49], leads us to the conclusion that practice can help minimize the adverse  
511 effect of ambiguity induced by orthographic similarity when visual input is degraded  
512 and access to text is only partial because of maculopathy.

513 These results are particularly relevant in the context of low-vision rehabilitation, as  
514 they reinforce the need to provide patients with individualized readaptive care of  
515 functional vision, in order to help maintain daily reading practice. More importantly,  
516 our results suggest that text simplification might be a powerful way to leverage text  
517 accessibility for low-vision patients. Text simplification is the process of reducing the  
518 linguistic complexity of a text, while still retaining the original information and  
519 meaning [50,51]. Its main goal is to make a text more accessible to people with low  
520 literacy [52] or individuals with reading disorders (e.g., aphasia [53], dyslexia [54]).  
521 For the first time, our results show that it could also be used efficiently to improve  
522 low-vision rehabilitation, especially for the most impaired patients, who have stopped  
523 reading on a daily basis (36.8% in our population sample). For these less proficient  
524 readers, substituting complex words (i.e., words with many orthographic neighbors)  
525 with synonyms that have less neighbors and equal or higher frequency should reduce  
526 reading difficulty. Therefore, using simplified texts with increased accessibility as  
527 rehabilitation training material might help (1) improve overall reading ability and  
528 fluency, while (2) fostering the long-term motivation necessary to resume daily  
529 reading practice. Text simplification could then be used daily as an efficient reading  
530 aid (made available through tablets, e-readers, or web plugins) to keep practicing  
531 reading at home and enhance everyday reading performance.

532 As a side note, we would like to point to the fact that our results were obtained using  
533 the occurrence percentage of trigrams (3-gram, i.e., sequence of three words) in the  
534 French literature. It is worth mentioning that we also ran the analysis with other n-  
535 gram values, namely 2- and 4-gram and that neither of them showed significant effect.  
536 Since most of our target words were common nouns (89%; against 9.4% of adjectives  
537 and 1.6% of verbs), they were most likely preceded by an article that did not convey

538 meaningful information. Therefore, an analysis based on 2-gram prediction was not  
539 likely to be meaningful. On the other hand, we expected 4-gram analysis to be highly  
540 significant. However, because we created our reading material so that target words  
541 were not too predictable, 77% of our 4-grams were highly infrequent (less than 40  
542 occurrences across the ‘French 2012’ corpus) and rated at 0 percent occurrence by  
543 Google Ngram. We suspect that the absence of significant effect with 4-grams is due  
544 to this highly skewed distribution towards 0.

545 Overall, the present work presents some limitations that should be considered in  
546 future investigations of neighborhood effects on low vision. First, the range of  
547 participants’ age and disease onset should be expanded to better represent the full  
548 spectrum of adaptation exhibited following early and late onset CFL. It is possible  
549 that the absence of effect reported here may be due to our highly skewed distribution,  
550 with 16 participants between 70 and 89, against only 3 young individuals (aged 32, 48  
551 and 59). Second, future investigations should also include measures of  
552 microperimetry (size and shape of the scotoma, fixation eccentricity, etc.) to take into  
553 account individual vision loss characteristics. Third, neighborhood frequency should  
554 be gauged thoroughly when designing the reading material in order to better control  
555 for its effect when assessing the effect of neighborhood size. Second, the definition of  
556 orthographic neighbor used in this work is letter-position-specific and length-  
557 dependent [15]. Given that letter position uncertainty is a crucial factor limiting  
558 peripheral word recognition, and reading without central vision in general [55],  
559 Coltheart’s definition should probably be extended to include letter transposition (e.g.,  
560 trial and trail), addition (e.g. trial and tribal) and deletion (e.g. trial and rial) in order  
561 to encompass a larger number of highly similar words. Finally, the results presented  
562 here should be interpreted cautiously in the context of reading under natural

563 conditions, since they were obtained with a paradigm that does not allow word  
564 skipping, forcing participants to read each single word of a sentence [56].  
565 Additionally, reading performance was measured with monocular vision, allowing to  
566 control for specific eye characteristics (e.g., lens status). Such approach is critical in  
567 research settings, but may not always mimic actual clinical conditions, where patients  
568 would read with one or two eyes, based on their own preference.

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778

779 **AUTHOR CONTRIBUTIONS**

780 LS, TF and NG prepared the linguistic material used for data collection. CA  
781 developed the program used for data collection. LS and NS collected the data. AC  
782 performed the data analysis and wrote the main manuscript text. All authors reviewed  
783 the manuscript.

784

785

786 **FIGURE LEGENDS**

787 Figure 1: The presence of a central scotoma occludes part of the word “father”,  
788 leading to possible misidentifications, potentially due to: (1) incomplete letters (e.g.,  
789 farmer); (b) eccentric letters, for which low acuity and increased crowding decrease  
790 identification performance (e.g., feather) or (c) both (e.g., halter). The overall lack of  
791 identification accuracy yields a greater need for linguistic inference.

792

793 Figure 2: Creation of the reading material.

794 Illustration of the reading material creation, using the synonym pair “*shore / coast*”.  
795 Both words in this example contain 5 characters. Their difference in number of  
796 neighbors is 10. Sentences A and B were created so either word of this synonym pair  
797 can fit in both sentences. In Condition 1, sentence A contains the target word 1  
798 (‘shore’) and sentence B contains the target word 2 (‘coast’). In Condition 2, the  
799 pairing is reversed. Note that this example is given in English to ease understanding.  
800 See Supplementary Material for the complete set of French sentences created.

801

802 Figure 3: Self-paced Reading paradigm.

803 Words are revealed one at a time by the participant, using keyboard presses. A press  
804 on the right arrow key will unmask the upcoming word (while masking the currently  
805 visible word) and a press on the left arrow key will unmask the previous word (while  
806 masking the currently visible word). For words unmasked only once (e.g. word 1), the  
807 total reading time equals the 1<sup>st</sup>-pass reading time. For words unmasked more than  
808 once (e.g. word 2), the total reading time is the sum of each individual reading time  
809 pass.

810

811 Figure 4: Effect of the neighborhood size (N) on word reading accuracy.

812 Each data point represents a target word. Raw data points and fitted curves estimated  
813 by the GLME model are grouped according to reading proficiency: blue for  
814 participants reading daily, red for participants who quit daily reading activities. The  
815 right-side panel shows a zoomed view of the left plot between 70 and 100% accuracy.

816

817 Figure 5: Effect of neighborhood size (N) on word reading time.

818 Data for both well-read words (yellow triangles) and misread words (grey circles) are  
819 plotted but the fitted line extracted from the LME model (solid black) only considers  
820 the words correctly read. The black dotted line marks N mean value.

821

822 Figure 6: Effect of neighborhood size (N) on reading time, depending on word  
823 predictability and reading proficiency.

824 Raw data points and fitted lines estimated by the LME model are grouped by reading  
825 proficiency: red for participants who quit reading on a daily basis, blue for  
826 participants still reading daily. Each subplot represents the effect of N for a different  
827 value of the trigram occurrence distribution, split into three equal-sized groups (i.e.,  
828 terciles): (A) median of the lower tercile, (B) median of the middle tercile, (C) median  
829 of the upper tercile (C).

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832

Participants	Gender	Age (years)	Etiology	Disease onset (years)	Low-vision rehabilitation	Visual acuity (logMAR)	Lens status	Daily reading time (min/day)	Former heavy reader	Current/former profession
1	M	76	Atrophic AMD	2	Yes	1	Phakic	0	No	Bus driver
2	F	77	Atrophic AMD	7	No	0.4	Pseudophakic	45	Yes	Housewife
3	F	80	Atrophic AMD	7	Yes	1	Pseudophakic	0	Yes	Cook
4	F	80	Atrophic AMD	5	Yes	0.8	Phakic	0	No	Daycare provider
5	F	83	Atrophic AMD	12	Yes	0.5	Phakic	60	Yes	Nurse
6	F	83	Atrophic AMD	2	Yes	0.5	Pseudophakic	0	Yes	Secretary
7	F	85	Atrophic AMD	15	No	0.7	Pseudophakic	60	Yes	Seamstress
8	M	86	Atrophic AMD	8	Yes	0.7	Pseudophakic	60	No	Driving instructor
9	M	88	Atrophic AMD	20	Yes	0.7	Phakic	60	No	Teacher
10	F	78	Exudative AMD	3	No	1.1	Pseudophakic	0	No	Postwoman
11	F	87	Exudative AMD	2	Yes	0.5	Pseudophakic	10	Yes	Secretary
12	M	89	Exudative AMD	3	Yes	0.4	Pseudophakic	30	Yes	Clerical worker
<b>13</b>	<b>F</b>	<b>48</b>	<b>Stargardt's disease</b>	<b>35</b>	<b>Yes</b>	<b>1.3</b>	<b>Phakic</b>	<b>25</b>	<b>Yes</b>	<b>Educator</b>
14	F	72	Stargardt's disease	16	No	1	Phakic	120	No	Housewife
<b>15</b>	<b>F</b>	<b>32</b>	<b>Cone dystrophy</b>	<b>30</b>	<b>No</b>	<b>1</b>	<b>Phakic</b>	<b>120</b>	<b>No</b>	<b>Physiotherapist</b>
16	M	73	Diabetic retinopathy	10	No	0.7	Pseudophakic	0	Yes	Company director
<b>17</b>	<b>M</b>	<b>59</b>	<b>Myopic retinopathy</b>	<b>15</b>	<b>Yes</b>	<b>1</b>	<b>Phakic</b>	<b>0</b>	<b>Yes</b>	<b>Computer specialist</b>
18	F	70	Myopic retinopathy	20	Yes	1.3	Pseudophakic	120	Yes	Art teacher
19	F	70	Myopic retinopathy	62	Yes	0.8	Pseudophakic	30	Yes	Teacher

837 **Visual acuity and lens status are given for the tested eye only. Participants with central scotoma**  
838 **only are highlighted in red. Participants with central scotoma and peripheral lesions are**  
839 **highlighted in blue. Participants who are still active workers are highlighted in bold font.**

840

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842

Variable name	Unit / Transformation	Centered	Description
<b>Target word characteristics</b>			
Neighborhood size (N)	--	--	Number of neighbors
Frequency (ln)	Natural log	Yes	Occurrences/million
Length	--	Yes	Number of characters
<b>Sentence characteristics</b>			
Trigram occurrence	Ordered quantile normalization	--	Percentage of occurrence for each trigram ending with a target word
<b>Participant's individual characteristics</b>			
Age	Years	--	--
Disease onset	Years	--	--
Visual Acuity	LogMAR	--	--
Type of field loss	<ul style="list-style-type: none"> <li>• Central only</li> <li>• Central + peripheral</li> </ul>	--	--
Still reading daily	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> </ul>	--	--
Former heavy reader	<ul style="list-style-type: none"> <li>• Yes</li> <li>• No</li> </ul>	--	--

843

844 **Table 2: Description of the different factors included as independent variables in the linear**

845 **mixed-effects models.**

846

	Estimate	Standard Error	z-value	p-value	95% Confidence Interval
Intercept	4.716	0.613	7.694	<0.001	[3.65; 6.17]
Word neighborhood size (N)	-0.058	0.054	-1.069	0.285	[-0.17; 0.05]
Word frequency (ln)	0.147	0.147	1.003	0.316	[-0.15; 0.46]
Word length	-0.028	0.213	-0.13	0.897	[-0.47; 0.41]
<b>Trigram occurrence</b>	0.361	0.292	1.236	0.216	[-0.21; 0.98]
<b>Daily reading</b> <i>No</i>	<b>-1.126</b>	<b>0.545</b>	<b>-2.064</b>	<b>0.039</b>	<b>[-2.31; -0.03]</b>

848

849 **Table 3: Fixed-effects estimates from the GLME model (Analysis 1).**

850 The dependent variable is ‘Target word reading accuracy’. The intercept estimate is the  
851 predicted value of the dependent variable when all independent variables are at 0 (continuous  
852 variables) or at their reference level (categorical variable). Reference level for the binary factor  
853 ”Daily reading” (representing reading proficiency) is ‘yes’. Factors showing a significant effect  
854 on reading accuracy are in bold font and highlighted in grey.

855

	Estimate	Standard Error	t-value	p-value	95% Confidence Interval
Intercept	0.841	0.143	5.855	<0.001	[0.55; 1.13]
<b>Word neighborhood size (N)</b>	<b>0.013</b>	<b>0.005</b>	<b>2.507</b>	<b>0.013</b>	<b>[0.003; 0.023]</b>
<b>Word frequency (ln)</b>	<b>-0.047</b>	<b>0.013</b>	<b>-3.419</b>	<b>&lt;0.001</b>	<b>[-0.07; -0.021]</b>
Word length	0.016	0.030	0.546	0.589	[-0.04; 0.08]
<b>Trigram occurrence</b>	<b>-0.115</b>	<b>0.027</b>	<b>-4.129</b>	<b>&lt;0.001</b>	<b>[-0.17; -0.06]</b>
Daily reading <i>No</i>	0.392	0.217	1.809	0.087	[-0.09; 0.87]

857

858 **Table 4: Fixed-effects estimates from the simple LME model (Analysis 2).**

859 **The dependent variable is log-transformed target word total reading time. The intercept estimate**  
860 **represents the log-transformed reading time when all factors included in the model are at their**  
861 **reference level (categorical variable) or at 0 (continuous variables). Reference level for the binary**  
862 **factor "Daily reading" is 'yes'. Factors showing a significant effect on reading time are in bold**  
863 **font and highlighted in grey.**

	Estimate	Standard Error	t-value	p-value	95% Confidence Interval
Intercept	1.099	0.136	8.09	<0.001	[0.84; 1.37]
Word neighborhood size (N)	-0.009	0.008	-1.043	0.298	[-0.02; 0.01]
<b>Word frequency (ln)</b>	<b>-0.046</b>	<b>0.014</b>	<b>-3.39</b>	<b>&lt;0.001</b>	<b>[-0.07; -0.02]</b>
Word length	0.013	0.028	0.48	0.633	[-0.04; 0.07]
<b>Trigram occurrence</b>	<b>-0.162</b>	<b>0.049</b>	<b>-3.24</b>	<b>0.002</b>	<b>[-0.26; -0.07]</b>
Daily reading <i>No</i>	0.044	0.234	0.188	0.853	[-0.42; 0.52]
<b>N:Daily reading <i>No</i></b>	<b>0.07</b>	<b>0.013</b>	<b>5.22</b>	<b>&lt;0.001</b>	<b>[0.04; 0.10]</b>
Trigram occurrence:Daily reading <i>No</i>	0.093	0.081	1.15	0.248	[-0.06; 0.25]
N:Trigram occurrence:Daily reading <i>Yes</i>	0.011	0.006	1.85	0.066	[-4e-04; 0.02]
<b>N:Trigram occurrence:Daily reading <i>No</i></b>	<b>-0.017</b>	<b>0.008</b>	<b>-2.03</b>	<b>0.043</b>	<b>[-0.03; -8e-04]</b>

864

865 **Table 5: Fixed-effects estimates from the complex LME model (Analysis 3).**

866 **The dependent variable is log-transformed target word total reading time. The intercept estimate**  
867 **represents the log-transformed reading time when all factors included in the model are at their**  
868 **reference level (categorical variable) or at 0 (continuous variable). Reference level for the binary**  
869 **factor "Daily reading" is 'yes'. Interactions are represented by the symbol ":". Factors showing a**  
870 **significant effect on reading time are in bold font and highlighted in grey.**

871

872