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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

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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 ± 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.

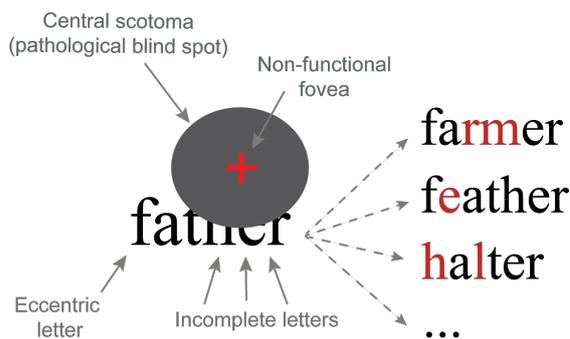
55 INTRODUCTION

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
13	F	48	Stargardt's disease	35	Yes	1.3	Phakic	25	Yes	Educator
14	F	72	Stargardt's disease	16	No	1	Phakic	120	No	Housewife
15	F	32	Cone dystrophy	30	No	1	Phakic	120	No	Physiotherapist
16	M	73	Diabetic retinopathy	10	No	0.7	Pseudophakic	0	Yes	Company director
17	M	59	Myopic retinopathy	15	Yes	1	Phakic	0	Yes	Computer specialist
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.

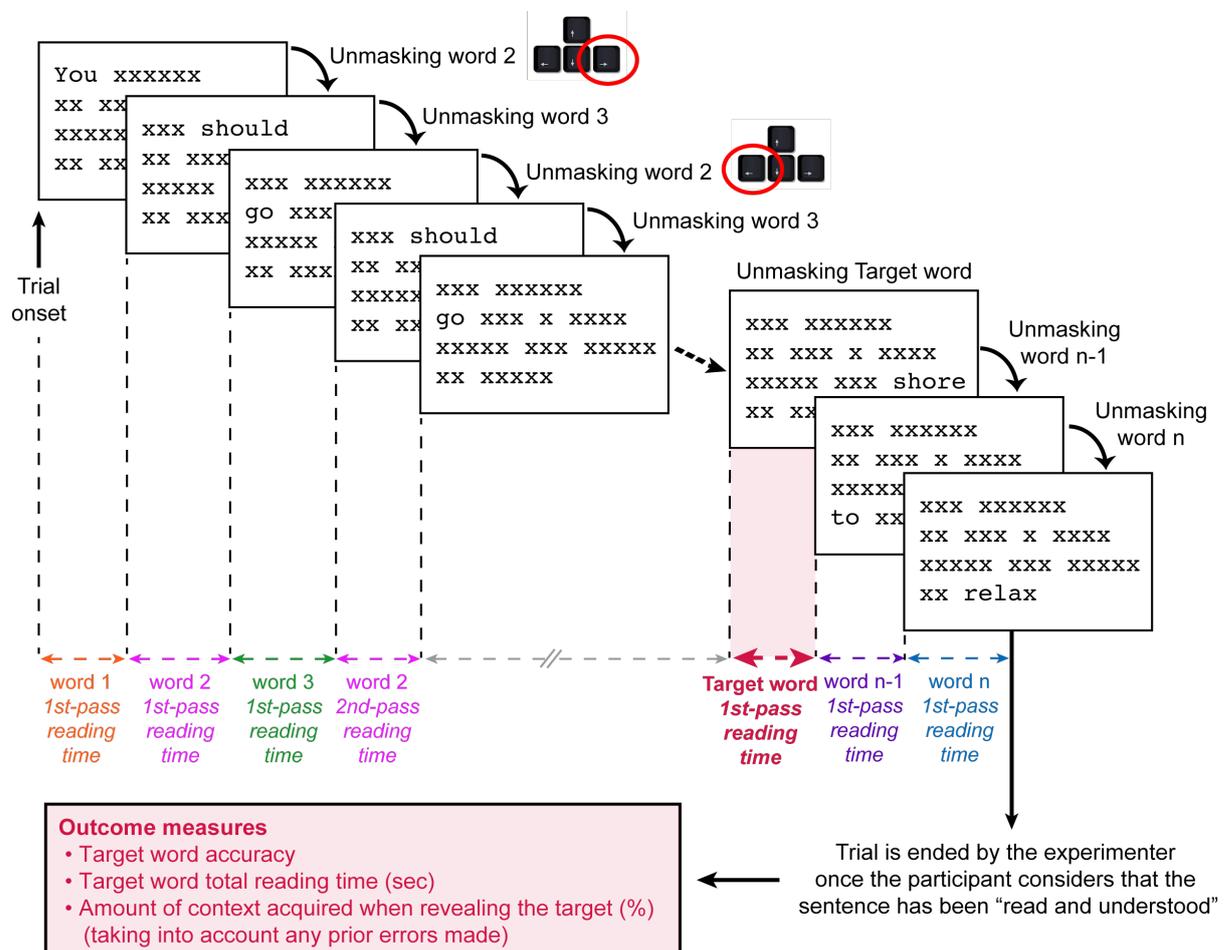
221 **Illustration of the reading material creation, using the synonym pair “shore / coast”. Both words**
222 **in this example contain 5 characters. Their difference in number of neighbors is 10. Sentences A**
223 **and B were created so either word of this synonym pair can fit in both sentences. In 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 1st-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
Target word characteristics			
Neighborhood size (N)	--	--	Number of neighbors
Frequency (ln)	Natural log	Yes	Occurrences/million
Length	--	Yes	Number of characters
Sentence characteristics			
Trigram occurrence	Ordered quantile normalization	--	Percentage of occurrence for each trigram ending with a target word
Participant's individual characteristics			
Age	Years	--	--
Disease onset	Years	--	--
Visual Acuity	LogMAR	--	--
Type of field loss	<ul style="list-style-type: none"> • Central only • Central + peripheral 	--	--
Still reading daily	<ul style="list-style-type: none"> • Yes • No 	--	--
Former heavy reader	<ul style="list-style-type: none"> • Yes • No 	--	--

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]
Trigram occurrence	0.361	0.292	1.236	0.216	[-0.21; 0.98]
Daily reading No	-1.126	0.545	-2.064	0.039	[-2.31; -0.03]

325

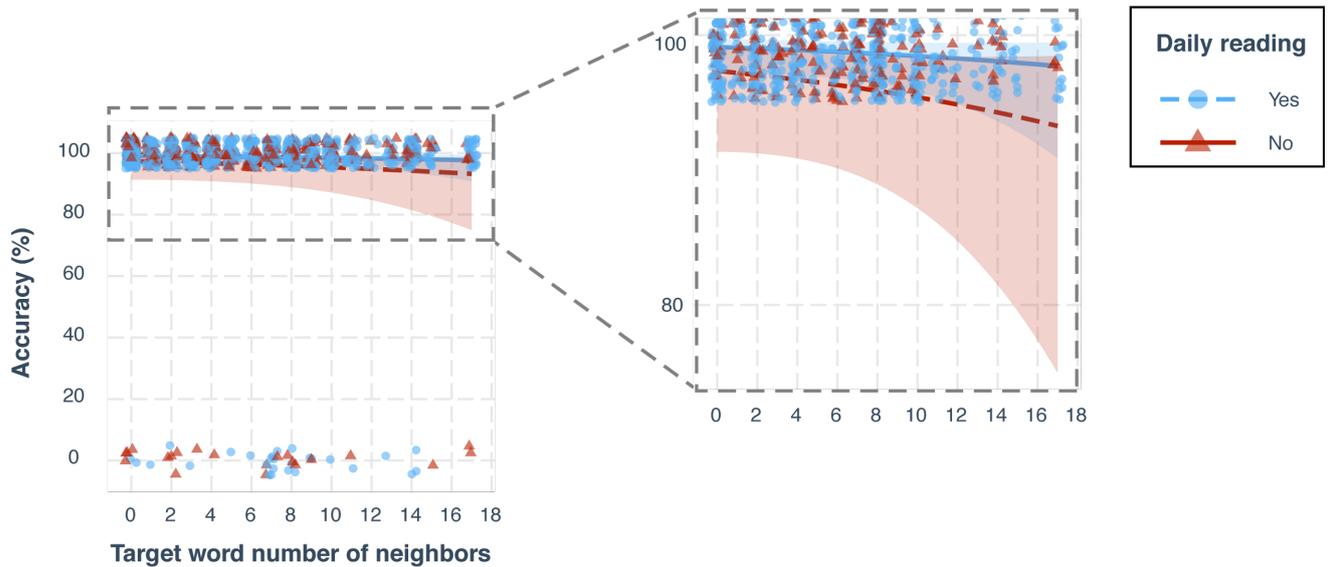
326 **Table 3: Fixed-effects estimates from the GLME model (Analysis 1).**

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

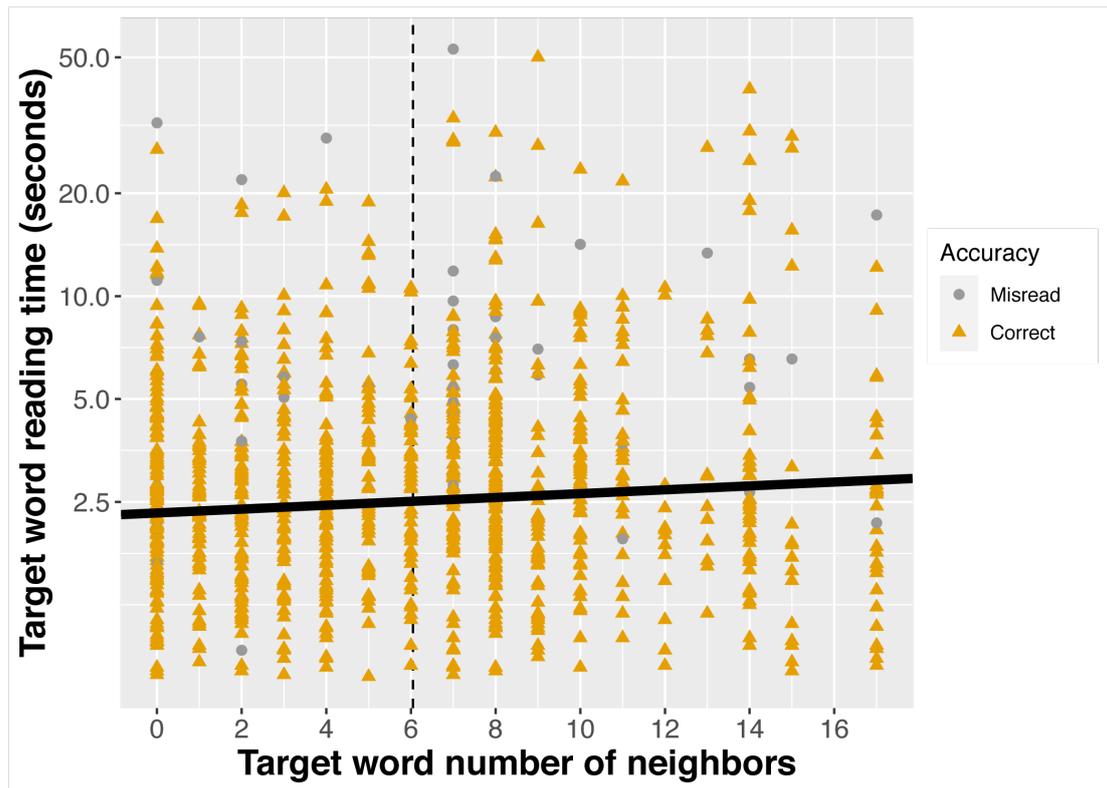
	Estimate	Standard Error	t-value	p-value	95% Confidence Interval
Intercept	0.841	0.143	5.855	<0.001	[0.55; 1.13]
Word neighborhood size (N)	0.013	0.005	2.507	0.013	[0.003; 0.023]
Word frequency (ln)	-0.047	0.013	-3.419	<0.001	[-0.07; -0.021]
Word length	0.016	0.030	0.546	0.589	[-0.04; 0.08]
Trigram occurrence	-0.115	0.027	-4.129	<0.001	[-0.17; -0.06]
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]
Word frequency (ln)	-0.046	0.014	-3.39	<0.001	[-0.07; -0.02]
Word length	0.013	0.028	0.48	0.633	[-0.04; 0.07]
Trigram occurrence	-0.162	0.049	-3.24	0.002	[-0.26; -0.07]
Daily reading <i>No</i>	0.044	0.234	0.188	0.853	[-0.42; 0.52]
N:Daily reading <i>No</i>	0.07	0.013	5.22	<0.001	[0.04; 0.10]
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]
N:Trigram occurrence:Daily reading <i>No</i>	-0.017	0.008	-2.03	0.043	[-0.03; -8e-04]

395

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

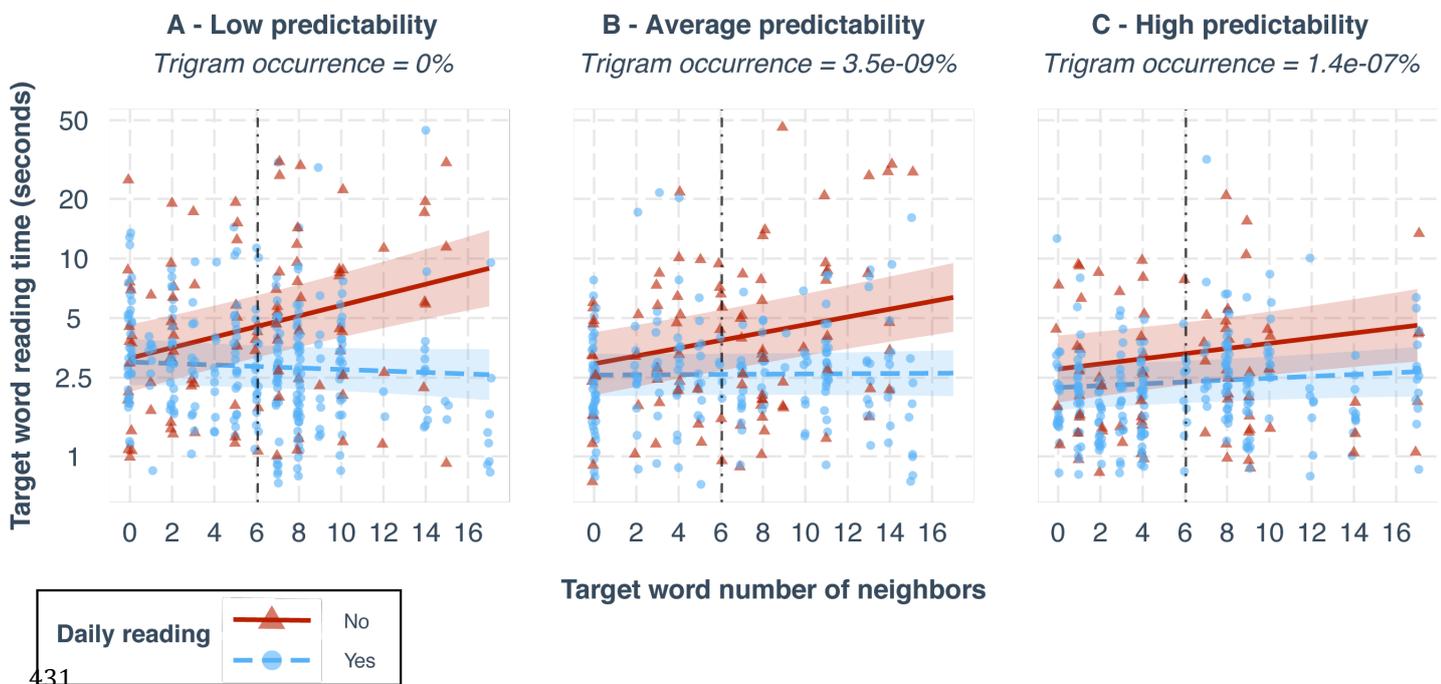
397 **The dependent variable is log-transformed target word total reading time. The intercept estimate**
398 **represents the log-transformed reading time when all factors included in the model are at their**
399 **reference level (categorical variable) or at 0 (continuous variable). Reference level 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

440

441

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

454 Effects of orthographic neighbors on word identification have been extensively
455 explored in readers with normal vision. Despite the many contradictory findings
456 accumulated over the years, it is now accepted that the neighborhood size effect
457 depends on the task and is modulated by the frequency of the neighbors themselves
458 (i.e. the neighborhood frequency effect). Indeed, large neighborhood has consistently
459 been reported to facilitate responses in a variety of tasks such as word naming [45]
460 and lexical decision [46,47], but this facilitative effect seems to be restricted to low-
461 frequency neighbors [48]. Despite their great interest to help understand the
462 underlying mechanisms of lexical processing, these results are difficult to interpret in
463 the context of our work with natural reading since they are restrained to isolated word
464 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.

569

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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 1st-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).

830

831

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
13	F	48	Stargardt's disease	35	Yes	1.3	Phakic	25	Yes	Educator
14	F	72	Stargardt's disease	16	No	1	Phakic	120	No	Housewife
15	F	32	Cone dystrophy	30	No	1	Phakic	120	No	Physiotherapist
16	M	73	Diabetic retinopathy	10	No	0.7	Pseudophakic	0	Yes	Company director
17	M	59	Myopic retinopathy	15	Yes	1	Phakic	0	Yes	Computer specialist
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

841

842

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

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]
Trigram occurrence	0.361	0.292	1.236	0.216	[-0.21; 0.98]
Daily reading <i>No</i>	-1.126	0.545	-2.064	0.039	[-2.31; -0.03]

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]
Word neighborhood size (N)	0.013	0.005	2.507	0.013	[0.003; 0.023]
Word frequency (ln)	-0.047	0.013	-3.419	<0.001	[-0.07; -0.021]
Word length	0.016	0.030	0.546	0.589	[-0.04; 0.08]
Trigram occurrence	-0.115	0.027	-4.129	<0.001	[-0.17; -0.06]
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]
Word frequency (ln)	-0.046	0.014	-3.39	<0.001	[-0.07; -0.02]
Word length	0.013	0.028	0.48	0.633	[-0.04; 0.07]
Trigram occurrence	-0.162	0.049	-3.24	0.002	[-0.26; -0.07]
Daily reading <i>No</i>	0.044	0.234	0.188	0.853	[-0.42; 0.52]
N:Daily reading <i>No</i>	0.07	0.013	5.22	<0.001	[0.04; 0.10]
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]
N:Trigram occurrence:Daily reading <i>No</i>	-0.017	0.008	-2.03	0.043	[-0.03; -8e-04]

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