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**Effects of inter-character spacing on saccade programming  
in beginning readers and dyslexics**

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### **Abstract**

The present study investigated the impact of inter-character spacing on saccade programming in beginning readers and dyslexic children. In two experiments, eye movements were recorded while dyslexic children, reading-age and chronological-age controls, performed an oculomotor lateralized bisection task on words and strings of hashes presented either with default inter-character spacing or with extra spacing between the characters. The results of Experiment 1 showed that (1) only proficient readers had already developed highly automatized procedures for programming both left- and rightward saccades, depending on the discreteness of the stimuli and (2) children of all groups were disrupted (i.e. had trouble to land close to the beginning of the stimuli) by extra spacing between the characters of the stimuli, and particularly for stimuli presented in the left visual field. Experiment 2 was designed to disentangle the role of inter-character spacing and spatial width. Stimuli were made the same physical length in the default and extra-spacing conditions by having more characters in the default spacing condition. Our results showed that inter-letter spacing still influenced saccade programming when controlling for spatial width, thus confirming the detrimental effect of extra spacing for saccade programming. We conclude that the beneficial effect of increased inter-letter spacing on reading can be better explained in terms of decreased visual crowding than improved saccade targeting.

Key words: saccade programming; inter-character spacing; oculomotor bisection task; developmental dyslexia; beginning readers

## INTRODUCTION

Literate adults have acquired a highly specific form of visual expertise that enables them to process written language with remarkable efficiency. In a single glance, lasting about two hundred milliseconds, the visual system is capable of extracting the critical information needed to identify written words. However, this apparent ease hides the many obstacles we all had to overcome throughout childhood in order to acquire the necessary skills for fluent, effortless reading. Processing written language naturally requires the development of a number of strictly linguistic skills. However, reading also requires a visual analysis that enables the precise decoding of written words. The high visual acuity that is needed to rapidly identify words is spatially limited (Lee, Legge, & Ortiz, 2003; Rayner & Bertera, 1979; Rayner & Morrison, 1981) and it has been argued that beginning readers learn to move their eyes in order to optimize the processing of the majority of words in the text being read (Legge, Klitz, & Tjan, 1997; O'Regan & Lévy-Shoen, 1987; Rayner, 1986). It is therefore possible that basic oculomotor skills might play a key role in the development of reading skills, and that their inadequate development might be one cause of reading disabilities (e.g., Biscaldi, Fischer, & Hartnegg, 2000; Fischer & Weber, 1990). As reading proficiency increases, a child becomes increasingly familiar with the printed form of letters within words and the mechanics of eye movement control during reading undergo substantial changes: The duration of fixations decreases, the size of the perceptual span and the length of saccades increases (Blythe, 2014; Blythe, & Joseph, 2011; Häikiö, Bertram, Hyönä, & Niemi, 2009). The main purpose of the present study was to further investigate the visual and attentional factors that determine the eyes' landing position in children and whether it might be possible to influence these low-level processes and/or contribute to their improvement.

In the present study, we focus on the saccadic computation involved in directing the eyes to a peripheral target, and therefore determining where the eyes first land in a word (i.e., the initial

landing position or ILP). In adult readers the ILP determines how quickly a word is processed (Vitu, McConkie, Kerr, O'Regan, 2001) and how likely it is that the word will be refixated (McConkie, Kerr, Reddix, & Zola, 1988; McConkie, Kerr, Reddix, Zola, & Jacobs, 1989). Furthermore, location of the initial fixation determines word skipping behavior (e.g. Rayner & McConkie, 1976). Most researchers in the field would agree that, for alphabetic writing systems, the decision about where to move next is mostly influenced by low-level visual factors, and in particular word length information provided by the spaces between words (e.g., Inhoff, Radach, Eiter, & Juhasz, 2003; Rayner, Fischer, & Pollatsek, 1998). Rayner (1979) first demonstrated that saccades are targeted to the so-called "preferred viewing location" (PVL) of a word, a point just left of the word's center for languages read from left-to-right. It is also generally agreed that the PVL reflects a combination of readers aiming for the center of the targeted word and failing to do so due to visuo-motor influences on saccade targeting (e.g., the saccadic range effect or the center of gravity effect: Coëffé & O'Regan, 1987; Findlay, 1982; McConkie et al., 1988, 1989; Nuthmann, Engbert, & Kliegl, 2005; O'Regan & Lévy-Schoen, 1987). In support of this are studies showing a similar PVL in non-linguistic stimuli (e.g., Ducrot & Pynte, 2002; Vitu, O'Regan, Inhoff, & Topolski, 1995). Furthermore, Rayner (1979) reported that, for regressive (right-to-left) saccades, the eyes tended to land close to the word centre, with a shift towards the end of words for longer words, which is what one would expect from an "aim-for-center" strategy accompanied by undershoot (see also Radach & McConkie 1998).

Several studies have shown that it is physical length (in degrees of visual angle - sometimes referred to as spatial width) rather than orthographic length (i.e., number of letters) that determines ILPs during reading (Hautala, Hyönä, & Aro, 2011; Hautala & Loberg, 2015; Hermena, Liversedge, & Drieghe, 2016; McDonald, 2006). Hautala and colleagues (2011) independently manipulated physical length and orthographic length by exploiting the variable letter size of proportional fonts, such that 4-letter and 6-letter words were matched on physical length when printed in Arial font and

had the same physical length as the 4-letter words printed in Courier New (a monospaced font), with the 6-letter words printed in Courier font therefore being physically longer. In line with the findings of McDonald (2006), ILPs were determined by physical length not orthographic length (see also Hermena et al., 2016). This provides further evidence that eye guidance in reading is influenced principally by visuo-motor factors.

In order to further isolate such purely visuo-motor influences on saccade targeting, one means is to examine eye movements in a paradigm that does not necessarily involve linguistic stimuli and linguistic processing. One such paradigm is the oculomotor lateralized bisection task . Using this task, Ducrot and Pynte (2002) found evidence that the presence of between-character space information influences saccade programming in conditions where there is only a single target. Ducrot and Pynte (2002) asked participants to move their eyes to the center of a stimulus presented to the right or the left of a central fixation point. The stimulus could either be a word, a nonword, a string of hash marks (#), a dotted line, or a solid line (depending on the experiment). The results showed that ILPs were on average left of center for stimuli presented to the right of fixation, and around the center for stimuli presented to the left. Furthermore, solid lines showed a more symmetrical pattern of ILPs across the visual fields than the other kinds of stimuli, with similar saccade amplitudes to the left and to the right. The stimuli with inter-character spacing, on the other hand, showed an asymmetrical pattern of ILPs, with shorter saccades to the right than to the left. These results suggest that reading habits have an influence of saccade targeting, and that “linguistic-like” stimuli (i.e., with inter-character spaces) encourage a saccade targeting strategy that aims to land left of the center of targets (i.e., the PVL), with a greater difficulty in reaching this goal for targets in the left visual field due to the greater distance.

In the present study, we use the same oculomotor lateralized bisection task as Ducrot and Pynte (2002) in order to study saccade programming in beginning readers and dyslexic children in conditions that minimize the influence of linguistic factors. Furthermore, even if the oculomotor

bisection task is not a reading task, it elicits saccade targeting which is an integral part of the reading process (Ducrot & Pynte, 2002), and it is particularly advantageous to use such a non-linguistic task when testing children with reading impairment. Oculomotor behavior changes during reading development, with longer saccades, shorter fixations, and more refixations (Blythe, 2014; Blythe & Joseph, 2011; Rayner, 2009). Furthermore, the perceptual span, measured using the moving window technique (McConkie & Rayner, 1975), increases during reading development, but the asymmetrical nature of the span (extending further in the direction of reading) is already present in beginning readers (Rayner, 1986; Häikiö et al., 2009). Concerning ILPs, several developmental studies suggest that an adult-like pattern is attained very rapidly during learning to read, and that although beginning readers do tend to initially fixate words closer to their beginning, the overall shift in ILPs is no greater than half a character (Ducrot, Pynte, Ghio, & Lété, 2013; Huestegge, Radach, Corbic, & Huestegge, 2009; Vorstius, Radach, & Lonigan, 2014; Joseph, Liversedge, Blythe, White, & Rayner, 2009 – see Blythe, 2014, and Schroeder, Hyöna, & Liversedge, 2015, for reviews). Joseph and colleagues (2009) further demonstrated that the influence of word length on ILP distributions in 10-year old children is similar to the pattern seen with adults. Also relevant for the present study are studies (MacKeben, Trauzette-Klosinski, Reinhard, Durrwachter, Adler, & Klosinski, 2004; Hawelka, Gagl, & Wimmer, 2010; Gagl, Hawelka, & Hutzler, 2014) reporting that dyslexic readers tend to target the word beginning more often than fluent readers.

In prior work using the oculomotor lateralized bisection paradigm with children, Bellocchi and colleagues (2013a) found that the average landing positions of fifth grade typical reading children were left of center for stimuli with inter-character spaces (words and strings of hash marks) in both visual fields. Interestingly, beginning readers and dyslexic children were also influenced by the linguistic nature of stimuli such that ILPs were shifted more toward the beginning of the string when the stimulus was a word compared with strings of hashes. In the present study, we build on this prior work using the oculomotor lateralized bisection task with children, providing a further

investigation of differences between dyslexic children and their reading-level matched and chronological-age matched controls. Here we specifically examine a possible role for inter-character spacing in eye-guidance in these children. There is indeed evidence that a small increase in inter-letter spacing is beneficial for reading (Perea & Gomez, 2012a;b), and particularly for dyslexic children<sup>1</sup> (Perea, Panadero, Moret-Tatay, & Gomez, 2012; Zorzi et al., 2012). Perea and colleagues (2012) compared the spacing benefits for adults, and children with and without developmental dyslexia. They used both the lexical decision task and eye movement recording of natural sentence reading. While all groups benefitted from slightly increased inter-letter spacing, the dyslexic group exhibited significantly larger benefits (see also Spinelli, De Luca, Judica, & Zoccolotti, 2002). Zorzi and colleagues (2012) reported a similar pattern in French and Italian: they found an advantage of extra inter-letter spacing in reading times and comprehension rates when reading aloud short texts with dyslexic children, but not with two groups of normally developing readers. Although the standard interpretation of these findings is expressed in terms of a greater

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<sup>1</sup> *Developmental dyslexia* is diagnosed when no sensory and intellectual deficits can explain reading and/or writing disorders and when adequate instruction and socio-cultural opportunities are available but fail to result in an adequate level of performance (W.H.O., 1992). Even if one of the most widely accepted explanations of *developmental dyslexia* posits a core deficit at the phonological level of processing, a number of studies highlighted alternative deficits associated to reading disorder. The general idea is that a lower-level deficit can be linked to dyslexia together with the phonological one (e.g. Goswami, Power, Lallier, & Facoetti, 2014). In particular, an important number of evidences showed the presence of visual deficits in developmental dyslexia, affecting both high-level visuo-attentional skills or low level visual-perceptual skills (e.g. Bellocchi, Muneaux, Bastien-Toniazzo, & Ducrot, 2013b; Bellocchi, Muneaux, Huau, Lévêque, Jover, & Ducrot, 2017; Bosse, Tainturier, & Valdois, 2007; Jainta & Kapoula, 2011).

benefit of decreased crowding for dyslexic children (e.g. Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009; Pelli & Tillman, 2008; Spinelli et al., 2002; see Gori & Facoetti, 2015 for a detailed review), it is possible that changes in inter-letter spacing also affect oculomotor control, with an increase in saccade targeting accuracy accompanying an increase in inter-letter spacing. The present study puts this complementary interpretation to test.

Summing up, in the present study we examined whether 7-year-old, 10-year-old typical developing readers and dyslexic children differ in their saccade targeting strategies, and whether an increase in inter-letter spacing could impact saccade programming in these children. We hypothesized that if a beneficial effect of increased inter-letter spacing is observed, this effect may occur especially for children who have not yet fully developed oculomotor mechanisms for efficient reading (i.e., dyslexics and the reading-level matched control group). In particular, an increase in inter-letter spacing may help these children to improve fine-tuned saccade targeting which would result in more accurate targeting of the PVL in both visual fields.

## **EXPERIMENT 1**

### **METHOD**

**Participants.** In total, 67 children took part in the study: 24 dyslexics (D) (mean age in months = 125.3; SD =7.8 months) and two control groups composed of typical developing readers, the first of these being a chronological-age matched group (CA) (15 children; mean age in months = 122.3; SD =3.8 months) and the second a reading-age matched group (RA) (28 children; mean age in months = 86.8; SD =6.7 months). Note that in this study we will also refer to RA group with the term ‘beginning readers’.

Dyslexic children were recruited at the Hospital of Aix-en-Provence, France. They all received a complete medical, psychological, neuropsychological, and cognitive assessment by an interdisciplinary team of psychologists, neurologists, and speech therapists. Criteria for inclusion in the sample were manifest reading deficits (at least 2 SDs below the normal level) on a standardized reading test (Lefavrais, 1967; 2005), IQ level measured with the WISC-IV (French version by ECPA- Wechsler, 2005) within normal limits ( $> 85$ ) and absence of sensory deficits regarding vision or hearing. They were excluded from the study if their oral language skills were in pathological range or they were diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) or developmental coordination disorder (DCD). All participants were native French-speakers with normal or corrected-to-normal vision.

The participants of the control groups were recruited from a primary school in a town in southern France, from Grade 1 to Grade 5, according to the reading (Grade 1 or 2) and chronological (Grade 5) age of the dyslexic children. They were native speakers of French and had normal or corrected-to-normal vision; none suffered from any neurological, psychiatric, or emotional disorders or were educationally disadvantaged. Inclusion criteria were normal reading level and absence of sensory deficits regarding vision or hearing. We also excluded children who were considered by their teachers as either having specific learning disabilities, cognitive deficits or behavioral difficulties (i.e., children who exhibited attentional or other behavioral problems in class).

Dyslexics' and normal readers reading abilities were tested using the standardized French reading test "L'Alouette" (Lefavrais, 1967; 2005) which provides a measure of reading age. As we noted by paired comparisons, the mean reading level of the dyslexic children (mean in months = 90.3,  $SD=5.5$  months) was significantly below the mean reading level of the chronological age matched group (mean in months = 116.1,  $SD=18.4$  months ;  $p < .001$ ,  $d = 2.54$ ). However, as expected, the mean reading level of the dyslexic children was not significantly different from that of

the reading-level matched children (mean in months= 87.7, SD=7.3 months;  $p=.13$ ,  $d=.46$ ) (ANOVA; group effect:  $F(2,64) = 40.47$ ,  $p < .001$ ,  $\eta^2 = .56$ ).

The study was approved by the local Ethics Committee Review Board (Comité de Protection des Personnes pour la recherche biomédicale, CNRS, France). In accordance with the Declaration of Helsinki (WHO, 2008), informed consent of children's parents was obtained for each participant.

**Materials, design, and stimuli.** In selecting materials, we manipulated three factors: (1) *Type of stimulus* (Words vs Strings of hashes), (2) *Visual Field* (VF; left visual field-LVF vs right visual field-RVF) and (3) the inter-character spacing (extra spacing vs default spacing) hereafter referred to as *Spacing*. Participants were presented two lists of stimuli: 48 words and 48 strings of hashes. Half of the words had a low frequency (LF)- that is, a mean printed frequency of 16 occurrences per million – and the other half were high frequency (HF), with a mean printed frequency of 419 occurrences per million. The words were selected from the first-grade lemma lexicon of Manulex (Lété, Sprenger-Charolles, & Colé, 2004). All the stimuli, words or strings of hashes, were 5 or 6 characters long (see Appendix, Table B.1). The stimulus was displayed on the right or left of the fixation point (LVF or RVF) at a distance of  $1.25^\circ$  from the end (LVF) and the beginning (RVF) of the stimulus, and each stimulus was presented with either extra-spacing or with default spacing (see Figure 1).

[Figure 1 about here]

All children were tested individually: dyslexics were tested at the “Laboratoire Parole et Langage”, CNRS & Aix-Marseille Université and normal readers were tested at their schools. Eye movements were collected by a mobile infrared, head-mounted eye tracker (Eyelink 2, SR Research Ltd., Canada). Prior to the experiment, the eye-tracker was calibrated using a 9-point calibration

grid that extended over the entire computer screen. The eye tracker was interfaced with a Dell D-type docking station and a Dell Latitude D600 laptop computer. The target stimuli were displayed in white lowercase letters against a black background in 22-point Courier New font<sup>2</sup>, using a 14-inch colour monitor, at a resolution of 1400×1050. Participants were seated 60 cm from the screen. At this distance, one letter subtended a visual angle of 0.38° and 1° is equal to 0.95 cm. In the default condition, the space between letters was 1 mm that corresponds to 2.8 pt or 0.09°. In the extra-spacing condition space between characters was 4 mm that corresponds to 11.3 pts or 0.38° (note that 1 pt = 0.353 mm in typesetting standards)<sup>3</sup>. The extra spacing was not greater than 35% of average letter width, as recommended by Slattery and colleagues (2016).

At the beginning of each trial, participants had to fixate the fixation cross displayed in the middle of the screen without moving their eyes. Five hundred milliseconds later, the fixation point

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<sup>2</sup> We used Courier New, a non-proportional fixed-width font, meaning that all characters are of equal width. This font ensures that the probability of any given character attracting a fixation is equal. Moreover, in order to facilitate legibility to beginning readers (Grade 1 and 2), we used a bigger font size than previous studies on adult readers (e.g., Perea & Gomez, 2012a;b; Perea et al., 2012; see Ducrot et al., 2013).

<sup>3</sup> In order to test this particular extra-spacing condition, we run a preliminary study where we tested 18 beginning readers (Grades 1 and 2) and 18 children skilled readers (Grade 5) in a lexical decision task. Each stimulus was presented with either extra-spacing or with default spacing. We found a significant lexicality effect [ $F(1,104) = 246.0, p < .001$ ] and longer lexical decision times for beginning readers than for skilled ones [ $F(1,34) = 16.3; p < .001$ ]. These findings suggest that, this particular extra-spacing condition did not totally disrupt word reading processing, allowing the lexical decision task to be sensitive to the lexical knowledge of the children.

was replaced by a stimulus that remained on the screen until the participant responded (time limit: 5000 ms) (see Figure 2 for a representation of the sequence of trials of the visual bisection task).

[Figure 2 about here]

Children were asked to perform an oculomotor lateralized bisection task: they were asked to move their eyes as quickly as possible to a position they thought to be the middle of the stimulus and to validate this position by pressing a button. They were instructed to respond as quickly and as accurately as possible. The stimuli were presented in two separate blocks with 48 trials each (48 words and 48 strings of hashes). The order of presentation of blocks was counterbalanced within the participants. In each frequency set of words (high and low frequency words), Visual Field and Spacing were randomly varied within the block. Furthermore, four lists of words were created and counterbalanced within the participants. Considering the string of hashes, Visual Field and Spacing conditions were randomized within the block. A five-item training phase was held at the beginning of each block. The entire experiment lasted approximately 15 minutes.

The eye-tracking data were analyzed using customized software script written in C++ (Emaa software package: Ducrot, Lété, Descottes, Muneaux, & Ghio, 2006).

**Data selection and analysis.** Trials were excluded from the analysis when an eye-tracker sampling error or a blink occurred during stimulus presentation, saccade latency was shorter than 80 ms or longer than 800 ms, the average eye position before saccade onset (as measured off-line) deviated from the fixation cross by more than  $\pm 1.5$  characters, the first saccade was smaller than 0.5 character, the first fixation in the stimuli lasted less than 40 ms or more than 2000 ms, the first fixation was not located inside the stimulus or participant took more than 5000 ms before pressing the button. After rejection, there remained 64 trials on average (range: 39-91) per participant.

The question of interest in the present study was whether saccade computation would be affected by reading level, type of stimulus, visual field and inter-character spacing. For each trial, the following eye-movement measures were computed: initial landing position (horizontal coordinate of the first fixation in the stimulus measured with respect to stimulus beginning, i.e. left side of the stimulus), latency (the duration of fixation on the cross before making a saccade) and the duration of the first fixation in the stimulus (the duration of fixation on the stimulus before making a refixation). Initial landing position was expressed in number of characters, saccade latency and initial fixation duration in milliseconds. In all analyses and for each dependent variable, means were calculated for each participant and each condition. Table A.1 (see Appendix A) shows mean of initial landing position, saccade latency, and initial fixation duration as a function of type of stimulus, inter-letter spacing, visual field, and group. By participants analyses of variance (F1) were run on these means using a 2 Visual Field x 2 type of stimulus x 2 spacing x 3 reading levels. All factors except Reading level were within-participant factors. By items analyses of variance (F2) were run using 3 reading levels (Group) as within-subject factor and 2 Visual Field x 2 type of stimulus x 2 spacing as between-subject factors. Bonferroni tests were used for post-hoc comparisons (i.e. p-values were Bonferroni corrected for multiple comparisons). Effect sizes are reported as eta-square ( $\eta^2$ , Bakeman, 2005) and Cohen's *d*.

## RESULTS

**Initial landing position.** There was a highly significant interaction between Visual Field x Spacing [ $F(1,64)=566.68$ ;  $p<.001$ ,  $\eta^2 = .881$ ;  $F(1,131)=200.37$ ;  $p<.001$ ,  $\eta^2 = .194$ , see Figures 3 and 4]. This interaction reflects the fact that while ILPs are further from the PVL in the LVF than the RVF in both the extra-spacing condition ( $p\ corr. < .001$ ,  $d = 3.59$ ) and the default spacing condition ( $p\ corr. < .001$ ,  $d = 1.22$ ), the effects are much stronger in the extra-spacing condition, with ILPs being on average to the right of the center of the stimulus in the LVF.

There was also a significant interaction between Visual Field and Group [ $F(2,64) = 5.51$ ;  $p < .05$ ,  $\eta^2 = .07$ ;  $F(2,262) = 21.84$ ;  $p < .05$ ,  $\eta^2 = .118$ ]. While in the RVF, the three groups of children did not differ with respect to ILPs, in the LVF ( $ps\ corr. > .22$ ), the children with higher reading levels (i.e. CA control group) tended to fixate closer to the PVL compared with the two other groups of children (Dyslexic and RA control groups,  $p\ corr. = .051$ ,  $d = .43$  and  $p\ corr. < .01$ ,  $d = .56$  respectively – see Figure 3).

As can be seen in Figures 3 and 4, these significant two-way interactions were conditioned by two significant three-way interactions. Firstly, there was a significant VF x Spacing x Group interaction [ $F(2,64) = 6.42$ ;  $p < .05$ ;  $\eta^2 = .020$ ;  $F(2,262) = 1.52$ ,  $p < .001$ ,  $\eta^2 = .044$ , see Figure 3]. Post-hoc analyses revealed that this interaction was due to the CA control group differing significantly from the two other groups in the two spacing conditions in the LVF ( $ps\ corr. < .01$ ,  $ds > .84$  and  $ps\ corr. < .001$ ,  $ds > .93$  for dyslexics and RA, respectively; other  $ps\ corr. > .73$ ). The proficient readers (CA control group) fixated closer to the PVL in the LVF compared with both the Dyslexic children and the RA-control group. Post-hoc tests also revealed that the effect of the VF was almost always significant ( $ps\ corr. < .01$ ,  $ds > 1.38$ ) except for CA-control children in the default-spaced condition ( $p\ corr. = .75$ ). This indicates that CA-control children were able to fixate the PVL in both visual fields only when the stimulus was displayed with a default-spacing. Children of all groups were disrupted (i.e. had trouble to land close to the PVL) when there were extra-spacing between the characters of the stimuli.

[Figure 3 about here]

Second, the VF x Spacing x Stimulus interaction was significant [ $F(1,64) = 14.25$ ;  $p < .001$ ,  $\eta^2 = .176$ ;  $F(1,131) = 2.89$ ,  $p = .09$ ,  $\eta^2 = .003$ ] (see Figure 4). Post-hoc tests revealed that this three-way interaction derived from the difference between words and hashes being significant in the LVF

for extra-spaced stimuli ( $p \text{ corr.} < .001$ ,  $d = .49$ ; other  $ps \text{ corr.} > .08$ ). In these particular conditions (extra-spaced stimuli displayed in the LVF), children had a stronger bias to fixate toward the end of the stimulus with hashes ( $M=6.4$ ;  $SD= 1.3$ ) compared with words ( $M=5.8$ ;  $SD= 1.2$ ).

[Figure 4 about here]

**Saccade latency.** There was a significant interaction between Group and Spacing [ $F(2,64)=4.43$ ,  $p<.05$ ,  $\eta^2 =.061$ ;  $F(2,262)<1$ ,  $p>.1$ <sup>4</sup>, see Figure 5]. Post-hoc analyses showed that saccade latencies were significantly longer in the extra-spacing condition compared to the default condition in all groups ( $ps \text{ corr.} < .01$ ,  $ds >.23$ ), confirming that extra-spacing incurs a cost for saccade programming. Furthermore, while dyslexic children differed significantly from the CA-control children in the two spacing conditions ( $ps \text{ corr.} <.001$ ,  $ds >.74$ ), they differed significantly from RA children only in the extra-spacing condition ( $p \text{ corr.} <.001$   $d =.63$ ) and not in the default condition ( $p \text{ corr.} = .17$ ). This reflects the fact that the lengthening of saccade latency due to extra spacing was less pronounced for Dyslexic children than for both the CA and RA control groups.

[Figure 5 about here]

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<sup>4</sup> The by item analysis revealed Spacing, Group and Visual Field effects [Spacing:

$F(1,131)=35.57$ ;  $p<.001$ ,  $\eta^2 = .197$ ; Group:  $F(2,262)=160.01$ ,  $p<.001$ ,  $\eta^2 = .527$ ; Visual Field:

$F(1,131)=9.91$ ,  $p<.05$ ,  $\eta^2 = .055$ ].

**Initial fixation duration.** There was a significant interaction between Visual Field and Spacing only in the by participants analysis [ $F(1,64)=14.07$ ;  $p<.001$ ,  $\eta^2 = .179$ ;  $F2<1$ ]<sup>5</sup>. This interaction reflects the fact that the effect of visual field was not significant in the extra-spacing condition (LVF:  $M= 327$  ms,  $SD = 250$  ms; RVF:  $m = 316$  ms,  $SD = 99$ ;  $p$  corr.  $>.99$ ), while in the default condition initial fixation durations were significantly shorter in the LVF ( $M= 600$  ms,  $SD = 249$  ms) than in the RVF ( $M = 682.5$  ms,  $SD = 141$  ms;  $p$ . corr.  $<.01$ ,  $d =.33$ ).

These results can easily be linked to a “first-fixation duration inverted-OVP effect” (Vitu, et al., 2001; Nuthmann et al., 2005), that predicts that initial fixation duration is greater when the eyes are at the center of the words or slightly to the left of it. In our experiment, this position would correspond to characters 2-3 of 5 in the default spacing condition and to characters 3.5-5 of 9 in the extra-spacing condition (see grey areas on Figure 3 and 4). Thus, when participants landed further from the PVL, as it was the case in the extra-spacing condition (see upper panels of Figure 3), they rapidly left the stimulus to target the PVL with the next fixation. To the contrary, when participants landed closer to the PVL, as it was the case in the default condition and particularly in the RVF (see lower panels of Figure 3), they fixated longer to process the stimulus. This finding was previously reported in Finnish (Hyönä & Bertram, 2001) and French (Vitu et al., 2001) and has been found in both adults and children (e.g., Gagl et al. 2014; Huestegge et al., 2009; Joseph et al., 2009; Vitu et al., 2001). However, only a few studies have investigated landing position effects in impaired readers (Gagl et al., 2014; Hawelka et al., 2010; MacKeben et al., 2004). Our results are in line with those of Gagl et al. (2014) showing that poor readers show an intact mechanism for performing corrective re-fixations. The authors suggested that this mechanism is not linked to linguistic

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<sup>5</sup> The by item analysis revealed a Spacing effect [ $F2(1,92)=86.82$ ;  $p<.001$ ,  $\eta^2 = .462$ ] showing that initial fixation duration was longer in extra-spacing condition ( $M = 312$  ms,  $SE = 26$  ms) than in default one ( $M = 650$  ms,  $SE = 26$  ms).

processing but to visual and oculomotor processes, which suggests the integrity of oculomotor and visual processes in poor readers.

## **DISCUSSION**

The results of Experiment 1 showed that rightward saccades toward stimuli located in the RVF were not significantly affected by stimulus type and reading level, and only slightly affected by spacing. On the other hand, leftward saccades toward stimuli in the LVF were affected by all three factors. Extra spacing caused a large shift in ILPs towards the end of stimuli in the LVF, and this shift was marginally greater for hashes compared with words. This negative effect was observable in all participants, although the proficient readers (CA control group) fixated closer to the beginning of the stimuli in the LVF compared with both the dyslexic children and the RA control group. Extra spacing also increased saccade latencies and decreased initial fixation durations, thus confirming the detrimental role of the extra spacing (e.g. Perea & Gomez, 2012b; Slattery & Rayner, 2013). These results suggest that, as a result of reading experience, the children tested in this experiment had already developed highly automatized procedures for programming rightward saccades. On the other hand, the fact that leftward saccades are much rarer than rightward saccades in reading (15% of all saccades) would lead to less automatized procedures for saccade targeting, hence allowing for a greater influence of the different variables that were manipulated.

## **EXPERIMENT 2**

Given that the increased inter-character spacing in Experiment 1 was confounded with an increase in stimulus length, a second experiment was run to disentangle the role of inter-letter spacing and spatial width on saccade computation.

## **METHOD**

**Participants.** Twenty-three children participated in the study (mean age in months = 129; SD = 3.8 months). The participants were recruited from a primary school in a city in southern France. As for experiment 1, the children's parents gave their written consent for participation. They were native speakers of French and had normal or corrected-to-normal vision; none suffered from any neurological, psychiatric, or emotional disorders or were educationally disadvantaged. Inclusion criteria were normal reading level and absence of sensory deficits regarding vision or hearing. We also excluded children who were considered by their teachers as either having specific learning disabilities, cognitive deficits or behavioral difficulties (i.e., children who exhibited attentional or other behavioral problems in class). As in Experiment 1, participants' reading abilities were tested using the standardized French reading test "L'Alouette" (Lefavrais, 1967; 2005) which provides a measure of reading level expressed as reading age (mean in months = 128.7; SD=20 months).

**Materials, design, and stimuli.** A pool of 96 five and nine-letter words was selected from Manulex (Lété, et al., 2004). In order to prevent the impact of morphological structure of words on saccadic computation (e.g. Hyönä & Pollatsek, 1998; Yan, Zhou, Shu, Yusupu, Miao, Krügel, & Kliegl, 2014), we controlled for the proportion of derived words (prefixed and suffixed in the two sets -5 extra-spaced letters words and 9 default inter-letter spacing words). Note that 20% of the words were derived in each set. As in Experiment 1, half of the words had a low frequency (LF)- that is, a mean printed frequency of 16 occurrences per million – and the other half were high frequency (HF), with a mean printed frequency of 419 occurrences per million (see list in the Appendices, Table B.2).

In order to disentangle the role of inter-letter spacing and spatial width on saccade computation, stimuli were made the same spatial width in the extra-spacing and default condition by reducing the number of characters in the extra-spacing condition (5 expanded letters words and 9

default inter-letter spacing words, see Figure 6). Extra-spaced stimuli were created following the same procedure used in Experiment 1. As in Experiment 1, the stimulus was displayed on the right or left of the fixation point (LVF or RVF) at a distance of  $1.25^\circ$  from it.

Three factors were thus manipulated: (1) *Type of stimulus* (Words vs String of Hashes), (2) *Visual Field* (VF; left visual field-LVF vs right visual field-RVF) and (3) *Inter-letter Spacing* (extra-spacing condition, corresponding to the 5-character strings vs default condition, corresponding to the 9-character strings) hereafter referred to as *Spacing*.

[Figure 6 about here]

**Apparatus and procedure.** Apparatus and procedure were the same as Experiment 1 (see Figure 2 for a schematic representation of the sequence of trials). Stimuli were presented in two separate blocks with 96 trials each (96 words and 96 strings of hashes). Here, as in Experiment 1, the order of presentation of blocks was counterbalanced within the participants. In each frequency set of words (high and low frequency words), Visual Field and Spacing were randomly varied within the block. Four lists of words were created and counterbalanced within the participants. Finally, considering the string of hashes, Visual Field and Spacing were randomized within the block. As in Experiment 1, children were asked to perform a oculomotor lateralized bisection task. The entire experiment lasted approximately 15 minutes.

**Data selection and analysis.** The eye-tracking data were analyzed using customized software script written in C++ (Emaa software package: Ducrot et al., 2006). The same exclusion criteria as in Experiment 1 were used for data of Experiment 2. This resulted in a rejection of 23 % of the trials. After rejection, there remained 148 trials on average (range: 97-176) per participant.

The question of interest in the present study was whether the saccade computation was affected by type of stimulus, visual field and inter-letter spacing when controlling for spatial width.

As in Experiment 1, the following eye-movement measures were computed for each trial: initial landing position, latency and the duration of the first fixation. In all analyses and for each dependent variable, means were calculated for each participant and each condition. Table A.2 (Appendix A) shows mean of initial landing position, saccade latency, and initial fixation duration as a function of type of stimulus, inter-letter spacing, and visual field. By participants analyses of variance (F1) were run on these means using a 2 Visual Field x 2 type of stimulus x 2 spacing. All factor were within-participant factors. By items analyses of variance (F2) were run using 2 Visual Field x 2 type of stimulus x 2 spacing as between-subject factors.

## RESULTS

**Initial landing position.** In line with Experiment 1, the results of Experiment 2 showed a VF x Spacing interaction [ $F(1,22)=16.09, p<.001, \eta^2= .019$ ;  $F(1,196)=22.57, p<.001, \eta^2= .007$ , see Figure 7]. As revealed by post-hoc analyses, this interaction is driven by the fact that although ILPs were further from the PVL in the LVF than the RVF in both spacing conditions (*ps corr.*  $<.001, ds > 2.48$ ), the effect of spacing was only significant in the LVF (*p corr.*  $<.001, d =.34$ ), but not in the RVF (*p corr.*  $= .19$ ). This indicates that in the LVF, ILPs were significantly closer to the PVL in the default condition compared with the extra-spacing condition.

[Figure 7 about here]

**Saccade latency.** There was a significant Spacing x VF interaction [ $F(1,22)=17.4, p<.001, \eta^2 = .011$ ;  $F(1,196)=7.52, p<.05, \eta^2 = .022$ ]. In line with the result of Experiment 1, post-hoc analyses showed that saccade latencies were significantly longer in the extra-spacing condition in both visual fields (Extra-spacing LVF:  $M = 187$  ms;  $SD = 20$  ms; Extra-spacing RVF:  $M = 195$  ms,  $SD = 20$  ms; Default LVF:  $M = 182$  ms,  $SD = 19$  ms, Default RVF:  $M = 183$  ms,  $SD = 17$  ms; *ps corr.*  $< .05, ds > .26$ ), confirming again that extra spacing induces a cost for saccade programming.

Furthermore, post-hoc tests highlighted that there was no difference between LVF and RVF in the default condition ( $p \text{ corr.} = .79$ ; see Ducrot & Pynte, 2002, for similar results) while there was a difference in the extra-spacing condition ( $p \text{ corr.} < .01$ ,  $d = .42$ ). However, the difference was only 8 ms on average.

**Initial fixation duration.** Initial fixation durations were affected by Visual field [ $F(1,22)=6.50$ ,  $p < .05$ ,  $\eta^2 = .049$ ;  $F(1,196)=32.76$ ,  $p < .001$ ,  $\eta^2 = .110$ ] and Spacing [ $F(1,22)=24.68$ ,  $p < .001$ ,  $\eta^2 = .061$ ;  $F(1,196)=59.30$ ,  $p < .001$ ,  $\eta^2 = .200$ ]. In line with Experiment 1, initial fixation durations were longer in the RVF ( $M = 333$  ms;  $SD = 112$  ms) compared with the LVF ( $M = 290$  ms;  $SD = 78$  ms) and were also longer in the default spacing condition ( $M = 335$  ms;  $SD = 109$  ms) compared with the extra-spacing condition ( $M = 288$  ms;  $SD = 81$  ms). Again, this finding can be linked to ILPs, since the closer the ILP was to the PVL, the longer was the first fixation duration.

## DISCUSSION

Experiment 2 was designed to disentangle the role of spacing and spatial width in saccade computation. If children were not able to reach the PVL in the extra-spacing condition of Experiment 1 solely as the result of the greater spatial width of the stimuli in the extra-spacing condition, then Experiment 2 (where spatial width was made constant in the default and extra-spacing conditions) should not have revealed any effect of inter-letter spacing. However, our results showed that inter-letter spacing still influenced saccade computation, thus confirming the detrimental effect of extra-spacing both for temporal and spatial eye-movement measures.

In particular, the ILPs were again significantly closer to the PVL in the LVF in the default condition than in the extra-spacing condition. Nevertheless, the effect of inter-letter spacing on ILPs was less pronounced in Experiment 2 than in Experiment 1. This suggests that the effect observed

in Experiment 1 was also due, at least partly, to the spatial width of the stimuli. If not, children would also have been able in Experiment 2 to reach the PVL in the LVF in the default-spaced condition (with 9-non-spaced characters). The key finding in Experiment 2 is that children were closer to the PVL with 9-non-spaced characters than with 5-spaced characters. A similar result had previously been reported by Hautala and Loberg (2015), who reported that, for a similar spatial width, the greater the number of letters, the easier it was to reach the center of the targeted stimulus. Our results showed that this was particularly true in the LVF.

The same pattern of results was observed for saccade latency. Children took longer to initiate their saccade towards extra-spaced stimuli compared with default-spaced stimuli. Moreover, the difference between the extra-spacing and default spacing conditions was larger in the RVF than in the LVF, thus suggesting a link with reading habits and left-to-right attentional scanning. This may suggest that the atypical visual configuration in the extra-spacing condition has a more marked detrimental effect on the visual field linked to reading direction, i.e. the RVF. In addition, as previously shown by Perea and Gomez (2012b) and by Slattery and Rayner (2013), our results showed that increased inter-letter spacing caused a decrease in initial fixation durations, thus confirming the detrimental role of the extra spacing. Indeed, short initial fixations are due to initially landing on suboptimal locations that typically causes a corrective saccade towards the PVL.

## **GENERAL DISCUSSION**

In the present study we examined whether 7-year-old, 10-year-old typical developing readers and dyslexic children differ in their saccade targeting strategies, and whether an increase in inter-letter spacing could impact saccade programming in these children. To do that, in two experiments, eye movements were recorded while children performed an oculomotor lateralized bisection task on isolated words and strings of hashes.

Results of Experiment 1 showed that rightward saccades toward stimuli located in the RVF were not affected by stimulus type and reading level and only slightly modulated by spacing. In contrast, leftward saccades toward stimuli in the LVF were influenced by stimulus type, reading level and spacing. In particular, extra spacing caused a large shift in ILPs towards the end of stimuli in the LVF, and this shift was marginally greater for hashes than words. This detrimental effect occurred for all participants, although proficient readers (CA control group) fixated closer to the beginning of the stimuli in the LVF compared with both the dyslexic and the RA control groups. Extra spacing also increased saccade latency and decreased initial fixation duration, thus confirming the detrimental role of the extra spacing on saccade computation (e.g. Perea & Gomez, 2012b; Slattery & Rayner, 2013). In line with the latter result, it has been recently shown that while average fixation durations are shorter when using increases of inter-character spacing, there are more fixations, and this cancelled out the effect of inter-character spacing in total reading times (Perea, Giner, Marcet & Gomez, 2016; Perea & Gomez, 2012b). Perea and colleagues (2016) showed this pattern during text reading in adult skilled readers and they concluded that inter-letter spacing does not seem to play a consistently facilitative role during text reading.

Experiment 2 provided evidence that inter-letter spacing still had an impact when controlling for spatial width by comparing 9-non-spaced characters with 5-spaced characters. Indeed, children were closer to the PVL with 9-non-spaced characters than with 5-spaced characters (see Hautala & Loberg, 2015, for similar results). Note that nevertheless, the effect of inter-letter spacing on ILPs was less pronounced in Experiment 2 than in Experiment 1 suggesting that the spatial width of the stimuli accentuated the effect in Experiment 1. Again, as it was observed in Experiment 1, children took longer to initiate saccade towards extra-spaced stimuli compared with default-spaced stimuli and initial fixation durations decreased (Perea & Gomez; 2012b; Slattery & Rayner, 2013). The overall results confirmed the detrimental effect of extra spacing for saccade computation, even when spatial width is controlled.

Interestingly, our study showed that all the children tend to first fixate a position between the middle and the beginning of the stimulus (PVL) while executing rightward saccades, regardless of their reading level (RA, dyslexic or CA group) and the spacing condition (default or extra spacing). In other words, from the first year of exposure to reading, children show a PVL targeting their saccades towards the word center, as it is observable in adult expert readers, while executing rightward saccades (for similar results, see Bellocchi et al., 2013a; Ducrot et al., 2013; Joseph et al., 2009). Moreover, this oculomotor pattern occurs for both linguistic and “linguistic-like” stimuli (i.e., with inter-character spaces). According to Ducrot and Pynte (2002), these findings confirm that, as a result of reading experience, our sample of children had already developed highly automatized procedures for programming rightward saccades. Sure enough, rightward saccades represent the most frequent saccades in left-to-right writing systems leading to an early development of automatized procedures for saccade computation.

On the other hand, leftward saccades toward stimuli in the LVF were affected by stimulus type, reading level, and spacing. Indeed, the left/right asymmetry in the size of saccades launched towards isolated and parafoveally located stimuli deserves particular attention. As stated before, “linguistic-like” stimuli encourage a saccade targeting strategy that aims to land at the PVL, with a greater difficulty in reaching this goal for targets in the LVF due to the greater distance and an unusual reading direction (i.e. right-to-left reading direction) (Ducrot & Pynte, 2002; Vitu et al., 1995). In that sense, for regressive saccades, the eyes tend to land close to the word center, with a shift towards the end for longer words (Rayner, 1979). In the default spacing condition of the Experiment 1, our results showed a more pronounced asymmetry in the LVF for CA-controls than dyslexic and beginning readers (see Bellocchi et al., 2013a, for similar results). Like adults, CA control children showed a PVL targeting their saccades towards the stimulus center, in both words and “linguistic-like” stimuli, even in the LVF. The results therefore suggest that the pre-processing mechanism responsible for the direction of attentional scanning (left-to-right) proposed in Ducrot

and Pynte (2002) is well automatized in these children. In contrast, beginning readers and dyslexic children were influenced by the linguistic nature of stimuli, in the LVF, such that ILPs were shifted more toward the beginning of the string for words compared with strings of hashes. The absence of an asymmetrical landing position pattern for “linguistic-like” stimuli suggests that in dyslexic and beginning readers the pre-processing mechanism responsible for the direction of attentional scanning is not entirely operational for the LVF. Only proficient readers had already developed highly automatized procedures for using a saccade targeting strategy that aims to land left of the center of targets (i.e., the PVL) in both VFs for all “linguistic-like” stimuli (i.e., with inter-character spaces). Considering the similar pattern of results for beginning readers (RA control group) and dyslexics, we suggest that the atypical saccade targeting we observed in dyslexic children, relative to chronological age controls, reflects their reading difficulties and/or a lack of experience with written language. Again, this atypical saccade computation especially emerged when executing leftward saccades in the LVF.

Since leftward saccades are much rarer than rightward saccades in reading (15% of all saccades), procedures for saccade targeting would be less automatized, hence allowing for a greater influence of spacing, stimulus type and reading level. Indeed, as already mentioned, extra spacing had a detrimental effect on saccade computation, especially in the LVF (i.e., extra spacing caused a large shift in ILPs towards the end of stimuli in the LVF). This negative effect occurred for all participants, although, proficient readers are less affected. This difference can be explained thanks to the pattern in the default condition. As a whole, our results suggest that when challenging reading habits (i.e. programming a right-to-left saccade), differences with respect to reading level and spacing emerged, i.e. beginning and dyslexic readers did not show highly automatized procedures for saccade computation, thus leading a detrimental effect of extra spacing on both temporal and spatial eye-movement measures.

As previously stated, Ducrot and colleagues (2013) have explored the effect of visual field on saccade computation on a classical reading task, i.e. lexical decision task (LDT), in normal readers from Grade 1 to 5. These authors clearly showed: 1) longer saccades for the left-presented stimuli than for the right-ones, with differences between reading levels; 2) longer lexical-decision time for left presentation than for right presentation for all reading levels. Former result is coherent with the fact that ILPs was located left of center for both left and right presentations, but only for proficient readers (Grade 4 and 5). The latter result suggested RVF advantage for words for all grades which is consistent with the finding that, from the first year of reading exposure, children had already developed highly automatized procedures for programming rightward saccades. As a whole, these results are consistent with some of the main findings of the present study based upon an oculomotor bisection task.

Indeed, the relevance of saccade computation on reading is well established in the literature. As stated in the Introduction section, numerous studies explored the effect of visuo-motor and linguistic constraints that may modulate saccade computation during reading. Several studies have shown that it is physical length rather than orthographic length that determines ILPs during reading (Hautala et al., 2011; Hermena et al., 2016; McDonald, 2006). Furthermore, in the present study we provided evidence that inter-letter spacing still had a negative impact when controlling for spatial width (Experiment 2). In other words, in accordance with Hautala and Loberg's findings (2015), children were closer to the PVL with 9-non-spaced characters than with 5-spaced characters, both stimuli having similar spatial width.

Moreover, concerning the main predictions of the present study, we hypothesized that if a beneficial effect of increased inter-letter spacing is observed on reading, this effect may occur especially for children who have not yet fully developed oculomotor mechanisms for efficient reading (i.e., dyslexics and beginning readers-RA control group). In particular, an increase in inter-letter spacing may help these children to improve fine-tuned saccade targeting which would result

in more accurate targeting of the PVL in both visual fields. In contrast with these predictions, extra spacing did not help to improve fine-tuned saccade targeting, but rather had a detrimental effect. Note that in our experiments, the stimulus appeared in the parafovea, either left or right of a central fixation point, and the participants were led to move their eyes so as to be in a more convenient position for performing the task. Although this technique made it possible to directly record landing positions in isolated words and to partly control for the possible influence of oculomotor constraints, we are aware that it can be considered only as a remote analogue of natural reading (i.e. sentence or text reading). Remember, however, that the hypothesis under consideration was precisely that some of the factors involved in the PVL effect in natural reading are also operating during the targeting of isolated words. If extra-spacing had no beneficial effect here, with a task in which eye guidance could more plausibly be directed by strategic factors, it is unlikely to improve saccade computation in natural reading. Consequently, the beneficial effect of increased inter-letter spacing reported for reading is more likely to be explained in terms of a decreased visual crowding than of an improved saccade targeting (e.g. Martelli et al., 2009; Pelli & Tillman, 2008; Spinelli et al., 2002, see Gori & Facoetti, 2015 for a detailed review). Some studies showed that beneficial effect of extra spacing is larger for dyslexics compared to normal readers (e.g. Perea et al., 2012; Spinelli et al., 2002; Zorzi et al., 2012, but see, Hakvoort, van den Boer, Leenaars, Bos & Tijms, 2017, for a different point of view). This seems to be coherent with evidence showing that dyslexics are abnormally affected by visual crowding (e.g. Martelli et al., 2009; Spinelli et al., 2002).

Summing up, our study showed that firstly, only proficient readers had already developed highly automatized procedures for programming both left- and rightward saccades, depending on the discreteness of the stimuli. Here, dyslexics showed an atypical saccade targeting, which might reflect reading difficulties and/or a lack of experience with written language. Secondly, for all children, extra spacing had a detrimental effect both on temporal and spatial eye-movement measures, especially for stimuli presented in the left visual field. Given its detrimental effect, our

results reinforce the idea that increased inter-letter spacing reduces visual crowding rather than improving saccade targeting.

From a developmental perspective, our study gives contributions to an important but yet less explored field of research. As a result of reading experience, children have quickly developed highly automatized procedures for programming rightward saccades. This occurs at the very early stages of reading development (after 1 year of exposure to reading) and, interestingly, despite the presence of reading impairment. However, when challenging reading habits by executing leftward saccades, beginning and dyslexic readers showed atypical targeting, suggesting less automatized procedures for saccade computation. As a whole, from the first year of exposure to reading, eye guidance in reading is massively influenced by visuo-motor factors.

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## Appendices

Stimulus	Initial landing											
	position				Saccade latency				Initial fixation duration			
	LVF		RVF		LVF		RVF		LVF		RVF	
	E	D	E	D	E	D	E	D	E	D	E	D
<b>Dyslexics</b>												
Hashes	6.53	2.94	2.44	2.04	185.73	176.76	185.02	175.24	328.00	575.75	297.96	677.49
Words	5.59	2.72	2.53	1.93	178.38	175.85	177.26	174.27	290.01	528.67	275.87	582.44
<b>CA</b>												
Hashes	5.51	2.21	2.35	1.94	163.25	157.78	168.76	159.74	369.20	815.46	284.27	808.58
Words	5.26	2.19	2.32	1.89	158.61	149.86	159.78	150.62	346.00	659.09	270.09	609.85
<b>RA</b>												
Hashes	7.12	2.92	2.20	2.05	200.62	182.52	203.18	191.95	341.59	681.05	387.62	775.31
Words	6.68	3.04	2.08	1.80	187.08	176.75	194.71	185.81	258.53	446.67	321.51	596.55

Table A.1. Mean of Initial Landing Position (in characters), Saccade Latency (in ms), and Initial Fixation Duration (in ms) as a function of Type of Stimulus, Inter-letter Spacing, Visual Field, and Group in Experiment 1.

*Note:* E=Extra-spacing condition; D=Default spacing.

Stimulus	Initial landing position				Saccade latency				Initial fixation duration			
	LVF		RVF		LVF		RVF		LVF		RVF	
	E	D	E	D	E	D	E	D	E	D	E	D
<b>Hashes</b>	5.63	5.23	2.57	2.71	193.06	186.91	200.48	188.54	307.21	367.41	263.00	322.13
<b>Words</b>	4.90	4.66	2.74	2.86	181.88	178.27	187.94	176.64	314.00	332.92	259.54	321.87

Table A.2. Mean of Initial Landing Position (in characters), Saccade Latency (in ms) and Initial Fixation Duration (in ms) as a function of Type of Stimulus, Inter-letter Spacing, and Visual Field in Experiment 2.

*Note* : E=Extra-spacing condition; D=Default spacing.

Table B.1. Linguistic stimuli used in Experiment 1

HF Words	LF Words
carte	amour
finir	bazar
forêt	câlin
glace	calme
lapin	chéri
maman	fable
mardi	gamin
photo	gifle
piste	gorge
plume	malin
poste	melon
route	mètre
besoin	carafe
carton	centre
citron	cirage
colère	flacon
écrire	limace
étoile	remède
jardin	nageur
légume	patate
milieu	poison

minute      potage

panier      prison

retour      rature

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Table B.2. Linguistic stimuli used in Experiment 2

5 letters words		9 letters words	
HF	LF	HF	LF
piste	bocal	casserole	plastique
carte	gorge	chaussure	chauffage
salir	calme	crocodile	carrefour
balai	canif	difficile	camembert
vache	givre	enveloppe	capitaine
élève	mètre	perroquet	jardinage
mardi	barbu	spectacle	cornichon
balle	gifle	téléphone	artichaut
texte	repos	confiture	élastique
plume	bûche	corbeille	cacahuète
poste	préau	parapluie	mandarine
piano	râler	commencer	moustique
leçon	bisou	framboise	spaghetti
poire	chéri	attention	poussière
nuage	météo	bouteille	équilibre
poche	poème	moustache	caractère
sapin	maçon	guirlande	radiateur
jouet	fable	pantoufle	saucisson
danse	punir	pharmacie	cartouche
crêpe	matou	vaisselle	madeleine
frère	écrou	catalogue	illustrer

soupe      album      continuer      grincheux

bâton      étage      descendre      serviette

taire      câlin      kangourou      maquiller

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Note. HF = high frequency. LF = low frequency.

Figure 1. Example of stimuli (words vs. hashes) presented in the default or extra-spacing condition to the left or to the right of the fixation cross in Experiment 1.

Figure 2. Schematic representation of the sequence of trials of the oculomotor bisection task. Examples are given for both types of stimuli (words vs hashes) and both visual field presentations (LVF vs RVF). Participants were asked to move their eyes as quickly as possible to a position they thought to be the middle of the stimulus.

Figure 3. Distributions of the initial landing position (in percentage) as a function of Group (CA control, Dyslexics or RA control), Spacing (extra spacing vs default) and Visual Field (left vs right) in Experiment 1. The grey areas on the graph indicate the approximate preferred viewing locations that correspond to the position slightly to the left to the center of the stimulus, i.e. characters 2-3 of 5 in the default spacing condition and characters 3.5-5 of 9 in the extra-spacing condition.

Figure 4. Distributions of the initial landing position (in percentage) as a function of the type of stimulus (Hashes vs Words), Spacing condition (extra spacing vs default) and Visual Field (left vs right) in Experiment 1. The grey areas on the graph indicate the approximate PVL.

Figure 5. Mean saccade latency (ms) as a function of Group (CA control, Dyslexics, RA control) and Spacing condition (extra spacing vs default) in Experiment 1. Error bars represent standard errors.

Figure 6. Example of stimuli (words vs hashes) presented to the left or the right of a fixation cross in Experiment 2. In both conditions of spacing (extra-spacing and default conditions), the stimulus covered the same spatial width.

Figure 7. Distributions of the initial landing position (in percentage) as a function of Spacing (extra spacing vs default) and Visual Field (left vs right) in Experiment 2. The grey areas on the graph indicate the approximate preferred viewing locations.