Advantage of detecting visual events in the right hemifield is affected by reading skill

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\textbf{A B S T R A C T}

Visual perception is often not homogenous across the visual field and can vary depending on situational demands. The reasons behind this inhomogeneity are not clear. Here we show that directing attention that is consistent with a western reading habit from left to right, results in a ~32% higher sensitivity to detect transient visual events in the right hemifield. This right visual field advantage was largely reduced in individuals with reading difficulties from developmental dyslexia. Similarly, visual detection became more symmetric in skilled readers, when attention was guided opposite to the reading pattern. Taken together, these findings highlight a higher sensitivity in the right visual field for detecting the onset of sudden visual events that is well accounted for by left hemisphere dominated reading habit.

1. Introduction

Perception is not homogenous across the visual field. While asymmetries of visual-spatial perception have been investigated in detail during stationary visual contexts (see Rezaul Karim & Kojima, 2010 for a review), it remains largely unknown whether they also extend to the processing of dynamic events (visual temporal perception) that dominate vision under more natural viewing conditions. Results from basic visual psychophysical tests collectively indicate a higher temporal resolution of perception in the right visual field (RVF) (Levy, Walsh, & Lavidor, 2010; Nicholls & Atkinson, 1993; Nicholls, 1994b, 1994a; Okubo and Nicholls 2005, 2008). Moreover, during more complex test situations that involve reading, subjects also respond more quickly and accurately to written words presented in the RVF than in the left visual field (LVF) (see Ellis, 2004 for a review). This RVF advantage for visual word recognition has been known for over 50 years (Hellige, 2001) and has traditionally been ascribed to RVF words benefiting from direct access to the left hemisphere (LH) (Brysbaert, 2004), which houses the reading network (Dehaene & Cohen, 2011) and more specifically the visual word form area (VWFA). Accumulating evidence indicates that the direction of the native language of reading has a deep influence on visual perception and the allocation of visual attention, which develops with the acquisition of reading skills. Hebrew readers, who read from right-to-left, bisect lines to the right of the true center, while native French readers, who read from left-to-right, do so to the left of the center (Chokron & De Agostini, 1995; Chokron & Imbert, 1993; Kazandjian, Cavézian, Zivotofsky, & Chokron, 2010). The direction of reading also seems to cause a left-to-right bias in inhibition of return (Spalek & Hammad, 2005). Search performance, which also requires sequential spatiotemporal sampling, is superior in the RVF for left-to-right readers, and superior in the LVF for right-to-left readers. Bilingual readers show no such asymmetries (Kermani, Verghese, & Vidyasagar, 2018). While the existing evidence indicates a close link between reading skills and perceptual asymmetries, the causal relationship remains to be determined. Here the analysis of subject populations with disturbed reading skills, such as in Developmental Dyslexia, appears promising.

Developmental Dyslexia (DD) is a learning disorder characterized by reading deficits that affect around 10% of the population. Dyslexics of different age groups and language backgrounds show deficits in processing visual temporal information. These deficits have been described in the context of the attentional blink (Badcock, Hogben, & Fletcher, 2011; Faccoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008; Hari, Valta, & Uutela, 1999; Lallier et al., 2010; Visser, Boden, & Giaschi, 2004); visible persistence (Badcock & Lovegrove, 1981; Conlon, Sanders, & Zapart, 2004; di Lollo, Hanson, & McIntyre, 1983; Schulte-Körne, Deimel, Bartling, & Remschmidt, 2004; Slaghuis & Lovegrove, 1985; Slaghuis & Ryan, 1999); temporal order judgement.

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Participants (4 males and 9 females) and 15 skilled readers (7 males and 8 females). The dyslexic participants were recruited based on their report of dyslexia. The dyslexic participants ranged in age from 18 to 40 years (M = 21.47, SD = 5.22). Four out of thirteen dyslexics were right eye dominant. Eleven out of thirteen were right-handed. The skilled readers ranged in age from 19 to 31 years (M = 21.89, SD = 5.27). Eight out of fifteen skilled readers were right eye dominant and 9/15 were right handed. All participants spoke and read English only.

Participants were recruited through an advertisement posted on a Newcastle University social media page, to take part in an eye-tracking experiment for a psychology dissertation project about dyslexia. Each participant was paid £30 in Amazon vouchers to compensate for their time.

Each participant gave written informed consent before the experiment began and confirmed that they were not taking any medication that could affect reaction times, were not a recovering alcoholic, and had no history or neurological or psychiatric disease. Experimental procedures complied with the Declaration of Helsinki and the local ethics committee at Newcastle University approved the ethics for the current research.

The experiment took place in a quiet psychophysics testing laboratory room with dimmed lighting, where participants were tested individually.

2.2. The Dyslexia Adult Screening Test (DAST)

All subjects completed three subtests of the Dyslexia Adult Screening Test (DAST; Nicolson & Fawcett, 1997).

Rapid Naming: There is strong evidence that dyslexics are slower than normal to name pictures (Denckla, 1976). We assessed the subject’s ability to name printed pictures of objects as fast as they could. The scores represent the amount of time in seconds they required to name all the objects. Every error would add 5 points to the measured time.

Nonsense Passage Reading test (NPR): There is considerable evidence that even when dyslexic adults score normally on standard tests of reading, they continue to have difficulty reading words they are unfamiliar with (Gross-glenn, 1990). We assessed subject’s abilities to read a passage that mixed nonsense words with real words. The scores were calculated by taking into account time required for reading and the amount of incorrectly read nonwords.

Phonemic segmentation test: Phonological difficulties are an established problem in dyslexia (Castles, 2014). Subjects had to orally report nouns after removing or inverting syllables. This test also included a spoonerism test, where subjects had to invent the syllables between words.

2.3. Temporal frequency increase detection thresholds

We used two Gabor patches (50% contrast) that were each 5 degrees in size, located at 14 degrees of eccentricity on the left and right sides of a central fixation cross. The gabor had a spatial frequency of 1 cycle per degree and a baseline temporal frequency of 1 Hz, which amounts to a drift speed of 1 degree per second. The orientation of each Gabor patch was one of 6 possible degrees: 0, 45, 90, 135, 215, or 270. Because the spatial frequency remained stable, an increase in temporal frequency amounts to an increase in speed. The increase in speed could occur on either gabor, within a uniform randomly distributed time interval from 500.1 to 966.86 ms.

We used an adaptive staircase procedure to estimate the temporal frequency increase detection thresholds for the right and left hemifields. Calculated threshold values represent the smallest added fraction of baseline speed needed for detection at 80%.

For each subject, the speed increase would be +1% for every correct response and −3% for every incorrect response. Trials were continuous until 15 reversals (correct response followed by an incorrect response and vice versa) had occurred and an estimated threshold for each visual field was calculated.

2.4. Microsaccade detection

To detect the onset of microsaccades (MS), we employed the

(Brannan & Williams, 1988; Riitta Hari & Renvall, 2001; Jaśkowski & Rusiak, 2008; Liddle, Jackson, Rorden, & Jackson, 2009) and visual search and change detection (De Boer-Schellekens & Vroomen, 2012; Jones, Branigan, & Louise Kelly, 2008; Rutkowski, Crewher, & Crewher, 2003; Vidyasagar & Pammer, 1999). Furthermore, a recent study (Pel, Boer, & van der Steen, 2019) that investigated how fast subjects reacted to crowded stimuli in the periphery, showed that normal readers had faster processing in the RVF, as indicated by lower reaction times to stimuli located in the RVF compared to the LVF. Dyslexics on the other hand, in addition to having generally slower reaction times, showed slower processing in the RVF compared to the LVF. To what extent these temporal processing deficits in dyslexia exhibit temporal perceptual RVF advantage seen in skilled readers (Levy et al., 2010; Nicholls & Atkinson, 1993; Nicholls, 1994b, 1994a; Okubo & Nicholls, 2008) is not clear, but seems particularly important, given reports of altered brain lateralization under this condition (Peterson & Pennington, 2012; Richlan, 2012). At the subcortical level, the size of the left lateral geniculate nucleus (LGN) has been shown to be smaller in dyslexics compared to skilled readers (Giraldo-Chica, Hegarty, & Schneider, 2015; Livingstone, Rosen, Drislane, & Galaburda, 1991). Furthermore, recent studies have reported in DD reduced structural connectivity from the left LGN to motion area MT (Müller-Axt, Anwander, & von Kriegstein, 2017) as well as from the left auditory thalamus to the motion-sensitive planum temporale (Tschentscher, Anwander, & von Kriegstein, 2017) as well as from the left auditory thalamus to the motion-sensitive planum temporale (Tschentscher, Anwander, & von Kriegstein, 2017). At the cortical level, consistent findings report abnormalities in the areas activated during reading in dyslexics, located in the left hemisphere (Peterson & Pennington, 2012; Richlan, 2012). Whether these findings of changes in brain lateralization in Dyslexia translate into altered asymmetries during temporal perceptual processing under this condition remains unknown and is, therefore, an important aspect of our investigation (Walker, Hall, Klein, & Phillips, 2006).

The reported abnormalities in the cortical networks underlying reading, and subcortical circuits involved in processing temporal information, lead us to believe that the RVF temporal advantage over the LVF might be absent in dyslexics. Furthermore, given the clear effect of the direction of reading on visuospatial attention, we hypothesize that the directional allocation of attention, either congruently or incongruently with reading direction, might also affect the RVF temporal advantage. We explored the links between reading and inter-hemifield differences in visual temporal processing by measuring the sensitivity of skilled readers and dyslexics to small sudden increases of temporal frequency of peripherally located drifting Gabor, in the left and right visual hemifields. We manipulated the direction of attentional allocation, either by moving the subjects’ attention congruently (first experiment) or incongruently (second experiment) with the reading direction of the English language. Our results reveal that skilled readers have an RVF advantage in processing visual temporal information when attention follows the reading direction of English, an asymmetry that is absent in dyslexics. The RVF advantage in skilled readers disappeared when the direction of attention was reversed. Skilled readers and dyslexics showed similar efficiency in their deployment of attention, as shown by the quasi-identity of their microsaccades rate (third experiment) and direction profiles.

2. Methods

2.1. Participants

The subjects for the current study comprised of 13 dyslexic participants (4 males and 9 females) and 15 skilled readers (7 males and 8 females). The dyslexic participants were recruited based on their report of dyslexia. The dyslexic participants ranged in age from 18 to 40 years (M = 21.47, SD = 5.22). Four out of thirteen dyslexics were right eye dominant. Eleven out of thirteen were right-handed. The skilled readers ranged in age from 19 to 31 years (M = 21.89, SD = 5.27). Eight out of
detection algorithm created by Engbert and Kliegl (2003) using the following parameters: relative velocity threshold = 6, minimum saccade duration = 8 ms). The quality of MS detection was verified by visual inspection of the eye traces on single trials, the main sequence and interval distribution. Microsaccades less than 0.1 deg were excluded. We calculated the rate of MS before the subjects’ response, by dividing each trial into 50 ms non-overlapping bins and counting the number of MSs within each bin. The average microsaccade rate was then calculated as the average MS rate across bins and trials.

2.5. Procedure

EventIDE (Okazolab) was used to both simulate the conditions and collect the data, and stimuli were displayed on a gamma corrected VIEWPixx monitor with 1920 × 1080 resolution at a refresh rate of 120 Hz and a diagonal length of 60.5 cm. The subjects were seated in front of the monitor, stabilized with a chin rest at a distance of 62 cm from the monitor. Eye movements were recorded and monitored binocularly using an EyeLink 1000 Desktop Mount.

At the beginning of each measurement session, subjects performed a 5-point calibration procedure. Starting a trial required the subject to maintain their gaze on a fixation cross (0.1 degrees) on a gray background (mean luminance = 60.5 cd/cm ± 1.27 s.e.m), within a 2 degrees diameter circular window, for 1300 ms. Successful fixation was followed by the sequential presentation of two Gabors separated by a 500 ms interval. In the first and third experiments, the Gabors were presented in the direction of reading (left-to-right), while in the second it was reversed.

Participants had to report the position at which the speed increase occurred as fast as they could, by making a saccade to one of the Gabors. If they completed the trial correctly, a high-pitched sound was given and if they completed the trial incorrectly, a low-pitched sound was given. If no response was made within 4 s after the speed increase, then the trial was reset. A schematic illustration of a sample trial sequence is shown in Fig. 1A (First experiment) and 2A (Second experiment).

3. Results

3.1. DAST

Analysis of the diagnostic DAST scores (see Methods) revealed that all three sub-tests discriminated between the skilled readers and dyslexics in our sample (summary of results in Table 1). The test that discriminated best between the two groups was the Nonsense passage reading.

|          | Skilled readers (Mean ± std) | Dyslexics (Mean ± std) | p     |
|----------|-----------------------------|------------------------|-------|
| Rapid Naming | 24.82 ± 6.7                | 33 ± 7.4               | 0.007 |
| Nonsense Passage | 90 ± 6.8                  | 74 ± 14.5              | 0.0029|
| Phonemic segmentation | 13.33 ± 1.3               | 11.46 ± 2.5            | 0.029 |

3.2. Experiment 1: Skilled readers, not dyslexics, display a visual temporal processing advantage in the RVF when attention follows the direction of reading

The first question that we aimed to answer was whether visual temporal processing of skilled readers is lateralized when attention is deployed in the English reading direction. For this purpose, we measured thresholds of temporal frequency increase detection in the LVF and RVF of skilled readers and Dyslexics while directing their attention sequentially from the LVF to the RVF.

Skilled readers showed a significant RVF advantage in the left-to-right condition (Fig. 1B) (LVF = 0.61 ± 0.05 s.e.m, RVF = 0.41 ± 0.02 s.e.m, Wilcoxon’s p = 0.001), indicating finer temporal resolution in the right hemifield, consistent with previous findings (Nicholls, 1994a; Okubo & Nicholls, 2008). Comparatively, dyslexics showed reduced lateralization in their detection thresholds condition (LVH = 0.87 ± 0.1 s.e.m, RVF = 0.73 ± 0.1 s.e.m, Wilcoxon’s p = 0.041). Eighty percent of skilled readers showed on average a 50.4% lower thresholds in the RVF compared to the LVF. On the other hand, 69% of our dyslexic participants showed on average a 30.1% lower threshold in the RVF compared to the LVF. Higher thresholds in the RVF compared to the LVF were observed in 20% skilled readers who showed a 21.06% higher threshold on average, and 31% of dyslexics who showed a 50.25% higher threshold on average.

Our results so far, therefore, demonstrate that the RVF advantage for temporal perception that occurs in skilled readers seems to be largely reduced in individuals with DD.

3.3. Experiment 2: The RVF advantage in skilled readers is cancelled, not inverted, when attention is opposite to reading direction

We hypothesized that reversing the attentional allocation of subjects against the direction of reading of the English language (from right to left), would interfere with the lateralization of temporal frequency increase detection found under the previous condition. To test this hypothesis, we conducted a new experiment, in which we reversed the direction of subjects’ attention by sequentially showing the right
grating first and the left grating second (Fig. 2A). Under these reversed attentional allocation conditions, there was no significant lateralization of visual temporal processing in either skilled readers (LVF = 0.53 ± 0.06 s.e.m, RVF = 0.46 ± 0.03 s.e.m, Wilcoxon’s p = 0.39) (Fig. 2B), or dyslexics (LVF = 0.76 ± 0.13 s.e.m, RVF = 0.78 ± 0.09 s.e.m, Wilcoxon’s p = 0.62). There were no differences in performance between experiments 1 and 2 that could account for the different perceptual sensitivity patterns observed between the left-to-right and right-to-left conditions (Skilled Readers: 83.7% ± 1.04 vs 82.2% ± 0.6 Wilcoxon’s p = 0.15, Dyslexics: 83.3% ± 0.85 vs 82.5 ± 0.86 Wilcoxon’s p = 0.37). Finally, comparing overall detection thresholds (across experiments 1&2 and therefore across attention direction conditions) between skilled readers and dyslexics shows that the latter across all conditions a greater difficulty in detecting a temporal frequency increase (SR = 0.51 ± 0.03 s.e.m, vs Dys = 0.79 ± 0.05 s.e.m, Mann-Whitney U test p < 0.001).

3.4. Experiment 3: MSs do not account for the observed RVF advantage in skilled readers

The direction and the rate of MSs have been shown to be an indicator of attentional deployment (Rolfs, 2009). In a separate control experiment, we investigated whether the MS rates of participants could explain the difference between skilled readers and dyslexics. The procedure was identical to the first experiment in all aspects, with the only difference being that the TF increase corresponded to the threshold value determined on the right and left visual hemifields for each subject. 14/15 skilled readers, and 11/13 Dyslexics participated in this experiment. MSs followed the main sequence (Fig. 3A) in both skilled readers (Pearson’s r = 0.66, p < 0.0000) and dyslexics (Pearson’s r = 0.8, p < 10^{-4}). Mean MS rates did not show any significant difference between the two populations (SR = 0.56 ± 0.09 s.e.m, vs Dys = 0.49 ± 0.08 s.e.m, Mann-Whitney U test p = 0.56). Comparing visual field specific MS rates (Fig. 3A), we found that there were significantly more MS oriented to the RVF than to the LVF in both populations (SR: LVF = 0.18 ± 0.03 ms/s vs RVF = 0.37 ± 0.07 ms/s, Wilcoxon’s p < 10^{-4}; Dys: LVF = 0.19 ± 0.04 vs RVF = 0.3 ± 0.06 Wilcoxon’s p < 10^{-3}). Robust regressions (Table 2), revealed no significant relationships between visual field specific MS rates and the thresholds measured in Experiment 1 (Fig. 3C).

In summary, our results show that skilled readers of the English language have an RVF advantage compared to the left hemifield, in detecting temporal frequency increase. The RVF advantage seems to be mainly perceptual, since attention in the LVF did not mirror the asymmetry. Dyslexics, on the other hand, who are poor readers, do not display any hemifield bias in detecting motion speed increase, in any condition of attentional deployment. This finding cannot be explained by a difference in microsaccade rate as both populations displayed significantly increased MS rates to the RVF.

4. Discussion

We hypothesized that the RVF temporal advantage reported in English skilled readers was linked to reading proficiency and reading
habits (Siéroff & Haehnel-Benoliel, 2015; Siéroff & Slama, 2018). To test this, we measured the smallest increase in visual temporal frequency that skilled readers could detect in their right and left visual hemifields, and compared this to the performance of dyslexics, a reading-impaired population. The contribution of reading habits, on the other hand, was tested by examining the effect of the direction of attentional deployment, by either cueing subjects’ attention in the direction of the English language (left-to-right) or against it (right-to-left). The skilled readers in our experiment, showed clear lateralization of attentional deployment, by either cueing subjects’ attention in the direction of the English language (left-to-right) or against it (right-to-left). The skilled readers in our experiment, showed clear lateralization of temporal processing in favour of the RVF, with thresholds in the RVF being 32% lower than in the LVF. Dyslexics showed an overall increased detection threshold compared to skilled readers with no visual field lateralization in the detection of temporal frequency increase. Inverting the direction of attentional deployment equalized thresholds in skilled readers, while it had no effect in dyslexics. In what follows we discuss our findings in relation to the existing literature with a specific focus on how the acquisition of specific reading skills and habits might account for a temporal perceptual asymmetry.

### 4.1. Temporal perception advantage in the right visual field

A substantial body of previous literature reported an advantage in the right visual field for the processing of static visual events (Rezaul Karim & Kojima, 2010 for a review). Our results along with other reports extend this RVF-LH advantage for the detection of fine temporal events (Levy et al., 2010; Nicholls, 1994b; Okubo & Nicholls, 2008). The 32% RVF advantage we found for processing motion speed increase, however, exceeds the effects in these previous reports. In their studies, (Nicholls, 1994a, 1994b; Okubo & Nicholls, 2008) asked subjects to report the presence or absence of a gap with variable duration between two flashes located parafoveally in either the LVF or the RVF. Their subjects showed on average 4% more correct responses in the RVF only at the shortest gap durations. On the other hand, (Levy et al., 2010) measured the coherence thresholds of large moving dots patches, 2.3 degrees on either the left or right of the fixation point. They reported 9% lower coherence thresholds in the RVF on average. The large difference in effect size between our current and previous studies could be due to a number of different factors, such as the nature of stimuli (flashes vs random dots vs drifting Gabors), their eccentricity and the baseline temporal frequency, as well as the different brain circuits recruited by these experimental designs. Using a design similar to ours, Traschütz, Zinke, and Wegener (2012) report that the mean threshold for detecting the acceleration at 80% detection rate, of a single horizontally oriented drifting Gabors (1 cycle/deg) placed in the RVF, were 25% at 10 degrees and 30% at 15 degrees eccentricity, showing that sensitivity to motion speed increment increases with increasing eccentricities. Similarly, Bao, Yang, Strasburger, and Po (2018) investigating the effect of attention on speed change detection, report average thresholds of around 20% at 10 degrees eccentricity, consistent with our mean threshold of 40% at 14 degrees eccentricity in the RVF for skilled readers. While our study confirms the presence of perceptual advantage for the RVF, it also provides new insights into its causative effects.

### 4.2. The role of microsaccades in the RVF advantage

Microsaccades are closely correlated with the dynamics of covert spatial attention and thus could be a reliable measurement of its deployment. Microsaccade rate and direction are strongly modulated after the onset of a visual stimulus, (Engbert & Kliegl, 2003; Laubrock, Engbert, & Kliegl, 2005), and the manipulation of attentional focus (Hafed & Clark, 2002; Lowet et al., 2018; Pastukhov & Braun, 2010; Pastukhov, Vonau, Stonkute, & Braun, 2013). Furthermore, it has been shown that spontaneous microsaccades inherently reflect the shift of spatial attention (Yuval-Greenberg, Merriam, & Heeger, 2014). In our study, microsaccades rates during fixation did not differ between the skilled readers and dyslexics and can therefore not account for perceptual differences between these subject groups. However, in both populations, microsaccades directed to the RVF were significantly more numerous than those directed to the LVF, which indicates a successful left-to-right deployment of attention induced by the sequential presentation of the stimuli, coherent with previous findings (Yuval-Greenberg et al., 2014). No significant linear relationship between visual field specific microsaccade rates and thresholds were found in either population. Combined, these results indicate that microsaccades, and thus orienting of covert attention cannot account for the observed RVF advantage in detecting temporal changes of skilled readers, and the lack thereof in Dyslexics.

### 4.3. RVF advantage likely shaped by perceptual learning during reading acquisition

Our data confirm the presence of temporal perceptual asymmetry in skilled readers. Covert attention in this population only improved sensitivity to small increases in visual temporal frequency when it was directed from the LVF to the RVF; directing it in the opposite direction, on the other hand, did not invert this asymmetry in favour of the LVF. Overall sensitivity to visual temporal frequency was worse in dyslexics. For these subjects, manipulating attention, in either direction, did not reveal any asymmetry in temporal processing between the LVF and the RVF. This novel finding in a reading impaired population, solidifies a hypothesized connection between reading skill, reading habits and visual temporal processing asymmetries between the LVF and the RVF, with a condition-specific contribution of attention (Siéroff & Haehnel-Benoliel, 2015). Acquiring reading skills in the English language requires the development of reading habits that allow the quick and efficient identification of novel and relevant information in the RVF. Thus, perceptual learning mechanisms are a likely candidate mechanism for the emergence of the RVF advantage.

The non-homogenous photoreceptor distribution in the retina between foveal and extrafoveal positions (Wikler, Williams, & Rakic, 1990) decreases the probability of recognizing letters with increasing eccentricity (Pelli, Tillman, Freeman, Michael, Berger, & Majaj, 2007). Interestingly, the RVF presents a less steep drop off in the probability of recognizing letters compared to the LVF in skilled readers (Nazir, 2000), which can be accounted for by neither isolated differences in temporal/nasal asymmetries in the retina, nor punctual manipulations of covert attention, as our results demonstrate. Instead, it has been argued that word stimuli in the RVF have faster access to the reading network in the left hemisphere (Brysbaert, 2004), which could explain, in conjunction with attention (Ducrot & Grainger, 2007), the word processing advantage in the RVF. The RVF advantage of word recognition (Fogays, 1953) develops with reading skill and language familiarity. This faster and rightward biased (Snell & Grainger, 2018) parallel processing of letters within the asymmetrical perceptual span (Rayner, 2009) develops with the acquisition of reading (Sperlich, Meixner, & Laubrock, 2016). It probably emerges through years of repetitive exposure to similar stimulus configurations in a specific retinotopic region. It could be then, that through the combined effects of faster access to the reading network, prioritized attention and
5. Conclusion

In this study, we show that deploying attention in the direction of reading privileged temporal processing in the right visual field of skilled readers. We furthermore show that such an asymmetry is in-existent in dyslexics, no matter the direction of attention deployment. The similarity of the microsaccade rate profiles between skilled readers and dyslexics indicates similar attention deployment for the two populations, suggesting that the asymmetry is more perceptual than attentional. This study strengthens the link between asymmetrical processing of temporal information between hemispheres and reading habits and proficiency.

Credit authorship contribution statement

Samy Rima: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization, Writing - original draft, Writing - review & editing. Grace Kerbyson: Investigation, Data curation, Formal analysis. Michael C. Schmid: Conceptualization, Methodology, Writing - review & editing, Supervision, Funding acquisition, Validation.

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