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Attentional asymmetry between visual hemifields is related to habitual direction of reading and its implications for debate on cause and effects of dyslexia

Running Head: **Effect of reading direction on spatial attention**

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ABSTRACT

A major controversy regarding dyslexia is whether any of the many visual and phonological deficits found to be correlated with reading difficulty cause the impairment or result from the reduced amount of reading done by dyslexics. We studied this question by comparing a visual capacity in the left and right visual hemifields in people habitually reading scripts written right-to-left or left-to-right.

Selective visual attention is necessary for efficient visual search and also for the sequential recognition of letters in words. Since such attentional allocation during reading depends on the direction in which one is reading, asymmetries in search efficiency may reflect biases arising from the habitual direction of reading. We studied this by examining search performance in three cohorts: (1) Left-to-right readers who read English fluently (2) Right-to-left readers, fluent in reading Farsi, but not any left-to-right script and (3) Bilingual readers fluent in English and in Farsi, Arabic or Hebrew. Left-to-right readers showed better search performance in the right hemifield and right-to-left readers in the left hemifield, but bilingual readers showed no such asymmetries. Thus reading experience biases search performance in the direction of reading, which has implications for the cause and effect relationships between reading and cognitive functions.

Keywords: Visual search, selective attention, direction of reading, Farsi

Introduction

Written documents and printed texts can be considered as among the most cluttered visual scenes, where each word, commonly consisting of 4-8 letters in the English language, is surrounded by hundreds of other words. It has been suggested (Vidyasagar, 1999, 2013; Vidyasagar & Pammer, 2010; Gori et al., 2014) that a critical brain process that is co-opted for achieving the rapid selection of the correct sequence of letters to form each word is selective attention, which employs a moving spotlight of covert attention, as for example in visual search tasks (Treisman & Gelade, 1980; Wolfe, 1994). Consistent with this idea is the large literature supporting the crucial role that visuo-spatial attention plays in reading and even the possibility that the core deficit in developmental dyslexia may be an impairment in visuo-spatial attention (Vidyasagar & Pammer, 1999; Facoetti & Molteni, 2000; Valdois, et al. 2004, Kevan & Pammer 2009; Franceschini et al., 2012; Gori et al., 2014; Cassim et al., 2014) rather than in phonological processing as traditionally supposed (Goswami & Bryant, 1990; Shaywitz & Shaywitz, 2005).

Though those who are faster in visual search tasks are also faster readers (Casco et al, 1998; Vidyasagar & Pammer, 1999; Verghese et al, 2014), the question remains whether and to what extent the very act of reading, by itself, affects spatial attention and visual search mechanisms. This goes to the heart of the controversy as to whether the many cognitive and perceptual deficits seen in developmental dyslexia are causal or consequences of the very much reduced levels of reading by the reading impaired

(Vidyasagar, 2014; Goswami, 2015). Though much correlation has been found between reading proficiency and many visual and phonological functions, establishing a causal connection has been elusive (Castles & Coltheart, 2004; Goswami, 2015).

One way of addressing this question is to make use of the fact that some people have grown up reading a script written left-to-right such as English and others a right-to-left script such as Farsi, Arabic or Hebrew. The effective area of visual field scanned by a putative spotlight of attention during each fixation in reading English is mostly 5-7 letters to the right of fixation with only 2-3 letters to the left and the converse for right-to-left scripts (Paterson et al., 2014). Thus, most covert scanning during reading is done in one hemifield - left or right, depending upon the reading direction. Therefore, irrespective of any constraints on reading performance by top-down attention mechanisms, the direction of reading imposes different demands on the attention networks related to the two hemifields.

In our study, we compared the visual search efficiency in left and right hemifields of three groups of participants, namely, left-to-right readers, who were fluent English readers, right-to-left readers, who were readers of Farsi and a third group consisting of bilinguals, who were fluent readers of English as well as a script such as Farsi, Hebrew or Arabic. We posited that an influence of habitual reading on visual attention scores would lead to left-to-right readers showing better search efficiency in the right visual field (RVF), right-to-left readers showing a bias for the left visual field (LVF) and bilingual readers showing no such asymmetry.

Since the primary goal of the current study was to examine the influence of reading habits on visual attention, we used two visual search paradigms to separate top-down and bottom-up factors – a serial search that required top-down visuo-spatial attention and a feature search that was essentially stimulus driven. The serial search required combining information from two or more features to detect a target. Such a search task entails selective, visuospatial attention mediated by enhanced neural activity in many cortical areas that can potentially affect the efficiency of the search (Bueichekú et al., 2015). Thus it is likely that performance in a serial search task is influenced by the individual's reading habit. In contrast, a feature search task that is guided by factors largely independent of the observer, and depend on a pre-attentive pop-out of target item from the raw sensory signals would not show differences between reading groups.

Methods

Participants

We calculated the sample size required to achieve 80% power to detect a significant 3 group (left-to-right, right-to-left and bilingual readers) x 2 visual hemifield (LVF, RVF) x 3 set-size (5, 7 or 11) interaction effect using G*power 3.1 (Faul et al., 2007) software. Since search efficiency effects are typically medium to large (Buchholz & McKone, 2004), an effect size of 0.3 (Cohen, 1988) elicited a sample size of 13 participants per group. Three groups of participants ranging in age from 26 to 36 years were recruited for this study and all 37 participants had normal or corrected-to-normal visual acuity. The first group, 'Left-to-right' readers, comprised 15 (9 female and 6 male) University of Melbourne staff and students, who were fluent English readers, but were unfamiliar with any script written from right-to-left. The second group comprised the "Bilingual" readers, which included 15 members from the University of Melbourne population (8 female and 7 male), who were fluent in English and also in Farsi (12 readers), Urdu (2) or Hebrew (1). Finally, the "Right-to-left" reading group comprised 10 Farsi readers (6 male and 4 female) who were naive to the English language. Although attempts were made to recruit 15 participants in this latter group, the stringent inclusion criteria that necessitated unfamiliarity with the English language or any left-to-right script, made further recruitment difficult. Hence, the stopping criterion was defined as those recruited within a one-month time frame at Shahid Beheshti University of Medical Sciences, Iran. The study was approved by the respective Institutional ethics committees – The University of Melbourne Human Experimentation Ethics Committee (Australia) and the University of Shahid Beheshti University of Medical Sciences, Iran and was done in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants.

Apparatus

Stimuli were implemented using Psychtoolbox (Version 3) in Matlab (The MathWorks, Inc., Natick, Massachusetts, United States) and displayed on a gamma-corrected CRT monitor (ELZO Flexscan F980 for the experiment conducted in Australia and LG Studioworks 700S CRT for the experiment in Iran), both running at

100 Hz refresh rate). Subjects were seated at a distance of 113 cm from the monitor, with the stimuli presented within a window of 10 x 15 deg to one side of the central fixation point, with the closest items being only 1 degree away from the fixation point. They were required to perform a parallel feature search and a serial visual search.

For the serial visual search task (Fig. 1 – left panel), a small white upright rectangular bar (0.50˚ X 0.12˚) was presented as a target amongst a set of distractors composed of large vertical and horizontal bars (0.98˚ X 0.24˚). In the feature search condition (Fig. 1 – right panel), the target was the same small vertical target presented amongst horizontal distracters (small horizontal bars; 0.50˚ X 0.12˚). The number of stimuli (set-size) varied across trials (5, 7, or 11). Although the task used in this study departs from traditional heterogenous visual search tasks (i.e. participants were searching for a small vertical bar among large vertical and large horizontal distractors instead of large vertical and small horizontal distractors), pilot experiments revealed that the present homogenous search was difficult enough and also serial. However, as the task was easier than a heterogenous search task, it also minimized the frequency of inadvertent eye movements, particularly for large set-sizes.

General procedure

The trial sequence, as shown in Fig. 1, commenced with a blank frame containing just the fixation cross. After an interval of either 100, 500 or 700ms, the stimuli (white bars; CIE co-ordinates, x =0.295, y =0.300, luminance = 89.7 cd/m2) were presented on the black background. Stimulus display time was varied such that each item was allocated 30ms (Buchholz & McKone, 2004). Thus, the search display and the fixation cross, remained visible for 150 ms, 210 ms or 330 ms for set-sizes of 5,7 and 11 respectively. Following a brief delay (100ms), a mask-frame containing random-lined patterns was presented (100ms) and this in turn was followed by a blank response window (maximum 5s).

Participants were instructed to maintain fixation throughout the trial and indicate whether the target (the small vertical bar) was present or absent among the distractors as accurately as possible. Responses were made by pressing either the ‘Q’ key with the left hand or the ‘P’ key with the right hand on a standard QWERTY keyboard.

Participants completed three blocks of tasks – 1 block of feature search, 1 block of serial visual search presented in the RVF and 1 block of serial visual search presented in the LVF. Each block comprised 360 trials, of which 50% contained the target. To minimize any location uncertainty, participants performed search only on one side for the duration of an entire block. The order of the three blocks was randomized for each subject.

Data Analysis

The proportion of correct responses for the target present and target absent conditions were calculated separately. Omnibus, one-way and two-way ANOVAs were carried out on the accuracy data for each of the two target conditions. Since the exposure time in our paradigm was limited to a maximum of 330 ms and there was never any requirement for the participants to respond as quickly as possible, response times were not evaluated. Importantly, target absent trials, which are generally selfterminated (Chun & Wolfe, 1996) have less significance in this limited exposure paradigm. The results for the target absent trials are hence reported briefly, but not explored in detail.

Results

Serial visual search

In order to detect differences in search accuracy in the target present condition between the three reading groups, we conducted a three-way ANOVA with reading group (Left-right readers, Bilingual readers and Right-left readers), visual hemifield (LVF & RVF) and set-size (5,7 &11), as fixed factors in an unbalanced Type III design. Although no three-way interaction effects were observed [$F(4, 240) = 0.092$, MSE=178.08, $p = 0.985$, $\eta_p^2 = 0.002$], we found a significant reading group x visual hemifield interaction [$F(2,240)= 3.59$, MSE=178.1, $p=0.029$, $\eta_p^2 = 0.031$]. This suggests that the individual's habitual reading experience differentially influences search performance in the two hemifields.

To further explore these effects, we then compared search accuracies for each group separately. As shown in Fig. 2 A, in target present trials, left-to-right (English) readers showed greater search accuracy in the right visual hemifield than in the left [$F(1, 84) = 6.420$, MS = 706.4, $p = 0.013$]. This pattern was consistent for all set-sizes reflected by the lack of interaction effects [$F(2, 84) = 0.07128$, MS = 7.844, $p = 0.93$] and set size effects ($F(2, 84) = 0.7660$, MS = 84.29, $p = 0.47$). This suggests that habitually reading from left-to-right biases search performance in the right visual hemifield relative to the left, regardless of set-size in our paradigm.

In contrast, as shown in Fig. 2B, bidirectional readers did not show differences between the right and left visual fields for the target present condition (Visual field: F (1, 84) = 0.2407, MS = 65.25, p = 0.62) nor was there any effect of set size (F (2, 84) = 0.2527, MS = 68.52, p = 0.77) or effect of interaction (F (2, 84) = 0.0.073, MS = 19.82, p = 0.92). Hence, search efficiency is symmetric across visual hemifields for bilingual readers.

Finally, as depicted in Fig. 2C, right-to-left (Farsi) readers showed a distinct reversal in search performance pattern in the two hemifields. Here accuracy in the target present condition was significantly better when stimuli were presented in the left visual field than in the right [F (1, 54) = 4.641, MS = 646.4, p = 0.035]. This suggests that search efficiency is biased towards the left hemifield in right-to-left readers. Again, no significant interaction [F (2, 54) = 0.07359, MS = 14.28, p = 0.929] or set-size effects [F (2, 54) = 2.75, MS = 383.9, p = 0.929] were observed. We also compared the overall performance between the reading groups. One-way ANOVA revealed generally poorer performance in bilinguals compared to left-to-right (Mean Diff= -14.82, s.e = 1.6, p < 0.001) and right-to-left (Mean Diff = -14.28, s.e = 1.6, p < 0.005) readers. There was no significant difference between right-to-left and left-to-right readers (Mean Diff= 0.53, s.e = 1.6, p > 0.05). Analysing each visual field separately, while there was no significant difference in accuracy between left-to-right and right-to-left readers in the LVF (Mean Diff = 0.315, s.e., 3.29, p < 0.05) and bidirectional readers showed poorer performance compared to left-to-right (Mean Diff = -12.87, s.e. 2.94, $p < 0.001$) and right-to-left (Mean Diff = -12.56, s.e. 3.28, $p < 0.000$) readers. In the RVF, left-to-right readers performed significantly better than bidirectional (Mean Diff = 16.77, s.e. 2.68, $p < 0.000$) and right-to-left (Mean Diff = 12.48, s.e. 3.00, $p < 0.001$) readers. Bidirectional and right-to-left readers, however, showed no accuracy difference (Mean Diff = - 4.29, s.e. 3.001, $p > 0.05$).

We also analyzed target absent trials. However, unlike the target-present condition, no significant third order or second order interactions featuring group were observed [reading group x visual field: F (2, 204) = 0.427, MSE = 4.4, p =0.65, η_p^2 = 0.004]. As mentioned earlier, target-absent trials are difficult to interpret in the context of our paradigm and are not examined further.

To further highlight the search asymmetries across the three groups, we computed a lateralization index (accuracy in the LVF minus accuracy in the RVF) for each set-size and for each group, but only for the target-present condition. A lateralization index <0 indicates greater search accuracy in the RVF while a lateralization index >0 indicates better performance in the LVF.

As shown in Fig. 3, comparing lateralization indices across the three groups for each set-size, revealed a significant main effect of reading group [F (2, 111) = 19.81, MS = 1346, $p < 0.0001$] but no set size [F (2, 111) = 0.31, MS = 21.59, p = 0.73] and interaction [F (4, 111) = 0.4987, MS = 33.88, p = 0.74] effects. Tukey's post-hoc comparison of the marginal means revealed significant differences between left-to-right readers and right-to-left readers (Mean Diff = -12.17, s.e = 1.94 $p < 0.0001$) as well as, between bilingual readers and right-to-left readers (mean difference = -8.267, s.e = 1.94, $p < 0.001$). Hence, search performance in the different hemifields varied depending on whether reading is habitually conducted in the left-to-right direction, right-to-left direction or both.

It could however be argued that shifts of gaze (despite instructions) and not of covert attention in the direction that participants usually read might have confounded the results. Therefore, we recorded eye positions and eye movements of five left-to-right readers (3 female and 2 male) while they performed the visual search. Three of these participants had previously performed the task, while two were naïve participants. All participants were found to maintain fixation within a very narrow range of less than 0.1 degree in the majority of trials with around 30% of trials showing fixations that were up to 0.5 degrees from the fixation point. No eye movements were observed during the trial itself. There was no difference in performance between groups with and without eye tracking in either hemifield ($p>0.05$) [Left Visual Field: (F (2, 54) = 0.2022, $P = 0.82$); Right Visual Field: (F (2, 54) = 0.03843, $P = 0.96$)]. Therefore, it is unlikely that the eccentric fixations up to 0.5^0 might have been a confounding factor, since (i) the stimuli were presented within a much larger window of 10 x 15 deg to one side of the fixation point and (ii) the small eccentric fixations were always towards the side where the stimuli were being presented in that block and not towards the usual reading direction.

Feature search

We also analysed the accuracies in the feature search condition using a 3 reading group x 2 visual fields x 3 set-size ANOVA design. No significant interactions were observed. (target present: F (4, 240) = 0.829, MSE = 7.4, p = 0.66, η_p^2 = 0.06], target absent: F (4, 240) = 0.301, MSE = 4.3, p = 0.58, η_p^2 = 0.001] indicating that the reading groups showed similar performance for the feature search condition with mean accuracies for all conditions being above 95%.

Discussion

Our results underscore the idea that reading has a profound influence on the brain (Castro-Caldas et al., 1998; Dehaene et al., 2010; Vidyasagar, 2014). The reversal in search performance patterns obtained for the English and Farsi readers, suggests that habitual reading direction influences visual search. Though, in light of the differing sample sizes, one may have to be cautious in this interpretation, the most likely factor driving these group differences is the reading direction of the two scripts. Consistent with this is the observation that the asymmetry between the hemifields was absent in those who read both English and Farsi frequently. Our finding of search asymmetry is also in agreement with perceptual span studies, where using gaze-contingent moving windows, asymmetries have been demonstrated for a range of right-to-left scripts such as Hebrew (Pollatsek et al., 1981), Arabic (Jordan et al., 2014) and Urdu (Paterson et al., 2014). Hence, even though attentional processes such as a moving spotlight of attention (Vidyasagar, 1999) involve both hemifields, at each fixation, the presence of a greater number of letters forming the perceptual span to the right of fixation than to the left in reading English scripts (Paterson et al., 2014) can cause the asymmetry we have observed. The above study by Paterson et al also showed that the attention span for right-to-left Urdu readers was longer left of fixation. Our study shows that the influence of reading direction may go beyond measures directly related to reading, extending to general cognitive functions, in our case, visuo-spatial attention.

Closer examination of the lateralization indices in our study, revealed a mirror reversal of the effect for the right-to-left and left-to-right readers and the bidirectional readers showed negligible lateralization, particularly for larger set-sizes. From the perspective of our hypothesis of an attentional spotlight scanning the string of letters sequentially at an early visual area, not only is our finding of lateralization itself predictable, but one could expect a lateralization also of the reading-related neuronal activity in the primary visual cortex (V1). In fact, fMRI studies done on native speakers of French (Szwed et al., 2014), which is also read left-to-right, show preferential activation of left V1, but not the right when reading French. However, when native speakers of Chinese read Chinese words, a script that is formed of complex characters and not read from left-to-right, no such preferential activation of left V1 was observed.

Our results suggest that there is over long-term, a gradual improvement in attentional performance from reading. This means that the overall length of time spent in reading may have a quasi-linear relationship to visual attention efficiency and explain the trend for general reduction in performance across all three set-sizes in both hemifields for the bidirectional readers compared to the unidirectional. By splitting their reading time between the two languages, bidirectional readers may have done less reading in any one script than the other two groups, which is in turn reflected in the search performance in both hemifields. While bilingualism may have many cognitive advantages (e.g., Bialystok, Craik & Luk, 2008; Costa et al., 2009; Kovács & Mehler, 2009; Christoffels et al., 2015), there could also be some costs (Hilchey & Klein, 2011). One such cost may be less improvement in visual search accuracy with bidirectional reading, which is a special case of bilingualism.

Our results are also consistent with an early study by Mishkin and Gorgays (1952), who found that accuracy of word perception was significantly better in the right visual field for English readers, whereas Yiddish readers showed a trend towards the left hemifield.

It was however intriguing that English (left-to-right) readers not only showed higher search accuracy in the attention task than the other two groups in the right hemifield, but that their performance was at least as good as the Farsi readers even in the left hemifield. We theorize that this could be due to the largely cursive nature of the Farsi script, in stark contrast to the highly discrete, alphabetic nature of English script. If reading involves the gradual sweep of a spotlight of attention across the letters (Vidyasagar, 1999), in reading English, the spotlight is trained to go over one or two letters at a time, whereas in reading the cursive Farsi script, the visual scan is perhaps larger and parts of words are taken in more holistically. If reading does influence attentional mechanisms, as it has been shown for other lateralized cognitive functions that can be influenced by environment and training (for review see Bryden

2012, Bradshaw and Nettleton 1983), this difference in reading may account for the relatively higher performance in the visual search task by English readers.

The increase in the laterality index with increasing set-size observed in the unidirectional readers is very likely due to an increase in task demand, as participants had to scan more items and locations on the screen. The relatively small bias to the right visual hemifield observed in the bidirectional reading group could be due to slightly more recent exposure to English than Farsi, as all participants of this group lived in Australia at the time of the experiment. With increasing set size, the error rate seems to increase more for English than for Farsi. We suggest that this may be due to the generally poorer proficiency in a second language, which may make it more error-prone with the higher set-size.

When Verghese at al (2014) reported that the functional size of the representation on the primary visual cortex of the central 10 degrees of the visual field correlated with the speed of visual search, they also noted that the relationship held only for the left V1, not the right. However, the subjects in that study were from the student population in Melbourne and readers of a left-to-right (English) script. Their letter processing would be largely to the right of fixation and thereby facilitating the attentional functions more in the right hemifield. It would be interesting to do a similar imaging study in a population that read predominantly or exclusively right-to-left scripts and in bilingual readers.

Many studies have proposed that words are mainly recognized in foveal vision, i.e., within the central 3°, without or with only limited influence from peripheral vision (e.g., Nazir et al, 1991, 1998). Consequently, one may dispute the relevance of our use of a stimulus display extending out to 10^{o} from foveal centre. However, there is increasing experimental evidence and theoretical support for a spatially extended attentional filter (e.g., Vidyasagar 1999; Facoetti & Molteni, 2000; Valdois et al., 2004; Bosse & Valdois, 2009; Kevan & Pammer, 2009; Vidyasagar & Pammer, 2010; Franceschini et al., 2012; Cassim et al., 2014; Gori et al., 2015), without which word recognition systems will be overloaded in the midst of the extreme clutter of a typical page of text. Thus, the top-down attentional processes, as assessed by visual search tasks, are critical for efficient reading. Thus, that our search task tests both foveal and extrafoveal mechanisms does not in any way imply that words are not recognized close to central fixation. Reading requires widespread suppression of the processing of irrelevant visual stimuli through an attentional mechanism - everywhere except close to foveal centre, but at the same time retaining the ability to throw attention to longer distances such as returning to the start of a paragraph or to a salient section on the same page. Moreover, electrophysiological recordings in non-human primates clearly show that cells in the ventral cortical areas that perform object recognition have large receptive fields (e.g., Boussaoud & Desimone, 1991). Their lack of precise positional information will confound the word recognition system in humans. This makes it imperative that selective attention suppresses all but a few letters near the fovea at any time during reading.

While visual processes seem to be vitally important for reading and their dysfunction may be the core problem in developmental dyslexia (Vidyasagar, 1999;

Facoetti & Molteni, 2001; Valdois et al., 2004; Facoetti et al., 2008; Vidyasagar & Pammer, 2010), the relationship between visual attention and reading could be mutual. Some visual functions may indeed be influenced by reading, as in the present study. However, it does not follow that the visual deficits seen in dyslexics are purely the result of lack of reading and that the basic deficit in dyslexia may be phonological, as suggested by Goswami (2015). There is now considerable evidence for a causal effect of visual attention deficits on reading in the development of dyslexia (Franceschini et al. 2012; Gori et al., 2015). It may even reflect an early perceptual defect arising from the magnocellular pathway (Cornelissen et al., 1995; Stein and Walsh, 1997; Vidyasagar & Pammer, 1999; Pammer & Wheatley, 2001; Stein, 2003; Gori et al., 2015). An asymmetry between the hemifields may develop as a result of the amount of reading done by the developing brain, but the initial deficit that causes the reading problem in the first instance, could be in visuo-spatial attention.

Our results stress the fact that reading could bring about substantial changes in many brain functions used in the process (Dehaene et al., 2015). The sites of these changes may range from the relatively early stages of the visual pathway as we found and also as hinted by our earlier imaging study (Verghese et al., 2014) to late stages such as the arcuate fasciculus (Boets et al., 2013; Vidyasagar, 2014). A recent study has also shown that literacy training of illiterate adults for just 6 months can indeed induce neuroplastic changes in the connections between cortex and subcortical structures such as the thalamus (Skeide et al., 2017).

Thus we add a note of caution that mere correlation of a function with reading performance cannot be taken as supporting causation (Goswami, 2015). This holds true for visual as well as phonological and auditory functions.

In conclusion, our study has shown further that there is a close association between visual attention and reading. It underscores the potential for understanding the neural basis of reading and its impairment by exploring the different writing systems that have evolved in human history.

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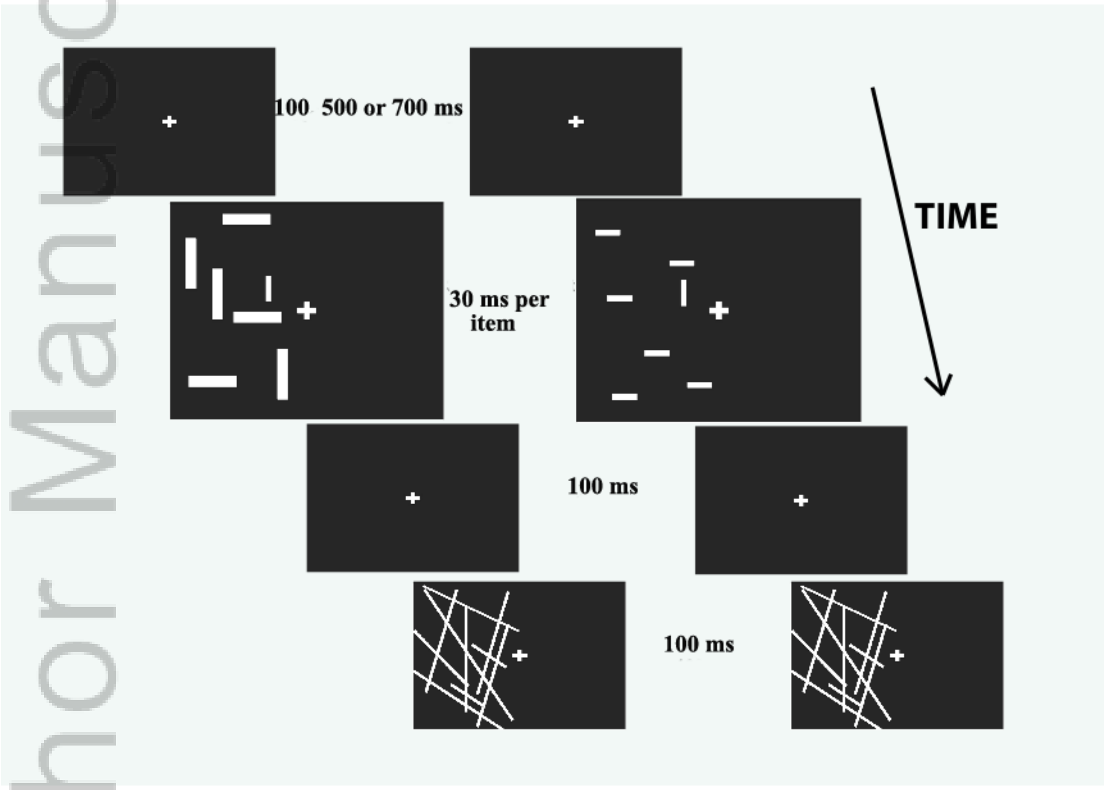
Figure Legends

Figure 1. Behavioral task. The left panel shows the trial sequence for the serial visual search task. Participants were required to report the presence or absence of a small vertical bar presented among 4, 6 or 10 distracters (large vertical and horizontal bars) that remained on screen for either 150, 210 or 330ms, depending on the set-size. The right panel represents an example trial for a feature search task, where participants detected the presence or absence of the same target presented among horizontal distracters.

Figure 2. Search accuracy for each reading group in the target-present condition: (A) Left-to-right (English) readers (N = 15), (B) Bilingual readers (N = 15) and (C) Right-to-left (Farsi) readers (N = 10). Error bars indicate SEM and * indicates significant main effect of visual hemifield at the $p < 0.05$ level.

Figure 3. Lateralization Indices across the three reading groups. Rightward biases (lateralization index < 0) were observed for all three set-sizes in the left-to-right reading group whereas the right-to-left reading group showed leftward biases (lateralization index > 0) for all three set-sizes. The bilingual group also showed a small rightward bias. Error bars indicate SEM and **** indicates a significant main effect of reading group ($p < 0.0001$).



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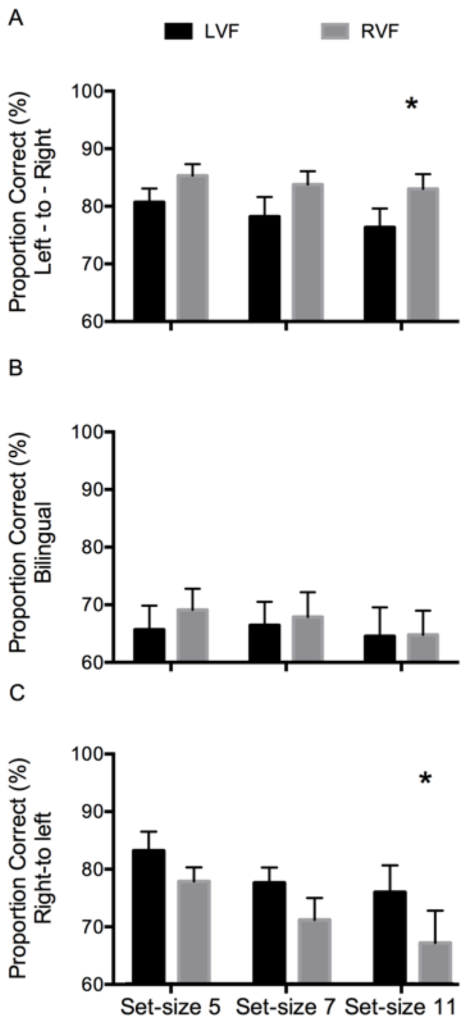

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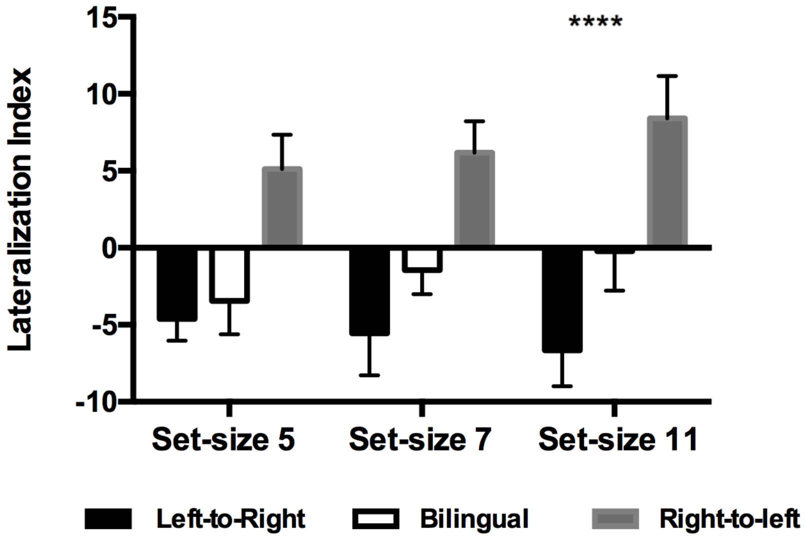

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