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Visuospatial Attention Deficits in Developmental Dyslexia: Evidence from Visual and Mental Number Line Bisection Tasks

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Abstract

Previous research has shown that individuals with DD (developmental dyslexia) demonstrated a left mini neglect on visual line (VL) bisection tasks, which has been commonly referred to as right parietal dysfunction. However, insufficient reading experience characterizes dyslexia and may call into question the validity of this interpretation, since the VL bisection task has been found to be influenced by reading habits. The current study investigated whether altered performance of individuals with DD on bisection tasks may be attributed to impaired attentional mechanisms or to insufficient reading exposure. DD and control groups performed visual and mental number line bisection tasks, which have been shown to be modulated differently by reading habits. In both tasks, the magnitude of left bisection errors was significantly larger in the DD group compared with controls. This finding suggests attentional mechanisms act differently in dyslexia and supports evidence linking dyslexia to decreased function of the left hemisphere.

Keywords: Developmental dyslexia; Numerical stroop; Mental number line bisection; Reading habits; Visual line bisection; Visuospatial attention

Introduction

Developmental dyslexia (DD) is among the most common neurodevelopmental disorders. Typical symptoms of DD include difficulties in reading, writing, spelling, word identification, and phonological decoding (Vellutino, Fletcher, Snowling, & Scanlon, 2004). Yet, it seems that the impairments in DD may not be restricted to the language domain. An accumulating body of evidence indicates the involvement of visuospatial attention in DD etiology. Research has demonstrated that individuals with DD exhibit difficulties in attentional orienting, as well as have deficits in focusing of visuospatial attention (for a review, *see* Valdois, Bosse, & Tainturier, 2004).

One of the methods that are being used to study visuospatial attentional mechanisms is the visual line (VL) bisection task (for a review, *see* Fischer, 2001). The line bisection phenomenon was first documented in people with neurological impairment suffering from hemineglect. Those people showed an ipsilesional bias in the VL bisection task. People with a right hemisphere lesion and left hemispatial neglect (which is more frequent than right hemispatial neglect) tended to present a rightward bias on the VL bisection tasks, as if they ignored the leftmost part of the visual field. In contrast, most non-impaired individuals present bisecting errors to the left of the true center, demonstrating what came to be termed as pseudo-neglect. Another task that was previously studied in this area is the mental number line (MNL) bisection task. In this task, participants are required to judge the numerical center of two presented numbers. Non-impaired participants tend to present leftward bias (Longo & Lourenco, 2007), while people with left hemispatial neglect demonstrate rightward bias—a systematic shift of their midpoint number judgment toward the higher

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number (Fischer, 2001). Interestingly, these tasks were shown to be modulated differently by reading habits. It has been demonstrated that reading direction is a crucial factor in determining performance on the VL bisection task. Left-to-right readers tend to exhibit leftward bias when bisecting VLs, whereas right-to-left readers present the opposite bias (Chokron & Imbert, 1993). However, reading direction does not have the same influence when people bisect MNLs. In a recent study, the usual leftward bias was observed in right-to-left controls (Hebrew readers) when bisecting MNLs (Ashkenazi & Henik, 2010). This finding suggests that different sorts of bisection tasks may be modulated differently by reading habits.

Several researchers examined VL bisection performance in individuals with DD. Polikoff, Evans, and Legg (1995) found that children with DD presented only a slight leftward bias, while non-impaired readers showed a stronger leftward bias. Other studies reported rightward bias in children with DD while performing the VL bisection task (Sireteanu, Goertz, Bachert, & Wandert, 2005; Waldie & Hausmann, 2010). This inconsistency might be related to age differences between the participants of each study, as well as to differences in hand-usage (left/right hand) to carry out the bisection in the DD sample. It is also possible that bisection performance of children with DD in these studies was compromised by their limited reading experience, given that the performance on this later task was found to be related to reading habits (Chokron & Imbert, 1993). Indeed, there is an accumulating body of evidence to suggest that reading experience shapes cognitive and neural processes. Learning to read is related to the development of a strong response to letter strings in the fusiform cortex in the left hemisphere, a region known as the visual word form area (Dehaene et al., 2010) and reading habits can influence visuospatial attention (Chokron & Imbert, 1993).

If VL bisection performance is modulated by reading habits, it is not clear whether impaired performance on this task among children with DD should be attributed to problems in visuospatial attention, as was suggested by previous studies (Sireteanu et al., 2005), or to limited reading experience which characterizes DD. One way to address this question is to examine individuals with DD in tasks that are modulated differently by reading habits. The above tasks fall into this category. The VL bisection task was found to elicit the opposite bias (from what is observed in left-to-right readers) in right-to-left Hebrew readers (Chokron & Imbert, 1993), while the MNL bisection task was found to elicit the usual pseudo neglect (that is observed in non-impaired left-to-right readers) in right-to-left Hebrew readers (Ashkenazi & Henik, 2010).

The present study investigates the performance of students with DD and non-impaired readers on both VL and MNL bisection tasks. Since the latter task involves number estimation, the performance of both groups was also examined on a numerical Stroop task in order to compare numerical skills. If insufficient reading experience can account for attentional problems in those with DD then we would expect to observe a difference between those with DD and non-impaired readers only on the VL bisection task. On the other hand, if impaired attentional mechanisms subserve the performance of those with DD on bisection tasks, we would expect that DD participants would behave differently on both tasks in relation to non-impaired readers.

Method

Participants

Twenty-four university and college students were selected for two experimental groups: A group with DD (9M, 3F) and a control group (10M, 2F). All participants were right-handed. Individuals with DD were recruited by advertisements and by approaching them through learning disabilities centers. Students were either paid 30 NIS (∼$7.5) for participation in the experiment or received a course credit. The study was approved by the Ben-Gurion University of the Negev ethics committee and written informed consent was obtained from participants. All participants were native Hebrew speakers with no reported signs of sensory or neurological deficits/attention deficit hyperactive disorder (according to the American Psychiatric Association, 2000) and came from middle to high socioeconomic status families. Participants with DD had a well-documented history of DD. They reported experiencing substantial difficulties in acquiring reading and writing skills during school entry. They were diagnosed as having DD during childhood, were identified as having DD by learning disabilities centers in their institutions, and received testing accommodations. All participants underwent a series of cognitive tests in order to evaluate their general intelligence (as measured by the Raven Progressive Matrices), reading abilities (Schiff & Kahta, 2009a, 2009b), verbal working memory (as measured by the Digit Span from the Wechsler Adult Intelligence Scale (Wechsler, 1997), rapid naming (Shany, Lachman, Shalem, Bahat, & Zeiger, 2006), and numerical skills (numerical Stroop task). The two groups did not differ according to their intelligence or numerical skills, but as expected the DD group performed worse than the control group on tests of reading measures, processing speed, and verbal working memory (Table 1). The reading achievement of the DD group on the reading tests was significantly below expectations given age, cognitive ability (all scored above the 50th percentile on the Raven test), and educational opportunities, scoring below the 50th percentile in word and non-word reading tests on either accuracy or speed measures.

Table 1. Demographic and psychometric data for individuals with DD and control groups

Measure	Controls		DD		*p*-value
	Mean (*SD*)	Range	Mean (*SD*)	Range	
Age (in years)	24.33 (1.92)	23–30	25.9 (2.35)	23–30	*ns*
Raven	56.08 (2.67)	50–59	56.58 (2.31)	53–60	*ns*
DF	7.14 (1.16)	6–9	6.08 (1.08)	5–8	<.008**
DB	5.14 (1.24)	3–7	4 (0.95)	2–5	<.004**
DS (combined)[a]	12.41 (2.83)	8–17	8.41 (1.67)	6–12	<.0003**
Letter naming	17.75 (3.16)	10–21	22.16 (4.58)	18–31	<.05*
Digit naming	15.66 (2.1)	12–19	19 (4.54)	14–28	<.009**
RT word reading	85.75 (15.61)	53–104	64.75 (15.41)	39–84	<.003**
Acc word reading	107 (2.92)	100–110	92.66 (7.21)	80–103	<.000**
RT non-word reading	56 (13.25)	34–78	25.08 (8.41)	16–40	<.000**
Acc non-word reading	39.25 (3.46)	33–44	18.83 (6.46)	8–29	<.000**

Notes: DS = Digit Span; DF = longest digits forward; DB = longest digits backward; Acc = accuracy; RT = reaction time; DD = developmental dyslexia.
[a]Standard scores, other raw scores.
*$p < .05$.
**$p < .01$.

Numerical Stroop Task

A computer display consisted of two numbers which appeared at the center of the screen. The center-to-center distance between the two numbers was 10 cm. The participants sat approximately 55 cm from the screen. The stimuli subtended a vertical visual angle of 0.7° or 0.9° and a horizontal visual angle of 1.7°–5.4°. Three types of pairs were presented: Congruent (a pair of digits in which a given digit was larger on both the irrelevant and relevant dimensions), neutral (a pair of digits that differed only on the relevant dimension), and incongruent (a pair of digits in which a given digit was simultaneously larger on one dimension and smaller on the other). The numbers, one through nine excluding five, were used to produce three numerical distances: 1, 2, and 5. Each number was presented for an equal number of times for each distance. Stimuli were arranged in blocks of trials with each block having 72 different stimuli that were presented twice (a total of 144 trials in each block). Each number and each physical size appeared for an equal number of times on the left and the right. Each block had nine different conditions: 3 numerical distances × 3 congruency conditions. Each condition was represented by 16 trials (i.e., 4 number pairs × 2 physical sizes × larger number on two sides of the computer screen) in a given block. Every block was preceded by 36 practice trials. In the numerical task, participants were requested to compare the numbers according to their numerical value and to ignore their physical size, while in the physical task participants had to compare the numbers according to their physical size and to ignore their numerical value. The two tasks were counterbalanced across participants.

VL Bisection Task

Different lines were presented to the participants, one at a time, on a computer screen. The lines were black, presented on white background. Participants were instructed to bisect the physical line by using the cursor as accurately and as quickly as possible. Participants were instructed to keep the fingers of their dominant hand on the cursor in order to avoid any arm or forearm movement during the task. The length of the lines ranged from 40 to 180 mm. After eight practice trials, participants performed four blocks of the experiment. Every block contained 80 lines that appeared in random order. The lines in every block were identical across blocks. Each trial started with the appearance of a single line for 1,000 ms. After each response, the line disappeared and another line was presented in its place. If a participant did not make a response, the line disappeared. Reaction times (RTs) were collected for every trial.

MNL Bisection Task

The procedure for this task followed that of Longo and Lourenco (2007). Participants bisected 320 pairs of numbers. In every trial, two numbers were presented on a computer screen, with the smaller number on the left and the larger number on the right. The small numbers ranged between 10 and 80 (mean 35.78, $SD = 22.84$) and the larger numbers ranged between 21 and 98 (mean 69.31, $SD = 20.95$). The distance between the two numbers of a given pair ranged between 10 and 77 (mean 33.53, $SD =$ 18.47). There was a small correlation between the range and the mean of the two numbers that was not significant

$r(79) = -.11$, ns. After 10 practice trials, participants performed four blocks of the experiment. Every block contained 80 pairs that appeared in random order. The pairs in every block were identical across blocks. Every trial started with the appearance of a fixation point for 1,000 ms, followed by a black screen. Five hundred milliseconds later, two numbers written in Arial font, size 38, appeared 6.5° to the left or right of the center of the screen, with the small number on the left and the large number on the right. Simultaneously, a white line (2 cm) was presented in the middle of the screen. The participant was asked to vocally name the number that should appear in the middle of the two numbers. The numbers disappeared after the subject's vocal response. The examiner keyed in the participant's response. The key-press of the examiner was followed by a black screen for 250 ms. RTs were collected for every trial. In this task, as opposed to the VL bisection task, there was no time limit, since it was less clear what an optimal time limit for the MNL task would be. Limiting participants' response time might have resulted in a high percentage of no responses. In the current study, it was emphasized to participants that they should perform the task as quickly as possible and avoid exact calculations.

Results

Numerical Stroop Task

The data of one DD participant was unavailable. For each condition, the mean RT was calculated for correct trials only (RT below 100 ms or greater than 1,500 ms were excluded from the analysis). These mean values were subjected to a mixed analysis of variance (ANOVA) with task (physical/numerical) and condition (congruent, incongruent, and neutral) as within-subject factors and with group (DD vs. controls) as a between-subject factor. There was a main effect for task such that participants responded more quickly in the physical task compared with the numerical task, $F(1, 21) = 130.17$, $p < .01$, $p\eta^2 = .86$. There was a main effect for condition, $F(2, 42) = 76.3$, $p < .01$, $p\eta^2 = .78$, such that participants responded more slowly to the incongruent condition compared with the congruent one. Finally, the condition by task interaction was significant, $F(2, 42) = 17.7$, $p < .01$, $p\eta^2 = .45$. Additional analysis showed faster RTs for congruent trials compared with incongruent trials in the physical task, $F(1, 21) = 26.24$, $p < .01$, $p\eta^2 = .96$, demonstrating the size congruity effect. Yet, this pattern was more pronounced in the numerical task, $F(1, 21) = 101.28$, $p < .01$, $p\eta^2 = .99$. The effect of group and interactions with group were not significant (minimum $p = .140$). In order to examine the automatic activation of numerical information, we compared the neutral and congruent conditions in the physical task for both the control and DD groups. Faster RT in the congruent condition compared with the neutral condition in the physical task would suggest participants activated numerical information automatically. This comparison revealed that participants did indeed respond more quickly in the congruent condition compared with the neutral condition, $F(1, 21) = 8.09$, $p < .01$, $p\eta^2 = .89$, and that there was no difference between the two groups in relation to that comparison, $F < 1$. This finding suggests an automatic retrieval of numerical information in both the DD and control groups.

VL Bisection Task

Directional deviations were measured to the nearest half millimeter with errors to the left of the midpoint given a negative value and errors to the right given a positive value. The mean was calculated for each participant. The control group had a small rightward bias (0.53 mm), whereas the DD group showed a leftward bias (−0.65 mm), $t(22) = 2.49$, $p < .05$, Cohen's $d = 1.05$ (Fig. 1).

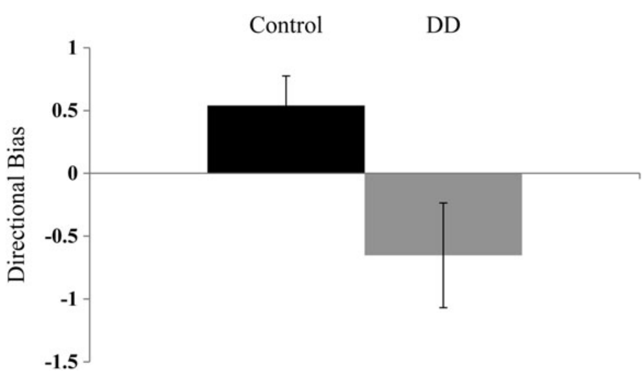

Fig. 1. Mean deviation as a function of group in the VL bisection task. A negative deviation means a leftward tendency. Error bars represent standard errors.

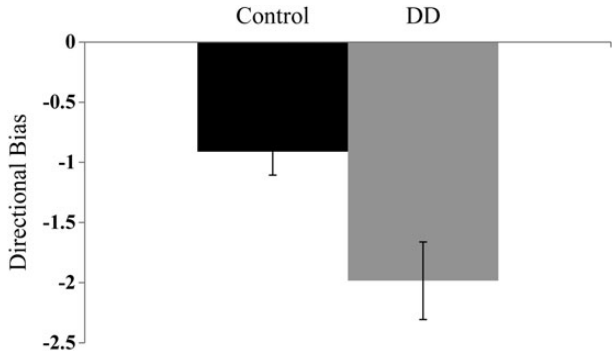

Fig. 2. Mean deviation as a function of group in the MNL bisection task. A negative deviation means a leftward tendency. Error bars represent standard errors.

MNL Bisection Task

Directional deviations were measured with errors to the left of the midpoint given as a negative value and errors to the right as a positive value. The mean was calculated for each participant. Both the control and DD groups presented a leftward bias (−0.91 numerical units for the control group and −1.98 for the DD group). Yet, this leftward bias was significantly larger in the DD group compared with the control group, $t(24) = 2.84$, $p < .01$, Cohen's $d = 1.19$ (Fig. 2).

Effects of Range on Error/Directional Bias

Longo and Lourenco (2007) found that overall error and not directional bias tended to increase as the range between the compared numbers increased. In order to test this finding, the effect of numerical range was examined on both (a) the directional bias and (b) the overall error. The performance of each participant was compared in the small range (i.e., 10–21 numerical units, e.g., 10_20), medium range (i.e., 22–35 numerical units, e.g., 67_90), and large range (i.e., 36–77 numerical units, e.g., 10_77). For directional bias, the mean deviations of each subject for each range were submitted to a 3 × 2 ANOVA with the range between the two numbers (small, medium, or large) as a within-subject factor and group (DD vs. controls) as a between-subjects factor. The group effect was significant, $F(1, 22) = 8.08$, $p < .01$, $p\eta^2 = .26$, indicating a larger leftward bias in the DD group in comparison with the control group. The range main effect was significant, $F(2, 44) = 26.8$, $p < .01$, $p\eta^2 = .55$. Further analysis revealed that deviations in the small range and in the large range did not differ from each other ($p = .29$). Yet, there were significant differences between the medium range and the large range, $F(1, 22) = 34.8$, $p < .01$, $p\eta^2 = .61$, and the medium range and the small range, $F(1, 22) = 62.3$, $p < .01$, $p\eta^2 = .73$, indicating that participants presented the largest bias in the medium range. The range by group interaction was significant, $F(2, 44) = 5.8$, $p < .01$, $p\eta^2 = .2$. Further analysis revealed that the DD and control groups differed mainly in the small range, $F(1, 22) = 21.966$, $p < .01$, $p\eta^2 = .5$, and in the medium range, $F(1, 22) = 15.71$, $p < .01$, $p\eta^2 = .41$, whereas no significant difference was observed in the largest range ($F < 1$). For overall error, the mean deviations in absolute values of each subject for each range were submitted to 3 × 2 ANOVA with the range between the two numbers (small, medium, or large) as a within-subject factor and group (DD vs. controls) as a between-subjects factor. The group effect was significant, $F(1, 22) = 30.297$, $p < .01$, $p\eta^2 = .57$, indicating that the DD group made overall more errors in comparison with the control group. The range main effect was significant, $F(2, 44) = 326.66$, $p < .01$, $p\eta^2 = .93$, indicating that the overall errors increased as the numerical range increased. The range by group interaction was also significant $F(2, 44) = 9.58$, $p < .01$, $p\eta^2 = .3$, with the finding that both groups exhibited more overall errors as the range increased but this tendency was more pronounced in the DD group compared with the control group.

Out-of-Range Error Analysis

An error was defined as a response outside the stimulus range (i.e., the answer was larger than the larger number in the pair or smaller than the smaller number in the pair, e.g., 82 in response to the stimulus numbers 60_70). The errors for each participant were submitted to a 2 × 3 ANOVA with range (small, medium, large) as a within-subject factor and group as a between-subject factor. The group effect was significant, indicating that participants with DD made more out-of-range errors than controls did, $F(1, 22) = 10.47$, $p < .01$, $p\eta^2 = .32$. There was also a main effect of range, $F(2, 44) = 18.44$, $p < .01$, $p\eta^2 = .45$, with 1.54 errors in the small range, 0.71 in the medium range, and 0.14 in the large range. The interaction of group by range was significant,

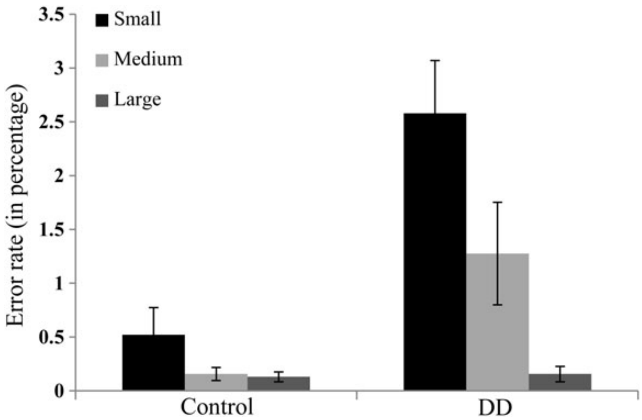

Fig. 3. Error rate as a function of group and range. Error bars represent standard errors.

$F(2, 44) = 9.53, p < .01, p\eta^2 = .3$. Further analysis revealed the error level for the control group was low, non-significant and was not affected by the range (minimum $p = .19$). In contrast, the performance of the DD group was modulated by range such that more errors were found in the small range compared with the large range, $F(1, 22) = 41.02, p < .01, p\eta^2 = .65$, and compared with the medium range, $F(1, 22) = 22.54, p < .01, p\eta^2 = .5$. In addition, more errors were found in the medium range in comparison with the large range, $F(1, 22) = 11.69, p < .01, p\eta^2 = .34$ (Fig. 3).

Reaction Time

RTs of the correct trials of the two groups were submitted to a 2 × 2 ANOVA with the range between the two numbers (small, medium, or large) as a between-subject factor and group (DD vs. controls) as a within-subject factor. These analyses did not reveal any significant effects or interactions, supporting the assumption that an estimation strategy was employed by participants rather than exact calculation of the numerical midpoint.

Discussion

The current study examined the performance of individuals with DD and non-impaired readers on VL and MNL bisection tasks. In the VL bisection task, participants with DD presented leftward bias, in contrast to the rightward bias demonstrated by normal right-to-left readers (Chokron & Imbert, 1993). The significant difference in bisection performance between the DD and the control groups is in agreement with previous studies revealing differences in VL bisection performance between children with DD and non-impaired readers (Sireteanu et al., 2005; Waldie & Hausmann, 2010). Yet, the direction of the bias seems to differ across studies. While the present study documented a leftward bias in adults who were right-to-left impaired readers, others reported a rightward bias in children who were left-to-right impaired readers (Sireteanu et al., 2005; Waldie & Hausmann, 2010). We believe that differences in reading habits may account for the discrepancy in the direction of the bias between the studies. The present study is the first to examine MNL bisection in a group of individuals with DD. In this task, participants with DD exhibited an exaggerated leftward bias and made more out-of-range errors in comparison with the controls. Furthermore, the effect of numerical range on this directional bias was modulated by group, with significant differences observed in the small and medium ranges. Possibly, the lack of difference in the largest range was a result of task difficulty masking the differences between the groups. Thus, the attentional differences between the groups were revealed only at easier levels of task demands. There are several possible explanations for the exaggerated leftward bias in the participants with DD. First, it can be argued that the impaired performance on the MNL bisection task may be attributed to deficit in numerical skills. However, in the current study, the DD group exhibited spared automatic retrieval of numerical information (as indicated by the comparison of congruent and neutral trials in the physical dimension of the numerical Stroop task). Thus, a numerical deficit in individuals with DD seems a less probable explanation for the current results. Alternatively, one may attribute the exaggerated leftward bias in DD participants to an attentional deficit. Indeed, an accumulating body of research suggests impairments in attentional mechanisms in individuals with DD. More specifically, it has been shown that DD is linked to difficulties in orienting and focusing of visuospatial attention (Valdois et al., 2004). Accordingly, DD participants' representational bias on the MNL task could result from deficit in the deployment of attention on the putative MNL. Most importantly, the purpose of the current study was to examine whether altered performance of individuals with DD on bisection tasks may be attributed to impaired attentional mechanisms. The fact that participants with DD exhibited the exaggerated leftward bias in comparison with controls on both bisection tasks suggests that reading habits might not be responsible for bisection differences between the groups, but rather that impaired attentional mechanisms subserve the performance of individuals with DD on bisection tasks.

Left hemispatial neglect is usually observed in people with right hemisphere lesions. However, the opposite right hemispatial neglect has been documented in persons with left hemisphere lesions. For example, Pia, Corazzini, Folegatti, Gindri, and Cauda (2009) demonstrated that a person with right hemispatial neglect who had a selective lesion to the posterior superior parietal region in the left hemisphere tended to misplace the subjective midpoint leftward when asked to bisect numbers and lines. In the current study, the DD group exhibited the similar exaggerated leftward bias on the MNL bisection task compared with the control group. Thus, it is logical to assume that individuals with DD present exaggerated attentional bias on the MNL bisection task due to deficiency or altered performance of the left hemisphere. This assumption is in agreement with previous studies indicating decreased activity in left hemisphere in individuals with DD (Shaywitz et al., 2002). The exaggerated bias of the DD group, along with spared numerical Stroop performance, may also point to impairment of the posterior rather than inferior attentional system, as the bisection task is associated with orienting of attention while the Stroop task, with executive attention (Posner & Petersen, 1990). However, this interpretation should be taken cautiously, since the significant out-of-range errors demonstrated by the DD group implies that monitoring of the required task (subserved by executive attention) was deficient.

In closing, the present study aimed to examine whether altered bisection performance of individuals with DD may arise from attentional impairments or may be attributable to insufficient reading exposure. This was carried out by using two bisection tasks shown to be influenced differently by reading habits. Individuals with DD exhibited altered performance on both tasks compared with normal readers. These results suggest that visuospatial attentional mechanisms are impaired in DD and support findings that link DD to decreased function of the left hemisphere.

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Conflict of Interest

None declared.

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