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Children with Dyslexia Utilize Both Top-Down and Bottom-Up Networks Equally in Contextual and Isolated Word Reading

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Abstract

Introduction: Executive functions (EF) include cognitive processes that support learning and reading. Children with dyslexia experience challenges with both reading and reading comprehension. The neurobiological support for EF deficits during reading comprehension, however, has yet to be defined. Here we aimed to identify the neural networks related to EF during a reading comprehension task focusing on top-down and bottom-up networks in children with dyslexia and typical readers (TR).

Method: Twenty children with dyslexia and 19 TR aged 8–12 were scanned during a sentence comprehension (SC) task that included isolated words and sentences that make sense, in addition to undergoing reading and EF behavioral assessment. Functional connectivity within and between four EF networks related to top-down and bottom-up processing were calculated.

Results: Children with dyslexia scored significantly lower in reading and EF testing in several subdomains compared to TR. Children with dyslexia displayed decreased accuracy in both task conditions compared to TR during the SC task. Neuroimaging data analysis revealed that TR had

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greater functional connectivity within and between top-down and bottom-up processes, in the sentence vs. isolated word condition, compared to children with dyslexia.

Discussion: TR demonstrate a reliance on top-down and bottom-up networks only during sentence comprehension. In children with dyslexia, however, this reliance was not found in either of the task conditions, suggesting that both conditions were equally challenging for them. These findings emphasize the involvement of EF networks in the reading comprehension process and highlight their impaired functionality among children with reading difficulties.

Keywords

Dyslexia; Executive Functions; Reading; Comprehension; Neuroimaging; Brain Networks

1. Introduction

Decades of research have confirmed that children with dyslexia experience significant challenges with various aspects of reading, such as reading fluency and reading comprehension (for example, see [1]). Behavioral studies suggest that these deficits are associated with challenges in executive functions (EF) [2, 3], although no empirical research has determined what neural pathways may contribute to the deficits in reading comprehension found in children with dyslexia. The current study uses fMRI to compare the neurobiological correlates for the involvement of EF during reading comprehension in children with dyslexia vs. typical readers (TR).

1.1 Reading comprehension

Reading comprehension, defined as the ability to comprehend written material, is a fundamental academic and life skill that has been studied across various disciplines, including psychology, education, and cognitive sciences [4], and it plays a primary role in academic success in school, college achievements, and career prospects [4]. Reading comprehension is a complex process that involves both linguistic and cognitive skills and, as such, relies on several corresponding neural systems [5]. Researchers have proposed a number of theoretical models describing the cognitive and linguistic processes that are involved in the complex task of reading comprehension. Based on the traditional LaBerge and Samuels [6] model for attention allocation, reading comprehension demands switching between both semantic and episodic memory. The model suggests that a reader is typically unable to allocate attention both to the technical skills of reading as well as comprehension, due to limited working memory (WM) capacity. Therefore, only when the technical skills become automatic, attention to comprehension can be achieved. A different approach model, known as Kintsch's model [7], suggests that reading comprehension is a bottom-up process that is highly influenced by top-down processes, and comprises two main components. The first is the "construction phase", during which the reader forms a mental representation of the meaning of the raw material that is presented, arising from the reader's knowledge about language, as well as knowledge about the world. The second is the integration phase that relies mainly on higher order cognitive abilities also referred to as EF [7].

1.2 Reading comprehension and executive functions

EF or cognitive control are an umbrella term for several cognitive abilities that support learning and control behavior. These functions are also referred to as “top-down” abilities [8]. EF play a role in the “attentional network”, which serves to alert and orient one’s attention to a specific environmental stimulus, as well as other bottom-up abilities [8, 9] [10]. The cognitive abilities associated with EF are divided into three main categories— inhibition, WM and cognitive flexibility [11], which, when combined, serve as the foundation for more complex tasks such as planning, organization, problem solving, and logical thinking [12], all of which are necessary for learning [13]. The attentional network model suggests that EF (associated with the cingulo-opercular (CO) and frontoparietal (FP) networks, related to top-down abilities, aka system 2) interact with bottom-up abilities (associated with the dorsal attention and ventral attention (DAN and VAN, respectively) networks, related to bottom-up abilities, aka system 1). Perfetti and Hart [14] suggested that word identification (related to bottom-up processing) and comprehension components (related to top-down processing) function in together and can substantially affect reading comprehension. The literature provides evidence for the relationship between WM and reading comprehension [15]. Children who suffer from developmental disorders such as dyslexia and dyscalculia show impairment in WM tasks, which is consistent with the LaBerge and Samuels model [5] mentioned above [16, 17].

1.3 Dyslexia – a specific reading disability

Dyslexia is a neurobiological learning disability, with a prevalence of 5–17% among children in elementary school [18, 19]. Dyslexia is defined as a disability in the reading domain, reflected in challenges with word recognition and poor spelling abilities that are inconsistent with the individual’s intelligence [20]. People with dyslexia also experience significant deficits in reading comprehension [21]. As explained by Richlan [22], dyslexia is mostly categorized by poor performance in reading accuracy, fluency, spelling and comprehension. It was claimed that the primary deficits in dyslexia include phonemic awareness [23] and sensory–motor abilities [24]. One reason for the complexity in diagnosing dyslexia, however, is its multifaceted characteristics. In other words, several secondary deficits such as in visual attention and EF, often worsen the individual’s performance level [25]. In many cases, the symptoms appear at early age and persist into adulthood [26]. Rimrodt, Clements-Stephens [27] found that children with dyslexia were significantly less accurate in their reading comprehension questions compared to age-matched TR. They identified a number of neural systems associated with this deficit, including the phonological and semantic systems, which have been observed to be impaired among children with dyslexia [27, 28]. Neuroimaging studies suggest that dyslexia is mainly characterized by neurobiological dysfunction related to phonological processes [29–33]. However, Rimrodt, Clements-Stephens [27] who examined sentences comprehension found increased activation in language related regions, including the left Middle Temporal Gyrus (MTG), the Superior Temporal Gyrus (STG) and the Inferior Frontal Gyrus (IFG, also involved in EF) in children with dyslexia [34]. Moreover, the findings reveal that the dyslexia group exerts more effort during sentence comprehension, as they rely heavily on regions associated with attention and response selection [35].

One assumption made by Rimrodt and Clements-Stephens is that the EF difficulties in children with dyslexia have contributed to their challenges in reading comprehension [27]. This was supported by a recent study that found differential activation in neural circuits supporting EF, such as the left inferior parietal region, in children with dyslexia during reading comprehension [36]. The authors suggested that children with dyslexia display altered activity in EF regions compared to TR during sentence reading tasks and non-lexical control tasks [36]. This work, however, examined specific regions associated with reading comprehension (i.e., activation) and did not focus on explicit neural circuits supporting EF during reading comprehension. Pinpointing specific neural circuits related to top-down and bottom-up processes, as well as the interaction between these networks, will provide a more accurate understanding of the specific cognitive processes that lead to difficulties with reading comprehension in children with dyslexia. Although the above-mentioned two works included individuals with a comorbidity of dyslexia and ADHD, their findings have been supported strongly by other papers that included only individuals diagnosed solely with dyslexia, as detailed in Section 1.4.

1.4 Executive functions in children with dyslexia

Executive functions such as WM, inhibition, shifting, and speed of processing, involved in the process of reading [37], have been found to be impaired among people with dyslexia [3, 38]. Among other challenges of individuals with impaired EF, the literature reports of difficulties in planning [16]. Neuroimaging studies examining the role of EF during reading in children with dyslexia demonstrated that there is an impairment in a number of neural circuits [39, 40]. These readers showed decreased activation of the anterior cingulate cortex (ACC) when reading words [36], a critical region within the EF networks [40]. The ACC is part of the cingulo-opercular network related to error monitoring and was previously reported to show decreased functional connectivity during reading in children with dyslexia [41]. Additionally, the frontoparietal network, also part of the EF networks, was found to be involved in improved reading following an EF-based reading intervention in children with dyslexia [42]. Interestingly, increased functional connectivity between the visual processing independent component and the frontoparietal independent component was related to improved reading comprehension in those readers [42].

Despite the accumulated data on the link between reading comprehension and EF, there is still a gap in knowledge in understanding the neurobiological correlates of EF during reading comprehension in children with dyslexia. The current study aims to pinpoint the neural circuits related to these components during reading comprehension in children with dyslexia using fMRI.

We hypothesized that overall, reading comprehension will be positively associated with EF. We also hypothesized, consistent with theoretical models and previous empirical studies, that during sentence comprehension, children with dyslexia will show decreased EF and increased functional connectivity in neural circuits related to EF, compared to TR. Based on an EEG study done by [28], we postulated that for reading comprehension vs. word reading, no differences between top-down neural networks related to higher order EF (i.e., cingulo-opercular, frontoparietal) and bottom-up stimulus-driven neural networks (i.e., VAN and

DAN) will be observed in children with dyslexia vs. TR. We also suggested that children with dyslexia will utilize both top-down and bottom-up networks to a greater extent during sentence comprehension compared to TRs.

2. Method

2.1 Participants

The current study included 20 children with dyslexia (10 females) and 19 TR (8 females), ages 8–12 years, with no history of other neurological or psychiatric diagnoses, such as ADHD. All participants were native English speakers. Once we reached the desired number of participants, we stopped recruiting. Prior to participation in the study, each participant was screened to ensure that there were no physical impediments, such as implants, that could impact the quality of the MRI scan. A researcher reviewed the procedures with the child and parent, and each parent and participant provided informed consent and assent, respectively. Participants received a gift card as compensation. The study was approved by the Institutional Review Board.

2.2 Behavioral measures

The measures selected for this study focused on aspects of general aptitude, as well as verbal ability, reading comprehension, and measures associated with EF skills. To assess for general aptitude independent of reading or verbal skills we administered the Test of Nonverbal Intelligence (TONI-3) [43]. The Peabody Picture Vocabulary Test, 4th edition (PPVT-4) [44] was used to assess the children's verbal skills. To distinguish between TR and children with dyslexia, the children completed a number of measures that assess reading abilities, including: (1) timed word and (2) timed nonword reading from the Test of Word Reading Efficiency, 2nd edition (TOWRE II) [45]; (3) nontimed word reading (letter–word subtest) from the Woodcock–Johnson- III (WJ-III) [46]; (4) nontimed nonword reading (word-attack subtest) from the WJ-III [46], (5) reading comprehension [47] and (6) reading fluency from the Gray Oral Reading Test 4th edition (GORT) [47], (7) phonemic awareness, (8) rapid object naming and (9) rapid letter naming from the Comprehensive Test of Phonological Processing (CTOPP) [48]. Following Kovelman, Norton [49], participants who received a standard score of –1 or below on at least two of these measures were assigned to the dyslexia group. Children with attention difficulties or with a history of attention difficulties based on the Conners self- and parents' reports [50] were excluded from the study.

A number of subtests were administered to assess the various domains associated with EF: (1) working memory was assessed using the Digit Span subtest (WISC) [51]; (2) inhibition was assessed using the Stroop Color–Word Interference subtest (D-KEFS) [52]; (3) speed of processing was assessed using Symbol Search (WISC) [51]; (4) switching was assessed using the Wisconsin card sorting test (WCST) [53]; and (5) general EF was assessed using the self-report Behavior Rating Inventory of Executive Function (BRIEF) [54].

2.3 Neuroimaging measures

2.3.1 Neuroimaging task—To assess neural activity associated with reading comprehension, participants completed the sentence comprehension (SC) paradigm previously reported by Rimrodt, Clements-Stephens [35] during an fMRI scan. This task included 12 blocks, each containing 5 stimuli, yielding a total of 60 stimuli for the task. Three types of stimuli were included: 1) Anomaly sentences (sentences that do not make sense), which were presented in 4 blocks; 2) non-anomaly sentences (sentences that made sense), which were also presented in 4 blocks; and 3) isolated words, which were presented one at a time, comprising 20 stimuli for each type [27], over all 4 blocks. The word condition was chosen to control the presentation of words on the screen and to “crystalize” the comprehension components. Each stimulus (both sentences and words) consisted of a sequence of 6 words, with each word presented for 800 ms, followed by a response screen presented for 1600 ms and a stimulus interval (ISI) of 200 ms. For the sentence conditions, in the response slide, the participants were asked to decide if the sentence makes sense or not by pushing the button corresponding to the “yes” or “no” signs on the screen. For the word condition, the words appeared on the screen, one by one (six per stimulus), and the participants were instructed to push the “yes” button if one of the words appeared twice and “no” if each word appeared only once. All responses were assessed for reaction time and accuracy. Participants viewed the paradigms on an LCD projector on a rear projection screen at the head of the scanner via a 45°-angled mirror affixed to the MRI head coil. To present the task and record the timing for the stimulus presentations and participants’ responses, we used Direct-RT software. Each block started with a two-second instruction slide, explaining if the block contained sentences or single words, followed by the six stimuli (sentences or sets of words), for a total duration of 37 seconds. All sentences were composed of words with an overall mean frequency of 62 and higher [55], a mean length of 30 letters, and a mean of nine syllables. Figure 1 presents the task graphically.

2.3.2 Neuroimaging data acquisition—This study used a 3T Philips Achieva MRI scanner. An MRI-compatible audio/visual system (Avotec, SS3150/SS7100) was used to present the stimuli. For anatomical co-registration as well as for use in spatial normalization, a 3D high-resolution, isotropic, T1-weighted turbo field echo (TFE) anatomical imaging sequence was performed using 8.05-ms repetition time (TR), 3.7-ms echo time (TE), contiguous slices with a 1 mm thickness, and $1 \times 1 \times 1\text{-mm}^3$ voxel size. A gradient echo planar sequence was used for a T2*-weighted BOLD fMRI scan with the following parameters: TR/TE = 2000/38 ms, BW = 125 kHz, FOV = 25.6×25.6 cm, matrix = 64×64 , and slice thickness = 5 mm. Elastic bands affixed to the head of the coil device were used to control participants’ head motions.

2.4 Behavioral data analyses

Two-way independent t-tests were used to compare reading and EF abilities in children with dyslexia and TR. Pearson correlations were used to examine the correlation between EF and reading comprehension in the entire sample. Data were corrected for multiple comparisons using a Bonferroni correction.

2.5 Neuroimaging data analyses

2.5.1 Functional MRI data preprocessing—Data preprocessing and first-level analyses were performed using SPM12 (Wellcome Department of Cognitive Neurology, London, UK). Preprocessing included slice time correction, realignment, and normalization using the 3D anatomical whole-brain scan (7th degree-spline interpolation) to match the Montreal Neurological Institute (MNI) standard template, resampling (3 mm³ voxels), and smoothing with 8-mm full width at half maximum or FWHM. We performed three-dimensional affine transformation to align the volumes, yielding six motion parameters: three translational and three rotational. To quantify the level of head motion, we calculated the mean frame-wise displacement (FD) for each subject [56] using the motion parameter files.

2.5.2 Task-based functional connectivity analyses—Following spatial preprocessing, the task-based data were fed into CONN [57], a functional connectivity toolbox for MATLAB (Version R2018b, The MathWorks, Natick, MA).

Using the default method offered by CONN toolbox (i.e., CompCor), motion related artifacts were controlled by 1) using images with a motion quality rating of 0–1; 2) applying linear regression and bandpass filtering; and 3) removing different sources of possible confounders—the Blood-Oxygenized Level Dependent (BOLD) signal from the white matter and Cerebral Spinal Fluid (CSF) masks—from the within-subject covariate (realignment and scrubbing parameters) [58]. Voxel-wise temporal de-noising of the BOLD signal was applied by regression of zero- and first-order derivatives of the six motion parameters, regression of each of the top five principle components of the average white matter and cerebrospinal fluid BOLD signal, and applying 0.008 Hz high pass filtering.

Several networks were specified for the purpose of the current analyses. Top-down networks include the cingulo-opercular (CO) network and the frontoparietal (FP) network [8, 9] and bottom-up networks include the ventral attention (VAN) network and the dorsal attention (DAN) network. Functional connectivity between and within the networks was calculated as the mean of the sum of pair-wise, Fisher-transformed, bivariate correlation coefficients for all regions of interest within or between the networks.

2.6 Defining the functional networks

To determine the functional connectivity within and between the CO, FP, VAN and DAN networks, we identified regions of interest (ROI) by defining the nodes of these networks based on coordinates reported by Dosenbach and colleagues [40] for the FP and CO networks, and coordinates reported by Fox, Corbetta [59] for the VAN and DAN networks. MNI coordinates were then input into the Talairach client [60, 61] and used as a mask for the CO, FP, VAN, and DAN networks using codes written in MATLAB. Figure 2 and Table 1 provide the networks' definitions and coordinates.

To determine the difference in functional connectivity of cognitive control networks in dyslexia vs. TR during reading comprehension, all the networks were defined in the non-anomaly and the isolated word reading conditions only.

To determine the functional connectivity patterns for sentence comprehension, functional connectivity within each network was calculated for the non-anomaly condition and the isolated words condition. The anomaly condition was used only to control for the child's sentence reading skills. The independent t-test analyses that were conducted for functional connectivity in the above conditions for the four networks were in TR, children with dyslexia, TR > children with dyslexia and children with dyslexia > TR.

To assess differences in the involvement of these cognitive control networks in children with dyslexia and TR, a 2×2×4 Repeated Measures ANOVA for Group (children with dyslexia, TR) × Modality (sentences, words) × Network (CO, FP, DAN, VAN) was conducted. To determine the differences in bottom-up and top-down (aka system1 and 2, respectively) involvement in children with dyslexia and TR within each modality, 2×2×2 Repeated Measures ANOVA for Group (children with dyslexia, TR) × System (top-down, bottom-up) × Modality (sentences, words) was conducted. All datasets were corrected for multiple comparisons using a Bonferroni correction.

2.7 Correlation of functional connectivity with the behavioral data

Pearson correlations were used to determine the association between functional connectivity of the EF networks with EF and reading behavioral and cognitive scores, between the within-network connectivity and each reading and EF measure mentioned above, for the entire sample. Data were corrected for multiple comparisons using a Bonferroni correction.

3. Results

3.1 Behavioral data

No differences were found between the two groups for general verbal and nonverbal abilities, as well as attention measures. Children with dyslexia, however, demonstrated significantly lower scores in all reading measures compared to TR, including oral reading fluency (comprehension, rate, accuracy, fluency, GORT), phonological processing (Ellison subtest, CTOPP), rapid object naming (Object Naming subtest, CTOPP), rapid letter naming (Letter Naming subtest, CTOPP), word decoding fluency (PDE subtest, TOWRE), word reading fluency (SWE subtest, TOWRE), nonword reading fluency (Letter Word subtest, Woodcock Johnson), and non-word decoding fluency (Word Attack subtest, Woodcock Johnson) (see Table 2). In addition, children with dyslexia also showed decreased EF ability in several subdomains: phonemic fluency (verbal fluency subtest, DKEFS), inhibition and switching (color word subtest, DKEFS) and visual attention (sky search attention, Teach). see Table 2 for these results.

3.2 Neuroimaging data results

3.2.1 Accuracy and reaction times

Accuracy: Children with dyslexia demonstrated lower accuracy in both sentences and isolated words compared to TR. Children with dyslexia also demonstrated a significantly lower accuracy rate for isolated words compared to sentences.

Reaction time: Though not significant, children with dyslexia demonstrated longer reaction times for sentences compared to TR, while in the isolated words they showed shorter reaction times compared to TR. See Tables 3 and 4 for the results.

3.2.2 Functional connectivity data—No differences were found in functional connectivity of the cognitive control networks between children with dyslexia and TR for each of the different task conditions (non-anomaly sentences, isolated words) (see Table 5 for details). When comparing the task's conditions (sentences > isolated words), however, a greater functional connectivity was observed within the CO network, and between the CO and the other three networks—FP, DAN, and VAN—for TR compared to children with dyslexia. In addition, results indicated a trend of a greater functional connectivity within the CO network for TR compared to children with dyslexia in the sentence condition. These results suggest a greater reliance on top-down and bottom-up networks for TR compared to children with dyslexia for sentence comprehension vs. isolated word reading. See Tables 6 and 7.

3.2.3 Main effects of networks, systems, and modality—A $2 \times 2 \times 4$ Repeated Measures ANOVA for Group (children with dyslexia, TR) $\times$ Modality (sentences, words) $\times$ Network (CO, FP, DAN, VAN) revealed a significant main effect of Network [$F(3,111)=8.977$, $P=0.000$, $\eta^2=0.195$], such that a greater functional connectivity was found within the FP and CO networks, and decreased functional connectivity for the DAN and VAN networks ($VAN < DAN < CO < FP$). No main effects of Group [$F(1,37)=0.134$, $P=0.717$, $\eta^2=0.004$] or Modality [$F(1,37)=0.802$, $P=0.376$, $\eta^2=0.021$] were found.

To determine the differences in system involvement in children with dyslexia and TR within each modality, a $2 \times 2 \times 2$ Repeated Measures ANOVA for Group (children with dyslexia, TR) $\times$ System (between network connectivity in top-down and bottom-up networks) $\times$ Modality (sentences, words) was run. A significant main effect of System [$F(1,37)=4866.607$, $P=0.000$, $\eta^2=0.992$] was revealed. The results suggest a greater functional connectivity of bottom-up vs. top-down networks. In addition, a significant Modality $\times$ System interaction [$F(1,37)=4.234$, $P=0.047$, $\eta^2=0.103$] was found, indicating a greater functional connectivity in bottom-up vs. top-down networks in both sentence and isolated word conditions, as a higher magnitude of the difference between the systems in the sentence condition compared to the isolated word condition was found. No main effect of Group was found [$F(1,37)=0.009$, $P=0.923$, $\eta^2=0.000$].

3.3 Correlation analyses

3.3.1 Correlations between reading comprehension and executive functions—Results showed positive correlations between reading comprehension measures from the reading comprehension battery (GORT; including comprehension and fluency) and several cognitive abilities (fluency, switching and inhibition, visual attention, and selective attention) for the entire sample (phonemic fluency, DKEFS, $r=0.554$, $P=0.000$, semantic fluency, DKEFS, $r=0.330$, $P=0.043$, switching and inhibition DKEFS, $r=0.364$, $P=0.025$, visual attention (TEACH Sky Search), $r=0.398$, $P=0.016$, and selective attention (TEACH),

$r=0.376$, $P=0.024$). Results suggest that higher comprehension and fluency are related to better EF in the entire sample.

When examining the correlation between reading comprehension and EF for each group separately, we found positive correlations between reading comprehension measures (GORT; including comprehension, fluency and rate) and several cognitive abilities (speed of processing, selective attention, and visual attention) only for the TR [(speed of processing, symbol search, WISC, $r=0.511$, $P=0.030$), selective attention (TEACH, $r=0.517$, $P=0.028$), and visual attention (sky search attention, TEACH, $r=0.494$, $P=0.037$)]. Results suggest that better comprehension, fluency, and rate are related to better EF in the TR group.

In contrast to the TR group, children with dyslexia showed a positive correlation only between the oral reading rate from the GORT, and phonemic fluency [verbal fluency, (DKEFS), ($r=0.490$, $P=0.028$)]. This suggests that faster oral reading was related to better phonemic fluency in children with dyslexia.

3.4 Correlation of behavioral and neuroimaging data

3.4.1 Functional connectivity within and between the cognitive control networks during the sentence reading condition and behavioral measures

Entire sample: Although several Pearson correlations between the behavioral-within-network connectivity during sentence reading and EF measures within the entire sample were conducted, only one survived the correction for multiple comparisons. It revealed significant positive correlations between top-down and bottom-up networks and EF abilities (from the Brief parents report) [within the VAN network ($r=0.336$, $P=0.039$), within the CO network ($r=0.387$, $P=0.016$), and between the CO and FP networks ($r=0.436$, $P=0.006$)]. Overall, greater functional connectivity within the CO and VAN networks, and between the FP and CO networks during sentence reading was related to higher EF in the entire sample.

TR: Number of Pearson correlations between- and within-network connectivity during sentence reading and EF measures for TR revealed only one significant positive correlation between top-down and bottom-up networks with EF abilities (from the Brief parents report) [within the CO network ($r=0.650$, $P=0.004$), within the VAN network ($r=0.472$, $P=0.048$), and between the CO and FP networks ($r=0.573$, $P=0.013$)], after correcting for multiple comparisons. Overall, greater functional connectivity within the CO and VAN networks, and between the FP and CO networks during sentence reading was related to higher EF in TR.

Children with dyslexia: For the dyslexia group, a negative correlation between top-down networks (between FP and CO network functional connectivity) and word reading fluency scores (sight word efficiency subtest, TOWRE, $r=-0.450$, $P=0.046$) was found, as it was the only correlation that survived the correction for multiple comparisons. Overall, greater functional connectivity between the top-down networks (FP, CO) during sentence reading was related to lower EF abilities in children with dyslexia.

3.4.2 Functional connectivity within the cognitive control networks during the word reading condition and behavioral measures

Entire sample: Negative correlations between and within top-down and bottom-up networks during isolated word reading using the oral reading rate from the GORT subtests [within the VAN network ($r=-0.376$, $P=0.018$), within the DAN network ($r=-0.330$, $P=0.040$), between the VAN and DAN networks ($r=-0.418$, $P=0.008$)] and between the FP and CO networks ($r=-0.406$, $P=0.010$)] were observed. In addition, negative correlation was found between and within top-down and bottom-up networks with word reading fluency abilities, using the TOWRE tests (SWE) [within the VAN network, $r=-0.373$, $P=0.019$), and between the FP and CO networks, ($r=-0.398$, $P=0.012$)] for the entire sample. Overall, greater functional connectivity within and between the DAN and VAN networks, and between the FP and CO networks during word reading was related to lower EF abilities in the entire sample.

TRs: Negative correlations between top-down and bottom-up networks with word reading fluency abilities using the TOWRE tests (SWE) [within the VAN network, ($r=-0.456$, $P=0.050$), within the DAN network ($r=-0.486$, $P=0.035$), between the VAN and DAN networks ($r=-0.505$, $P=0.027$), and between the FP and CO networks ($r=-0.512$, $P=0.025$)] were observed only for the TR. Overall, greater functional connectivity within and between the VAN and DAN networks, and between the FP and CO networks during word reading was related to lower EF abilities in the TR group.

Children with dyslexia: In contrast to the TR group, positive correlations between top-down networks and EF (from the Brief parents report) [within FP network ($r=0.496$, $P=0.026$)], and negative correlation within and between bottom-up networks with reading comprehension abilities [within the DAN network ($r=-0.468$, $P=0.037$), and between the VAN and DAN networks ($r=-0.549$, $P=0.012$)] were observed only for children with dyslexia. Overall, greater functional connectivity within FP networks during word reading was related to higher EF abilities in children with dyslexia, whereas greater functional connectivity within the VAN network, and between the VAN and DAN networks was related to lower reading comprehension abilities.

4 Discussion

The current study examined the role of EF in reading comprehension among 8–12-year-old children with dyslexia and TR. We hypothesized that children with dyslexia will exhibit decreased EF during sentence comprehension, which will also be prominent in terms of functional connectivity, as we expected to see greater functional connectivity in neural networks related to EF (i.e., top-down and bottom-up networks), in children with dyslexia compared to TR. In order to test these hypotheses, we used fMRI to observe these specific neural circuits related to EF and reading during sentence comprehension tasks. In line with our hypothesis, children with dyslexia exhibited deficits in all reading measures and in several EF subtests, which is consistent with previous findings [62, 63]. In addition, children with dyslexia displayed lower accuracy rates in both sentence and word reading conditions. Though not significant, and in contrast to our hypotheses, these differences were also found

in the neuroimaging results. Children with dyslexia had decreased functional connectivity in both bottom-up and top-down networks, which are related to alerting and orienting attention, and EF, respectively.

4.1 Executive function impairments in children with dyslexia

The behavioral results of the current study indicate a deficit in phonemic fluency, switching, inhibition and visual attention among children with dyslexia, as they scored significantly lower than TR in these measures. These results are consistent with previous findings regarding impairments in EF among children with dyslexia [38], [16], [39]. The Confidence Intervals (CI) presented in Table 2, signify that visual attention abilities are vastly different between the groups, compared to the other significant EF abilities (e.g. fluency, switching and inhibition), as manifested by the relatively smaller CI width for this measure. This finding is in line with several previous studies indicating visual attention challenges in children with dyslexia [64, 65]. Additionally, when examining the CI for the behavioral reading measures, significant differences in several abilities were observed: the greatest differences between the groups were found for oral reading fluency, phonological processing, rapid letter naming and rapid object naming abilities. This minimal CI range for these measures reflect the significant differences between the groups, which emphasize the difficulties that children with dyslexia experience, in the abilities listed above. Furthermore, accuracy and RT results (from the fMRI task) pointed at non-automatic contextual reading abilities in children with dyslexia, demonstrated through their slow RT in the sentence condition. These results also echo previous findings showing that controls were significantly more accurate than children with dyslexia in the sentence condition [35]. It is important to mention, however, that although children with dyslexia were slower than TR in 25 ms in the sentence condition, these results have not reached significance (as was also demonstrated by the wide CI range in Table 4. Although children with dyslexia did demonstrate faster RT in the isolated word condition, this finding is most likely due to pressing the button before decoding or encoding the words, as shown by their poor accuracy in this condition.

Additionally, our behavioral findings indicate that children with dyslexia have significant correlations only between oral reading fluency (rate, GORT) and phonemic fluency (verbal fluency subtest, DKEFS). The fact that no more correlations were found presumably reflect the fact that the behavioral scores in the dyslexia group in our study were more homogenous, compared to the more heterogenous scores for TR, as apparent from the mean and SD scores (see Table 2). Therefore, more correlations were prominent in the TR group compared to the dyslexia group, as they exhibited significant correlation between reading comprehension measures and number of EF sub-domains, including speed of processing (visual symbol search, WISC), visual attention (sky search attention, TEACH), and selective attention (TEACH). This finding might also explain why these correlations were not found also in the dyslexia group, as these tasks are usually highly difficult for the latter group.

4.2 The need for an overall top-down monitoring as well as basic attention while reading sentences among TR

The current study focused on four networks related to top-down (CO and FP) and bottom-up (VAN and DAN) processes. The results obtained in this study suggest that TR rely more on

top-down processes during reading comprehension compared with children with dyslexia. When contrasting the task's condition (sentences > words), we can see that the former group engaged more functional connectivity within and between top-down and bottom-up networks. In addition, they showed a trend of greater functional connectivity within top-down processes (CO network) in the sentence reading condition vs. the word condition. Our findings support previous evidence that TR exhibit greater activation during sentence reading than isolated word reading, as was shown in a study by Rimrodt, Clements-Stephens [35]. Although Rimrodt, Clements-Stephens [35] focus was not on functional connectivity, their findings revealed that TR show activation in areas associated with word and sentence reading, such as the left inferior frontal gyrus and left superior frontal.

The results from the SC task showed that TR exhibited faster RT in the sentence reading condition and were more accurate in this condition compared to the word condition. Despite the fact that the RT finding is not significant, it may explain why they engaged more functional connectivity in cognitive control networks during this condition, in contrast to children with dyslexia. It is probably easier for TR to rely on the context in order to read better. This finding is supported by previous literature, as Helland and Asbjørnsen [66] and Horowitz-Kraus [38], showed that children with dyslexia demonstrate slower RT in tasks that involve EF, such as the Wisconsin Card Sorting test and the Stroop Color Word test, which supports our neuroimaging results.

4.3 Top-down and bottom-up networks are equally involved in contextual and isolated word reading in children with dyslexia

The findings of this study suggest that the difficulties in reading comprehension that are shared in children with dyslexia may be derived from a more basic difficulty in isolated word reading, since no differences were seen in these children between the two task conditions (sentence vs. word reading). Hence, as no difference in functional connectivity was found between the conditions, clearly, both top-down and bottom-up networks were equally involved in sentence and word reading. Based on Kintsch's model [7], reading comprehension is a bottom-up process that is vastly influenced by context, thus it also relies on top-down processing to achieve proficient comprehension. Cain and Oakhill [67] suggested that reading comprehension deficits stem from, among others challenges, deficiency in more basic primary abilities linked to basic linguistic skills, such as vocabulary skills, and word decoding. This assertion can explain why bottom-up networks are needed to achieve decoding, which is the basis for proficient reading comprehension [68, 69]. In other words, impairment in bottom-up skills is related to a weakness in decoding and, therefore, poor reading comprehension abilities may result. On the other hand, even if all words are correctly decoded and top-down processes are impaired, poor reading comprehension will be demonstrated. To test this idea, future studies should compare children with dyslexia to children with specific language impairment suffering from intact decoding but impaired reading comprehension.

4.5 Study's limitations

Although our study opens a new research direction in terms of the involvement of cognitive control networks during reading comprehension in children with dyslexia and TR, it has its

limitations. First, we had a relatively small number of participants (39), and as such, our findings may have somewhat limited generalizability. Second, our results included English speaking children, and differences between orthographies (i.e., shallow vs. deep orthography) may be associated with a different reliance on cognitive control networks. Third, we only focused on analyzing functional connectivity data obtained during the fMRI scan at one time-point.

4.6 Conclusions

The uniqueness of our study lies in the focus on functional connectivity in four specific networks, related to top-down and bottom-up processing, as opposed to previous studies, which mainly focused on brain regions. The current study provides a basis for future studies investigating the role of EF in children with dyslexia in reading comprehension. Future studies should include a larger number of participants, from both dyslexia and TR groups. Additionally, children speaking different orthographic languages should be included in future studies to control for language-specificity effects. Also, future research should include longitudinal studies, including studies with EF-focused interventions, to determine the role of EF in reading comprehension in both children with dyslexia and TR and to provide a broader insight on EF in reading comprehension.

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Highlights

- Decreased accuracy and slower reaction times in sentence reading in dyslexia vs typical readers.
- Decreased functional connectivity in EF networks in children with dyslexia.
- EF networks are equally involved in sentence and word reading in dyslexia and unequally in typical readers.

Word	Word	Word	Word	Word	Word		+	ISI
0.8 sec	0.8 sec	0.8 sec	0.8 sec	0.8 sec	0.8 sec	1.6 sec	0.8 sec	0.2 sec

Figure 1. The sentence comprehension task
Figure 1: Display of the stimulus presentation in the sentences task.

Top-down:

Bottom-up:

Figure 2. Spatial maps for the cognitive control networks

Figure 2: Top images present the maps for top-down networks (frontoparietal (FP), in red, cingulo-opercular (CO), in green). The bottom part presents the maps for bottom-up networks (dorsal attention (DAN), in yellow, ventral attention (VAN), in blue). Images are presented in neurological orientation (L=left, R=right).

Table 1:

Regions of interest and their corresponding coordinates:

	ROI	X	Y	Z	BA
Frontoparietal	Left dorsolateral prefrontal cortex	-43	22	34	9
	Right dorsolateral prefrontal cortex	43	22	34	9
	Left inferior parietal lobule	-51	-51	36	40
	Right inferior parietal lobule	51	-47	42	40
	Left intraparietal sulcus	-31	-59	42	7
	Right intraparietal sulcus	30	-61	39	19
	Left precuneus	-9	-72	37	7
	Right precuneus	10	-69	39	7
	Mid cingulate cortex	0	-29	30	23
Cingulo-Opercular	Left anterior prefrontal cortex	-28	51	15	10
	Right anterior prefrontal cortex	27	50	23	10
	Left lateral anterior insula	-51	18	13	44
	Right lateral anterior insula	45	23	-4	47
	Left medial anterior insula	-33	24	1	13
	Right medial anterior insula	33	25	-1	13
	Left anterior insula	-35	14	5	13
	Right anterior insula	36	16	4	13
	Dorsal anterior cingulate/medial superior frontal cortex	-2	13	44	32
Dorsal-Attention	Right FEF	28	-10	53	6
	Left FEF	-25	-12	55	6
	Right posterior IPS	20	-67	51	7
	Right anterior IPS	35	-47	45	7
	Left posterior IPS	-22	-68	46	7
	Left anterior IPS	-42	-41	43	40
	Left SMA/pre-SMA	-4	-1	53	6
	Right inferior frontal gyrus	52	6	27	6
	Right fusiform gyrus	51	-63	-7	37
	Right middle frontal gyrus	37	38	20	9
	Right insula	30	17	9	13
	Left MT+	-46	-68	-7	19
Ventral-Attention	Right putamen	28	12	2	49
	Right supramarginal gyrus (TPJ)	57	-43	34	40
	Left insula	-41	11	1	13
	Right superior frontal gyrus	29	44	29	9
	Right inferior frontal gyrus	41	41	5	46
	Right inferior / Middle frontal gyrus	47	14	32	44
	Right superior frontal gyrus	4	20	49	8

	ROI	X	Y	Z	BA
	Right middle temporal gyrus	52	-32	-7	21
	Left superior temporal gyrus	-60	-49	19	39
	Right precuneus	2	-53	51	7
	Right medial frontal gyrus	8	3	62	6
	Right middle temporal gyrus	41	-13	-7	13
	Right sulcus Callosomarginalis	6	-28	43	31

ROI region of interest, BA Brodmann area, FEF frontal eye field, IPS intraparietal sulcus, SMA supplementary motor area

Table 2.

Independent t-test analyses of behavioral data between the groups

Ability	Cognitive ability	Measures	TR (A) M (SD)	Children with dyslexia (B) M (SD)	Contrast	T (P)	Mean difference	95% Confidence interval	
								Lower	Upper
General ability	Nonverbal IQ	IQ, TONI (Standard Score)	103.22 (7.313)	103.05 (7.619)	A > B	-0.071 (-0.944)	-0.172	-5.098	4.754
	Attention	Child report, Conners (T score)	46.24 (14.822)	50.95 (9.703)	B > A	1.161 (0.254)	4.715	-3.529	12.959
	Attention	Parents report, Conners (T Score)	44.17 (12.706)	52.35 (16.388)	B > A	1.706 (0.097)	8.183	-1.545	17.911
	Verbal fluency	Vocabulary, WISC (Standard Score)	9.56 (2.995)	10.65 (2.560)	B > A	1.214 (0.232)	1.094	-.733	2.922
Reading	Oral reading fluency and comprehension	Rate, GORT A (Scaled Score)	10.68 (1.857)	6.45 (2.819)	A > B	-5.508*** (0.000)	-4.234	-5.792	-2.677
		Accuracy, GORT A (Scaled Score)	11.16 (2.141)	6.85 (2.907)	A > B	-5.526*** (0.000)	-4.308	-5.972	-2.644
		Fluency, GORT A (Scaled Score)	10.68 (1.857)	6.30 (2.755)	A > B	-5.796*** (0.000)	-4.384	-5.917	-2.851
		Comprehension, GORT A (Scaled Score)	11.84 (1.708)	7.90 (2.511)	A > B	-5.502*** (0.000)	-3.942	-5.343	-2.541
		Rate, GORT A (Percentile)	56.95 (20.195)	10.15 (8.080)	A > B	-9.592*** (0.000)	-46.797	-56.683	-36.912
		Accuracy, GORT A (Percentile)	67.84 (22.154)	15.15 (12.115)	A > B	-8.223*** (0.000)	-46.692	-58.197	-35.187
		Fluency, GORT A (Percentile)	56.95 (19.340)	10.30 (7.138)	A > B	-10.093*** (0.000)	-46.647	-56.012	-37.283
		Comprehension, GORT A (Percentile)	69.68 (15.381)	21.30 (14.217)	A > B	-10.209*** (0.000)	-48.384	-57.987	-38.781
	Phonological processing	Ellison, CTOPP (Scaled Score)	11.84 (1.608)	7.25 (3.076)	A > B	-5.796*** (0.000)	-4.592	-6.197	-2.987
	Rapid object naming	Object Naming, CTOPP (Scaled Score)	7.89 (2.787)	5.50 (2.763)	A > B	-2.694* (0.011)	-2.395	-4.196	-.594
	Rapid letter naming	Letter Naming, CTOPP (Scaled Score)	9.89 (2.713)	6.80 (2.262)	A > B	-3.817*** (0.000)	-3.095	-4.738	-1.452
	Word decoding fluency	PDE, TOWRE (Scaled score)	105.00 (9.363)	76.50 (10.364)	A > B	-8.995*** (0.000)	-25.784	-32.486	-19.083
	Word reading fluency	SWE, TOWRE, (Scaled score)	103.68 (9.713)	77.90 (10.872)	A > B	-7.796*** (0.000)	-28.500	-34.920	-22.080
	Word non fluent	Letter Word, Woodcock Johnson (Standard Score)	105.95 (15.09)	85.55 (7.917)	A > B	-5.325*** (0.000)	-20.397	-28.159	-12.636

Ability	Cognitive ability	Measures	TR (A) M (SD)	Children with dyslexia (B) M (SD)	Contrast	T (P)	Mean difference	95% Confidence interval	
								Lower	Upper
	Decoding non fluent	Word Attack, Woodcock Johnson (Standard Score)	107.47 (9.709)	89.45 (8.532)	A > B	-6.167*** (0.000)	-18.024	-23.946	-12.102
EF	Memory	Digit Span, WISC (Standard Score)	8.94 (2.561)	7.76 (1.437)	A > B	-1.652 (0.108)	-1.176	-2.627	.274
	Speed of processing	Symbol, WISC Search (Standard Score)	10.28 (2.421)	9.84 (2.340)	A > B	-0.557 (0.581)	-0.436	-2.024	1.153
	Phonemic fluency	Verbal Fluency, DKEFS (C1 FAS) (Standard Score)	11.33 (2.452)	8.10 (2.594)	A > B	-3.956*** (0.000)	-3.233	-4.891	-1.576
	Semantic fluency	Verbal Fluency (C2 Animals and Boys Names), DKEFS (Standard Score)	10.67 (3.144)	9.30 (1.922)	A > B	-1.635 (0.111)	-1.367	-3.062	.328
	Switching/inhibition	Color Word (Condition 3), DKEFS (Standard Score)	10.22 (3.001)	7.05 (2.645)	A > B	-3.464** (0.001)	-3.172	-5.030	-1.315
	Visual attention	Sky Search Attention, Teach (Scaled Score)	8.56 (2.229)	6.44 (2.572)	A > B	-2.632** (0.013)	-2.111	-3.741	-.481
	Sustained attention/inhibition	Walk Don't Walk, Teach (Scaled Score)	15.83 (2.526)	14.05 (4.161)	A > B	-1.575 (0.124)	-1.783	-4.080	0.514
	Selective attention	Teach Score Standard Score	10.22 (3.671)	8.56 (2.874)	A > B	-1.517 (0.139)	-1.667	-3.900	0.567
	Sustained divided attention	Sky Search DT (dual task decrement), Teach (Scaled score)	7.94 (2.839)	7.00 (3.844)	A > B	-0.827 (0.414)	-0.941	-3.254	1.371
	EF	Parents report, Brief (Percentile)	36.29 (32.93)	48.70 (23.868)	B > A	1.325 (0.194)	12.409	-6.598	31.410
	EF	Child reports, Brief (Percentile)	47.61 (30.40)	50.70 (27.534)	B > A	0.329 (0.744)	3.089	-15.972	22.150

EF: executive functions, TR: typical readers,

* P < .05;

** P < .01;

*** P < .001

Table 3.

Accuracy (in percentage) and reaction times (in msec) for children with dyslexia and the TR group for sentence vs. isolated word conditions

	Sentences		Words		Contrast	T (P)
	TR M (SD) (A)	Children with dyslexia M (SD) (B)	TR M (SD) (C)	Children with dyslexia M (SD) (D)		
Accuracy (%)	85.05 (10.60)	69.42 (20.85)	83.83 (16.78)	49.20 (25.57)	A > C	-0.267 (0.793)
					B > D	-2.406* (0.029)
					A > B	-2.736*** (0.000)
					C > D	-4.623*** (0.000)
Reaction times (msec)	508.71 (42.36)	534.06 (72.89)	518.80 (135.78)	476.17 (78.57)	A > C	0.288 (0.777)
					D > B	-1.760 (0.098)
					A > B	1.230 (0.230)
					D > C	-1.112 (0.275)

*
P < .05;

***
P < .001,

TR: typical readers, M: mean, SD: standard deviation

Table 4.

Mean difference and Confidence interval for accuracy and reaction time rates for the two task conditions (sentences, isolated words) for children with dyslexia and TRs.

	Task condition	Mean difference	Confidence interval	
			Upper	Lower
Accuracy	Sentences	−0.156	−0.274	−0.037
	Words	−0.346	−0.500	−0.191
Reaction times	Sentences	25.344	−17.342	68.031
	Words	−42.626	−120.795	35.532

Table 5.

Within network functional connectivity values during sentence comprehension for children with dyslexia and TR

	Network	Children with dyslexia (A) Mean (SD)	TR (B) Mean (SD)	T (P)
Sentences	Frontoparietal	0.268 (0.151)	0.307 (0.155)	11.736 (0.00)
	Cingulo-Opercular	0.188 (0.098)	0.255 (0.146)	10.867 (0.00)
	Ventral Attention	0.212 (0.137)	0.231 (0.153)	9.602 (0.00)
	Dorsal Attention	0.206 (0.130)	0.240 (0.128)	10.814 (0.00)
Isolated words	Frontoparietal	0.297 (0.160)	0.287 (0.123)	12.891 (0.00)
	Cingulo-Opercular	0.281 (0.138)	0.247 (0.105)	13.437 (0.00)
	Ventral Attention	0.239 (0.129)	0.206 (0.099)	12.027 (0.00)
	Dorsal Attention	0.250 (0.131)	0.252 (0.110)	13.114 (0.00)

TR: typical readers, M: mean, SD: standard deviation

Table 6.

Within and between functional connectivity for the different task conditions (sentences, isolated words) for children with dyslexia and TR, separately

Condition		TR				Children with dyslexia			
		VAN T (P)	DAN T (P)	FP T (P)	CO T (P)	VAN T (P)	DAN T (P)	FP T (P)	CO T (P)
Sentences	VAN	6.565 *** (0.00)	33.904 *** (0.00)	25.858 *** (0.00)	17.608 *** (0.00)	6.893 *** (0.00)	32.521 *** (0.00)	26.297 *** (0.00)	24.880 *** (0.00)
	DAN		8.175 *** (0.00)	43.638 *** (0.00)	18.412 *** (0.00)		7.076 *** (0.00)	43.388 *** (0.00)	20.277 *** (0.00)
	FP			8.599 *** (0.00)	4.903 *** (0.00)			8.599 *** (0.00)	5.568 *** (0.00)
	CO				7.584 *** (0.00)				8.607 *** (0.00)
Words	VAN	8.983 *** (0.00)	39.555 *** (0.00)	34.585 *** (0.00)	28.042 *** (0.00)	8.264 *** (0.00)	34.099 *** (0.00)	27.648 *** (0.00)	18.771 *** (0.00)
	DAN		9.990 *** (0.00)	51.233 *** (0.00)	17.791 *** (0.00)		8.545 *** (0.00)	42.837 *** (0.00)	15.110 *** (0.00)
	FP			10.200 *** (0.00)	5.620 *** (0.00)			8.272 *** (0.00)	5.902 *** (0.00)
	CO				10.257 *** (0.00)				9.076 *** (0.00)
Sentence > Words	VAN	0.947 (0.177)	0.636 (0.266)	0.944 (0.178)	0.208 (0.42)	-0.692 (-0.751)	-0.883 (0.806)	-0.464 (0.676)	-2.094 (0.975)
	DAN		-0.484 (0.683)	-0.134 (0.552)	0.074 (0.418)		-1.075 (0.852)	-0.698 (0.753)	-2.334 (0.984)
	FP			0.547 (0.295)	-0.225 (0.587)			-0.528 (0.698)	-2.693 (0.992)
	CO				0.309 (0.380)				-2.756 (0.993)

***
P < .001,

TR: typical readers, CO: cingulo-opercular, FP: frontoparietal, VAN: ventral attention network, DAN: dorsal attention network

Table 7.

Within and between functional connectivity for children with dyslexia vs. TR and for TR vs. children with dyslexia contrasts for the different contrasts (ROI to ROI):

Condition		TR > Children with dyslexia				Children with dyslexia > TR			
		VAN T (P)	DAN T (P)	FP T (P)	CO T (P)	VAN T (P)	DAN T (P)	FP T (P)	CO T (P)
Sentences	VAN	0.424 (0.336)	0.927 (0.179)	0.490 (0.313)	1.228 (0.113)	-0.424 (0.663)	-0.927 (0.820)	-0.490 (0.686)	-1.228 (0.886)
	DAN		0.806 (0.212)	0.635 (0.264)	1.271 (0.105)		-0.806 (0.787)	-0.635 (0.735)	-1.271 (0.894)
	FP			0.797 (0.215)	0.829 (0.206)			-0.797 (0.784)	-0.829 (0.793)
	CO				1.679 (0.0506)				-1.679 (0.949)
Words	VAN	-0.910 (0.815)	-0.382 (0.647)	-0.628 (0.733)	-0.653 (0.741)	0.910 (0.184)	0.382 (0.352)	0.628 (0.266)	0.653 (0.258)
	DAN		0.060 (0.476)	-0.020 (0.508)	-0.813 (0.789)		-0.060 (0.523)	0.020 (0.491)	0.813 (0.210)
	FP			-0.203 (0.580)	-0.940 (0.823)			0.203 (0.419)	0.940 (0.176)
	CO				-0.862 (0.802)				0.862 (0.197)
Sentences > Words	VAN	1.092 (0.140)	1.068 (0.146)	0.857 (0.198)	1.724 * (0.046)	-1.092 (0.859)	-1.068 (0.853)	-0.857 (0.801)	-1.724 (0.953)
	DAN		0.634 (0.264)	0.522 (0.302)	1.855 (0.035)		-0.636 (0.735)	-0.522 (0.697)	-1.855 (0.964)
	FP			0.732 (0.234)	1.670 (0.051)			-0.732 (0.765)	-1.670 (0.948)
	CO				2.326 * (0.012)				-2.326 (0.987)
Words > Sentences	VAN	-1.092 (0.859)	-1.068 (0.853)	-0.857 (0.801)	-1.724 (0.953)	1.092 (0.140)	1.068 (0.146)	0.857 (0.198)	1.724 * (0.046)
	DAN		-0.634 (0.735)	-0.522 (0.697)	-1.855 (0.964)		0.636 (0.264)	0.522 (0.302)	1.855 (0.035)
	FP			-0.732 (0.765)	-1.670 (0.948)			0.732 (0.234)	1.670 (0.051)
	CO				-2.326 * (0.987)				2.326 * (0.012)

* P < .05,

TR: typical readers, CO: cingulo-opercular, FP: frontoparietal, VAN: ventral attention network, DAN: dorsal attention network