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Initial evidence of altered functional network connectivity in children with developmental language disorder

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Abstract

Developmental Language Disorder (DLD) is a common neurodevelopmental condition characterized by not only significant difficulty with language learning, comprehension, and expression but also with executive, procedural and/or motor functions. The understanding of the brain abnormalities in DLD remains largely unclear and functional MRI (fMRI) studies have largely focused on the language network. Using resting-state fMRI, we investigated whole-brain functional connectivity (FC) in 22 children with DLD and 23 with typical language development (TD), aged 7-to-13-years. Using a non-parametric network-based statistics approach, we found that children with DLD had an extensive network of lower FC across the whole brain, compared to the TD children. In particular, the sensorimotor (SM), cognitive control (CC) and default-mode (DM) networks included the largest amounts of altered FC. In detail, FC links within the DM network and between the SM and DM networks, and between the SM and CC networks were the most altered. No FC was found to be significantly higher in the children with DLD than in their peers with TD. To our knowledge, this is the first investigation of resting-state FC in children with DLD, showing widespread functional brain abnormalities that are not limited to the language network, but rather involve networks supporting other cognitive and motor functions.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Gaelle E. Doucet: Writing – original draft, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jordanna A. Kruse:** Writing – review & editing, Project administration, Data curation. **Nichole M. Eden:** Writing – review & editing, Supervision. **Lisa Goffman:** Writing – review & editing. **Karla K. McGregor:** Writing – review & editing, Supervision, Conceptualization.

Such extensive functional abnormalities offer a potential explanation for the other cognitive and motor impairments characterizing DLD.

Keywords

Functional connectivity; Sensorimotor network; DLD; Resting-state fMRI; Resting-state networks

1. Introduction

Developmental Language Disorder (DLD) is a neurodevelopmental disorder characterized by limitations in learning, understanding, and producing language. It is similar in prevalence to Attention Deficit Hyperactivity Disorder (ADHD) and dyslexia and arguably more impactful; nevertheless, it does not receive nearly as much research attention as these conditions (McGregor, 2020). DLD was previously referred to as specific language impairment (SLI; e.g., Leonard, 2014; Rice et al., 1995) and was presumed to be a condition involving only deficits in language. However, more recently, it has become clear that DLD should be construed as a broader neurodevelopmental disorder. This less categorically constrained and language specific approach is in-line with the work of Astle et al. (2022), who argue for a transdiagnostic rather than a categorical approach to neurodevelopmental disorders, one that embraces the variability within standard diagnostic categories as well as the presence of co-occurring deficits. This perspective perhaps helps, after the fact, explain why the term developmental language disorder (DLD) emerged as the term of choice from a group of 59 experts drawn from six English-speaking countries (Bishop et al., 2016; Bishop et al., 2017). Language is a complex and multi-faceted skill and the term DLD captures this fact. DLD refers to significant deficits in the development of language that are not explained by other developmental disorders such as autism, intellectual impairment, or hearing impairment. This definition and term was initially selected by experts, relying on the DELPHI approach, and more recently has also been adopted by families and individuals with lived experience of DLD (Norbury et al., 2024). The term DLD accounts for the inclusion of functional outcomes as well as co-occurring deficits.

Particularly relevant to the present work is the frequently attested presence of co-occurring deficits in DLD, as would be predicted in a neurodevelopmental disorder (Astle et al., 2022). One such co-occurrence is a domain-general learning deficit. Specifically, several researchers have identified motor deficits in children with DLD (Hill, 2001; Sack et al., 2022; Sanjeevan & Mainela-Arnold, 2019; Zelaznik & Goffman, 2010). Recent accounts of these deficits purport that the learning and production of sequential patterns, such as those incorporated in music (Kreidler et al., 2023), bimanual timing (Vuolo et al., 2017), and novel sign or gesture (Goffman et al., 2023) are especially implicated in DLD. Some theoretical accounts transcend language and propose that procedural (Ullman et al., 2020) and sequential (Goffman & Gerken, 2023) learning are implicated in DLD. Other cognitive domains are also affected in DLD, such as executive function (EF) (Tomas & Vissers, 2018) or fine and gross motor skill (Kisjes et al., 2025). The focus of the present work is to identify for the first time the overall brain functional differences in DLD which should drive future

works with more focused hypotheses centered on specific cognitive impairments, depending on which functional brain networks are more strongly altered.

The understanding of the neural origins of DLD remains largely unclear (Asaridou & Watkins, 2022; Bahar et al., 2024). Recent task-based functional Magnetic Resonance Imaging (fMRI) studies have been unable to find functional abnormalities in the language network during language tasks in children with DLD (Krishnan et al., 2021; Pigdon et al., 2020). A *meta*-analysis conducted by Ullman et al. (2024) suggested that brain abnormalities in DLD are more commonly reported in the basal ganglia, with 100 % and 79 % of 577 participants with DLD presenting with structural and functional abnormalities in the anterior neostriatum, respectively. Such findings are in line with the Procedural Deficit Hypothesis (PDH), which posits that DLD is the result of atypical development of the neural structures and functions that support procedural memory (Ullman & Pierpont, 2005). In this account, behavioral markers include those that are procedural in nature, including in cognitive, motor, and language (especially morphosyntactic and phonological) domains. Nevertheless, there is other compelling evidence indicating atypical brain structures and functions in the frontal, temporal, and parietal lobes (Krishnan et al., 2022; Mayes et al., 2015; Ullman et al., 2024). Overall, these findings highlight the importance of considering the whole brain when investigating the brain mechanisms behind DLD, as they may not all emerge from the language network or subcortical regions that are classically expected to be implicated (see also Abbott and Love (2023)).

One neuroimaging approach that has been widely used across neurodevelopmental disorders is resting-state fMRI (rs-fMRI), which allows the measurement of functional connectivity (FC), defined as the temporal correlation between the signal from two distinct brain regions during a resting-state condition (Biswal et al., 1995). In that condition, participants are instructed to stay still and awake. This technique has been instrumental in gaining insight into how brain regions and networks interact among each other (Buckner et al., 2013; Buckner et al., 2009; Doucet et al., 2011) and how neurological or neuropsychiatric disorders impact the brain (Greicius, 2008; Kaiser et al., 2015; Kuhn & Gallinat, 2013; Sha et al., 2019; Tracy & Doucet, 2015; Zouraraki et al., 2023). More recently, rs-fMRI has even been used to classify adolescents with and without ADHD with relative success (Taspinar & Ozkurt, 2024; Wang et al., 2023) and is increasingly used in infants and young children as they can tolerate it better than task-based designs (Muetzel et al., 2016; Uddin et al., 2010; Zhang et al., 2019).

In the context of language and neurodevelopmental disorders, rs-fMRI studies have demonstrated various FC abnormalities across multiple brain networks. For instance, dyslexia has been associated with lower FC along the visual pathways as well as between visual and prefrontal regions; decreased lateralization of language to the left hemisphere; increased FC to limbic regions and the default mode network (DMN) (Finn et al., 2014). The DMN covers the medial prefrontal cortex (MPFC), precuneus and bilateral angular gyri and is typically involved in self-referential functions such as introspection, prospection, episodic memory or planning (Buckner et al., 2008; Buckner & Carroll, 2007; Buckner & DiNicola, 2019). This network is also well characterized as frequently impaired across many neuropsychiatric and neurodevelopmental disorders (Doucet et al., 2020; Hu et al.,

2017; Padmanabhan et al., 2017; Sha et al., 2019). A study by Taran et al. (2024) suggested that the FC emerging from the network supporting visual attentional processing was the most predictive of dyslexia, in comparison to the networks supporting auditory, visual, and executive functions. In children with developmental coordination disorder (DCD), a recent rs-fMRI study has reported altered FC in the sensorimotor network that may underlie hallmark motor deficits (Rinat et al., 2020). Together, these studies emphasized significant neurobiological differences among brain networks and reveal deficits in multiple functional systems and inter-connections between them which can help us better understand each disorder with their specificities and similarities. However, in the case of DLD, no rs-fMRI study has yet been conducted and it is unknown whether individuals with DLD show altered FC and which brain functional network is more severely impacted (Asaridou & Watkins, 2022). Rs-fMRI approach may therefore help provide potential explanations for the neural origins behind the various cognitive and motor deficits described in DLD.

In this context, we investigated rs-fMRI in children with DLD and age- and sex- matched TD children, aged 7 to 13 years old. For this, we used a whole-brain approach extracting the FC across 432 cortical and subcortical regions, divided into 8 networks (subcortical, sensorimotor, visual, cognitive control, dorsal attention, ventral attention, default mode, limbic) (Schaefer et al., 2018; Tian et al., 2020). Using the Network-based statistics (NBS) toolbox (Zalesky et al., 2010), we conducted non-parametric permutations to compare the two study groups. We had two major hypotheses: (1) given the behavioral evidence of language deficits in children with DLD, we would expect lower FC within left-lateralized regions supporting language processing, and between them and other major cognitive networks (e.g., cognitive control and default mode networks); and/or (2) based on the PDH, children with DLD should show lower FC emerging from the subcortical regions, especially from the basal ganglia, compared to the TD children.

2. Material and Method

2.1. Participants

A total of 50 children aged 7 to 13 years were partially recruited from either a longitudinal study on DLD (McGregor, 2023), local pediatrics services offered at Boys Town National Research Hospital or through flyers and local ads. Among them, 26 were classified as having DLD and 24 as TD. Each participant was categorized as either DLD or TD based on a cut-off of 92 from the Test of Narrative Language, 2nd ed. (TNL-2) (Gillam & Peason, 2017). This standardized test has high levels of sensitivity (0.92) and specificity (0.92) to DLD for children across the age range included here (Gillam & Peason, 2017). Other inclusion criteria included: if he/she (1) was not on the autism spectrum based on the Social Communication Questionnaire (< 15) (Rutter et al., 2003) nor had any other neurodevelopmental disorder such as schizophrenia (note that we did include one child with DLD who also had ADHD, a condition that is commonly comorbid with DLD (Sciberras et al., 2014)) based on parental report, (2) had normal hearing (thresholds > 20 dB at 1, 2, and 4 kHz), bilaterally; based on a pure tone audiometric screening (ASHA, 1997), and (3) had an IQ > 80 (based on the WASI-II). From this sample, five participants were excluded for not completing the MRI scan (n = 1) or having severe head motion during the resting-state

fMRI scan (maximum head motion > 3 mm or > 40 % of volumes with a framewise displacement (FD) > 0.3, n = 4), leading to a final sample of 22 children with DLD and 23 TD children (Table 1). The two groups did not significantly differ in level of head motion ($p > 0.05$). The study was approved by the institutional review board (IRB) from Boys Town National Research Hospital and parents consented to have their children participate in the research, while the children provided written assent.

2.2. MRI acquisition and preprocessing

Participants were scanned on a 3 T Siemens Prisma scanner using a 32-channel head coil. Structural images were acquired using a T1-weighted, 3D magnetization-prepared rapid gradient-echo (MPRAGE) sequence with the following parameters: Repetition Time (TR) = 2,400 ms, Echo Time (TE) = 2.05 ms, Field of View (FOV) = 256 × 256 mm, 1 mm isotropic resolution, Inversion Time (TI) = 1,000 ms, 8 flip angle, bandwidth =240 Hz/Pixel, echo spacing =7.0 ms, in-plane acceleration GRAPPA (GeneRalized Autocalibrating Partial Parallel Acquisition) factor 2, total acquisition time ~ 6 min. The resting-state fMRI (rs-fMRI) was collected using the following acquisition parameters: TR/TE = 480/29.2 msec, 56 axial slices, flip angle = 44°; FOV = 248 mm × 248 mm; voxel-size = 3 × 3 × 3 mm^3, number of volumes = 700, multi-band = 8. Participants were instructed to keep their eyes open on a fixation cross, and to not fall asleep. After each scan, we confirmed with each participant that they stayed awake the whole time.

The first 10 volumes of the rs-fMRI were removed and then preprocessed using *fMRIprep* v.23.0.2 using the default pipeline. Following this, we further applied denoising strategies using the nilearn package, using the ica_aroma strategy, which included high pass filtering, basic white matter and CSF correction, global signal regression, and regression of the confounds derived from ICA-AROMA. This preprocessing was chosen based on the recommendations by Ciric et al. (2017) showing that this approach is among the best to prevent the impact of head motion on functional connectivity.

2.3. Functional connectivity analyses

The Schaefer-400 Atlas and the Melbourne Subcortex Atlas were used to extract blood oxygen-level dependent (BOLD) signals from 432 regions in the brain across all volumes (Schaefer et al., 2018; Tian et al., 2020). The assignment of each parcel into its corresponding network (1–8) was provided as part of the atlas download: Default-Mode (DM), Cognitive Control (CC), Ventral Attention (VA), Limbic (LIM), Dorsal Attention (DA), Sensori-Motor (SM), Visual (VIS) and Subcortical (Sub) (Supplementary Fig. S1; https://github.com/yetianmed/subcortex/tree/master/Group-Parcellation/3T/Cortex-Subcortex).

Functional connectivity (FC) was computed for each pair of regions, using Pearson's correlations following by a r-to-z transformation. FC metrics were compared between the study groups using an age-, sex- and mean FD-adjusted ANOVA model, using the Network-based statistics (NBS) toolbox (Zalesky et al., 2010). The NBS toolbox has been described in detail previously (Zalesky et al., 2012; Zalesky et al., 2010). In short, NBS applies nonparametric testing to identify robust FC differences between groups. Pairs of

regions with a *t* statistic exceeding an uncorrected threshold of 3.5 were systematically searched for any interconnected regions that may be evidence of a between-group difference. A familywise error (FWE)-corrected *p* value was then ascribed using permutation testing. For each permutation, participants were randomly exchanged between the DLD and TD groups. A total of 10,000 permutations were generated to yield an empirical null distribution for the size of the largest network. Finally, connections presenting a p value < 0.05 after permutations were considered to be part of the altered functional connectivity pattern and reported in the result section. Significant FCs were further investigated at the network level and classified as within-network or between-network and discussed accordingly. Within-network FC refers to all the FC links between regions part of the same network, while between-network FC includes all the FC links between regions from different networks.

3. Results

3.1. Overall findings

Our analyses reported an extensive and widespread network of altered FC in the DLD group, compared to the TD group, beyond any effects of age, sex, IQ and head motion. In detail, a total of 602 FC links across 224 regions were found to differ between the two groups (Figs. 1 & 2, Table 2, Supplementary Fig. S2), with all of them being lower in the children with DLD than in the TD children. Given the large extent of altered FCs in DLD, we investigated them in the context of their brain networks and whether the FCs involved regions between networks or within a specific network. 90 % of the altered FCs were FC links between regions from different networks (542/602; Table 2). Fig. 2 displays the top 20 regions with the most altered FC in children with DLD, revealing widespread regional alterations across multiple networks such as the cognitive control, sensorimotor and ventral attention networks, with a strong lateralization towards the right hemisphere. Interestingly, regions typically supporting language function such as the left inferior frontal cortex or the left superior temporal gyrus did not appear to be particularly represented here in contrast to regions located in the right dorsolateral frontal cortex (Fig. 2). The subcortical, visual and limbic networks were the networks the least impacted by DLD. Among within-network FC, the DMN showed the most altered FC links in the DLD, compared to TD children.

3.2. Between-network FC differences between DLD and TD

In regard to the between-network FC links, the networks the most impacted in DLD were the SM (46 % of all altered between-network links), CC and DM (44 % and 38 %, respectively) networks (Table 2, Fig. 1). In detail, FC links between the SM and CC networks (22 %), and between the SM and DM networks (15.5 %) were the most commonly altered (Fig. 3A and B).

3.3. Within-Network FC differences

In regard to within-network FC links the most impacted by the DLD status, the large majority of the altered within-network FC differences involved regions within the DM network (33 out of 60 within-network links, 55 %, Table 2). Within the DM network, the regions with the most altered FC were located in the left hemisphere (18 left-sided regions

vs 9 right-sided regions), including the left superior orbitofrontal cortex, (medial) superior/middle frontal cortices, as well as bilateral middle temporal gyri (Fig. 3C).

4. Discussion

The current study revealed widespread altered FC in children with DLD, with all of them being lower than in TD children. A striking and unexpected finding was that most of the functional alterations were not specifically located in regions known to support language processing nor procedural memory. In contrast, the networks most impacted were the somatomotor, cognitive control, and default-mode. Overall, these findings provide initial evidence that children with DLD have deficits in multiple functional systems and in the connections between them. These results are consistent with behavioral findings that a specific array of linguistic, cognitive, and motor deficits are attested in DLD (Goffman & Gerken, 2023; Hsu & Bishop, 2014; Ullman et al., 2020).

Our first finding was that the brain networks showing the most altered FC were among the SMN, CC and DMN. The SMN covers primary sensory, motor and auditory cortices, as well as supplementary motor area and typically supports motor, auditory processes and somatosensory processing. The CC network largely includes lateral frontal and parietal cortices and its functions include executive functions, such as goal-oriented cognition, working-memory, inhibition and task switching (Uddin et al., 2019). Lastly, the core regions of the DMN covers the MPFC, posterior cingulate cortex and the inferior parietal lobule (Supplementary Fig. S1). Other regions may include the inferior frontal gyrus, middle temporal gyrus and superior temporal sulcus, and hippocampus. While its function has been linked to self-referential processing such as mind-wandering, imagination, future-thinking, episodic memory, some studies have suggested it also accommodates predictive coding, semantic associations, and plays a role continuously monitoring the environment (Dohmatob et al., 2020).

The functional alterations among these networks are in line with current accounts that propose that the deficits observed in individuals with DLD are not only linguistic, but also transcend to motor (including sequential and rhythmic tasks) and cognitive domains, including EF (Goffman et al., 2023; Ladanyi & Lukacs, 2019; Niu et al., 2024; Sack et al., 2022; Tomas & Vissers, 2018), with these functions being supported by these networks. In particular, our findings point toward the presence of a functional imbalance between sensorimotor and fronto-parietal cortices, which could reflect the large overlap between language and motor deficits well described in children with DLD (Hill, 2001; Sack et al., 2022; Zelaznik & Goffman, 2010). Studies have documented impairments in fine and gross motor skills (Hill, 2001), with some of these motor deficits predicting language outcomes in children with DLD (Sack et al., 2022). Our current findings involving reduced functional integration of the sensorimotor network also align with a recent diffusion study demonstrating that children with DLD show lower fractional anisotropy (a measure of white matter integrity) in the inferior cerebellar peduncles, which are fiber tracts that carry motor and sensory input via the inferior olive to the cerebellum (Asaridou et al., 2024). It is therefore possible that altered functional connectivity in the sensorimotor network may be linked to a general alteration of the brain system supporting motor development,

with structural and functional alteration of the cerebellum, known to be essential for motor control (Manto et al., 2012). Unfortunately, the atlas used for this study was limited to the cortex and did not have a cerebellar parcellation. Cerebellar FC in children with DLD should be further tested to determine the extent of the brain alterations related to motor problems in DLD.

A recent rs-fMRI study done on children with DCD also reported altered FC in the sensorimotor network and in the posterior cingulate cortex (PCC), precuneus, and the posterior middle temporal gyrus (pMTG) which could provide an explanation as to why children with DCD struggle to learn motor skills (Rinat et al., 2020). Combining our findings with theirs, it supports that DCD and DLD, which already show considerable overlap across language and motor deficits (Kisjes et al., 2025), may also show similar brain functional alterations in the sensorimotor network.

In DLD, two current theoretical accounts, the procedural deficit hypothesis (Ullman & Pierpont, 2005) and the sequential pattern learning deficit (Goffman & Gerken, 2023) posit that the domain general deficits that characterize DLD share common mechanistic features related to procedural or sequential learning. Overall, our findings support that motor and cognitive deficits in DLD do not just co-occur independently but are likely inter-related through alterations of the connections between the corresponding brain networks. However, it is important to note that in contrast to the procedural deficit hypothesis that states a strong involvement of basal ganglia in DLD (Krishnan et al., 2016; Ullman et al., 2020; Ullman & Pierpont, 2005), we were only able to identify limited alterations in FC linked to these subcortical regions. Possible reasons for this discrepancy are: our fMRI sequence had high multi-band and was therefore not ideally set up to detect strong signal in subcortical regions (Krishnan et al., 2016; Risk et al., 2021); alternatively, functional connectivity may not be as sensitive to alterations in the basal ganglia in DLD or the behavioral deficits known in DLD may be due to functional alterations in cortical regions, rather than in subcortical regions as suggested by the current findings. Another possible reason is that the motor deficits are more nuanced than proposed by the procedural deficit hypothesis. Behavioral work has indicated that only some aspects of procedural motor skill are implicated in DLD—those related to the learning and implementation of novel sequences (Goffman & Gerken, 2023; Hsu & Bishop, 2014).

Another interesting finding was the large amount of altered FC within the DMN, compared to all the other networks, suggesting a reduced functional integration of the DMN in children with DLD. The DMN has been commonly reported as abnormal across many neuropsychiatric and neurodevelopmental disorders (Doucet et al., 2020; Harikumar et al., 2021; Padmanabhan et al., 2017; Sha et al., 2019). Changes in the DMN's functional integration have been linked to many self-referential cognitive processing capacities such as mind-wandering, episodic memory, future planification, social cognition or theory of mind (Buckner et al., 2008; Buckner & Carroll, 2007) as well as anxiety or depression (Andreescu et al., 2014; Sheline et al., 2010). Children and adolescents with DLD are at higher risk for emotional health symptoms such as anxiety and depression (Wadman et al., 2011; Wilmot et al., 2024), with these symptoms persisting in adulthood (Botting, Durkin, et al., 2016; Botting, Toseeb, et al., 2016). Children with DLD have also been reported as

having poorer theory of mind (Nilsson & de Lopez, 2016) and social cognitive (Forrest et al., 2023) abilities than their TD peers. Lastly, our DMN findings may support previous reports suggesting that inner speech emerges at a later age in children with DLD than in typically developing children (Abdul Aziz et al., 2017; Lidstone et al., 2012). Future studies should further investigate the link between mind-wandering and self-referential tasks and the DMN activity in DLD.

Overall, our findings did not reveal a specifically large amount of FC alterations in left-sided regions as one may expect with DLD. In contrast, we may have rather found more alterations with right-sided regions, especially when involving the CC network (Fig. 2 and 3A). Recent task-based fMRI studies have also reported no significant alteration in the language network activation or lateralization in children with DLD during language fMRI tasks (Krishnan et al., 2021; Pigdon et al., 2020). In the *meta*-analysis by Ullman et al. (2024), the authors reported a similar distribution of brain abnormalities in the basal ganglia across the two hemispheres. Although this might be surprising to some given the left lateralization of language functions, there are a number of potential explanations. First, subclinical deficits in nonverbal cognition also characterize DLD, thus right hemisphere involvement should be expected (Plante et al., 2001). Second, it could be that more than one pathway or circuit must be affected in order for DLD to become symptomatic (Ullman et al., 2024). Third, the effects apparent in the right hemisphere could reflect compensations for the language impairment rather than cause (Verly et al., 2019).

While this study brings the first evidence of widespread resting-state functional brain abnormalities in children with DLD, we should acknowledge some limitations. First, the sample size was relatively modest and our findings should be replicated in larger samples. However, we chose to apply a robust non-parametric permutation approach that has been shown to be reliable. We therefore believe in the robustness of our findings. Second, we did not have any in-depth measures of procedural memory, motor or morphosyntactic performance to further test the link between FC and cognitive and motor hallmarks of DLD. There is behavioral evidence that aspects of procedural memory (especially sequential processing) provide a unified explanation for the observed deficits in motor and language skills in DLD (Goffman & Gerken, 2023). It will be important to link specific hallmark motor and language metrics with whole-brain FC. Third, the resting-state scan was relatively short and a longer sequence could lead to more reliable functional connectivity metrics (Birn et al., 2013). However, given the young age of the participants, it was chosen to be a compromise on how long they can stay still in the scanner and still have good quality data. Lastly, while we chose to investigate FC across the whole brain using the Schaefer-Tian brain parcellation and NBS, other approaches could have been tested such as other graph-theory metrics or independent component analyses (Bijsterbosch et al., 2020) or even just another brain atlas. There is currently no perfect approach, and we see our results as initial evidence of widespread FC alterations in children with DLD, which may lead the field to follow-up analyses with more specific hypothesis-driven approaches focused on specific brain networks (e.g., sensorimotor or executive network) to investigate the neurological mechanisms behind DLD.

In conclusion, this study is among the first to evaluate whole-brain FC in children with DLD. We found widespread functional alterations between networks supporting sensorimotor and other higher-order cognitive functions in DLD, relative to their TD peers. Overall, our current study provides initial evidence that children with DLD have deficits in multiple functional systems and in the connections between them, which could be at the origin of the specific language, motor, cognitive and social impairments characterizing DLD.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Appendix A.: Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bandl.2025.105637.

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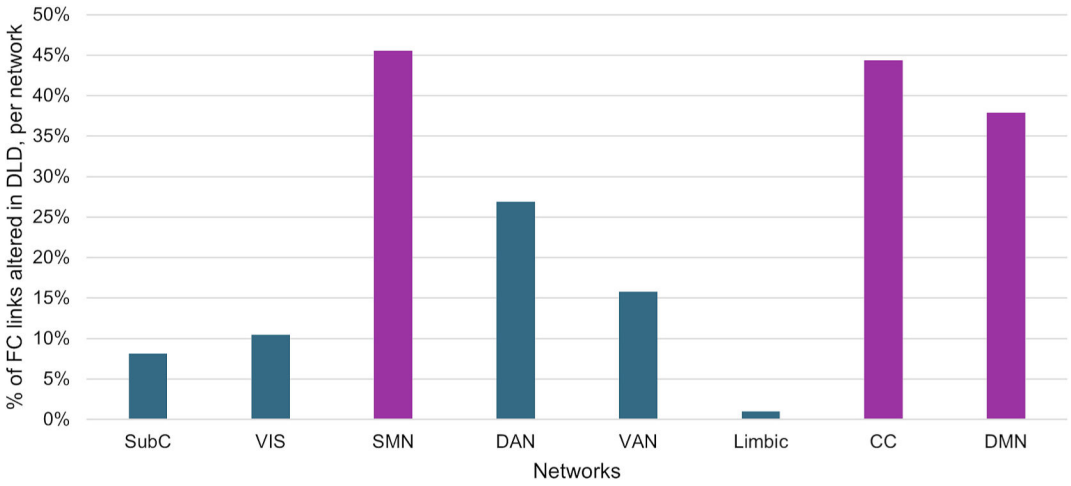

Fig. 1. Altered functional connectivity (FC) links per network in DLD.

% of altered FCs in children with DLD, compared to the TD children, for each network. Purple bars highlight the networks with the most altered FCs. For instance, 46% of the altered FC links (274/604) include a region that is part of the SMN.

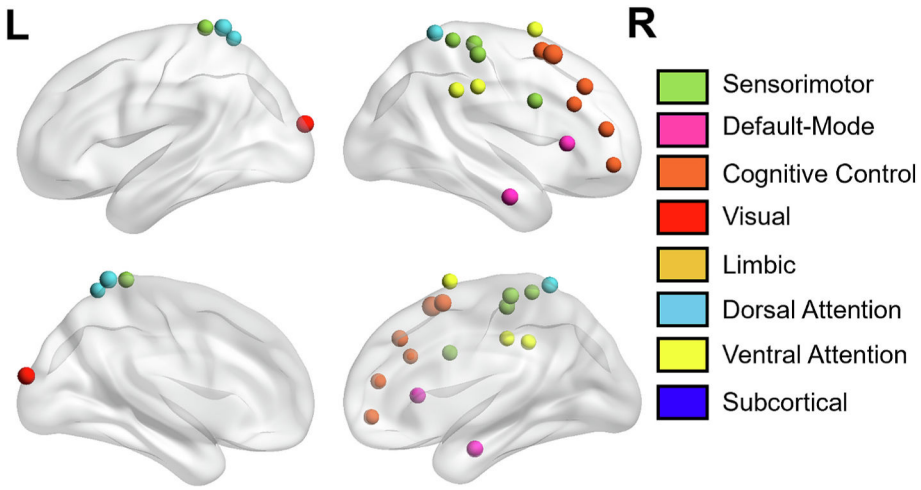

Fig. 2. Top 20 regions with the most altered FC links in DLD.

Regions are illustrated as spheres, where larger sizes indicate a greater number of significantly altered FCs (from 14 to 52 altered FCs / region) Both within- and between-network FC are combined.

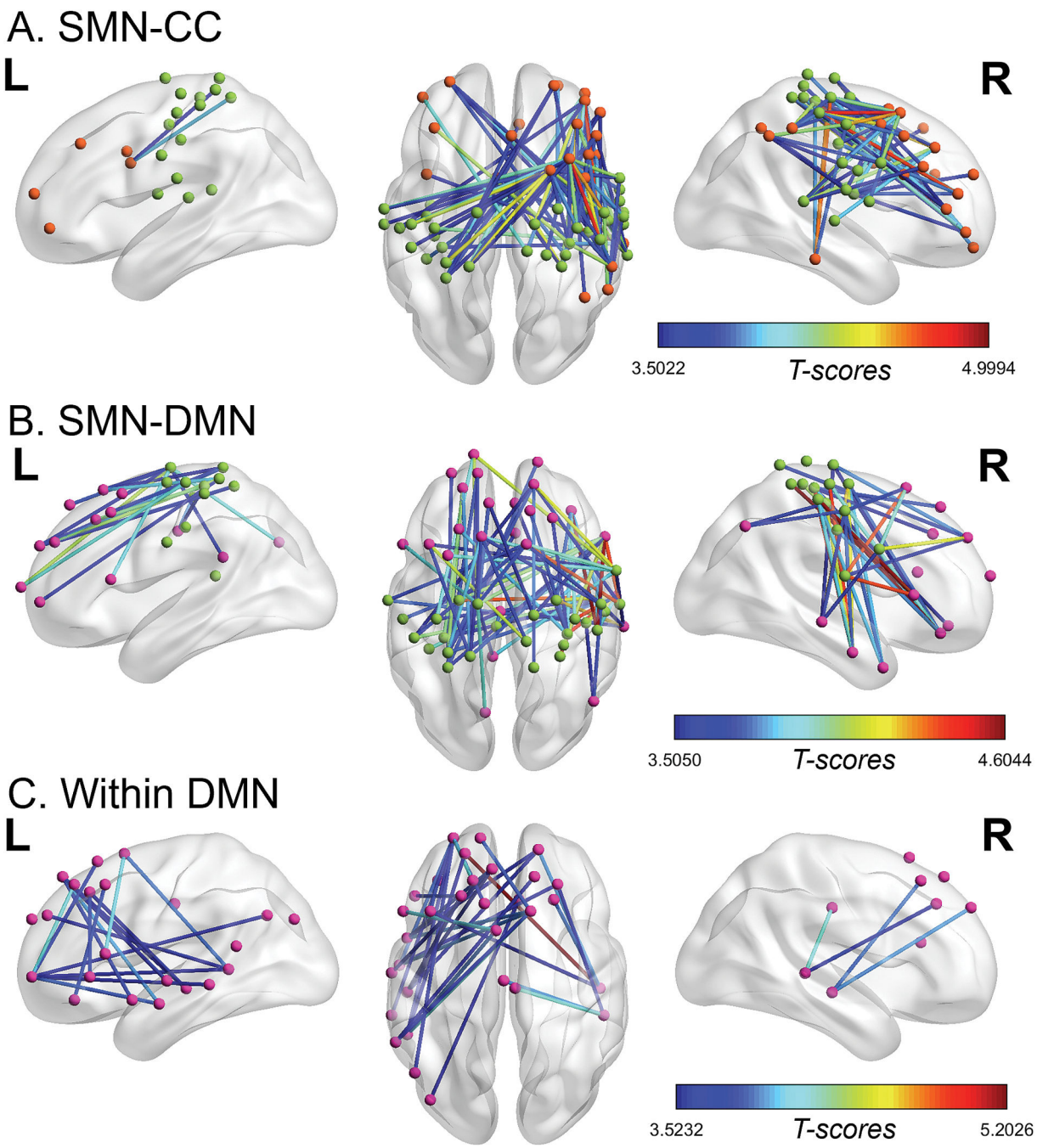

Fig. 3. Major altered FC links between the sensorimotor (SMN), cognitive control (CC) and default-mode (DMN) networks in the children with DLD.

(A) Altered FC links between the SM and CC networks in DLD. Orange nodes denote regions part of the CC network, green nodes regions part of the SMN. (B) Altered FC links between the SMN and DMN. Pink nodes denote regions part of the DMN, green nodes regions part of the SMN. (C) Altered FC links within the DMN.

Table 1

Demographic information.

	Children with DLD	TD children	t / Chi square test	Effect size (Cohen d)
N (n males)	22 (11)	23 (13)	X = 0.19, p = 0.7	
Age (years)	9.87 (1.63)	9.57 (1.65)	T = 0.78, p = 0.5	D = 0.23
TNL-2 total score	82.95 (7.95)	105.52 (7.54)	T = 9.89, p < 0.001	D = 2.95
TNL range	61–91	94–116		
FSIQ2	100.77 (13.89)	115.30 (15.51)	T = 3.3, p < 0.001	D = 0.99
FSIQ2 range	82–136	79–143		
Vocabulary, t-score	47.64 (7.83)	58.52 (9.62)	T = 4.2, p < 0.001	D = 1.24
Matrix reasoning, t-score	53.14 (7.09)	56.78 (7.97)	T = 1.6, p = 0.11	D = 0.48
Household income			X = 8.85, p = 0.2	
$10,000 - $14,999	3	0		
15,000 - $24,999	0	1		
40,000 - $59,999	2	0		
60,000 - $89,000	7	8		
90,000 - $179,000	9	9		
Greater than $180,000	1	4		
Prefer not to Answer	0	1		
Mean framewise displacement	0.18 (0.07)	0.17 (0.09)	T = 0.3, p = 0.7	

Continuous variables are shown as mean (SD). FSIQ: Full-scale Intelligence Quotient; TNL: Test of Narrative Language.

Table 2

Altered within- and between-FC in DLD, organized by brain network.

	Sub	Vis	SMN	DAN	VAN	Lim	CC	DMN
Sub	0 (0 %)	4 (0.7 %)	10 (1.8 %)	12 (2.2 %)	6 (1.1 %)	0 (0 %)	11 (2.0 %)	6 (1.1 %)
Vis		1 (1.7 %)	11 (2.0 %)	15 (2.8 %)	5 (0.9 %)	0 (0 %)	26 (4.8 %)	1 (0.2 %)
SMN			5 (8.3 %)	15 (2.8 %)	30 (5.5 %)	0 (0 %)	**119 (22.0 %)**	**84 (15.5 %)**
DAN				**10 (16.7 %)**	12 (2.2 %)	4 (0.7 %)	50 (9.2 %)	44 (8.1 %)
VAN					2 (3.3 %)	1 (0.2 %)	16 (3.0 %)	23 (4.2 %)
Lim						1 (1.7 %)	0 (0 %)	0 (0 %)
CC							**8 (13.3 %)**	37 (6.8 %)
DMN								**33 (55 %)**

Results related to the between-network FC are in the upper triangle (e.g., Sub-Vis), while those related to the within-network FC are shown in the diagonal of the table (e.g., Vis-Vis).

The number represents the number of altered (lower) FC links in DLD, compared to TD. The % represents the % of abnormal FC links relative to the total number of altered FCs links (60 total for within-network FC and 542 for between-network FC).

Bold numbers highlight the highest %'s (>10 % relative to the number of altered FCs links).

Abbreviations: CC: Cognitive Control Network, DAN: Dorsal Attention Network, DMN: Default-Mode Network, Lim: Limbic Network, SMN: Sensorimotor Network, Sub: Subcortical, VAN: Ventral Attention Network, Vis: Visual Network.