Visual training of executive functions in dyslexia: fMRI evidence for neural plasticity following intervention in children with dyslexia

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Introduction

- Developmental dyslexia is among the most common learning disabilities, affecting around 10% of the population [1].
- Current interventions for dyslexia have limited effectiveness, and there is a controversy regarding the most effective type of training [2, 3].
- The beneficial effect of an Executive Function (EF) based reading intervention has been reported previously [4, 5, 6].

Aim

The goal of the present project was to determine the effect of the EF-based reading training on the functional connectivity of cognitive control and attention-related brain networks during a reading fluency fMRI task.

Method

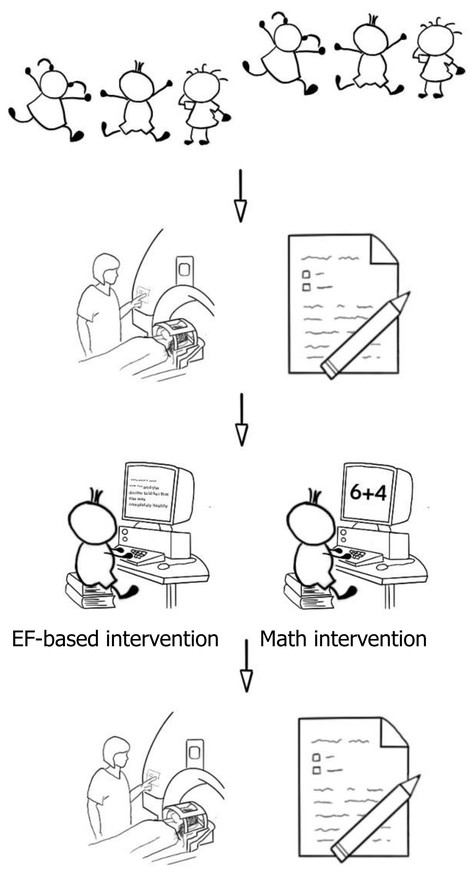
Participants

Eighty children participated in the study:

- 44 children with dev. dyslexia (DD)
  (mean age = 9.3 ± 1.36, 14 females)
- 36 typical readers (TR)
  (mean age = 10.04 ± 1.45, 21 females)

fMRI reading fluency task

fMRI data was acquired before and after intervention (T1, T2), while performing a reading task with two conditions:
Still text reading, mimicking natural reading settings, and Deleted text, a condition similar to the EF-based intervention.
Participants from both groups were randomly assigned to one of two intervention groups.



All participants underwent cognitive assessments (visual attention, executive functions, reading...) in T1 and T2.

EF-based reading intervention

Participants in this group completed a computerized training based on EF components where the sentences are being deleted from the screen, letter by letter, in a speeded manner. This task tackles several EF, visual attention and speed of processing [7]. The difficulty of the task is increasing gradually: the letters are deleted at a faster pace, while monitoring comprehension.

A control (math) intervention

A computerized math intervention targeting general mathematical knowledge was administered as an active control condition (www.ixl.com).

functional Magnetic Resonance Imaging

T2* functional MRI was acquired using the following sequence parameters: TR/TE=1000/30ms, FOV=20x20x14.4 cm, matrix=80x80, slice thickness=3 mm. Whole brain anatomical T1 images were acquired for spatial co-registration.

fMRI data was analysed using GLM-based seed-to-voxel with EF and attention networks (dorsal and ventral attention networks, cingulo-opercular and fronto-parietal networks) as seeds [8].

Results (behavioral)

Baseline

Typical readers outperformed children with dyslexia in multiple cognitive and reading domains:

Executive functions: Working memory (t=2.74, df=79, p<.01), cognitive flexibility (t=3.44, df=79, p<.001), problem solving (t=2.01, df=79, p<.05), Visual attention – selective visual attention (t=2.18, df=79, p<.05).

Reading: Phonological awareness (t=6.09, df=79, p<.001), letter reading (t=4.47, df=79, p<.001), word reading (t=6.19, df=79, p<.001), pseudoword reading (t=8.95, df=79, p<.001), and reading comprehension (t=7.1, df=79, p<.001).

Effect of intervention

Children with dyslexia undergoing the EF-intervention (compared to Math intervention) improved their scores in visual attention (F=5.127, df=1,34, p<.05), and reading rate (F=6.924, df=1,34, p<.05). Typical readers improved in visual attention only (F=22.85, df=1, p<.001).

Children undergoing both math intervention and the EF reading intervention improved their scores in inhibition (t=2.31 p<.05).

Results (fMRI)

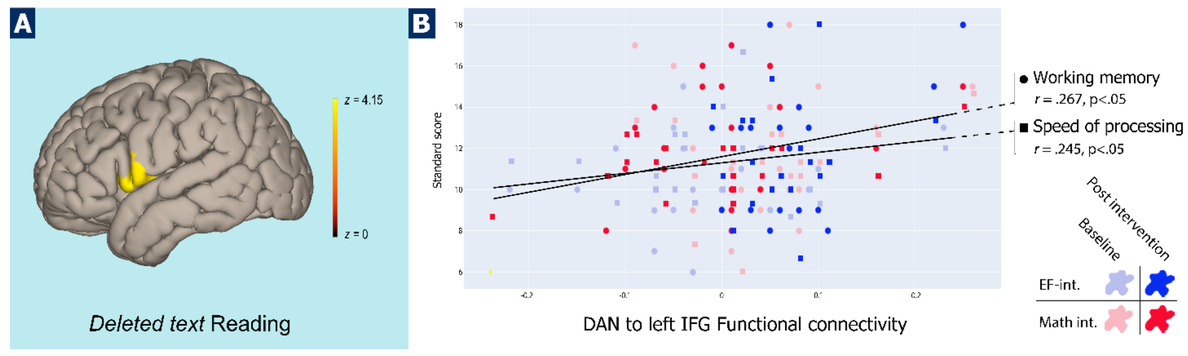
Seed-to-voxel

The EF-based reading intervention resulted in increases in functional connectivity in both groups (TR and DD), but different networks were showing higher FC for each group.

	EF-based reading intervention		Math intervention
	Typical readers	Children with dyslexia	
Ventral attention	null results	null results	null results
Dorsal attention	↑ functional connectivity left IFG **Figure 1**	null results	null results
Cingulo-opercular	null results	↑ functional connectivity right occipital cortex **Figure 2**	null results
Fronto-parietal	null results	null results	null results

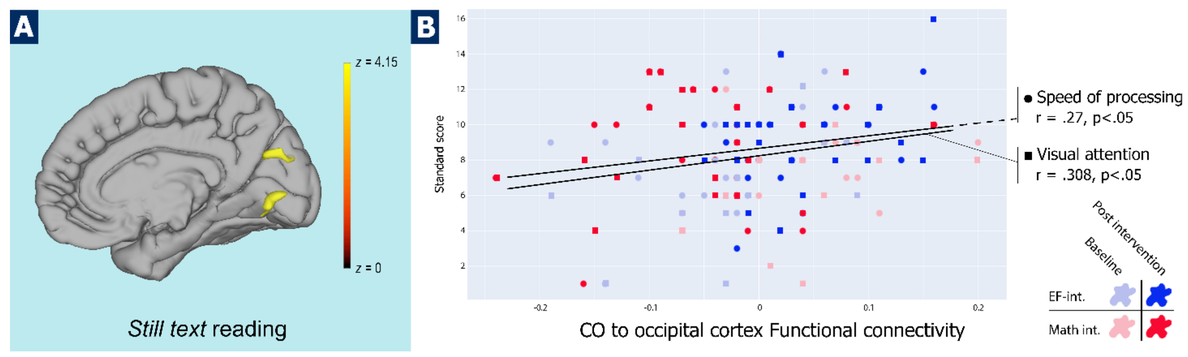
The functional connectivity index between the dorsal attention network and the left Inferior Frontal Gyrus (IFG) (p-FDR corrected<.05, p-uncorrected<.001, **Figure 1 A**) showed a positive correlation with working memory and speed of processing measures in typical readers in all timepoints ($0.2 < r < 0.3$; p<.05, **Figure 1 B**).

Figure 1 Typical Readers, Dorsal Attention Network
Post intervention > Baseline



The functional connectivity index between the Cingulo-Opercular Network and occipital regions within the visual network (p-FDR corrected<.05, p-uncorrected<.001, **Figure 2 A**) showed a positive correlation with visual attention and speed of processing measures in children with dyslexia ($0.2 < r < 0.4$; p<.05, **Figure 2 B**).

Figure 2 Children with dyslexia, Cingulo-Opercular Network
EF-intervention > Math, Post intervention > Baseline



Discussion

The EF-based reading intervention improved switching/inhibition abilities, visual attention and, most importantly, reading rate in children with dyslexia, but only visual attention in typical readers. Lower initial abilities in individuals with dyslexia may allow larger improvements after the intervention [4].

The functional MRI findings suggest that typical readers recruited visual attention areas together with brain areas related to semantic processing to a higher degree after the EF-based reading intervention.

Children with dyslexia showed a greater synchronization between EF-related networks (Cingulo-opercular) and visual processing regions in the right hemisphere, previously found as a compensatory region in dyslexia [9].

Two different mechanisms were found here: in typical readers, enhanced neural integration between semantical-related areas and visual attention areas during fluent reading were related to improved working memory and speed of processing after time constrained reading training. In children with dyslexia, cognitive control played a key role in the cognitive improvement, boosting reading rate via speed of processing and visual attention.

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