Reading Intervention Duration and Brain Activation Changes Before and After Treatment: A meta-regression study

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Check out the results of our meta-analysis on poster A42, Presenter: Meaghan Perdue

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INTRODUCTION

- Reading disability (RD) is the most common disability in school aged children and effects about 7% of the population, many of whom receive remedial intervention.[1]
- Neuroimaging studies of reading intervention generally find one of three profiles:
  - 1. Normalization - pre-to-post activation changes are observed in canonical reading areas such that children's brain activation during reading comes to resemble that of typically developing children.[5,6]
  - 2. Compensation - pre-to-post changes are observed in brain areas not typically associated with reading, particularly in right hemisphere homologues of the reading network and areas associated with executive function.[7,8]
  - 3. Mixed Results - A mixture of normalization and compensation is observed.[9,10]
- While intervention is generally considered to have positive outcomes, the specific features of intervention programs that lead to these positive outcomes are not well understood.
  - Several studies, including a recent meta-analysis, have found that neither number of weeks nor total hours of intervention predict intervention outcomes.[11,12,13,14]
  - In contrast, other studies have found that duration of intervention does predict significant differences in pre-to-post intervention reading gains.[15,16, 17]

The goal of the current study was to use a meta-regression analysis to explore whether pre-to-post brain activation changes were related to intervention duration (number of weeks/hours).

METHODS

- First, we conducted a systematic review and meta-analysis of reading intervention studies that featured pre- and post-intervention fMRI imaging for participants with or at-risk for RD (Perdue et al., In Prep).
- We conducted two exploratory meta-regression studies in which we considered the total number of hours and total number of weeks of intervention as possible predictors of brain activation changes
- For the hours analysis: we used a binary definition of longer and shorter interventions Longer =>100 total hours; Shorter <= 100 total hours[11]
- For the weeks analysis: we coded total number of weeks continuously.
- Our reporting threshold was set to p≤0.005, uncorrected and a voxel size≥10.

Table 1: Studies Included in Meta-Analysis with Total Number of Hours and Weeks

Author	N	Analysis Contrast	Voxel-wise Threshold	Number of foci	Hours	Weeks
Eden, 2004[9]	19	Post vs. Pre for intervention group > non-intervention RD group	p < .001, unc.	15	112.5	8
Gebauer, 2012[10]	10	Post vs. Pre in training group	z > 2.0	7		5
Heim, 2015[18]	33	Post vs. Pre in RD intervention group	p < .05, FWE-corrected	2	10	4
Meyler, 2008[11]	35	Good vs. Poor readers at post-intervention	p < .002, unc.	5	100	24
Nugiel, 2019[12]	21	Post-intervention fMRI correlation with reading gain score	uncorrected z-map provided		<100	16-32*
Partanen, 2019[13]	29	Poor readers > Good readers at Post vs. Pre	z > 2.3	1	24 or 189**	12
Richards, 2006[14]	8	Post vs. Pre in orthographic treatment group	z > 2.4	5	14	3
Shaywitz, 2004[6]	25	Follow-up > Pre in RD experimental intervention group	p < .05	7	105	32
Temple, 2003[16]	20	Post vs. Pre in RD group	p < .005, unc.	14	46.5	5.58*
Yamada, 2011[17]	7	Post vs. Pre in at-risk group	z > 2.33	41		

* Weeks coded as a mean number of weeks (Eden, 2004) or a median number of weeks (Nugiel, 2019). **Participants from two interventions were pooled in this study. It was not included in the hours analysis because of the large difference in hours.

RESULTS

Total Hours of Intervention

- 7 studies were included in the regression analysis

Regions	Voxels	MNI Coordinates			SDM-Z	p
		x	y	z		
R Superior temporal gyrus (BA 22)	108	52	-46	14	4.111	<0.001
L Middle occipital gyrus (BA 19)	198	-42	-78	14	-4.583	<0.001

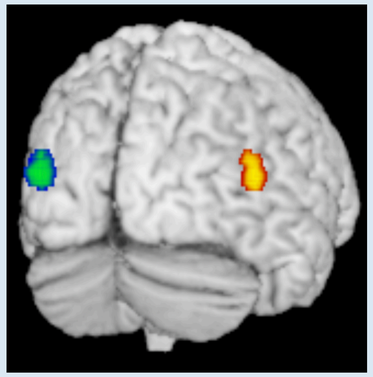

Figure 1 (Left): Activation difference for longer vs. shorter intervention in hours (>100 hours vs <100 hours)

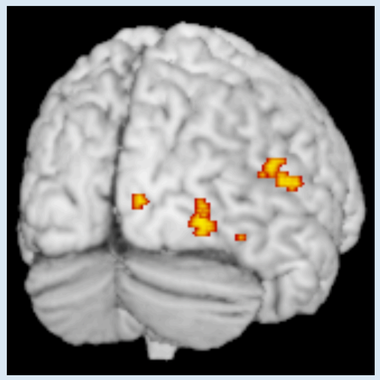

Figure 2 (Right): Activation difference for longer vs. shorter intervention in weeks (continuous analysis)

Total Weeks of Intervention

- 9 studies were included in the regression analysis

Regions	Voxels	MNI Coordinates			SDM-Z	p
		x	y	z		
R Occipito-temporal	36	36	-72	6	3.078	0.001
R Superior temporal gyrus (BA 22)	26	64	-36	12	3.117	<0.001
R Superior temporal gyrus (BA 42)	16	56	-40	20	3.230	<0.001

DISCUSSION

- Longer interventions (coded by weeks and hours) were associated with greater compensatory activation.
- Our analysis of total hours of intervention shows that longer interventions (<100 hours) increased activation in the R STG while shorter interventions (>100 hours) increased activation in the L MOG. This result might indicate that longer interventions provide more training for right hemisphere homologues which may help supplement activity in canonical L hemisphere reading areas.
- Our analysis of total weeks of intervention reveals an increase in activation along the R STG and R Occipito-temporal regions, again suggesting that increasing intervention duration may increase engagement of RH compensatory regions.
- Across both analyses (hours and weeks), we saw increased activation in R STG. This suggests that this region may play an important role in reading remediation, possibly by providing an alternate route for phonological processing. [25,26]

REFERENCES

1. Elliott, J. G., & Grigorenko, E. L. (2014). *The dyslexia debate*. Cambridge University Press.
2. Fuchs, L. S., Fuchs, D., & Malone, A. S. (2018). The taxonomy of intervention intensity. *Teaching Exceptional Children*, *50*(4), 194-202.
3. Partanen, M., & Siegel, L. S. (2014). Long-term outcome of the early identification and intervention of reading disabilities. *Reading and Writing*, *27*(4), 665-684.
4. Barquero, L.A., Davis, N., & Cutting, L. E. (2014). Neuroimaging of reading intervention: a systematic review and activation likelihood estimate meta-analysis. *PloS one*, *9*(1).
5. Davis, N., et al. (2011). Functional correlates of children's responsiveness to intervention. Developmental Neuropsychology, 36(3), 288–301. https://doi.org/10.1080/87565641.2010.549875
6. Shaywitz, B. A., et al. (2004). Development of left occipitotemporal systems for skilled reading in children after a phonologically-based intervention. *Biological psychiatry*, *55*(9), 926-933.
7. Odegard, T. N., et al. (2008). Differentiating the neural response to intervention in children with developmental dyslexia. *Annals of dyslexia*, *58*(1).
8. Aylward, E. H., et al. (2003). Instructional treatment associated with changes in brain activation in children with dyslexia. *Neurology*, *61*(2), 212-219.
9. Eden, G. F., et al. (2004). Neural changes following remediation in adult developmental dyslexia. *Neuron*, *44*(3), 411-422.
10. Gebauer, D., et al. (2012). Differences in brain function and changes with intervention in children with poor spelling and reading abilities. *PloS one*, *7*(5).
11. Warnzek, J., Stevens, E. A., Williams, K. J., Scammacca, N., Vaughn, S., & Sargent, K. (2018). Current evidence on the effects of intensive early reading interventions. *Journal of Learning Disabilities*, *51*(6), 612-624.
12. Suggate, S. P. (2016). A meta-analysis of the long-term effects of phonemic awareness, phonics, fluency, and reading comprehension interventions. *Journal of learning disabilities*, *49*(1), 77-96.
13. Warnzek, J., & Vaughn, S. (2007). based implications from extensive early reading interventions. *School Psychology Review*, *36*(4), 541-561.
14. Warnzek, J., et al. (2016). Meta-Analyses of the Effects of Tier 2 Type Reading Interventions in Grades K-3. Educational Psychology Review, *28*(3), 551–576.
15. Katzir, T., et al. (2013). Intensity vs. duration: Comparing the effects of a fluency-based reading intervention program, in after-school vs. summer school settings. *Journal of Education and Training Studies*, *1*(2), 61-73.
16. Al Otaiba, S. et al. (2005). Reviewing core kindergarten and first-grade reading programs in light of No Child Left Behind: An exploratory study. *Reading & Writing Quarterly*, *21*(4), 377-400.
17. Donnelly, P. M., Huber, E., & Yeatman, J. D. (2019). Intensive summer intervention drives linear growth of reading skill in struggling readers. *Frontiers in psychology*, *10*.
18. Heim, S., et al. (2015). Shared vs. specific brain activation changes in dyslexia after training of phonology, attention, or reading. *Brain Struct. and Func.*, *220*(4), 2191-2207.
19. Meyler, A., et al. (2008). Modifying the brain activation of poor readers during sentence comprehension with extended remedial instruction: A longitudinal study of neuroplasticity. *Neuropsychologia*, 46(10), 2580–2592.
20. Nugiel, T., et al. (2019). Brain activity in struggling readers before intervention relates to future reading gains. *Cortex*, 111, 286–302.
21. Partanen, M., Siegel, L. S., & Gaschi, D. E. (2019). Effect of reading intervention and task difficulty on orthographic and phonological reading systems in the brain. *Neuropsychologia*, 130, 13–25.
22. Richards, T. L., et al. (2006). Individual fMRI activation in orthographic mapping and morpheme mapping after orthographic or morphological spelling treatment in child dyslexics. *Journal of Neurolinguistics*, 19(1), 56–86.
23. Temple, E., et al. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI. *PNAS*, 100(5), 2860–2865.
24. Yamada, Y., et al. (2011). Emergence of the neural network for reading in five-year-old beginning readers of different levels of pre-literacy abilities: an fMRI study. *Neuroimage*, *57*(3), 704-713.
25. Simos, Panagiotis G et al. (2000). Brain mechanisms for reading. *NeuroReport* 11(11), 2443-2446.
26. Hickok, G., Poeppel, D. The cortical organization of speech processing. *Nat Rev Neurosci* 8, 393–402 (2007). https://doi.org/10.1038/nrn2113

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