Differences in brain activation following reading intervention: A meta-analysis Meaghan V. Perdue^{1,2}, Kelly Mahaffy^{1,2}, Kara Vlahcevic^{1,2}, Emma Wolfman¹, Florina Erbeli³, Fabio Richlan⁴ & Nicole Landi^{1,2}

Introduction

- Many children with Reading Disability (RD) improve with reading intervention^{1,2}.
- Both initial brain structure and activation as well as changes in these measures have been associated with reading intervention³.
- Elevated activation in frontal regions, subcortical regions, and righthemisphere homologues of the reading network has been hypothesized to play a compensatory role in individuals with RD^{3,4}.
- Alternatively, intervention may engage the typical left-hemisphere reading-related regions (temporo-parietal [TP], occipitotemporal [OT], inferior frontal gyrus [IFG]) and result in normalization of the reading network³.
- A prior meta-analysis of 8 studies showed that reading intervention was associated with increases in activation in L. thalamus, L. IFG, L. middle occipital gyrus, R. IFG/insula, and R. posterior cingulate cortex³.
- Brain mechanisms underlying successful reading remediation remain poorly understood.
- Aim: Conduct an updated meta-analysis and systematic review to evaluate the neural changes associated with reading intervention.

Methods

Literature search & screening:

- Databases searched: PsychInfo, ERIC, Academic Search Ultimate, MedLine, EBSCOhost eBook Collection, PubMed
- Inclusion criteria (systematic review):
 - 1. Primary research studies with full-text in English
 - 2. Must include participants with or at-risk for developmental RD
 - 3. Studies must have included reading related instruction/intervention.
 - 4. Studies must have included pre- and/or post-intervention neuroimaging in structural MRI or functional MRI or MEG modality using a reading or reading-related task (e.g. phonological processing, orthographic processing)
- Additional inclusion criteria for the meta-analysis:
 - 1. Neuroimaging acquired using fMRI modality
 - 2. Neuroimaging acquired at a post-intervention time point
 - 3. Whole-brain analysis must have been used, and peak coordinates of results must be reported in standard space

Meta-analysis:

- Contrasts: RD Time 2>Time 1, groupXtime interaction (RD vs. Typ), correlation of post-intervention activation and reading gain in RD group
- Peak coordinates and statistics from significant clusters or Z-map for contrast of interest entered into meta-analysis
- Voxel-based meta-analysis was conducted via permutation of subject images for seed-based d mapping (SDM-PSI)⁵.

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Author	N	Task contrast	Analysis Contrast	Voxel-wise Threshold	Number of foci
Eden, 2004 ⁶	19	sound deletion > word repetition	Post vs. Pre for intervention group > non-intervention RD group	<i>p</i> < .001, unc.	15
Gebauer, 2012 ⁷	10	pseudoword lexical decision > fixation	Post vs. Pre in training group	z > 2.0	7
Heim, 2015 ⁸	33	word/pseudoword reading > baseline	Post vs. Pre in RD intervention group	p < .05, FWE-corrected	2
Meyler, 2008 ⁹	35	sentence reading > fixation	Good vs. Poor readers at post-intervention	<i>p</i> < .002, unc.	5
Nugiel, 2019 ¹⁰	21	sentence comprehension > baseline	Post-intervention fMRI correlation with reading gain score	unthresholded z-map	provided
Partanen, 2019 ¹¹	29	words > symbols	Poor readers > Good readers at Post vs. Pre	z > 2.3	1
Richards, 200612	8	word pair spelling decision > letter string matching	Post vs. Pre in ortographic treatment group	z > 2.4	5
Shaywitz, 200413	25	audio-visual letter identification > baseline	Follow-up > Pre in RD experimental intervention group	<i>p</i> < .05	7
Temple, 200314	20	letter rhyming > letter matching	Post vs. Pre in RD group	<i>p</i> < .005, unc.	14
Yamada, 2011 ¹⁵	7	one-back letters > false fonts	Post vs. Pre in at-risk group	z > 2.33	41

Results

- 47 studies met criteria for qualitative review

Table 2. Meta-analysis results: locations and statistics of peak effects, p < .025, TFCE-corrected

Region

R. lingual/fusiform gyrus L. lingual gyrus Bilateral calcarine fissure/R. precuneus R. superior temporal R. cuneus

- readers.
- reading^{19,20,21}.



Table 1. Studies included in quantitative meta-analysis. N indicates number of subjects included in the analysis contrast used in our meta-analysis

• 10 studies met criteria for quantitative meta-analysis (Table 1)

• Meta-analysis revealed 5 clusters of significant effects related to post-intervention changes in brain activity in groups with/at-risk for RD (p < .025, TFCE-corrected; Table 2, Fig. 1)

is and statistics of peak encets, $p < 1025$, if $c = concetca$							
		MNI Coordinates		SDM-			
	Voxels	X	Y	Z	Ζ	p	
	1812	16	-92	-14	3.611	>.001	
	928	-20	-70	-10	3.108	.006	
	698	-2	-72	22	3.057	.003	
	256	46	-42	18	3.565	.008	
	103	14	-78	34	2.709	.016	

Discussion

 Meta-analysis results show engagement of right-hemisphere structures following interventio which may serve a compensatory role for reading in individuals with RD. Reading intervention may also support engagement of left OT regions that are active in typic

 Systematic literature review indicated that improvement in reading ability over intervention associated with greater post-intervention activation in left temporal¹⁶, left TP⁹, left OT¹⁷, left frontal¹⁸, and right OT regions¹⁰. Increases in connectivity among reading, visual, and execu functioning networks over the course of intervention has been associated with improvement

 Additional empirical studies of functional and structural neural correlates of intervention-related reading gains are needed to characterize brain mechanisms of reading remediation.

Fig. 1. Meta-analysis results. Numbers indicate slices in MNI Z-



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