fNIRS Naturalistic Comprehension Approach Reveals Hypoactivation of Language Networks in Dyslexia

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Dyslexia is a life-long difficulty in learning to read that affects about 5-10% of the population (Wagner et al., 2020). It is now well established that most children diagnosed with dyslexia experience phonological deficits that impede their ability to map language sounds onto print. At the neurological level, these phonological deficits have been linked to hypoactivation of language regions, especially those associated with phonological processing (e.g., Paz-Alonso et al., 2018). Much of this evidence comes from phonological reading tasks that involve isolated words or word pairs presented without context and often without cues (e.g., prosodic cues) that may be available in more naturalistic language—leaving a gap in our understanding of how dyslexia affects more naturalistic language comprehension. To address this gap, we employed a novel neuroimaging approach using a broad-coverage computational model to examine brain activity during a naturalistic story listening paradigm.

Guided by the phonological deficit hypothesis of dyslexia, we predicted that children with dyslexia may exhibit differences in the engagement of brain regions associated with phonological processing, including hypoactivation of left dorsal IFG and posterior STG regions, during natural spoken language comprehension.

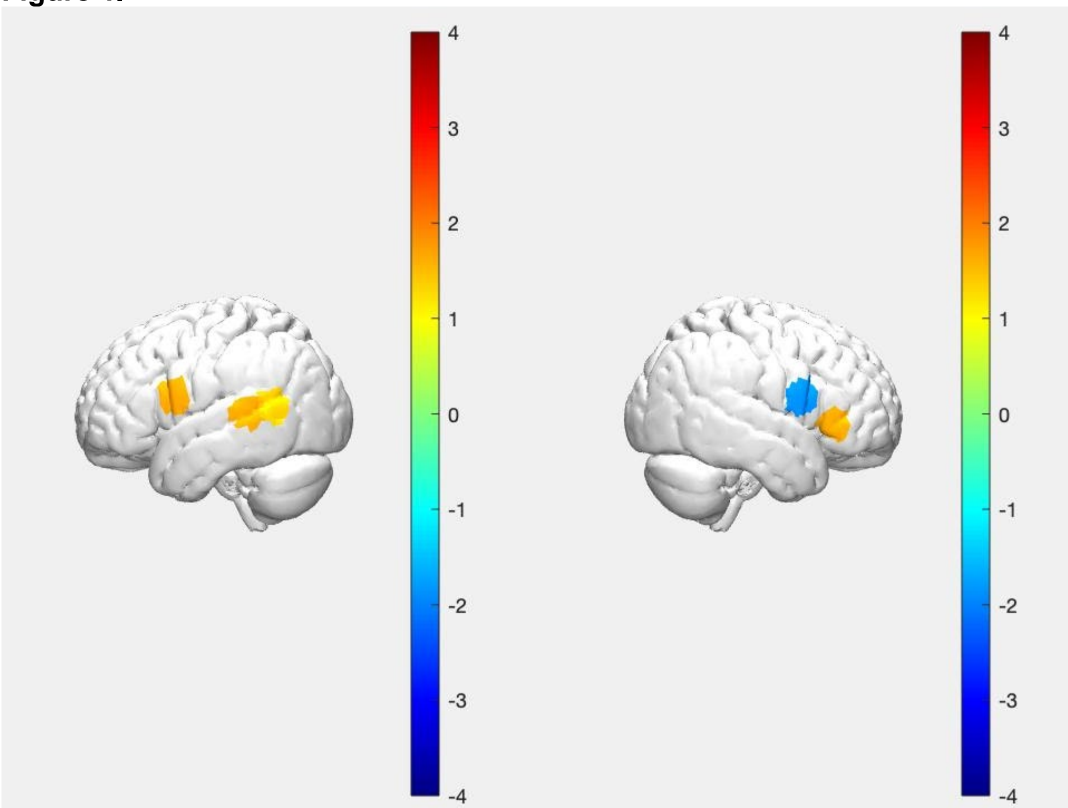
We evaluate how 38 children with dyslexia and 59 typically developing children (all monolingual English speakers, ages 7-12) process an English audiobook in which the speech is natural, contextualized within a story, and contains the typical cues (e.g., prosodic) present in every-day language. We employ functional near-infrared spectroscopy (fNIRS) neuroimaging and take a computational approach using the large, pre-trained artificial neural network GPT2—a tool that helps us assess prediction at different levels. We used GPT-2 to quantify predictability of words within the story context using next-word surprisal, and then correlated model-predicted brain activity with children's fNIRS-recorded brain activity (e.g. Heilbron et al. 2022). Using this approach, we evaluate differences between the brain activity of typically developing children vs. children with dyslexia during naturalistic listening comprehension.

Consistent with our primary predictions, our findings suggest (see Figure 1) that, compared to children with dyslexia, typically developing children showed stronger left posterior IFG/motor cortex and left posterior STG activation during naturalistic language comprehension—brain regions associated with phonological processing (Matchin & Hickock, 2020). These results align remarkably well with prior research using less naturalistic language comprehension tasks, such as rhyme judgments and pseudoword processing (summarized in Norton et al., 2015).

Additionally, our results show that children with dyslexia show stronger activation in right IFG during natural comprehension, homologous to typically developing children's *left* IFG activation. Given that many of our participants with dyslexia had received remediation, this finding aligns with prior work showing that intervention in people with dyslexia can result in increased right hemisphere activation, potentially as a compensatory mechanism (e.g., Zuk et al., 2021).

In sum, patterns of brain activation for children with dyslexia observed in isolated language tasks extend to how they process language in more natural spoken language contexts. These findings indicate that the language difficulties of children with dyslexia likely extend to natural language comprehension. However, their success in daily life/communication suggests that they may be able to capitalize on context and cues such as prosody to compensate for difficulties, perhaps especially so when they have received remediation. Overall, this study highlights the benefits of using a more ecologically valid neuroimaging approach to better understand the impact of language impairments on children's daily life.

Figure 1.



Note. Positive values reflect regions where typically developing children's brain activity had greater alignment with the surprisal-based-model's estimated brain activity, whereas negative values reflect regions of greater alignment for brain activity of children with dyslexia. Values shown for activity with $p < 0.05$, uncorrected.

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