Correlation between socioeconomic disadvantage in preschool children and brain organization: a functional NIRS connectivity study

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Abstract: Socioeconomic status (SES) has been shown to be related to brain development and cognitive performance. We present a functional NIRS connectivity analysis in children with different SES during a working memory task.

1. Introduction

Early-childhood poverty and low socioeconomic status (SES) have been shown to have lasting adverse effects on child health and development, increasing risk for developmental delays, low achievement, and behavioral/emotional problems [1]. This study aims to assess the correlation between early childhood SES risk and prefrontal cortex activation during a working memory task utilizing functional NIRS connectivity analysis.

2. Method

2.1 Participants and task description

We included 30 children (13 males) ranged from 4 to 7 years old in our data analysis. SES is described numerically by Income to Need Ratio (INR), where parents reported their annual income, including salary and additional financial support sources, and need is based on U.S. Census Bureau estimates. In this study, INR ranged from 0.14 to 2.11 (Mean = 1.13, StdDev= 0.59), where INR<1 is classified as living in poverty (14 families).

Participating children were instructed to keep track of a monkey jumping across the computer screen and hiding his bananas behind cartoons. For each trial, the monkey appeared on the screen and jumped between cartoon objects for 2 seconds before disappearing. After a delay period that lasted 2, 3, 4, 5, or 6 seconds, the child was prompted to touch the screen's location where the monkey last hid his bananas. Each block contained four trials, and five total blocks were administered for this task. There was a 15-second break between each block, during which children viewed the monkey resting before completing the next block. Reaction time (RT) and task accuracy data were collected for each trial. All children were required to complete a series of practice trials before completing the task. The child was required to answer 3 out of 4 trials correctly to pass the practice trials.

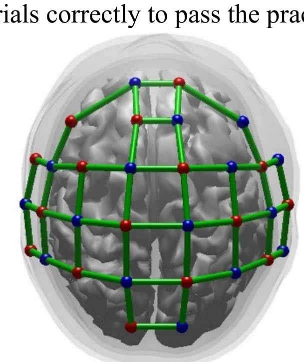

Figure 1. The probe covered frontoparietal regions bilaterally.

2.2 fNIRS measurements and processing

A continuous-wave fNIRS system (NIRScout, NIRx Medical Technologies LLC, Glen Head, NY) with a sampling frequency of 6.25 Hz and 50 channels (16 optical sources and 16 light detectors at 760-nm and 850-nm) was used in this study. The probe extended from prefrontal to parietal areas bilaterally (Fig. 1). Before data collection, the quality for each channel was inspected using the PHOEBE software program [2]. Preprocessing and most statistical analyses were carried out using the NIRS Brain AnalyzIR toolbox (Santosa, Zhai, Fishburn, & Huppert, 2018). Raw fNIRS intensity signals were first resampled to 4 Hz and converted to changes in optical density. Intensity signals were then converted to HbO and HbR concentration values using the modified Beer-Lambert Law with a differential pathlength factor of 5 and a partial volume correction of 50 for both wavelengths.

2.3 Functional Connectivity analysis

Functional connectivity analysis was performed by computing the correlation across channels in an *all-to-all* fashion [3]. We only included the hemoglobin data captured during the stimulation periods. We partitioned the data set into two subgroups: A (INR<1) and B (INR>=1). A group-level analysis was performed using a linear mixed-effects model denoted as indicated by the `R ~ -1 + group + (1|subject)` Wilkinson notation. In order to highlight the meaningful relationships between pairs of channels, we only considered values $R \geq 0.5$. Two connectivity models were obtained from HbO2 depicting connectivity patterns from subgroup A, subgroup B, and the subgroup differences (Figs. 2a, 2b, and 2c). The differences between the two groups were computed by applying a set difference operation B-A from thresholded ($R \geq 0.5$) connectivity matrices (links existing in B but not in A).

3. Results

We present HbO2 results only due to space limitation and a higher signal-to-noise ratio. After subgroup division is made, a richer connectivity pattern is observed in subgroup B, indicating higher SES was associated with increased connectivity largely in frontal regions (Figs 2a and 2b). The diminished number of links in the network from subgroup A may elucidate reduced cooperation among key brain regions during working memory processing, which correlates with the weaker activation pattern observed in the left dorsolateral prefrontal cortex and the inferior frontal gyrus during a working memory task [4]. From the network difference, we observed that subgroup B contains higher centrality hub nodes linking the modularity patterns (Fig. 2c), representing the small-world characteristic in the usual brain topology [5]. On the other hand, the subgroup A network only exhibited modularity without the presence of hubs.

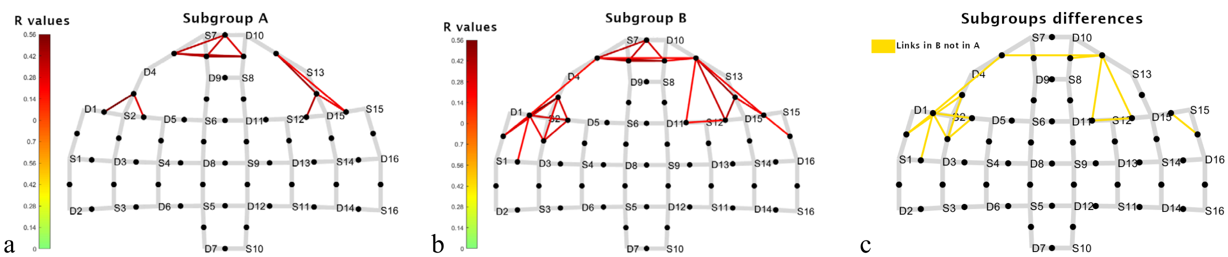

Figure 2. Connectivity patterns for subgroups A (a), B (b), and subgroup differences (c). Only the network links with $R \geq 0.5$ are displayed.

5. Conclusion

In summary, our study used fNIRS to examine the working memory-related functional connectivity associated with socioeconomic risk in preschool children. Our results showed children exposed to greater socioeconomic disadvantage (lower income to needs ratio) exhibited decreased functional connectivity in frontal regions. Our findings indicate exposure to early childhood socioeconomic risk may lead to changes in the developing brain and subsequent adverse neurocognitive outcomes.

6. Acknowledgments

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3. References

[1] Rosen ML, Hagen MP, Lurie LA, Miles ZE, Sheridan MA, Meltzoff AN, McLaughlin KA. Cognitive Stimulation as a Mechanism Linking Socioeconomic Status With Executive Function: A Longitudinal Investigation. Child Dev. 2020 Jul;91(4):e762-e779. doi: 10.1111/cdev.13315.
[2] Pollonini L, Bortfeld H, Oghalai JS. PHOEBE: a method for real time mapping of optodes-scalp coupling in functional near-infrared spectroscopy. Biomed Opt Express. 2016 Nov 15;7(12):5104-5119. doi: 10.1364/BOE.7.005104.
[3] Santosa H, Aarabi A, Perlman SB, Huppert TJ. Characterization and correction of the false-discovery rates in resting state connectivity using functional near-infrared spectroscopy. J Biomed Opt. 2017 May 1;22(5):55002. doi: 10.1117/1.JBO.22.5.055002.
[4] Wijeakumar S, Kumar A, Delgado Reyes LM, Tiwari M, Spencer JP. Early adversity in rural India impacts the brain networks underlying visual working memory. Dev Sci. 2019 Sep;22(5):e12822. doi: 10.1111/desc.12822.
[5] Rubinov M, Sporns O. Complex network measures of brain connectivity: uses and interpretations. Neuroimage. 2010 Sep;52(3):1059-69. doi: 10.1016/j.neuroimage.2009.10.003.