Neural correlates of spatial short-term memory in children with Down syndrome measured with wearable fNIRS

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Synopsis

Characterizing the neural mechanisms of spatial short-term memory (SSTM) in children with Down syndrome (DS) remains limited, in part due to challenges in acquiring neuroimaging data in pediatric clinical populations. We used wearable functional near-infrared-spectroscopy (fNIRS) to measure prefrontal cortex (PFC) activation in children with DS and typically developing (TD) peers during a tablet-based SSTM task with increasing memory load. Children with DS showed lower behavioral performance and a different load-dependent PFC response compared to TD children. These preliminary findings demonstrate the feasibility and added value of fNIRS for quantifying task-related brain function in pediatric DS beyond behavioral measures alone.

Background

Down syndrome (DS, Trisomy 21), is associated with challenges in executive functions, including short-term and working memory compared to typically developing (TD) peers (Raitano Lee et al., 2010). SSTM supports the temporary maintenance of spatial sequences and has been linked to PFC engagement in TD individuals. Behavioral studies indicate reduced SSTM capacity in DS relative to TD peers (Vicari and Carlesimo, 2006), but the associated neural dynamics in DS are not well characterized. Wearable fNIRS offers a non-invasive, child-friendly approach to quantify cortical activation during cognitive tasks and may help resolve dissociations between performance and neural recruitment (Barreto et al., 2021; Barreto et al., 2024).

Methods

Thirteen children with DS (six male) and nineteen TD (nine male) children were included in this preliminary analysis. An fNIRS ultra-thin flat sensor pad with 16 optodes was placed over the participants' forehead to monitor the PFC activity (Fig.1B). During measurement, participants completed the SSTM task from the Arizona Memory Assessment for Preschoolers and Special Populations (A-MAP™). In this task, participants watch a frog jumping on lily pads on the tablet screen. Then, participants are asked to touch the lily pads in the same order in which the frog jumped on them. The number of lily pads increases each time the participant responds correctly. The task is discontinued when the participant makes two consecutive incorrect responses. Accuracy is computed as the percentage of correct responses (number of correctly recalled jumps/total jumps)*100. fNIRS signals were filtered to minimize the artifact effects, as previously described (Ayaz et al., 2019) oxyhemoglobin (HbO) and deoxyhemoglobin(HbR) concentration changes were computed and averaged for each optode and condition. The difference in hemoglobin, oxygenation (Oxy) changes (Oxy = HbO – HbR) was used in our analysis as in prior studies to indicate a more inclusive cortical activation measure using both types of hemoglobin

(Ayaz et al., 2012). Task accuracy and Oxy changes were analyzed using linear mixed models with subject as a random effect and age as a covariate; group and task load were included as fixed effects for both models. fNIRS results were corrected for multiple comparisons with FDR ($q < 0.05$).

Results

Behaviorally, accuracy showed significant main effects of **age** *($F(1, 28.5) = 11.67$, $p < 0.002$)*, and **group** *($F(1, 28.6) = 17.35$, $p < 0.001$)*, with children with DS performing worse than TD peers (Fig. 1A).

Neurally, after FDR correction ($q < 0.05$), **Optode 2** showed a significant **group × task load** interaction *($F(1, 84.8) = 8.69$, $p < 0.004$)*. Bonferroni-corrected post hoc tests indicated a significant TD vs. DS difference at **load 2**. Within-group contrasts showed Oxy modulation between **loads 1 and 2** in children with DS (Fig. 1B) with no within-group differences for TD children.

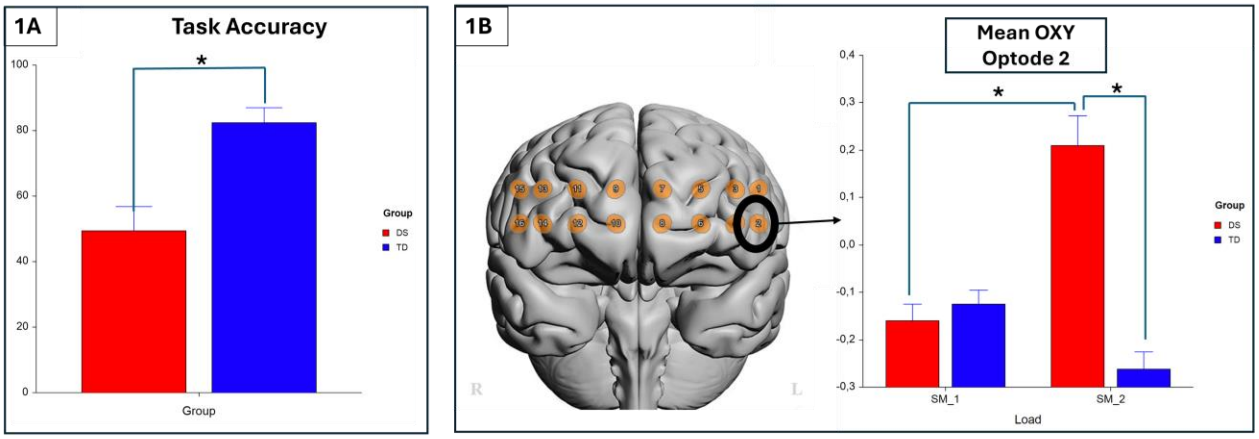

Figure1: 1A) Task accuracy results. Percentage of correct responses per group (read and blue bars represent DS and TD groups, respectively). 1B) in the left, 16 orange circles with numbers depict the optodes' location projected onto the PFC. The black circle highlights the left lateral region covered by optode 2, the region where differences in brain activity were found within and across groups. The graph on the right side shows the mean OXY values per group and task load.

Discussion

These preliminary findings indicate that SSTM performance is shaped by developmental and cognitive factors, with robust effects of task load, group and age. Consistent with prior behavioral work, children with DS showed lower accuracy than TD children (Jarrold and Baddeley, 2001). At the neural level, the significant group × load interaction suggests differential PFC recruitment with increasing task demands. Children with DS exhibited significant modulation of oxyhemoglobin (Oxy) concentration between loads 1 and 2 (Fig. 1B), reflecting load-sensitive neural recruitment, whereas TD children showed no significant differences across loads. These findings suggest an atypical load-dependent neural response pattern in DS, with greater sensitivity to increasing task demands at this prefrontal site compared to TD peers.

Together, behavioral and OXY results highlight the potential utility of mobile fNIRS to provide complementary, objective markers of cognitive workload and neural engagement in pediatric DS, supporting more ecologically valid assessment in clinical populations.

Disclosures

Study was funded by NIH/NICHD award number R21HD100997. Dr. Ayaz has equity in fNIR Devices LLC that licensed IP from Drexel University and manufactures optical brain imaging sensor used in the study.

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