Prefrontal Cortex Activity during Executive Control Tasks in Adults with Down Syndrome

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Synopsis

Prefrontal cortex (PFC) activity in adults with Down syndrome (DS) was investigated during tablet-based executive control (EC) tasks through the application of functional near-infrared spectroscopy (fNIRS). The task involved *Simple* and *Complex* conditions; participants were stratified into low and high-developmental levels assessed via Kaufman Brief Intelligence Tests. Based on Linear Mixed Models analysis, a significant task load * developmental level interaction was identified, with higher PFC activation observed in the lower developmental level group during the *Complex* condition. These preliminary findings establish the feasibility of utilizing wearable neuroimaging to assess executive functioning within the adult DS population.

Background

Down syndrome is a genetic condition caused by the presence of an extra copy of chromosome 21 (Antonarakis et al., 2020). Executive control (EC) is mediated, in part, by the prefrontal cortex (PFC) and includes working memory, inhibtory control, task switching, problem solving and decision making (Lanfranchi et al., 2010; Loveall et al., 2017; Song et al., 2025). Individuals with Down syndrome are known to show impairments in executive control (Lanfranchi et al., 2010). However, the neural mechanisms underlying these difficulties in adulthood remain insufficiently characterized, largely due to the limited availability of accessible and population-appropriate neuroimaging methods (Carbo-Carrete et al., 2020).

Methods

A total of 23 participants between ages 21 and 39 (14 females; mean: 27.18, SD: 4.75) completed the Executive Control task from the Arizona Memory Assessment for Preschoolers and Special Populations (AMAP™) on a touch screen tablet. The *Simple* condition had three sub-components. In the *Baseline* component they tapped all objects on the screen; in the *Inhibit* component they tapped one target on each different display while refraining from tapping non-target objects; and in the *Switch* component the target objects switched to the non-target objects shown in the *Inhibit* component. In the *Complex* condition, they alternated between tapping objects on the left or the right side of the screen dependent on whether they were associated with a target that was presented in the middle of the screen.

Participants' prefrontal cortex activity was recorded via a continuous wave fNIRS device (fNIR Devices, LLC, Potomac, MD, USA) operating at 730 nm and 850 nm. Sampling frequency was 10 Hz. The sensor pad covered the prefrontal cortex bilaterally.

For signal preprocessing, physiological artifacts and high frequency noise were eliminated by applying a low pass finite impulse response (FIR) filter of order 100 and cut-off frequency of 0.1 Hz. To reduce motion artifacts, a sliding window motion artifact rejection (SMAR) filter was applied, and each optode was visually inspected for channel saturation. Preprocessed light intensity was then converted into oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR) using the Modified Beer-Lambert Law using local baselines for each optode and each block. The difference in hemoglobin, Oxy, was calculated via HbO – HbR. Each task block was averaged to obtain the mean Oxy values for each optode (Ayaz et al., 2019).

In addition, each participant was administered Kaufman Brief Intelligence Test – II (KBIT-II) with Verbal Knowledge and Matrices Subtests. A raw composite score of the two subtests was used as an estimate of cognitive developmental level (DevLevel). Participants were assigned to low and high DevLevel groups based on the median DevLevel score (M = 39).

A Linear Mixed Model (LMM) Analysis was applied to the Oxy values from each optode, including Task Load (*Simple* vs. *Complex*) as a fixed effect, Subject as a random effect and DevLevel (Low vs. High) as a covariate.

Results

LMM analysis indicated a significant interaction between DevLevel ***** TaskLoad ($F_{1,84.0} = 5.61$, $p < 0.05$) in Optode 10 (Figure 1) that was measured from right medial prefrontal cortex. Post-hoc analysis showed that in the *Complex* condition, the high DevLevel group showed lower brain activation ($F_{1,84.0} = 8.76$, $p < 0.01$). For the low DevLevel group, there was a significant difference in brain activation between *Complex* and *Simple* tasks, with *Complex* tasks eliciting higher brain activity ($F_{1, 84.0} = 6.13$, $p < 0.05$). There was also a significant main effect of DevLevel ($F_{1,84.0} = 7.61$, $p < 0.01$) with lower DevLevel group having overall higher brain activity.

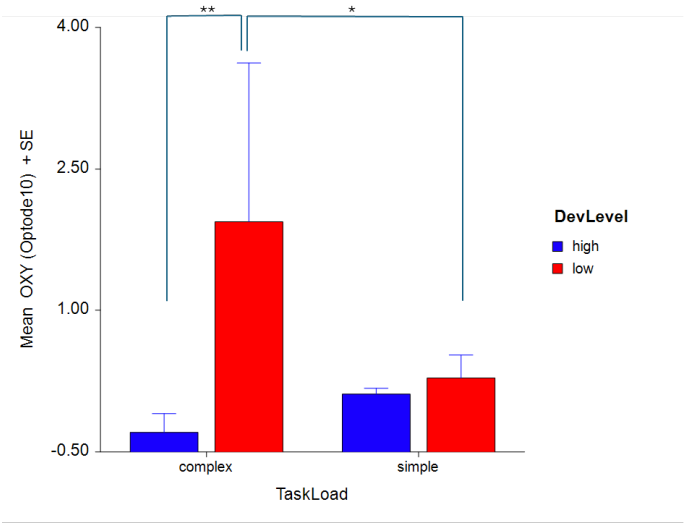

Figure 1: Brain oxygenation (Oxy) changes with respect to TaskLoad and DevLevel in Optode 10. *: $p < 0.05$, **: $p < 0.01$

Discussion

This study investigated brain activity in the PFC related to executive control in adults with Down syndrome using wearable neuroimaging (fNIRS) and an executive control assessment

(AMAP™). Results revealed both a main effect of group (such that the low developmental group demonstrated higher brain activation overall) as well as a task by group interaction in the medial PFC. Regarding the interaction, level of brain activation was higher during the complex than the simple task for those in the low developmental level group only. There were no differences in brain activation between the simple and complex tasks for the high developmental level group. In addition, the low developmental level group also showed higher Oxy levels than the high developmental level group during the complex (but not simple) condition. These results are consistent with evidence that individuals with lower cognitive abilities may need to recruit additional prefrontal resources to complete cognitively challenging tasks (Vermeij et al., 2017; Song et al., 2025). As such, these results suggest that fNIRS may be a valuable tool to assess brain activity in individuals with Down syndrome.

Disclosures

This project was funded by NIH. HA 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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