Revealing Cortical Activation Patterns of Novel Task Performance in Children With Low Coordination via fNIRS

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Introduction.

Developmental Coordination Disorder (DCD) is a neurodevelopmental condition characterized by deficits in acquiring and executing motor skills (DSM-V; American Psychiatric Association, 2013). DCD is prevalent among 5-6% of school-aged children often manifested as clumsiness, slowness, and can impact personal, social, academic, and occupational functioning (APA, 2013; Zwicker et al., 2012). Diagnosis entails a complex of developmental and medical history, physical examination, school or workplace report, and often the Movement Assessment Battery for Children (MABC-2). The etiology of DCD remains unclear, however previous studies using functional Magnetic Resonance Imaging (fMRI) and Electroencephalogram (EEG) have revealed different cortical activation patterns between DCD children and Typically Developed (TD) children (Brown-Lum and Zwicker 2015; Wilson et. al 2017). Children with DCD often have difficulty performing novel tasks and appear to use more executive control during tasks to maintain performance or adapt to new movements (Caçola, P. et al). Previous studies have explored the Prefrontal Cortex (PFC) due to its functional relationship with working memory, decision making, and executive control.

While these tools have proved fruitful, they limit our understanding of DCD due to rigid body confinement and large motion artifacts via fMRI and EEG respectively. Seeing as the deficits in DCD are motor-related, an ecologically valid neuroimaging tool is needed to be robust in handling motion artifacts.

Functional Near Infrared Spectroscopy (fNIRS) is a non-invasive optimal imaging technique used to monitor tissue oxygenation and cerebral blood flow (CBF). fNIRS is resistant to motion artifacts making it ideal to study motor disorders in real-world environments (Villringer and Chance, 1997; Ayaz et al., 2012). fNIRS uses infrared light between 630nm and 900nm to measure cerebral oxygenated and deoxygenated states of hemoglobin correlated with Blood-Oxygen-Level Dependent (BOLD) contrast used in fMRI. fNIRS has been validated against fMRI for motor and cognitive tasks (Cui et al., 2011).

In this study we employ the use of more ecologically valid neuro-imaging modalities to compare brain activation patterns between DCD and TD populations during specific novel tasks.

Methods.
Design: Randomized Controlled Trial with Repeated Measures 1118 students in year 9 (13-14yr) across 3 mainstream schools in Oxfordshire were screened for 4 fitness parameters including coordination (MABC-2), strength (grip strength), power (broad jump) and endurance (shuttle-run) (ACSM 2013; Leger et. al 1988). 293 students were selected being among the lowest 25% for the overall fitness parameters to be eligible for the study. 103 consented however 85 continued to show interest, attended the baseline experiment and participated in the study.

The University Research Ethics Committee approved the study (UREC Registration No: 161033) and the trial is registered under ClinicalTrials.gov on April 4th, 2017.

Experimental Procedure.
Each participant completed the same 10-minute assessment comprised of 3 tasks involving rhythmic stepping, auditory stroop, and dual tasks (stepping and auditory stroop). Tasks had a duration of 42.5s. The stepping instructions were displayed on a laptop via a customized LabView Program in front of the participant at 0.5Hz. Auditory stroop was presented by smart phone at 0.33Hz. Rest periods between tasks varied between 20-30s. Physical activity/quality was measured by Inertial Measurement Units (IMU; LPMS-B, Life Performance Research, Japan) at 100Hz comprised of three-axial accelerometers, gyroscopes and magnetometers, synced to the visual stimulus while Auditory Stroop performance was manually recorded. During the assessment, cortical activity was recorded in the PFC via a NIRSport device (8 detectors, 8 sources, 20 channels) sampling at 7.81Hz with sources and detectors located relative to the 10-20system as used for EEG.

Pre-Processing.

fNIRS data was recorded and processed via the NIRStar(v14.0) and NirsLab(v2017.06) (NIRSport, NIRx Medical Technologies LLC, Glen Head, NY, USA) softwares. Attenuation changes in the wavelengths (850nm and 760nm) were transformed to concentration changes of Oxygenated Hemoglobin (HbO) and Deoxygenated Hemoglobin (HbR) respectively using the modified Beer-Lambert approach. The differential path length factor was calculated per subject (Scholkmann and Wolf 2013). A bandpass filter between 0.01Hz and 0.2Hz and a 15% roll off width was applied to remove noise, cardiovascular affects, low frequency motion artifacts and signal drift. A customized MATLAB Program averaged the response for each task (f10s into the task to end of task) per channel and corrected for baseline effects (5 seconds before task). Total Hemoglobin (HbTot) was calculated using the sum of HbR and HbO while Oxygenation was calculated using the difference.

Analysis/Results.

85 students (33 male; 10 left-handed) (13.92yrs +/- 0.33) participated in the study. 37 Students (20 male) scored between the 15th and 25th percentile on the MABC-2 and categorized as TD and 48 participants (13 male) scored below the 15th percentile on the MABC-2 were categorized as probable DCD (pDCD). (Brown-Lum and Zwicker 2015).

All channels for HbTot and oxygenation had normal distribution. Descriptive statistics and Independent Sample t-tests were calculated per channel between DCD and TD groups for stepping, audio, and dual tasks. Channels that showed a p-value less than 0.05 were considered significant.

pDCD participants had significantly increased HbTot in channels (CH) 9 and 19, and significantly increased Oxygenation in CH19 during Auditory Stroop as depicted in Table 1. Within the Stepping Task, pDCD participants had significantly increased HbTot in CH4,6,13,16,20 compared to TD participants. Oxygenation showed significant differences in CH3,4,13,16. This is depicted below in Table 2.

Within the Dual Task, pDCD participants had significant increased Oxygenation in CH11,13,16,19 compared to TD participants. HbTot showed significant differences in CH1,6,11,16,19. This is depicted below in Table 3.

Discussion/Conclusion: The current study highlighted unique cortical activation patterns for the stepping and dual task, while fewer differences were observed in auditory stroop. More positively increased changes in HbTot and Oxygenation were observed in the pDCD population particularly within the inferior regions of the PFC with notice to the rDLPFC. Increased activity and HbTot within the pDCD group suggest different ability in executive function within the PFC possibly explaining

motor learning difficulties and impaired physical task performance. The diagnosis of DCD encompasses a variety of time-consuming tests; however, the current study highlights the potential for fNIRS to screen for potential DCD in children with less cumbersome and expensive ways than traditional neuro-imaging modalities.

Figure 1.

Table 1: Functional Hemodynamic Data associated with the Auditory Stroop Task

AUDITORY STROOP TASK	Channel	Probable DCD (in mM)	TD (in mM)	P
Oxygenation	19	**1.94x10^{-3}**	5.75x10^{-4}	0.005
HbTot	9	**2.45x10^{-5}**	-3x10^{-4}	0.02
	19	**1.57x10^{-3}**	1.66x10^{-4}	0.012

Oxygenation = HbO (Oxygenated Hb) – HbR (Deoxygenated Hb); HbTot = Total Hemoglobin; All measurements were taken in millimolar concentrations (mM). DCD, Developmental Coordination Disorder; TD, Typical Development; P < 0.05 is significant; only shows significant channels. **BOLD-values** indicate higher value.

Figure 2.

Table 3: Functional Hemodynamic Data associated with the Dual Task (Auditory Stroop and Stepping Task simultaneously)

DUAL TASK	Channel	Probable DCD (in mM)	TD (in mM)	P
Oxygenation	11	**1.1x10^{-3}**	-1.45x10^{-3}	0.043
	13	**1.88x10^{-3}**	1.16x10^{-3}	0.004
	16	**1.46x10^{-3}**	2.12x10^{-4}	0.017
	19	**2.56x10^{-3}**	8.59x10^{-4}	0.005
HbTot	1	-3.5x10^{-5}	**3.5x10^{-4}**	0.019
	6	**1.24x10^{-3}**	1.79x10^{-4}	0.029
	11	**1.5x10^{-3}**	-2.7x10^{-4}	0.023
	16	**1.21x10^{-3}**	-5.4x10^{-4}	0.028
	19	**2.09x10^{-4}**	3.17x10^{-4}	0.011

Hb, Hemoglobin; Oxygenation = HbO (Oxygenated Hb) – HbR (Deoxygenated Hb); HbTot = Total Hemoglobin; All measurements were taken in millimolar concentrations (mM). DCD, Developmental Coordination Disorder; TD, Typical Development; P < 0.05 is significant; only shows significant channels. **BOLD-values** indicate higher value.

Figure 3.

Table 2: Functional Hemodynamic Data associated with the Stepping Task

STEPPING TASK	Channel	Probable DCD (in mM)	TD (in mM)	P
Oxygenation	3	**1.40×10^{-3}**	8.82×10^{-4}	0.019
	4	1.7×10^{-3}	**9.0×10^{-3}**	0.012
	13	**1.47×10^{-3}**	-6.41×10^{-4}	0.01
	16	**1.57×10^{-3}**	1.66×10^{-4}	0.039
HbTot	4	**1.55×10^{-3}**	5.36×10^{-4}	0.03
	6	**1.36×10^{-3}**	2.83×10^{-5}	0.002
	13	**1.48×10^{-3}**	3.06×10^{-4}	0.004
	16	**1.39×10^{-3}**	1.99×10^{-4}	0.023
	20	**7.96×10^{-4}**	4.31×10^{-4}	0.047

Oxygenation = HbO (Oxygenated Hb) – HbR (Deoxygenated Hb); HbTot = Total Hemoglobin; All measurements were taken in millimolar concentrations (mM). DCD, Developmental Coordination Disorder; TD, Typical Development; P < 0.05 is significant; only shows significant channels. **BOLD-values** indicate higher value.

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