Exploring developmental changes in functional connectivity associated with cognitive flexibility

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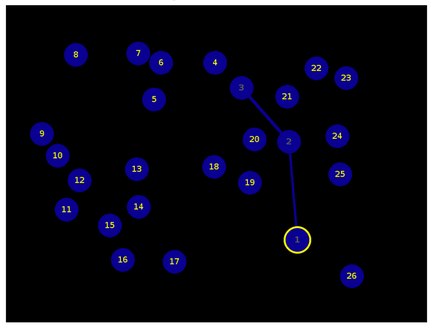
Introduction

- Cognitive flexibility is an aspect of executive function that involves flexibly shifting attention to different dimensions of a stimulus or switching between following different rules during a task. This skill rapidly develops between the ages of 6 and 9 (Anderson, 2002) and is thought to be supported by a frontal-parietal neural network (FPN) (Dajani and Uddin, 2015). During tasks that require cognitive flexibility, adults tend to show greater long-range functional connectivity (FC) between the frontal and parietal cortices than children (Fair et al., 2007; Mehnert et al., 2013). However, no studies have looked at task-related changes in FC at the age range when this skill rapidly improves. The current study used fNIRS to explore changes in FC associated with cognitive flexibility between children at age 5, 7, and 9.

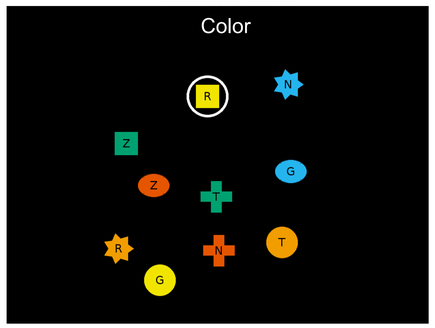
Tasks and Stimuli

- 20 five year-olds, 19 seven year-olds and 18 nine year-olds completed this experiment (N=57)
- Completed the pTrails and Switcher task of the PEBL battery (Mueller & Piper, 2014).

pTrails Task

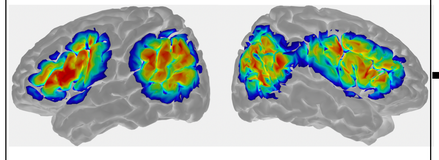


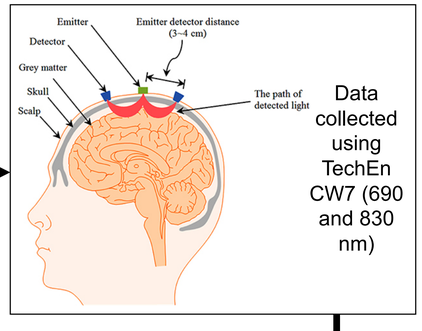
Switcher Task



fNIRS Data Collection and Analyses

Probe designed to record from a network involved in cognitive flexibility: bilateral prefrontal and parietal cortices





Data collected using TechEn CW7 (690 and 830 nm)

Standard pre-processing in EasyNIRS:
- Convert to optical density
- Motion artifacts removed (optical density exceeding +/- .3 units
- Conversion to concentration values using modified Beer-Lambert equations (dpf=ppf=6.0)
- Average HbO and HbR calculated within participants' specific time window for each task

Functional connectivity calculated using MATLAB:
- Channel x Channel correlation matrices with HbO values at the group level and individual level
- Significant channel pair correlations at $p < .001$ selected for analyses

- Age group x FC ANOVAs for each channel pair

Results

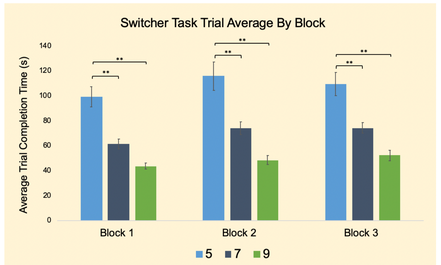
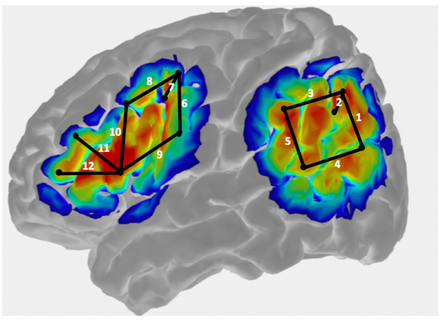


Figure 1. Age differences in average trial completion times per block of the Switcher task are shown. 5-year-olds took significantly longer than 7 and 9-year-olds. ** $p < .01$



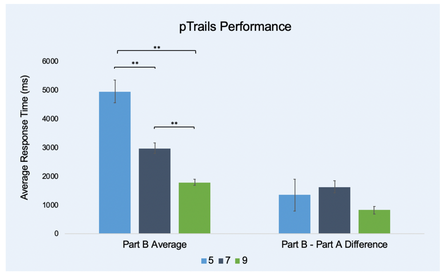


Figure 3. Average time per response on Part B and differences in completion time for Part B compared to Part A of the pTrails task are shown. ** $p < .01$

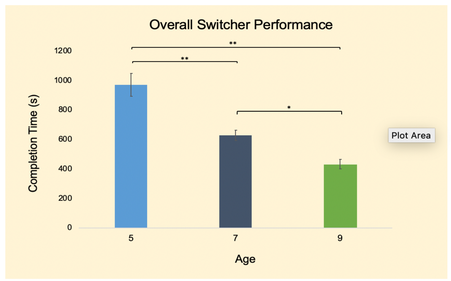
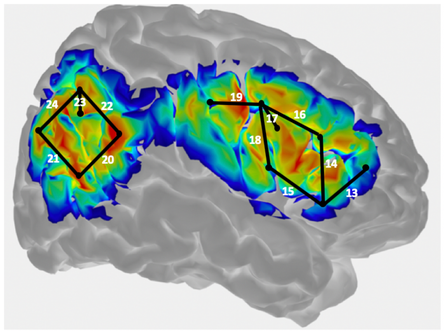


Figure 2. Overall completion time (in seconds) for the Switcher task is shown for each age group. Completion times decreased with age ** $p < .01$, * $p < .05$



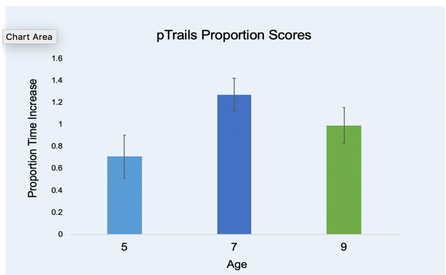


Figure 4. pTrails Proportion scores for each age group are, defined as [(Part B - Part A) ÷ Part A]. There were no differences in proportion scores.

Functional Connectivity

Table 1.
Differences in connectivity strength from part A to part B of pTrails

	Channel Pairs			
	Ch 4,6 *L Parietal – L Frontal*		Ch 4,8 *L Parietal – L Frontal*	
Age	*M*	*SD*	*M*	*SD*
5	.002	.270	-.037	.214
7	-.026*	.305	-.098*	.374
9	.193*	.185	.175*	.197

* $p < 0.05$

Table 2
Age-effects in FC during the Switcher task

Block 1

	Channel Pairs													
	Ch 6,10 *L Frontal*		Ch 6,11 *L Frontal*		Ch 8,11 *L Frontal*		Ch 8,12 *L Frontal*		Ch 9,11 *L Frontal*		Ch 3,12 *L Frontal – L Parietal*		Ch 13,24 *R Frontal – R Parietal*	
Age	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
5	.212	.256	.257	.269	.223	.221	.163	.175	.647	.181	.113	.20	.18	.23
7	.269*	.276	.313*	.268	.237*	.244	.286*	.221	.608*	.189	.115*	.23	.19*	.16
9	.058*	.170	.109*	.188	.072*	.171	.103*	.204	.765*	.169	-.03*	.19	.02*	.30

Block 2

	Channel Pairs													
	Ch 4,12 *L Parietal – L Frontal*		Ch 6,10 *L Frontal*		Ch 6,11 *L Frontal*		Ch 6,12 *L Frontal*		Ch 8,9 *L Frontal*		Ch 8,11 *L Frontal*		Ch 8,12 *L Frontal*		Ch 14,16 *R Frontal*	
Age	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
5	.108	.208	.234	.256	.276	.270	.273	.279	.169	.179	.231	.208	.201	.187	.166	.260
7	.20*	.135*	.284*	.267	.312*	.259	.259*	.235	.169*	.251	.233*	.220	.276*	.215	.194*	.317
9	.036*	.249*	.040*	.149	.094*	.185	.084*	.205	.013*	.202	.067*	.180	.103*	.206	.395*	.241

* $p < 0.05$

Conclusions

- Although there were no clear performance differences on the pTrails task, performance on the Switcher task improved with age, indicating improvements in cognitive flexibility with age.
- Task-evoked changes in FC between frontal and parietal nodes was greater for 9-year-olds during the pTrails task
- During the Switcher task, strongly connected channel pairs within the frontal cortex increased in strength, while the channel pairs that were less strongly connected decreased in strength. However, long-range connections between frontal and parietal nodes decreased in strength from age 7 to 9 on this task.
- These findings suggest that frontal cortex dynamics are being refined from age 7 to 9 to support cognitive flexibility. There is evidence to suggest that with increasing task demands, 9-year-olds show greater FC of nodes between the frontal and parietal cortices.

References

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