Brain Structural Correlates of Ocular Tracking in Preadolescent Children and Young Adults

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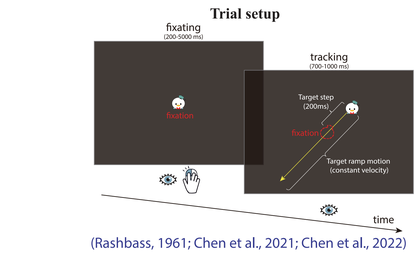
Introduction

Although extensive research in neurophysiology, neuropsychology, and neuroanatomy suggests the involvement of widespread brain regions in ocular tracking, there is still a lack of anatomical evidence for the development of ocular tracking abilities. The current study aims to fill this gap by investigating the relationship between performance in ocular tracking an unpredictable target and gray matter volume in preadolescent children and young adults.

General Methods

Ocular tracking task



(Rashbass, 1961; Chen et al., 2021; Chen et al., 2022)

Task: keep head still and track the **unpredictable** step-ramp motion of a cartoon target (0.64°) with its speed (16-24°/s) and moving direction (2°-358°) randomly varied from trial to trial.

Child-friendly design

targets: cartoon characters

task duration: ~8 min

trial-by-trial positive feedback (verbal praise) regardless of performance

Experiment procedure

Participants

	Overall group		Ocular-tracking + MRI participants	
	Children	Adults	Children	Adults
Number of participants	81(47F)	77 (43F)	52 (34F)	72 (42F)
Age (years)	8.6 ± 0.4	22.6 ± 2.6	8.6 ± 0.4	22.7 ± 2.6
Age range (years)	7.8-9.3	18.0-30.5	8.0-9.3	18.0-30.3

Dependent variables

Ocular tracking task

Four different aspects of ocular tracking ability (12 metrics)

Stage of ocular tracking	Aspects of ocular tracking	Oculometric measures	Function
Open-loop	Pursuit initiation	Latency	Measuring smooth pursuit
		Open-loop acceleration	
Closed-loop	Steady state tracking	Pursuit gain	
		Proportion smooth	
		Saccadic amplitude	Measuring coordination between smooth pursuit and saccades
		Saccadic dispersion	
		Saccadic rate	
Open-loop	Direction tuning	Direction noise	Measuring the visual processing of target motion signals during ocular tracking
		Anisotropy	
		Asymmetry	
Closed-loop	Speed tuning	Speed noise	
		Speed responsiveness	

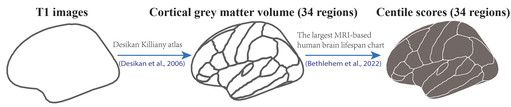
Open-loop: the 160-ms interval immediately following pursuit onset
eye movements are primarily driven by input target motion signals

Closed-loop: the interval from 400 to 700 ms after target motion onset
eye movements are also driven by extra-retinal information

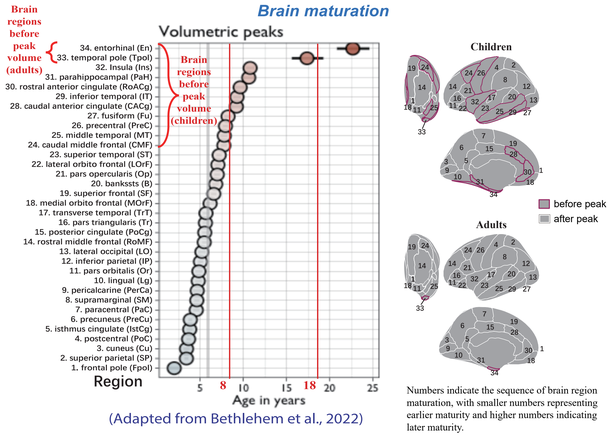
Overall ocular tracking performance

Ocular-tracking index: 12 metrics were combined to compute a composite performance index. The index value indicates how closely an individual participant's ocular-tracking performance matches the average performance of the adults.

Structural MRI



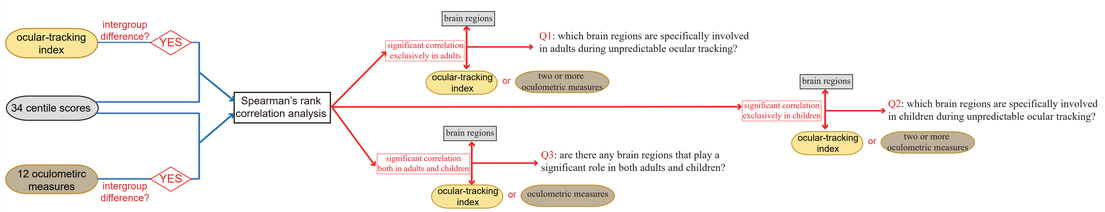
Brain maturation



(Adapted from Bethlehem et al., 2022)

Numbers indicate the sequence of brain region maturation, with smaller numbers representing earlier maturity and higher numbers indicating later maturity.

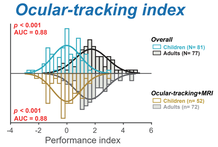
Data analysis



Results

Ocular tracking

Ocular-tracking index

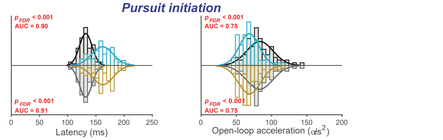


• **Ocular-tracking index**
lower performance index in children

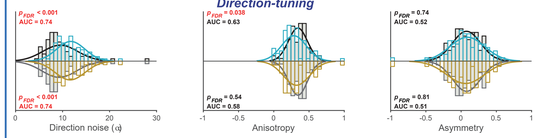
Oculometric measures

Open-loop response

Pursuit initiation

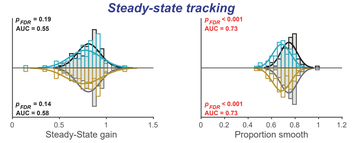


Direction-tuning

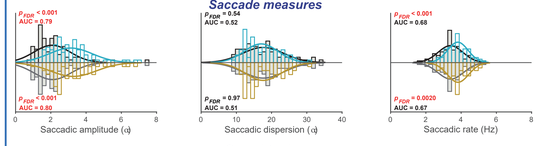


Closed-loop response

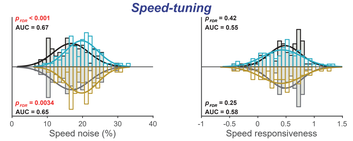
Steady-state tracking



Saccade measures



Speed-tuning



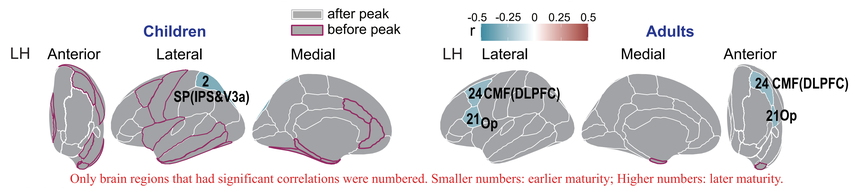
• **Smooth pursuit**
prolonged latency and slower eye acceleration in children for pursuit initiation.
lower proportion of smooth pursuit in children.

• **Coordination between smooth pursuit and saccades**
larger catch-up saccadic amplitude and higher saccadic rate in children.

• **Visual processing of target motion signals during ocular tracking**
responsive magnitudes for open-loop pursuit direction (except for anisotropy) and close-loop tracking speed were similar in children and adults but both were less precise in children than in adults.

Structural MRI

Brain regions associated with ocular-tracking index

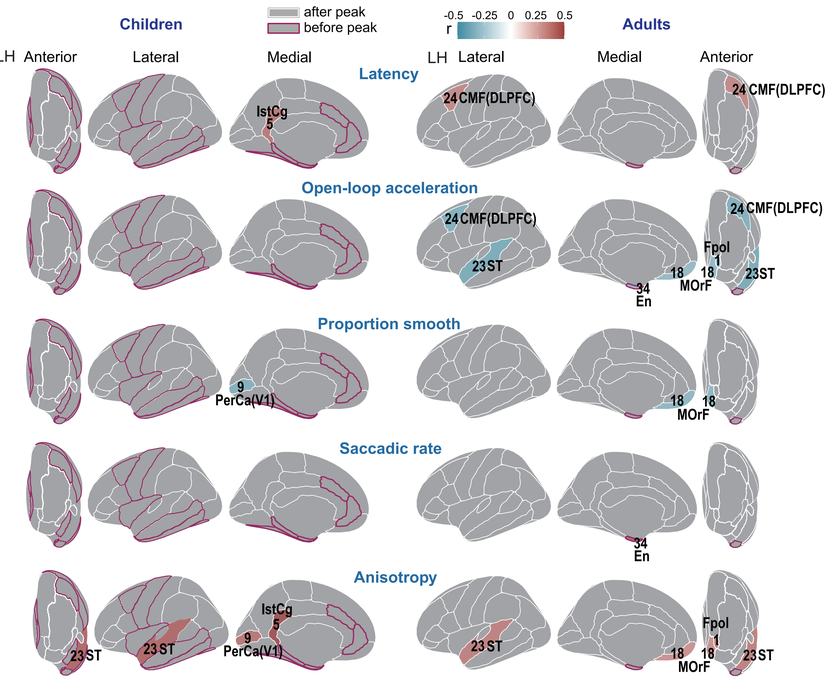


Only brain regions that had significant correlations were numbered. Smaller numbers: earlier maturity; Higher numbers: later maturity.

• The brain regions associated with the overall tracking performance index in adults enter volume reduction stages later than those in children. In adults, these later-developing regions are primarily located in the frontal cortex, including the pars opercularis (Op, region 21) and the caudal middle frontal region (CMF, region 24, including the DLPFC). In contrast, in children, the relevant region is the superior parietal region (SP, region 2, including IPS and V3a) in the parietal cortex.

• All brain regions associated with the overall tracking performance index are in the stage of cortical volume reduction (i.e., after peak). The smaller the volume centile scores in these regions, the better the ocular tracking abilities (i.e., the larger performance index).

Brain regions associated with oculometric measures



• Most brain regions associated with oculometric measures in adults enter volume reduction stages later than those in children. In adults, these later-developing regions include the medial orbitofrontal (MOrF, region 18), the caudal middle frontal (CMF, region 24), and the entorhinal cortex (En, region 34). In contrast, in children, the relevant regions include the pericalcarine region (PerCa, region 9, including V1) of the occipital cortex and the isthmus cingulate (IstCg, region 5).

• All brain regions associated with oculometric measures, except for the entorhinal cortex (En, region 34) in adults, are in the stage of cortical volume reduction (i.e., after peak). The smaller the volume centile scores in these regions, the better the ocular tracking performance.

• The ocular-tracking brain network in adults is correlated with more oculometric measures (such as pursuit acceleration and saccade rate) than the network in children.

Conclusion

• Children's ocular tracking abilities are inferior to adults, particularly in smooth pursuit, coordination between smooth pursuit and saccades, and visual processing of motion signals.

• The ocular-tracking brain network in adults includes regions that are absent in the network of children, and these regions generally mature later. Conversely, the ocular-tracking brain network in children contains regions that are absent in adults, and these regions usually develop earlier. This may be due to the fact that certain brain regions in children have not yet reached a considerable level of development (e.g., in the stage of cortical volume reduction). Consequently, the connections between these brain regions and ocular tracking performance observed in adults have not yet been established.

• Compared to adults, children's inferior ocular tracking abilities are due to delayed brain maturation. Specifically, they rely on brain regions that developed earlier to compensate for the functions of the later-developing regions in the adult network.

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