Investigating 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

Ocluar 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: Disney 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

Ocluar tracking task

Four different aspects of ocular tracking (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

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

Ocluar tracking

Ocular-tracking index

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

Oculometric measures

Open-loop tracking responses

- **Smooth pursuit**
  prolonged latency and slower eye acceleration in children
  pursuit velocity lagged more behind the target velocity in children
  lower proportion of smooth pursuit in children.

Closed-loop tracking responses

- **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 number: earlier maturity; Higher numbers:later maturity.

- In adults, the centile scores of the caudal middle frontal region (CMF, region 24, including DLPFC) and the pars opercularis (OP, region 21) in the frontal cortex specifically exhibited correlations with the performance. In contrast, in children, the superior parietal region (SP, region 2, including IPS and V3a) in the parietal cortex specifically showed correlations with the performance index.
- Both the brain regions associated with the performance index in adults and children are in the stage of cortical volume reduction. However, the former (brain regions in adults) develop later compared to the latter (brain regions in children).
- For both children and adults, the smaller the volume percentile scores of the related brain region, the better the overall ocular tracking abilities (i.e., the larger performance index).

Brain regions associated with oculometric measures

Distinct correlations

- Most brain regions associated with oculometric measures in adults develop later compared to those in children. In adults, these brain regions were primarily located in the frontal cortex, including the caudal middle frontal (CMF, region 24), medial orbitofrontal (MOrF, region 18), and frontal pole (Fpol, region 1). In children, these brain areas were located in the pericalcarine of the occipital cortex (PerCa, region 9, including V1) and the isthmus cingulate (IstCg, region 5).
- In both adults and children and, a smaller volume centile score of the related brain region were corelated with better ocular tracking performance. These findings align with the fact that the respective brain regions in both adults and children are in stages of cortical volume reduction.

Overlapping correlations

- The correlation analysis on oculometric measures revealed certain brain regions that exhibit overlapping correlations in both age groups. These shared regions include precentral (PreC, region 26, including FEF) and superior temporal areas (ST, region 23).
- Interestingly, PreC were in different developmental stages in adults (i.e., reduction) and children (i.e., enlargement). Accordingly, in adults, a smaller volume centile score of PreC is associated with larger open-loop acceleration, whereas in children, a larger volume centile score of the PreC is associated with larger open-loop acceleration.

Conclusion

- This study represents the first investigation into the underlying neural basis of ocular tracking development. We found that the ocular-tracking brain network in adults includes regions that are absent in the network of children, and these regions generally develop 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. Consequently, the connections between these brain regions and ocular tracking performance observed in adults have not yet been established. Instead, children rely on brain regions that have already developed and are functional for them but absent in adults.
- A critical brain region, i.e., the FEF responsible for generating oculomotor commands and having major outputs to subcortical regions for controlling ocular tracking behavior, exhibits a significant correlation with children's performance despite their incomplete development in this region.
- The relationship between brain structure and ocular-tracking performance can be described as follows: if the cortical volume of these brain regions has not yet reached their peak, then the larger volume centile score, the better the ocular-tracking performance, and vice verse.

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