Binocular Discoordination Kinetic Features: A Novel Approach to Evaluate Neurodegenerative Diseases

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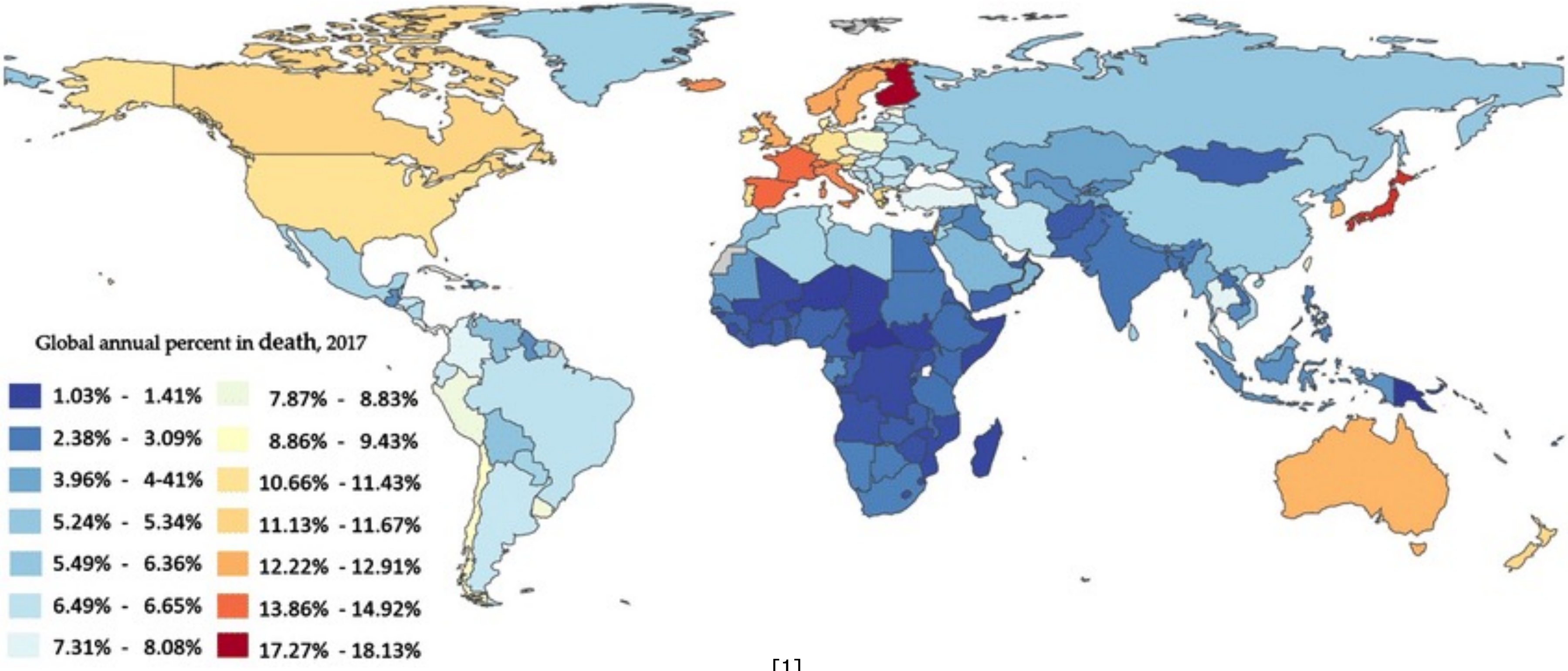
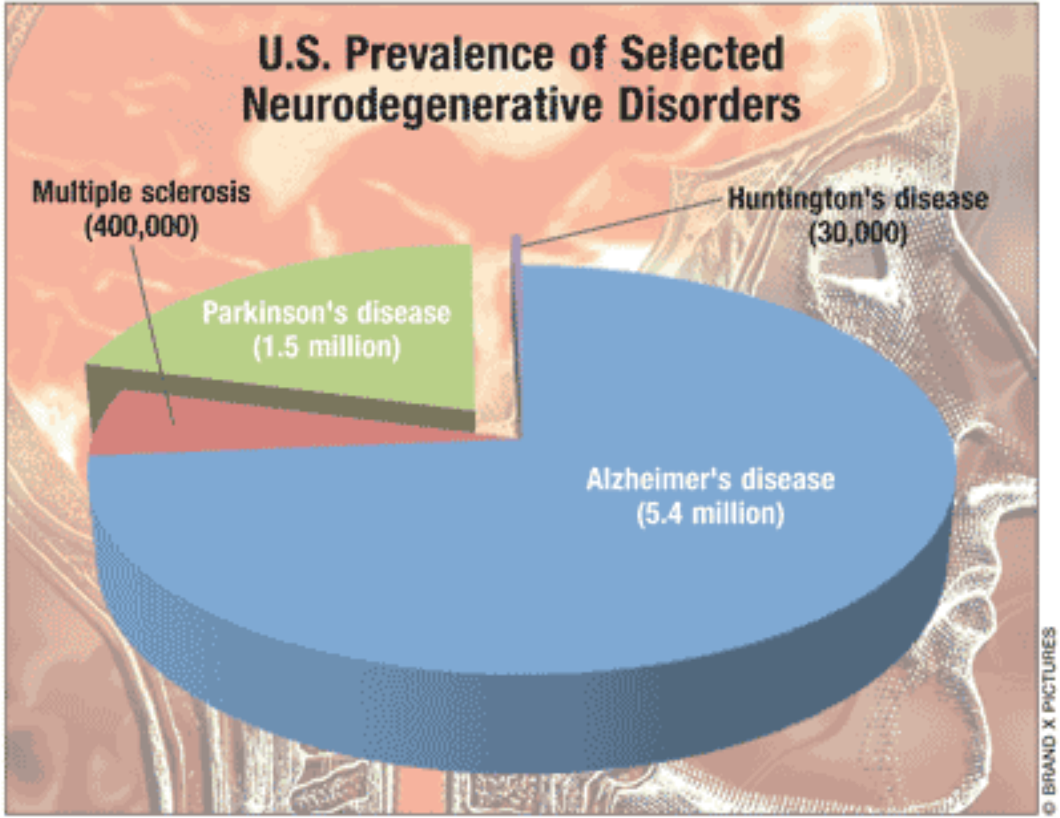
Neurodegenerative Disease (ND)



[1]

AD and PD


U.S. Prevalence of Selected Neurodegenerative Disorders
Multiple sclerosis (400,000)
Huntington's disease (30,000)
Parkinson's disease (1.5 million)
Alzheimer's disease (5.4 million)
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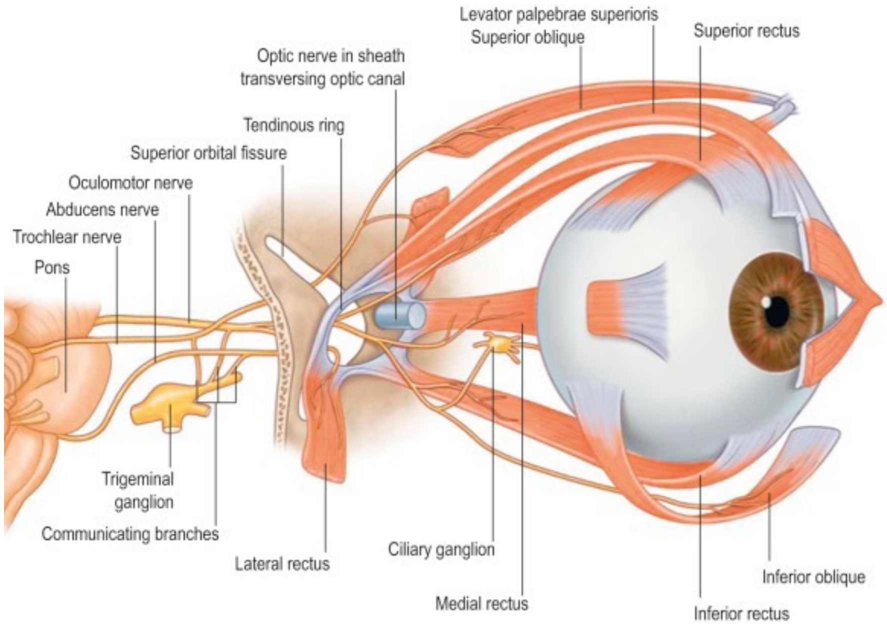
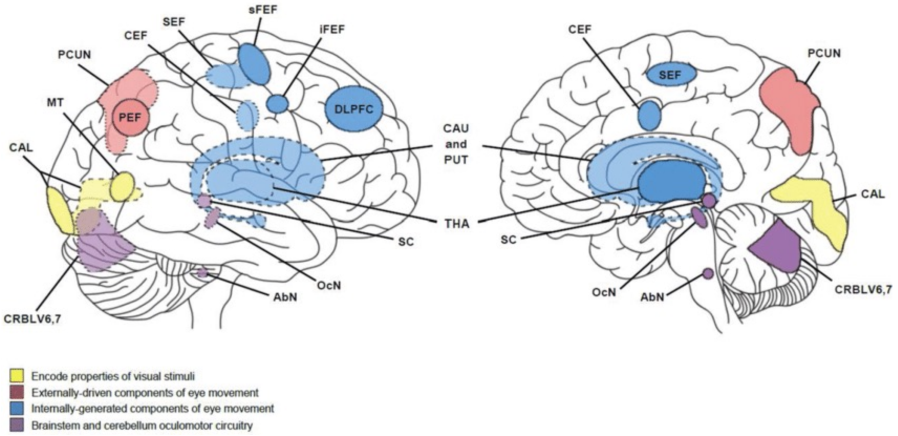
[2]

Early diagnosis is important

Eye Movement



[3]



[4]

Related Work

- Frei et al. conducted a systematic review of 29 studies on smooth pursuit eye movement in Parkinson's Disease (PD), identifying key biomarkers like directionality, speed, latency, accuracy, and saccadic movements for PD diagnosis.
- Bargagli et al. found common visual issues in PD include blurred vision, diplopia, abnormal eye alignment, and convergence insufficiency.
- Fernandez et al. found that individuals with Alzheimer's Disease (AD) experience visual impairments even in early stages, which can aid in early detection.
- Javaid et al. noted that ocular motor impairment is common in AD, with eye tracking being a promising non-invasive method for early detection.

Related Work

- "Eye movements remain an active field of investigation across a variety of neurodegenerative conditions. Progress continues to be made at the clinical level as well by using laboratory techniques." -- MacAskill [5]

Goals

- To employ eye tracking methods to acquire eye movement time-series data of different ND cohorts.

- To analyze eye movement time-series data to explore binocular discoordination in ND with the goal of identifying potential diagnostic biomarkers.

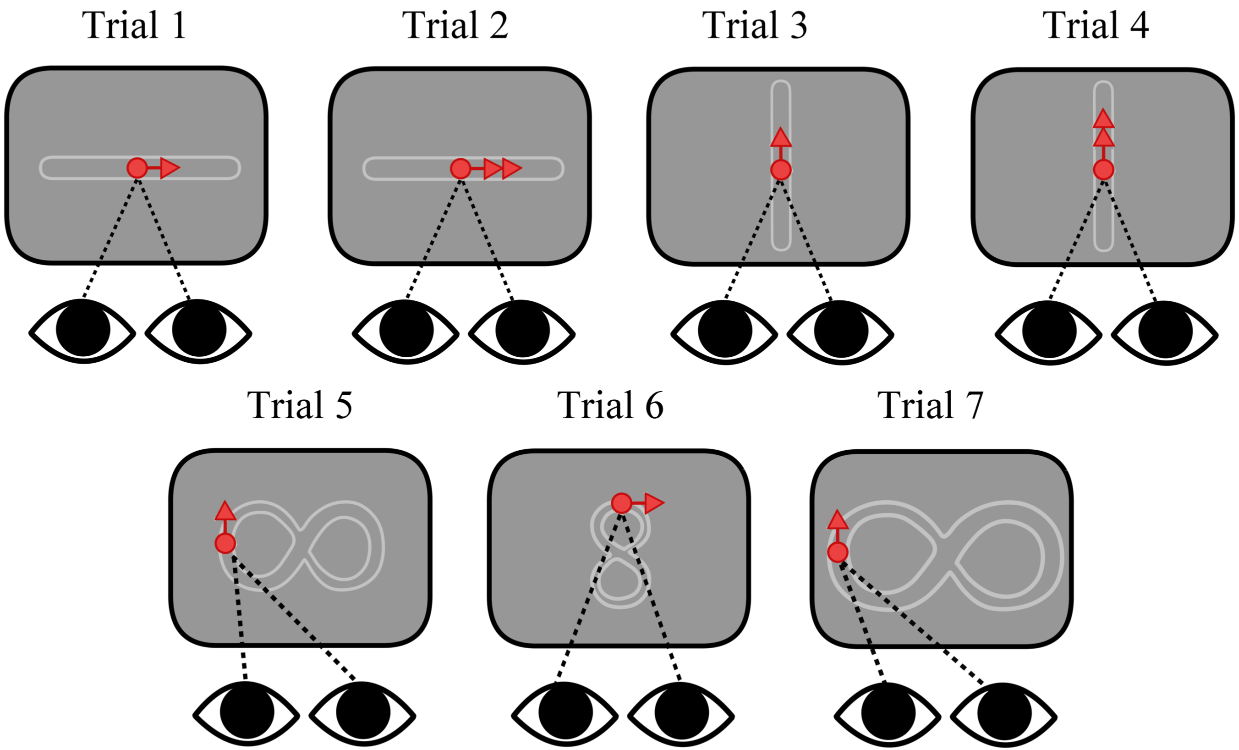
Methods

Cohorts

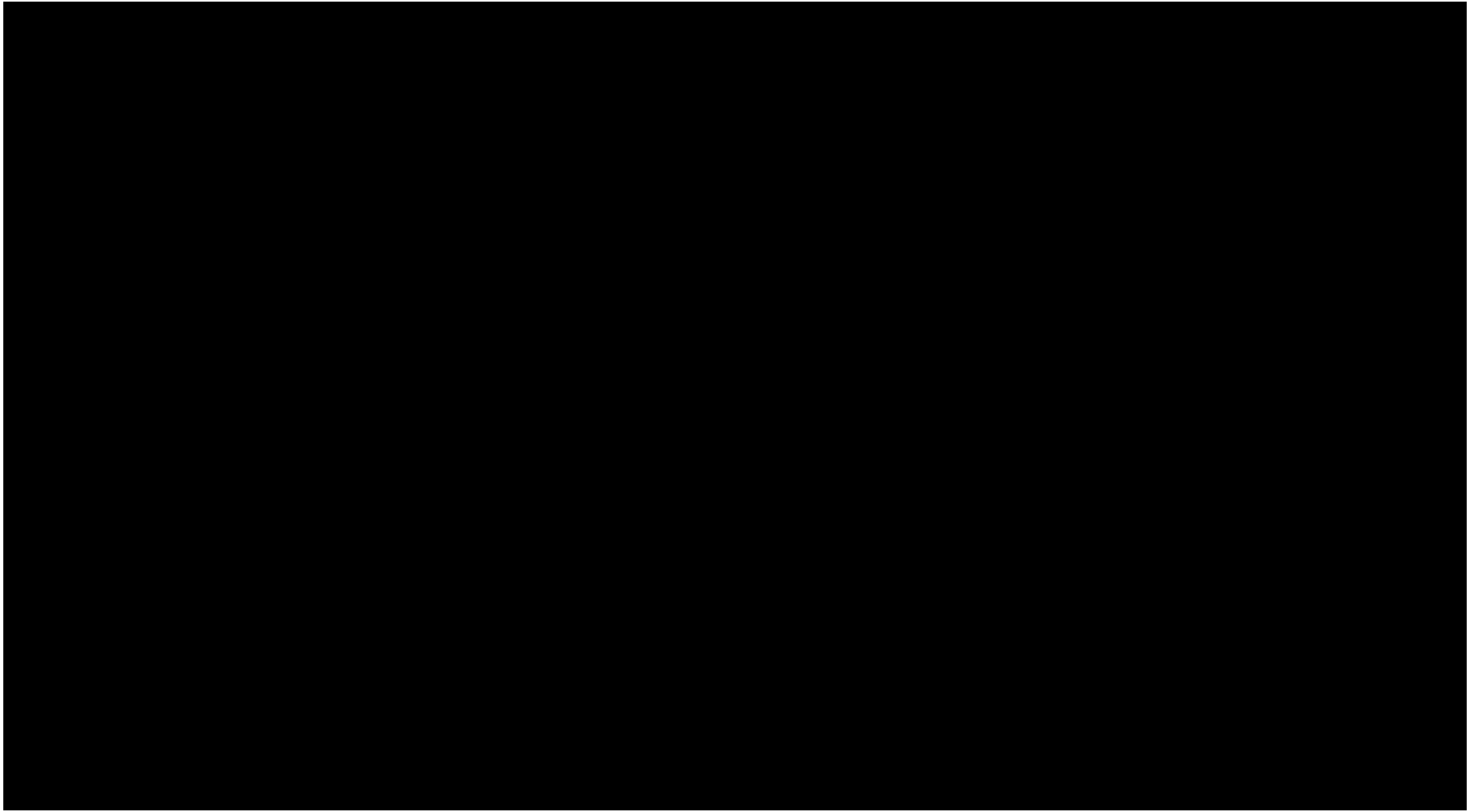
Category	Sample (n)			Age	
	tot	female	male	avg	range
CTL	33	14	19	66.30	34-94
AD/MCI	17	13	3	71.44	58-84
PD	23	13	10	65.96	41-82
PDM	16	9	7	57.44	31-77

- **CTL**: Cohort of healthy control group
- **AD/MCI**: Cohort with Alzheimer's Disease and Mild Cognitive Impairment. We combine the MCI and AD into a single group (AD/MCI) as the MCI individuals have their cognitive impairment due to AD etiology
- **PD**: Cohort with Parkinson’s Disease
- **PDM**: Cohort with a collection of NDs that mimic Parkinsonian symptoms, and we categorize this group as PDM

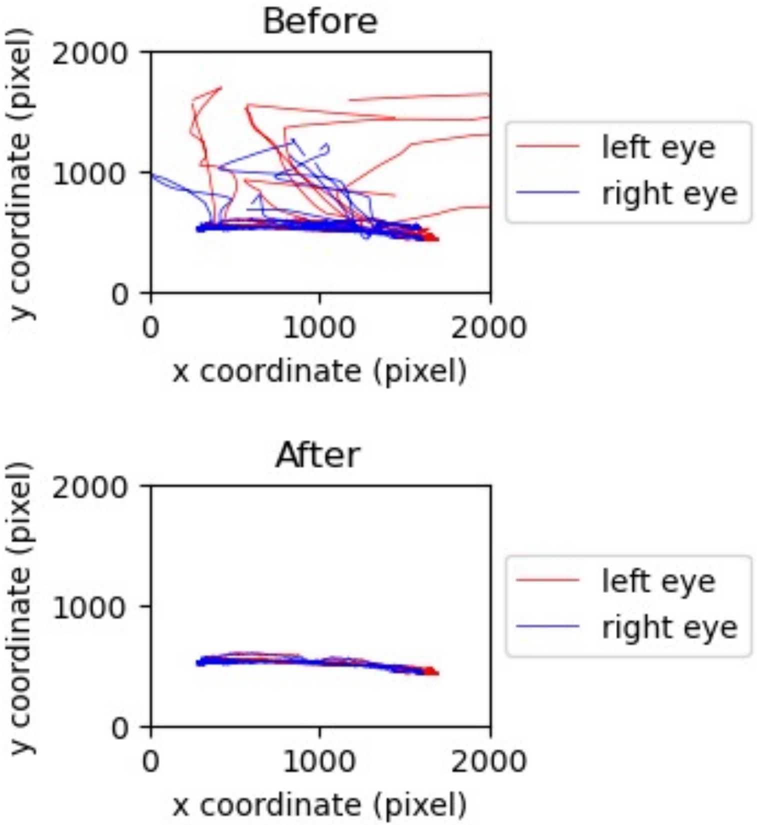
Smooth Pursuit Trials



EyeLink Portable Duo

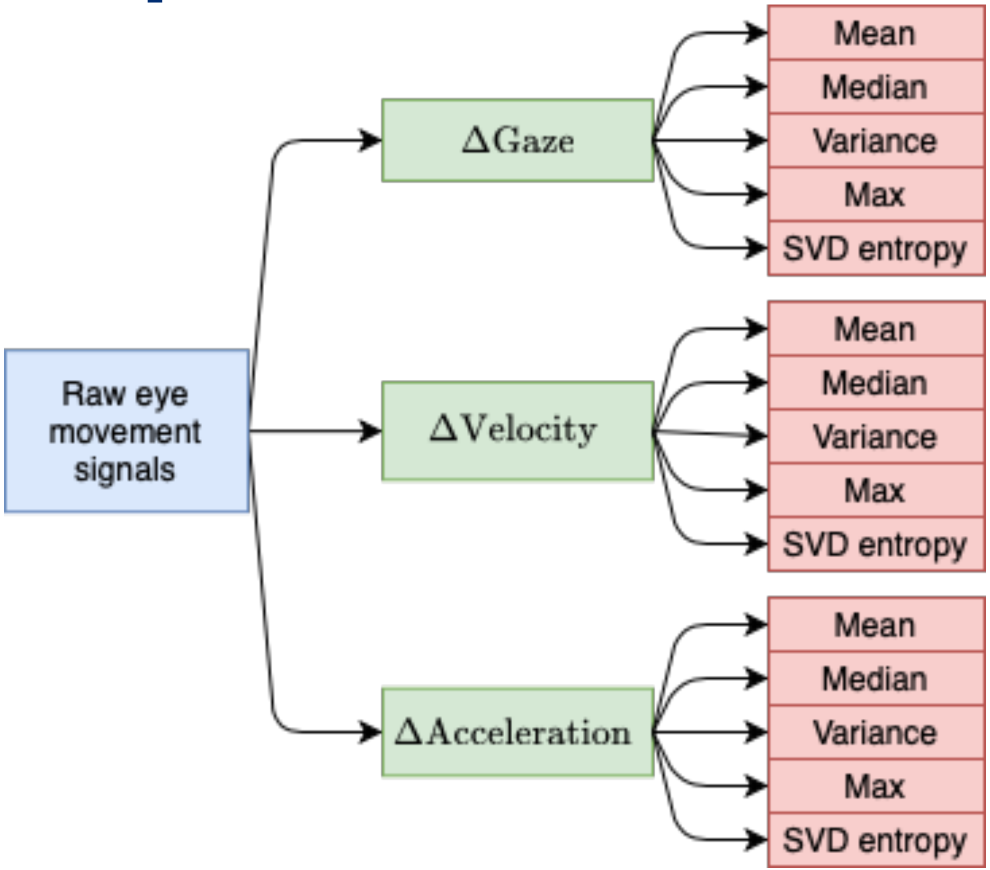


Data cleaning



Feature Analysis

Main components



Singular Value Decomposition entropy (SVD entropy)

SVD entropy is an indicator of the number of orthogonal vectors needed an adequate explanation the time series data.

It measures the complexity of the time series.

The SVD entropy of a signal x is defined as: $H = -\sum_{i=1}^{M} \overline{\sigma}_i log_2(\overline{\sigma}_i)$

where M is the number of singular values of the embedded matrix Y and σ_1, σ_2,..., σ_M are the normalized singular values of Y.

Where Y is given by

$$y(i) = [x_i, x_{i+\text{delay}}, \ldots, x_{i+(\text{order}-1)*\text{delay}}]$$

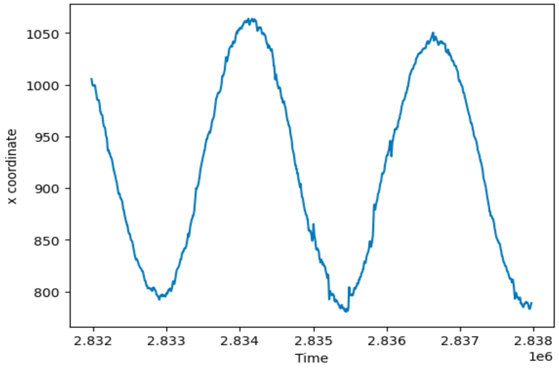
$$Y = [y(1), y(2), \ldots, y(N - (\text{order} - 1)) * \text{delay})]^T$$

[4]

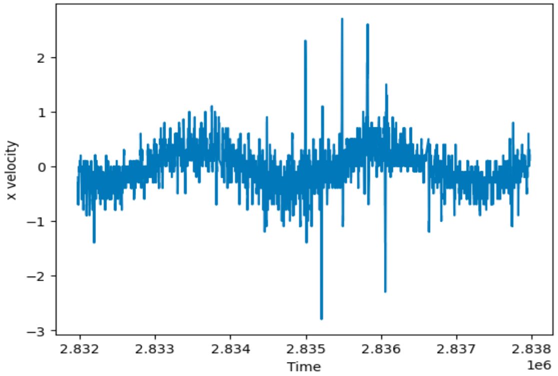
NLS_075 left eye

Compute the finite difference of the gaze location with Δ t = 1 ms

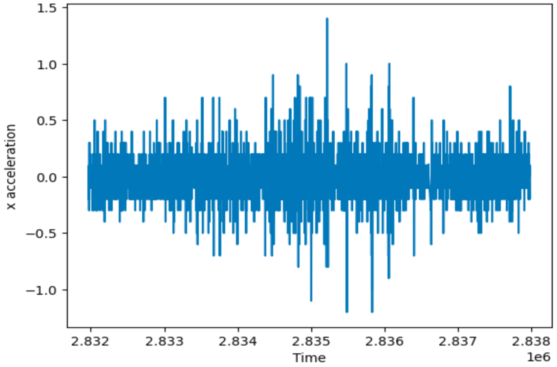
Compute the finite difference of the eye velocity with Δ t = 1 ms



X coordinates

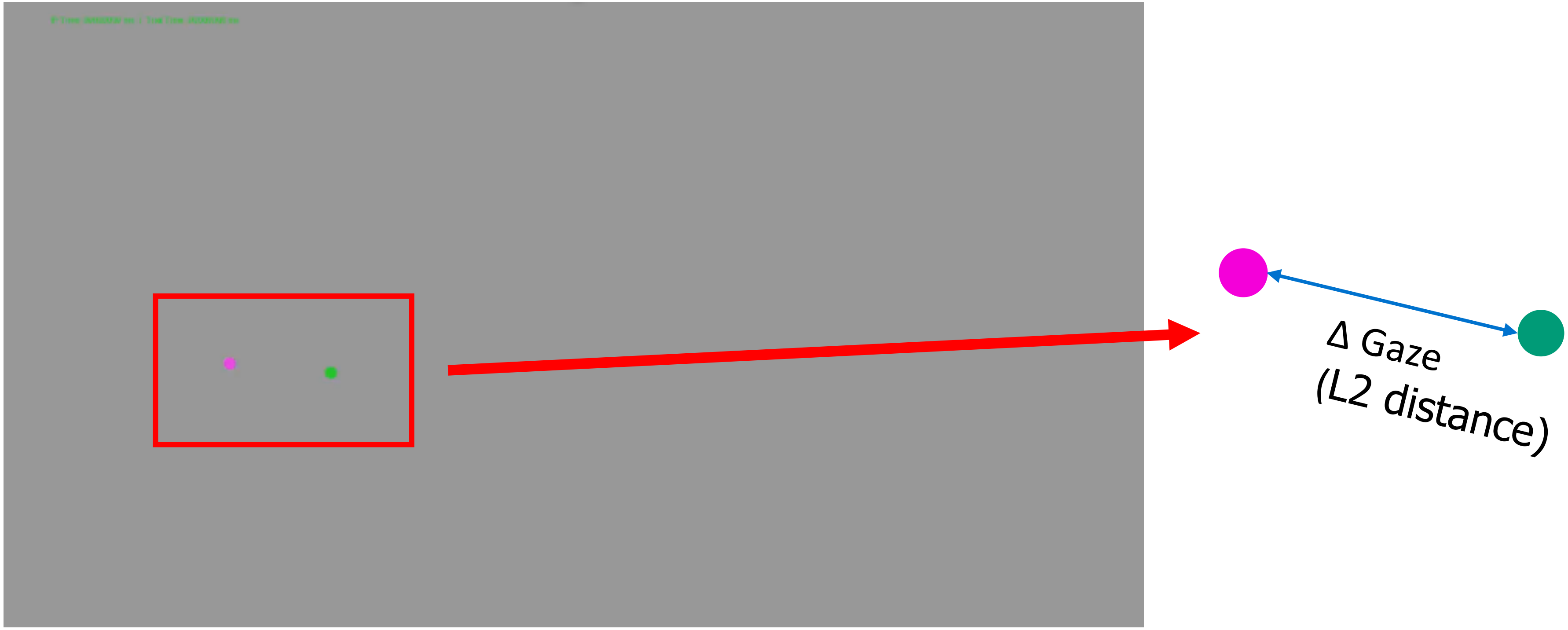


X velocity

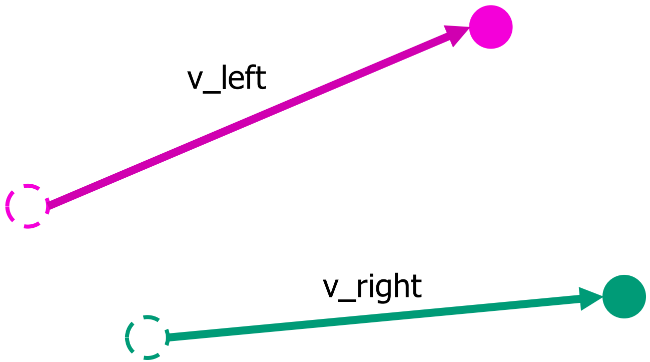


X acceleration

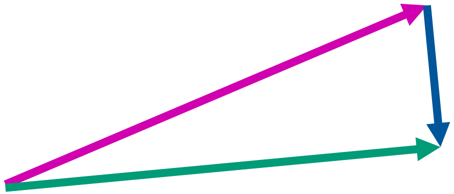
Δ Gaze



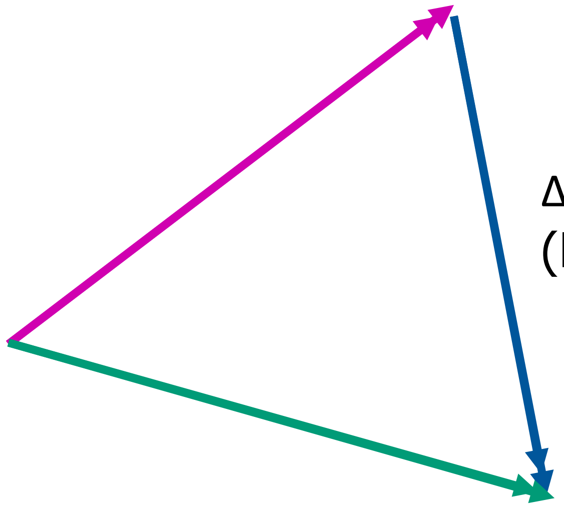
Δ Velocity



Take the difference of the velocity vectors of the two eye

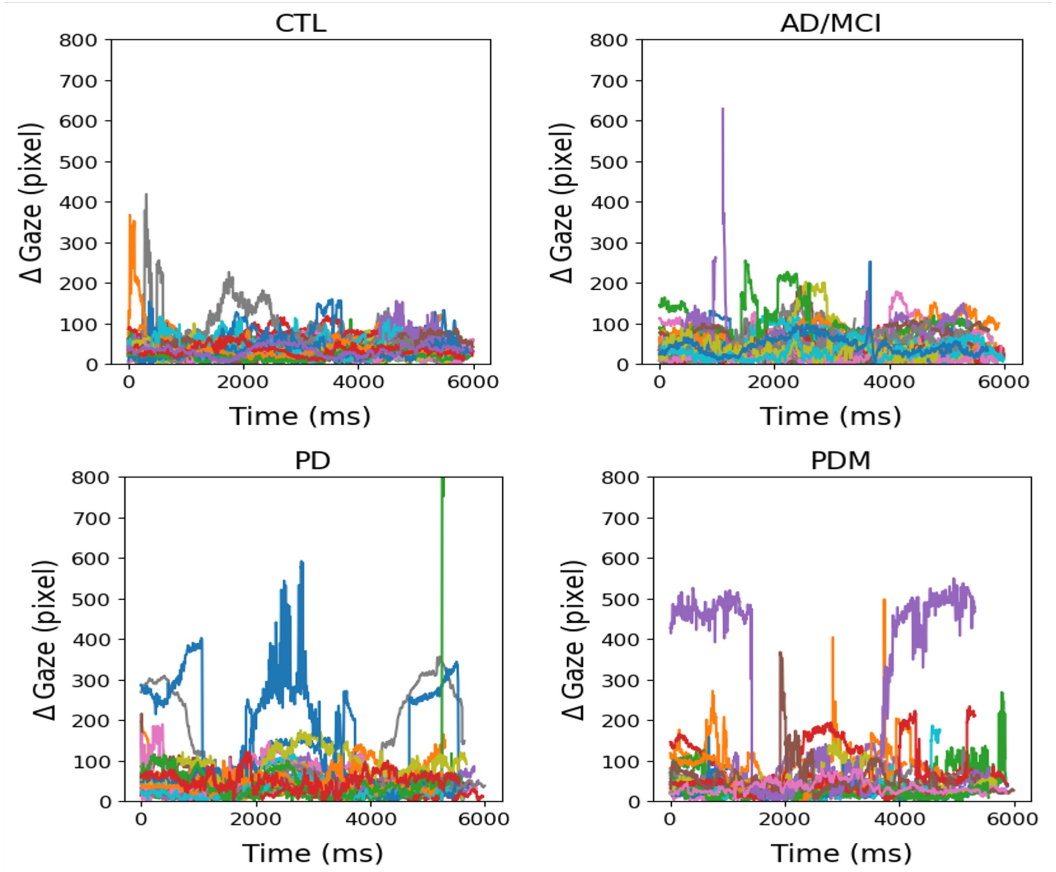


Δ Acceleration



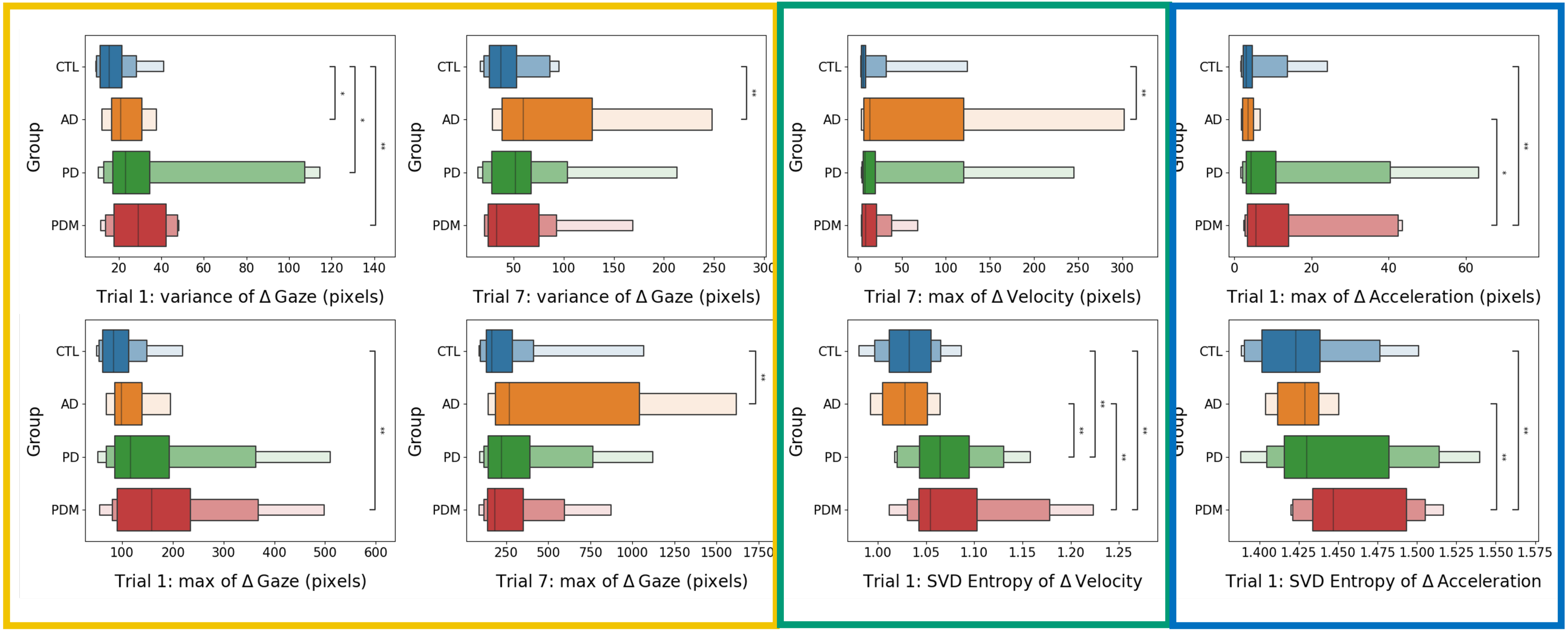
Δ Acceleration
(L2 norm)

An example of Δ Gaze of the four groups with respect to time



Results

All significant features



Δ Gaze

Δ Velocity

Δ Acceleration

P-value

Table 2. Kruskal-Wallis H test results with Benjamini–Hochberg correction method of all significant features ($p < 0.05$)

Trial	Feature	Pair	*p*-value
Δ Gaze			
1	Variance	CTL-AD/MCI	0.02
		CTL-PD	0.01
		CTL-PDM	0.006
	Max	CTL-PDM	0.003
7	Variance	CTL-AD/MCI	0.003
	Max	CTL-AD/MCI	0.005
Δ Velocity			
1	SVD entropy	CTL-PD	0.002
		CTL-PDM	0.007
		AD/MCI-PD	0.001
		AD/MCI-PDM	0.008
7	Max	CTL-AD/MCI	0.007
Δ Acceleration			
1	Max	CTL-PDM	0.008
		AD-PDM	0.01
	SVD entropy	CTL-PDM	0.002
		AD-PDM	0.003

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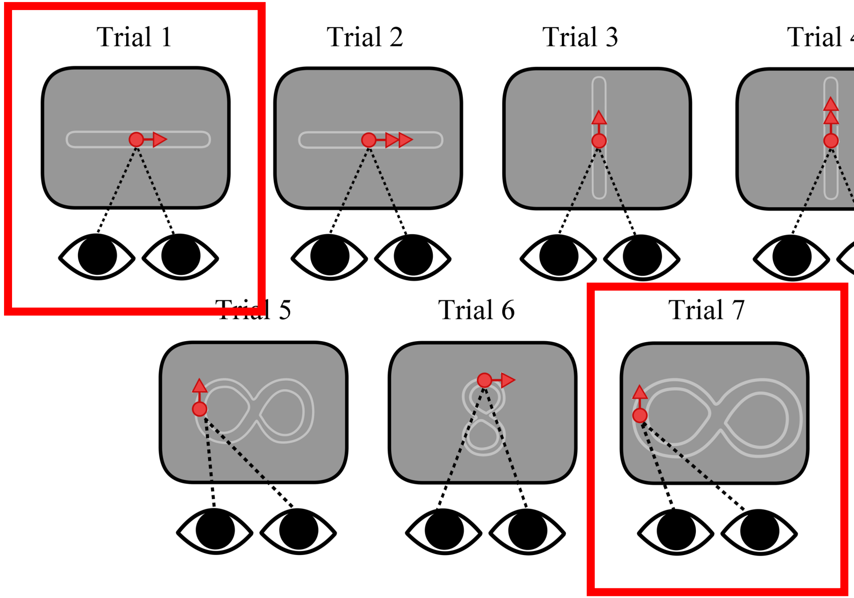
of ENGINEERING



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	Δ Velocity		
1	SVD entropy	CTL-PD	0.002
		CTL-PDM	0.007
		AD/MCI-PD	0.001
		AD/MCI-PDM	0.008
7	Max	CTL-AD/MCI	0.007
	Δ Acceleration		
1	Max	CTL-PDM	0.008
		AD-PDM	0.01
	SVD entropy	CTL-PDM	0.002
		AD-PDM	0.003

Conclusions

- ND group demonstrated worse binocular coordination functionality by larger gaze distances and larger difference in velocities and accelerations of the two eyes.
- ND groups presented more irregular coordination behaviors characterized by SVD entropy, possibly caused by ocular tremors.
- The study demonstrated the difference between CTL vs AD/MCI, CTL vs PD. The study further demonstrated the the difference among NDs, including AD/MCI vs PD and AD/MCI vs PMD.

Summary

- We designed statistical analysis to identify potential biomarkers for ND evaluation and identified significant deviations in binocular coordination, especially in AD\MCI and PD groups compared to CTL group.
- Demonstrated the potential of using binocular discoordination features as biomarkers to differentiate between various NDs.
- Filled gaps in literature on binocular discoordination impairments in multiple NDs.

Future work

- Increase participant numbers for a balanced dataset by age and sex.
- Investigate novel eye movement features.
- Introduce new complexity measurements.
- Employ machine learning methods to automate the evaluation of NDs

Reference

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