Artificial Intelligence Based Ocular Motor Digital Biomarkers for Neurologic Disease Phenotyping

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Introduction

- Neurological disorders affect over 40% of the global population, yet diagnosis still relies on **costly, time-consuming**, and often **inaccessible techniques**.
- Digital saccade analysis, which tracks rapid eye movements in response to visual stimuli, offers a **fast, non-invasive alternative.**
- However, developing AI models for saccade analysis is limited by **scarce**, **noisy** real-world data and raises **patient privacy concerns**.
- These challenges can be addressed by generating **synthetic saccade data** that closely **mimics patterns** observed in clinical data

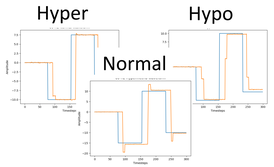
Objectives

- Generate a **synthetic saccade dataset** using predefined parameters and a generative AI model.
- Ensure synthetic waveforms and videos reflect physiologic saccadic patterns.
- Train a classification model **on synthetic data** to distinguish **normal, hypometric, and hypermetric** saccades for potential disease localization.
- Evaluate model performance of the model on **real-world clinical data** to assess generalizability.

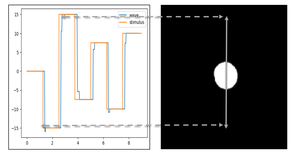
Methods

	Normal	Hypermetria	Hypometria
Accuracy	70 - 120	120 - 150	10 - 70
Latency	0.2 - 0.4	0.4 - 0.7	0.4 - 0.7

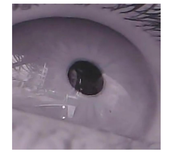
Sample clinically observed saccade parameters



Generate saccade waveforms



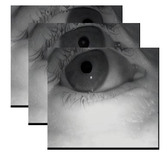
Linear mapping onto pupil mask



TEyeD[1] public dataset

ControlNeXt[2]

Pose-guided generative model



Synthetic videos

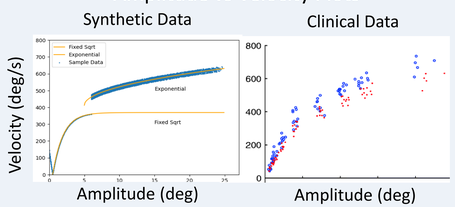
MViTv2[3]

Train classification model

Evaluate on clinical dataset

Validating Synthetic Data

Amplitude vs Velocity Plots



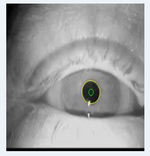
Amplitude > 6

$$V(x) = 412.256 + 49.036\sqrt{x-5}$$

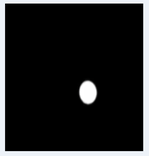
Amplitude < 6

$$V(x) = 368.938 * (1 - e^{(\frac{-x+0.492}{1.487})})$$

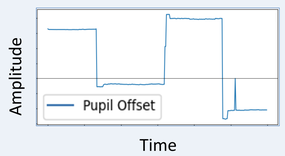
Synthetic waveforms replicate the **main sequence**, reflecting clinical saccade parameters



Synthetic Videos



Pupil Segmentation

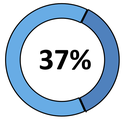


Extracted Waveform

Waveforms extracted from synthetic videos **closely match** original synthetic waveforms

Clinical Data Labeling

Ocular Testing Data 2020 - 2024



Saccade Data 1001/2787

Labeling protocol

50 Normal
15 Hyper
48 Hypo

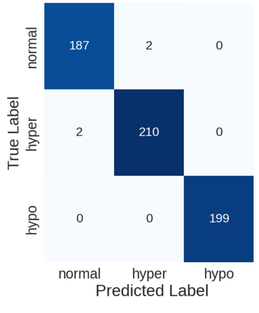
The distribution of the accuracy parameter in the clinical data resembles the synthetic data distribution

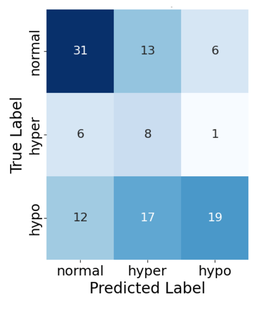
Results

Normal vs Abnormal (Hypo & Hyper)

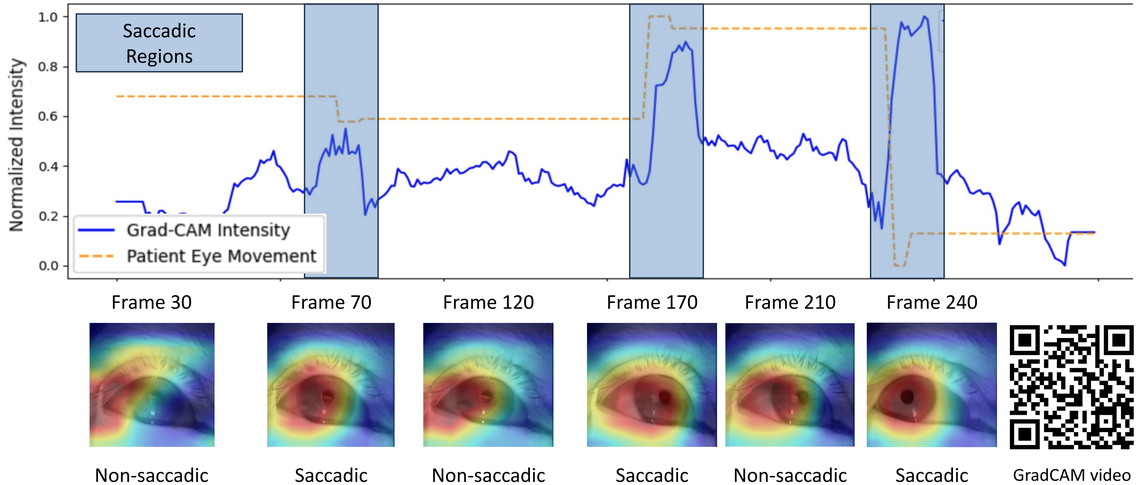
Metric	Synthetic Data	Clinical Data
AUROC	0.98	0.80
AUPRC	0.99	0.81
Sensitivity	0.96	0.71
Specificity	0.97	0.62

Model performs well on synthetic data, but struggles on **normal vs hypo** on clinical data





Grad-CAM intensity **peaks during saccades** and remains **centered on the pupil**



Discussion

- A key strength of this work is the development of a synthetic saccade dataset **generated entirely from public datasets**, without any protected patient information.
- With a sensitivity of 0.81, the classification model shows strong potential to be used as a **screening tool** in emergency settings or even at home via mobile devices.
- A limitation is the **lack of an additional clinical dataset** to externally validate our model performance.
- Future work includes modeling other eye movement types associated with different neurological disorders. Also, further refinements could be made to the synthetic saccadic data to capture subtle pathological variations.

References

1. Fuhl, W., Kasneci, G., & Kasneci, E. (2021, October). Teyed: Over 20 million real-world eye images with pupil, eyelid, and iris 2d and 3d segmentations, 2d and 3d landmarks, 3d eyeball, gaze vector, and eye movement types. In 2021 IEEE International Symposium on Mixed and Augmented Reality (ISMAR) (pp. 367-375). IEEE.
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3. Fan, H., Xiong, B., Mangalam, K., Li, Y., Yan, Z., Malik, J., Feichtenhofer, C.: Multiscale vision transformers. In: Proceedings of the IEEE/CVF international conference on computer vision. pp. 6824–6835 (2021)

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