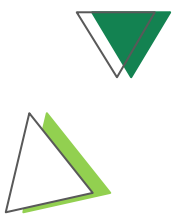
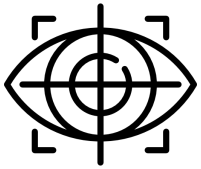
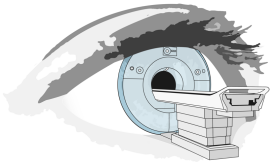
Decoding Gaze Position in the Light and in the Dark

Sina **Kling**, Uriel **Lascombes**,
Matthias **Nau**, Guillaume **Masson**
& Martin **Szinte**







DeepMReye

x,y

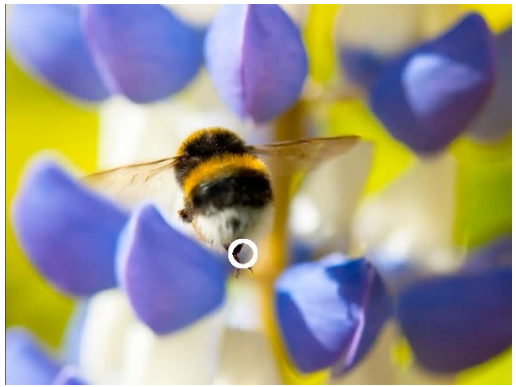
Magnetic resonance-based eye tracking using deep neural networks

nature neuroscience

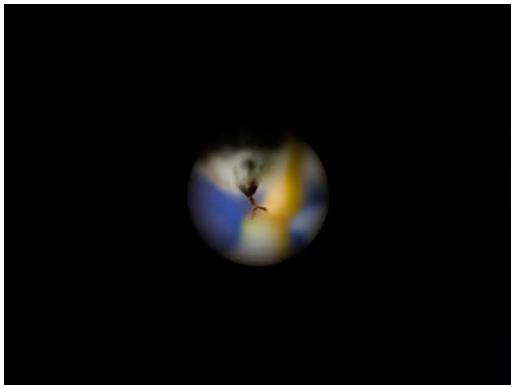
Magnetic resonance-based eye tracking using deep neural networks

Markus Frey, Matthias Nau & Christian F. Doeller

Perceived Scene



On the fovea



Problem of space constancy

We perceive the world as stable despite drastic retinal input changes at every eye movement

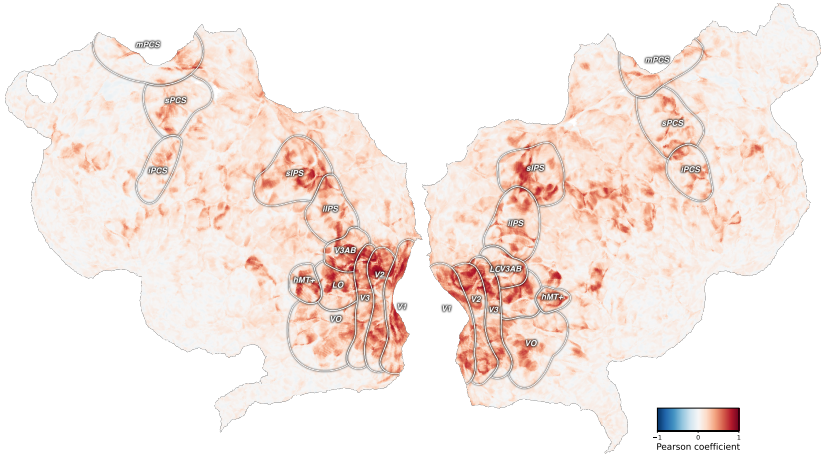
→ Computation in the visual areas that takes eye movements into account [2]

How are oculomotor signals represented in visual areas?

Motivation

Goal: Characterization of spatial structure of motor-related activations in the visual system by modeling oculomotor signals with population gaze fields

Problem: Vision related signal over-powers every other signal in the visual cortex



Let’s do an experiment in full darkness

Motivation

Goal: Characterization of spatial structure of motor-related activations in the visual system by modeling oculomotor signals with population gaze fields

In order to isolate motor-related activations from visual input, participants perform a set of structured gaze direction changes in **complete darkness** while in a 7T scanner

Challenge: No camera-based eye-tracking possible. Need to find a new way to decode gaze position

- **Solution 1:** Use the theoretical gaze position
- **Solution 2:** Use DeepMReye network

Motivation

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In order to isolate motor-related activations (from visual input), participants perform a set of structured gaze direction changes in **complete darkness** while in a 7T scanner

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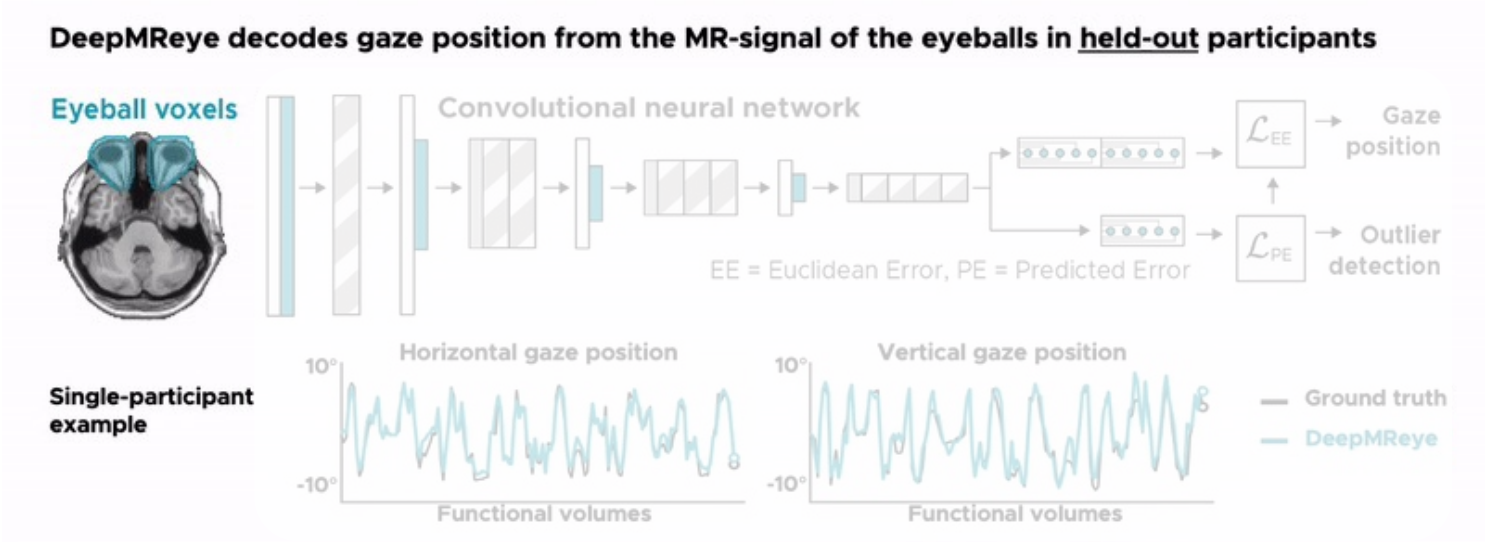
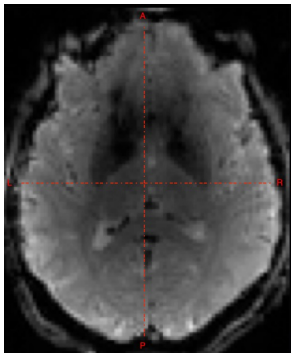
- **Solution 1:** Use the theoretical gaze position
- **Solution 2: Use DeepMReye network**

DeepMReye

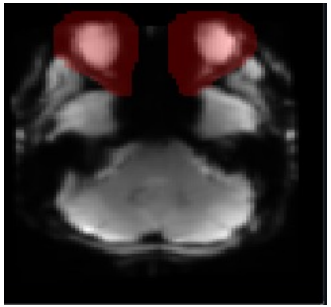

DeepMReye decodes gaze position from the MR-signal of the eyeballs in held-out participants
Eyeball voxels
Convolutional neural network
$\mathcal{L}_{EE}$
Gaze position
$\mathcal{L}_{PE}$
Outlier detection
EE = Euclidean Error, PE = Predicted Error
Single-participant example
Horizontal gaze position
Vertical gaze position
10°
-10°
Functional volumes
Ground truth
DeepMReye

[3]

Training DeepMReye: Preprocessing

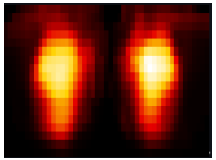


Fmrpiprep T1w bold runs (head motion corrected data)



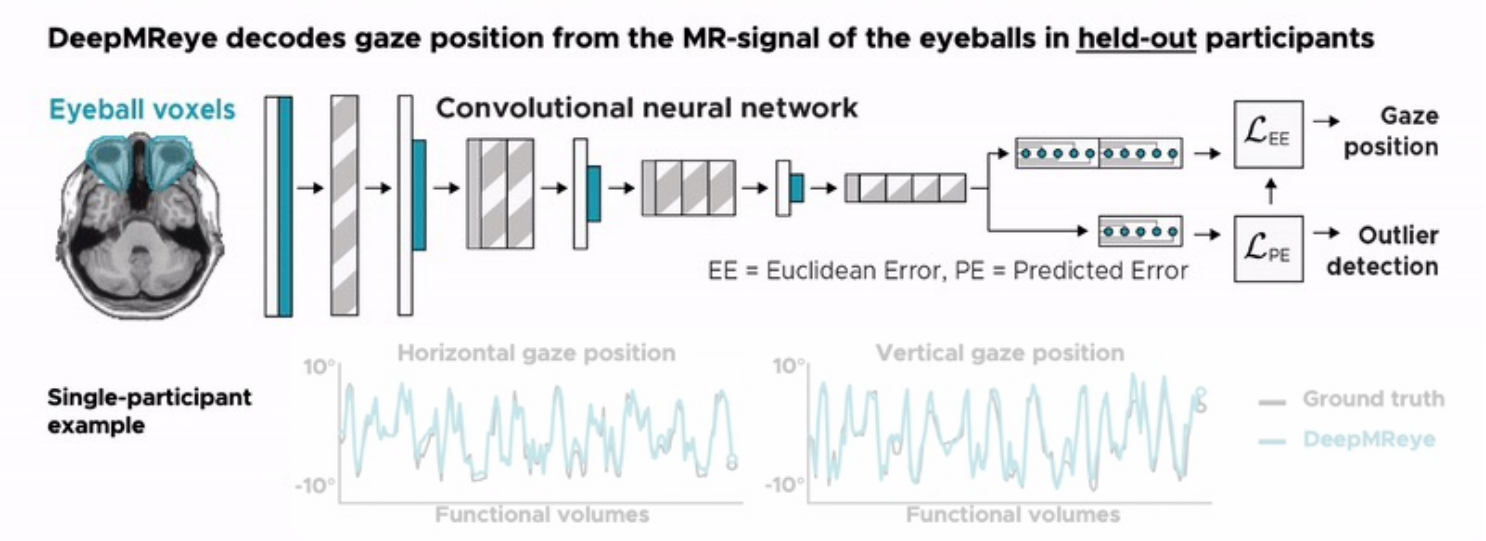
Co-register to MNI template

Model input



Apply eye masks

DeepMReye



[3]

Final bottleneck layer consists of 7,680 units, which is resampled to achieve sub–TR resolution

10 resampled layers produce a 10 times higher virtual resolution than the original TR

Training DeepMReye

Trained and tested on data from 268 participants acquired on five 3T MRI scanners resulting in 6 Datasets:

1. Fixation and saccades
2. Smooth pursuit 1
3. Smooth pursuit 2
4. Smooth pursuit 3
5. Visual Search
6. Fixation, smooth pursuit, free viewing and eyes-closed movements (= calibration procedure)

Pretrained DeepMReye = using weights from all 6 datasets

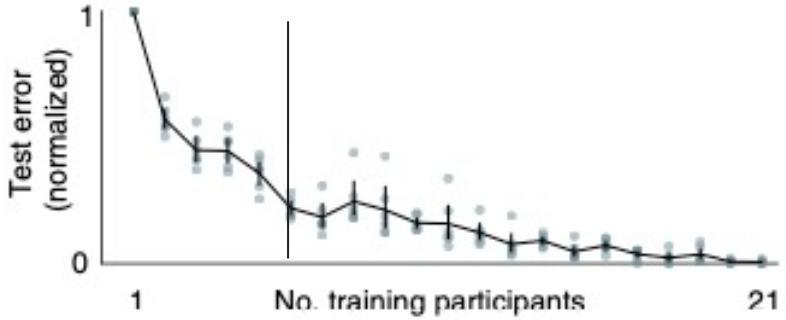
Training DeepMReye

Simple visual tasks to fine-tune the pretrained model:

fixation task, **smooth** pursuit task and **free-viewing** task

It is recommended to

- scan calibration data for a few participants with the same imaging protocol on the same MRI scanner if possible
- acquire calibration data for at least 8 participants



[3]

Training DeepMReye

Train DeepMReye model with data from experimental set-up used in to be decoded data

Work in progress: running experiment for this in order to gather:

- fMRI data of a task where people are performing structured eye movements
- camera-based eye tracking data to train, validate and evaluate performance later
- data from eyes closed periods to check if it works when there is no visual input

DeepMReyeCalib

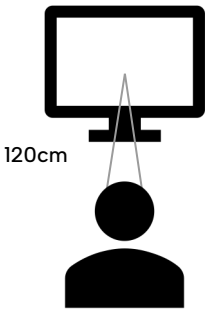
DeepMReyeClosed

Experiment

Session 01

Training session in Eyetracking room

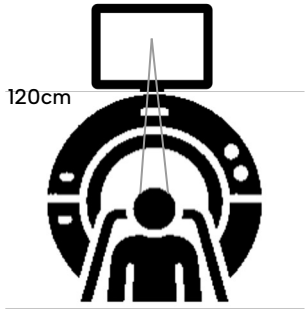
3 runs DeepMReyeCalib, 3 runs DeepMReyeClosed



Session 02

3T scanning session at CERIMED

3 runs DeepMReyeCalib, 3 runs DeepMReyeClosed

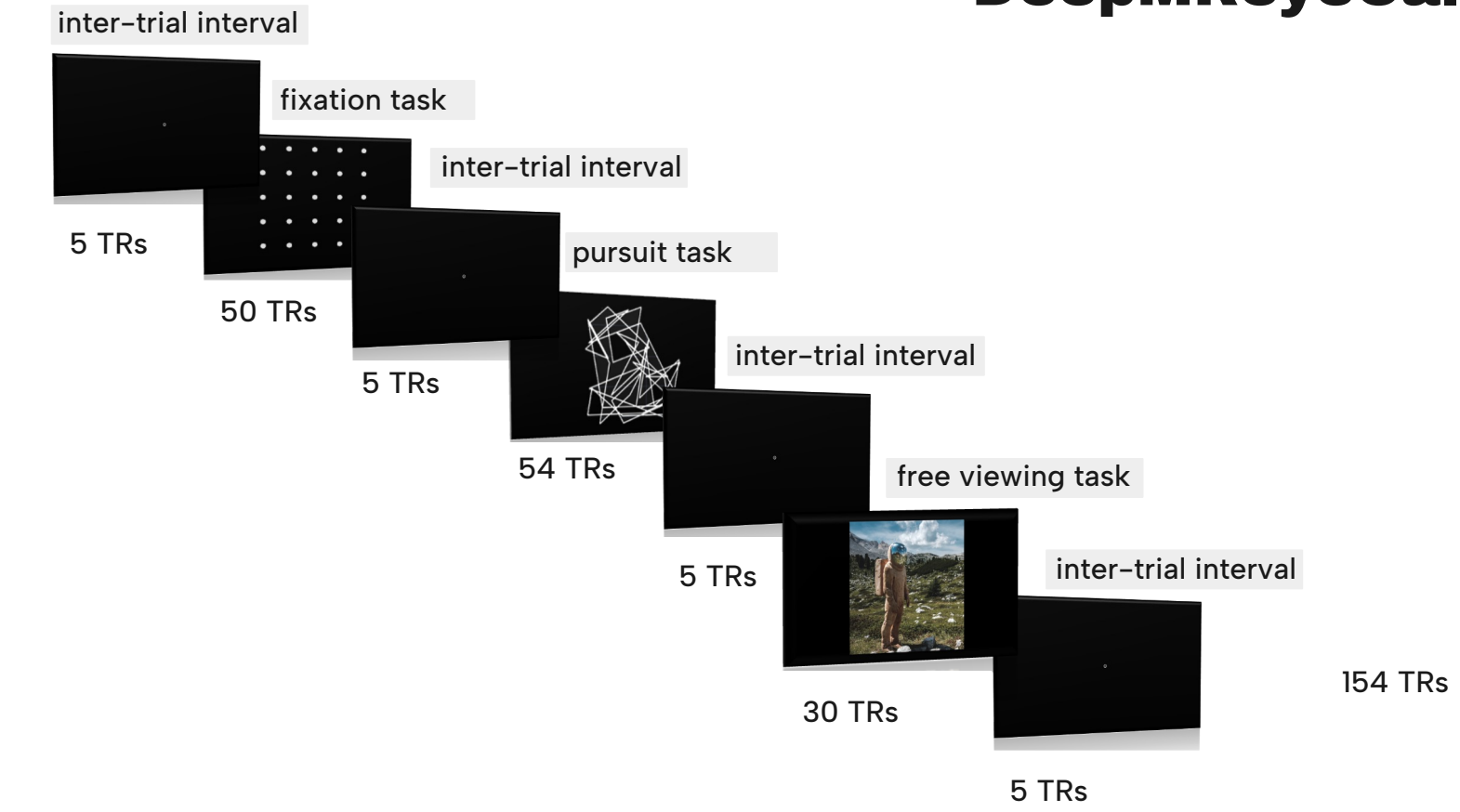


DeepMReyeCalib

Does training improve eye tracking decoding accuracy in DeepMReye?

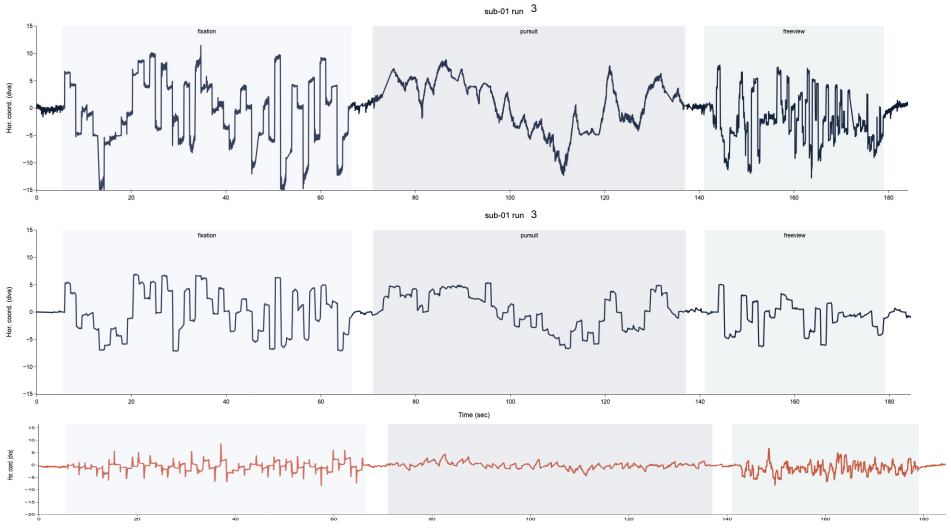
Does pretrained DeepMReye make sense using preliminary data?

DeepMReyeCalib

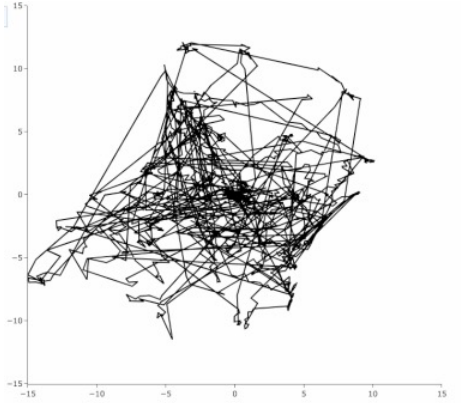


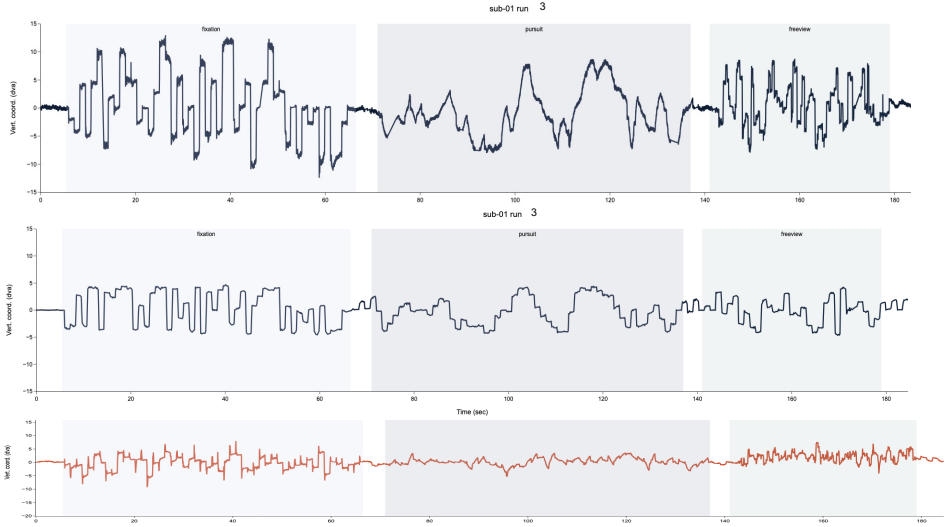
Sequence details

Anatomical T1w (ABCD_T1w_MPR_vNav_setter3; T1w_MPRAGE_vNav_0p8mm)	4:05 min
Anatomical T2w (ABDC_T2w_vNav_setter2, T2w_vNav_08mm)	2:35 min
Fieldmap_topup_AP	0:35 min
Fielmap_topup_PA	0:35 min
DeepMReyeCalib bold (run 1, 2, 3)	3:13 min
DeepMReyeClosed bold (run 1, 2, 3)	6:26 min
Total scanning time	35:27 min

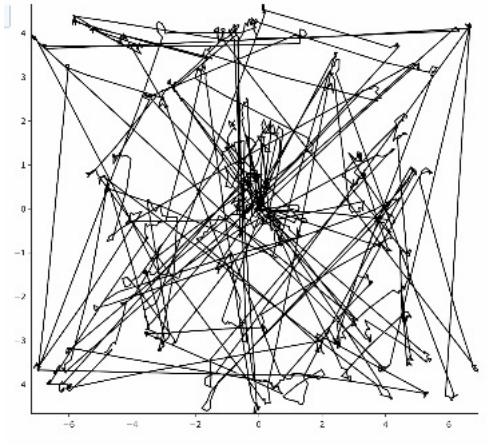


Scanner Eyetracker

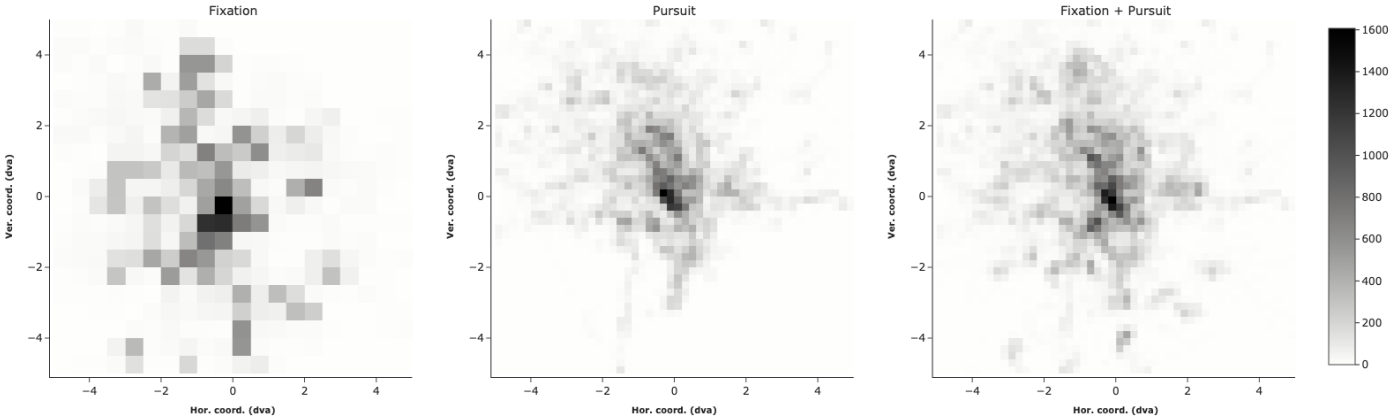




Pretrained DeepMreye

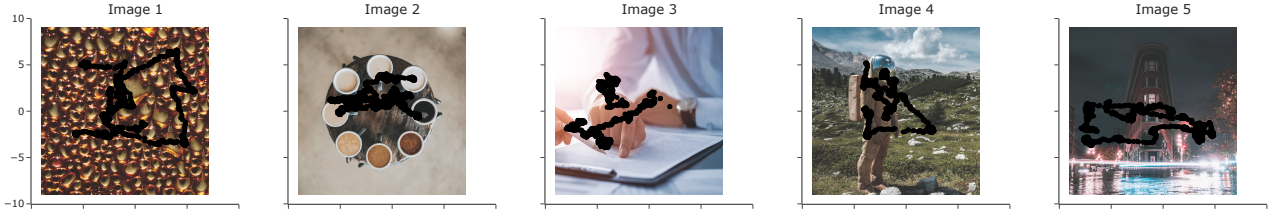


Average error (sub-01)

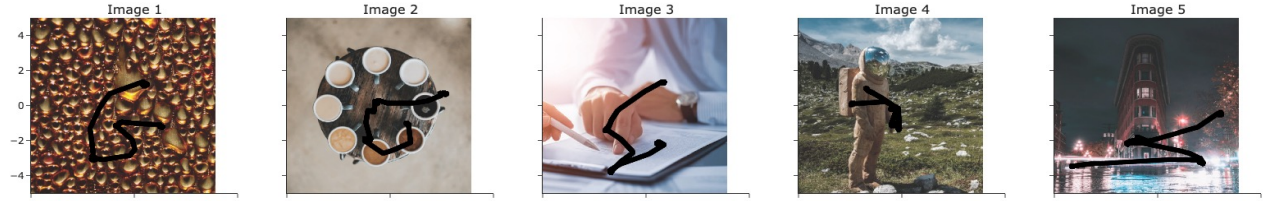


Free viewing task (sub-01)

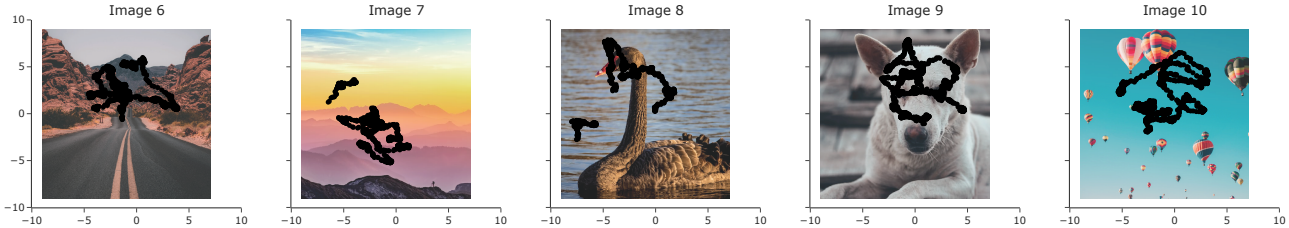
Scanner Eyetracker



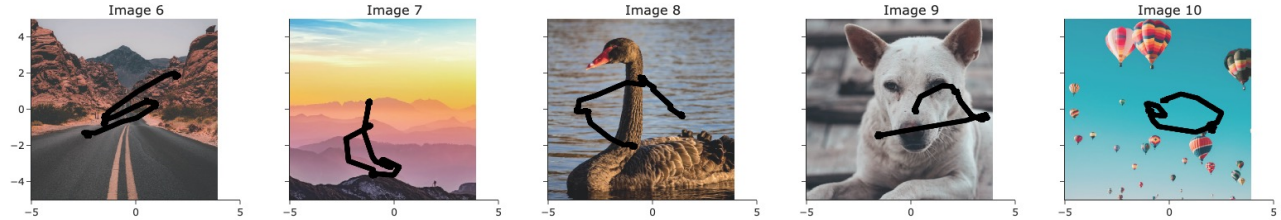
Pretrained DeepMReye



Scanner Eyetracker



Pretrained DeepMReye



DeepMReyeCalib

Does training improve eye tracking decoding accuracy in DeepMReye?

Does pretrained DeepMReye make sense using preliminary data?

Yes it does!

DeepMReyeClosed

How well can pretrained and trained DeepMReye decode gaze when the eyes are closed?

Can we use the pretrained DeepMReye model for eyes closed eyetracking?

DeepMReyeClosed

Why opt for eyes closed rather than complete darkness?

- Ease of implementation
- Particularly beneficial for studies necessitating closed-eye conditions while retaining gaze position data (resting-state fMRI and REM sleep fMRI studies)

Instructions

The experiment is composed of four distinct parts.
Each part starts with the presentation of a central bull's eye
presented with low tones.

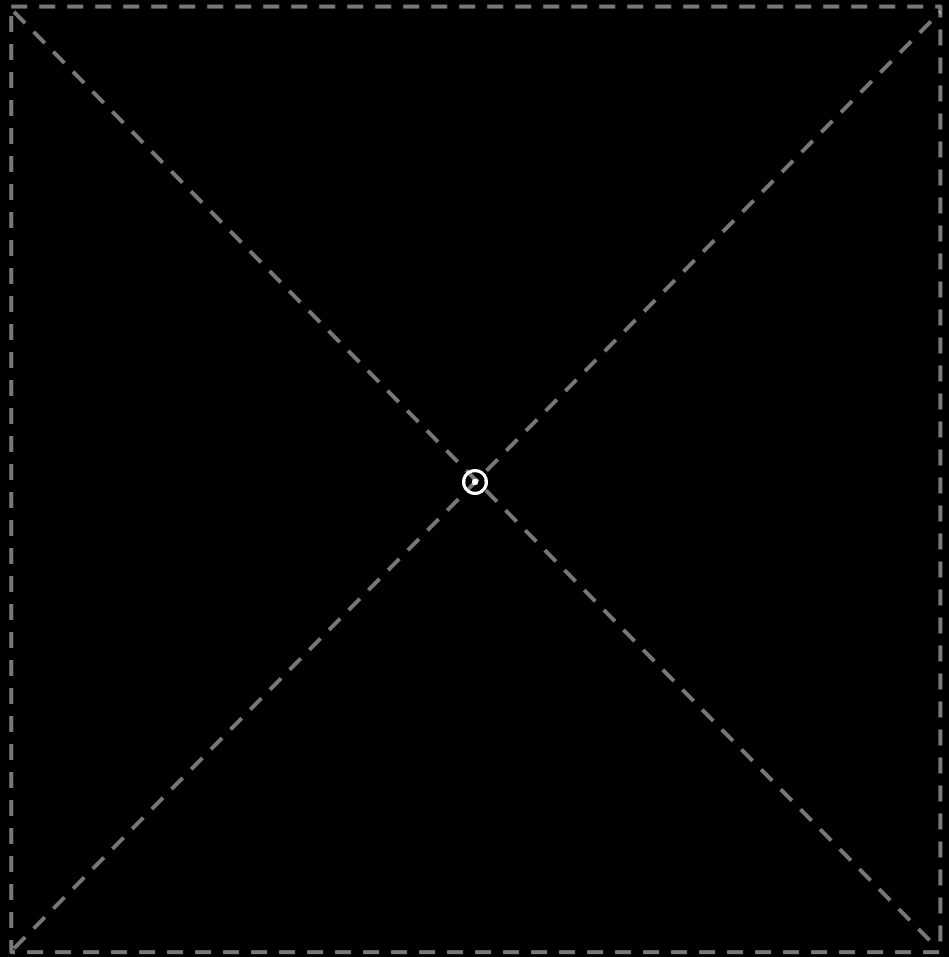
Your main task is to move your gaze following the placement
of the bull's eye presented with three distinct tones.

1st part: move your gaze at the onset of the first tone.

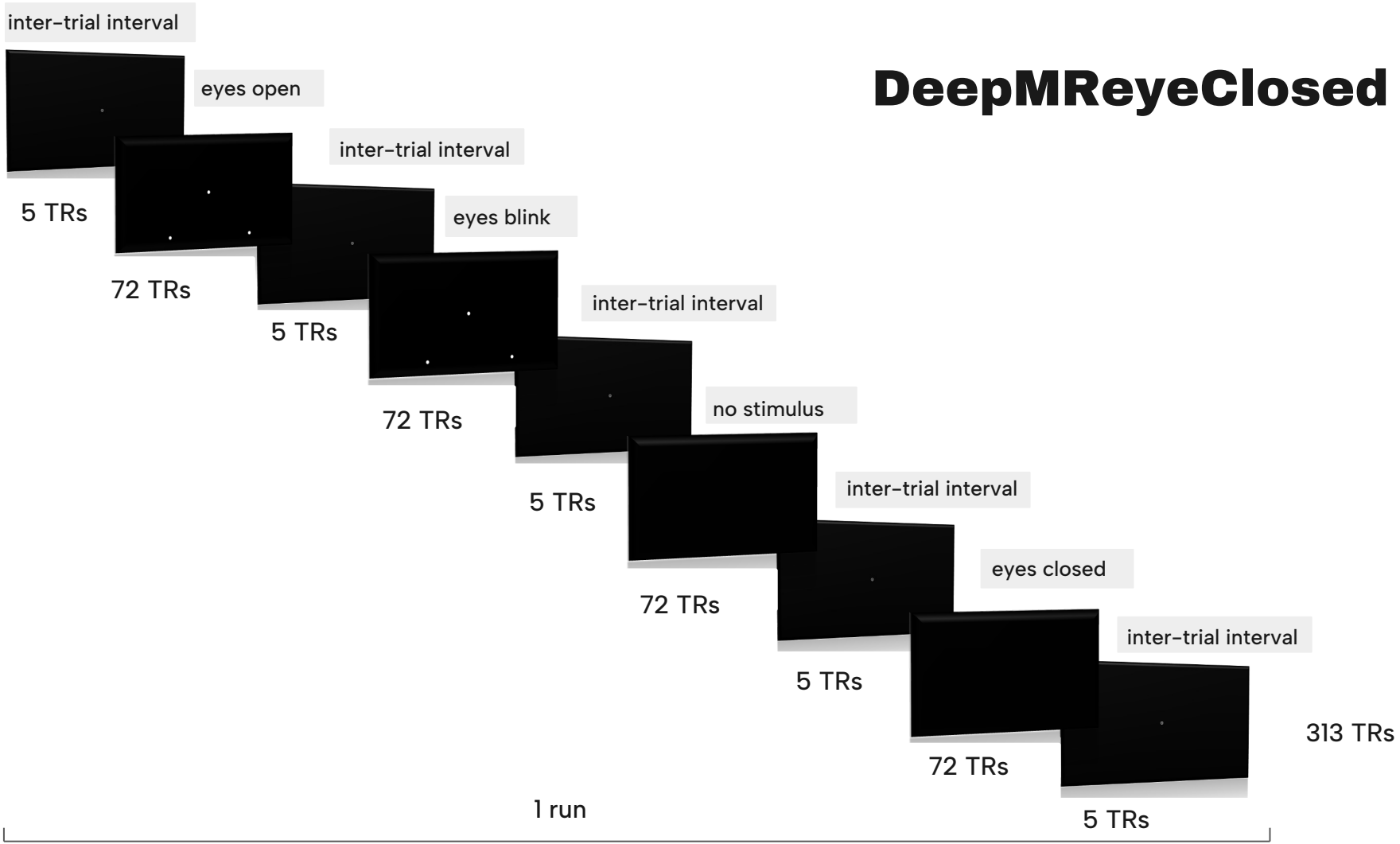
2nd part: move your eyes at the onset of the first tone, close your eyes
at the onset of the second tone and reopen your eyes
at the onset of the third one.

3rd part: move your eyes at the onset
of the first tone reproducing the sequence of the two first parts

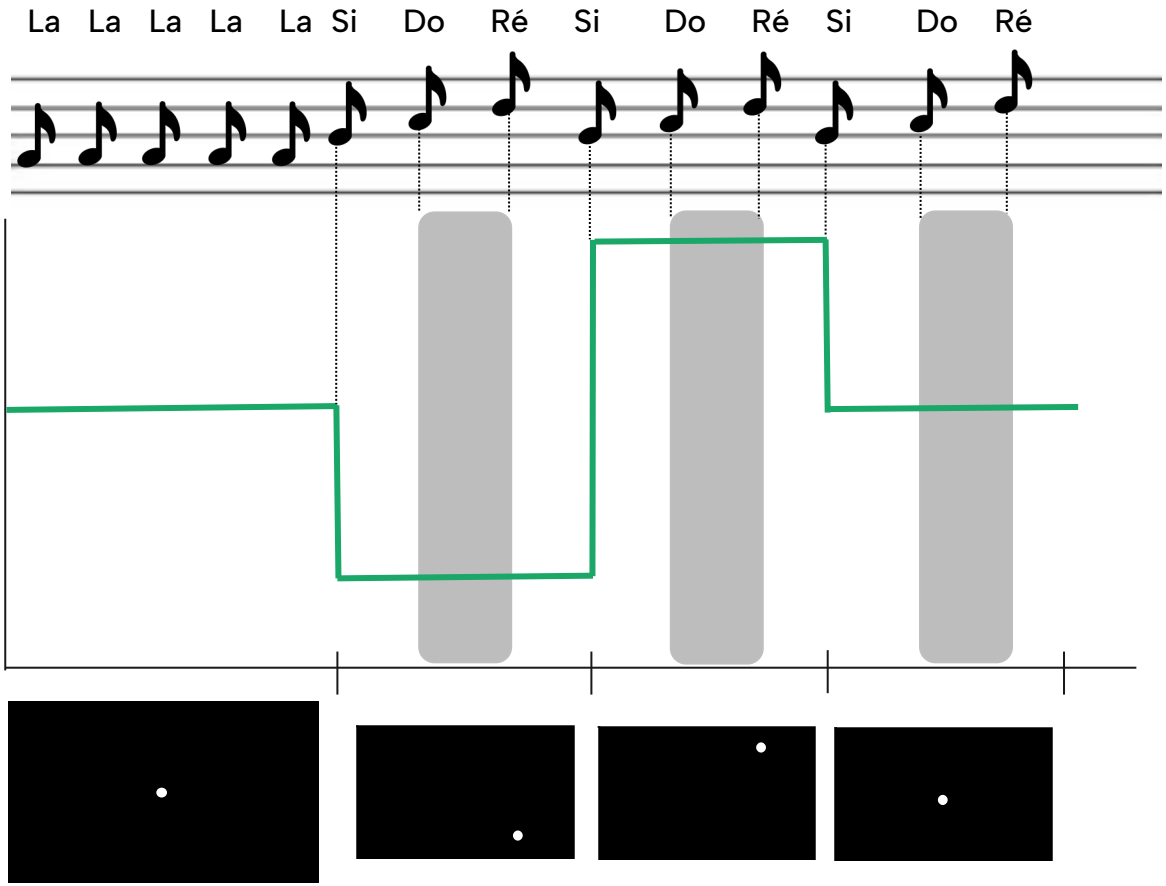
4th part: while keeping your eyes closed, move your eyes at the onset
of the first tone reproducing the sequence of the two first parts.



DeepMReyeClosed



Sound schema



sound

blink

expected Y gaze position

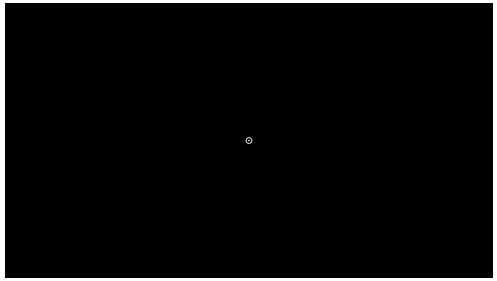
Task eyes blink:

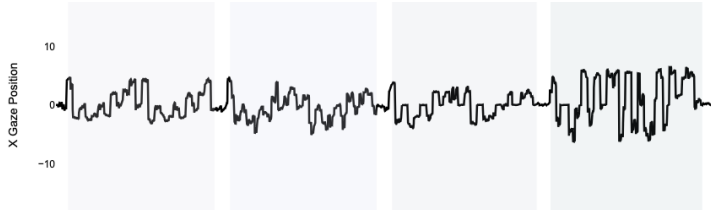
Move at 1st sound, blink at 2nd sound, reopen at 3rd sound

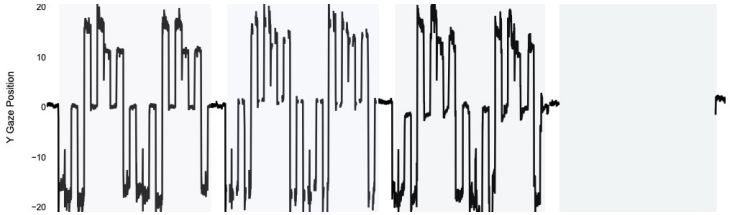
All other tasks:

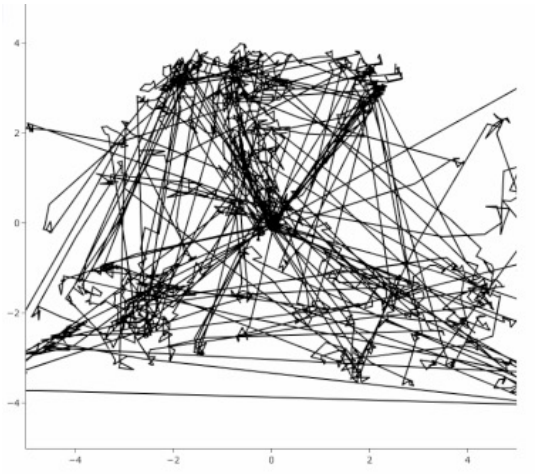
Move at 1st sound and fixate

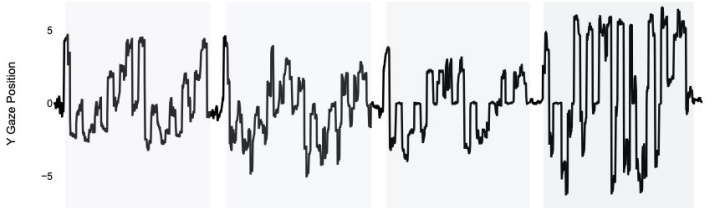

X Gaze Position
20
10
0
−10
−20



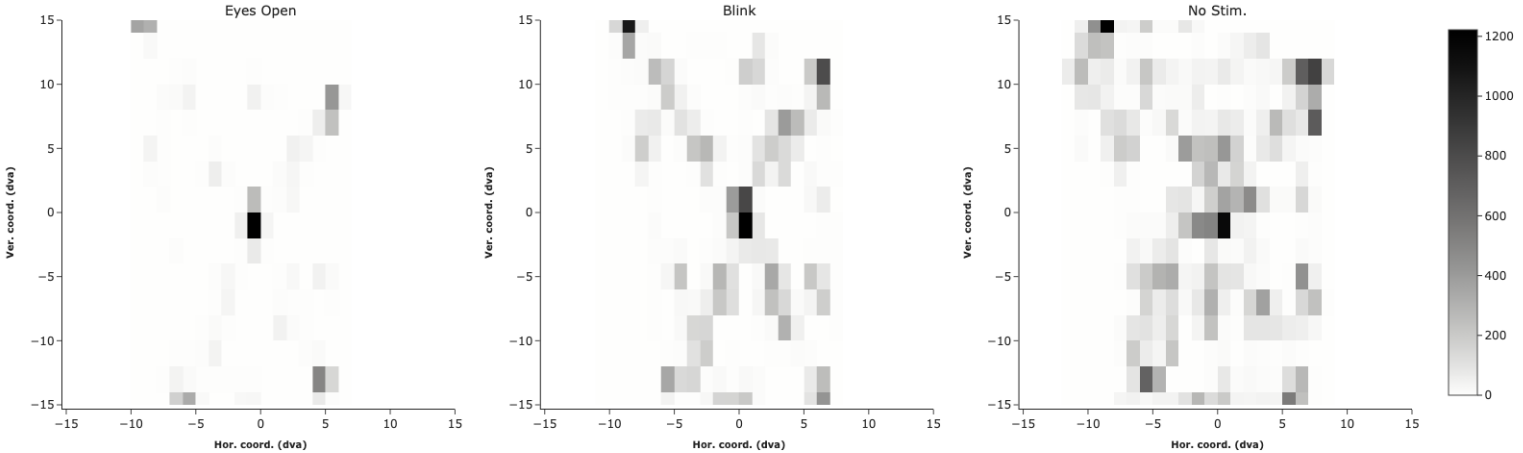

X Gaze Position
10
0
−10


Y Gaze Position
20
10
0
−10
−20

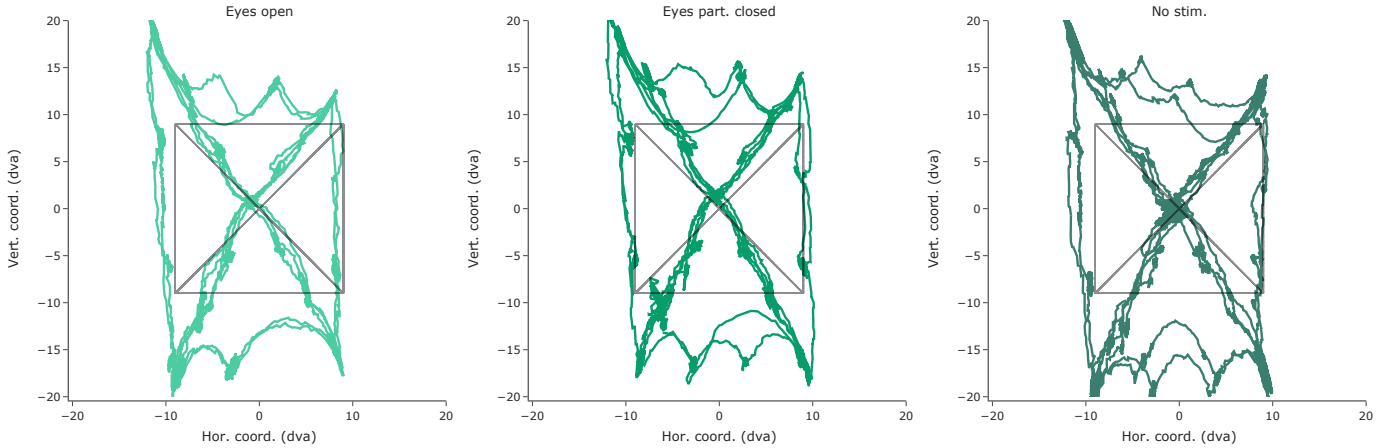

4
2
0
−2
−4
−4
−2
0
2
4


Y Gaze Position
5
0
−5

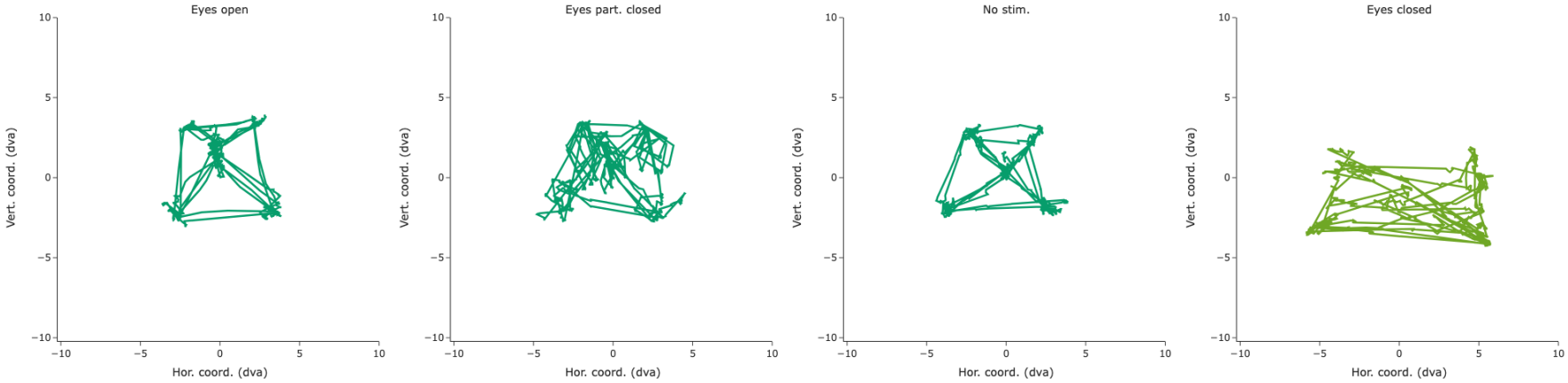
Average error (sub-01)



Scanner eye tracker



Pretrained DeepMReye



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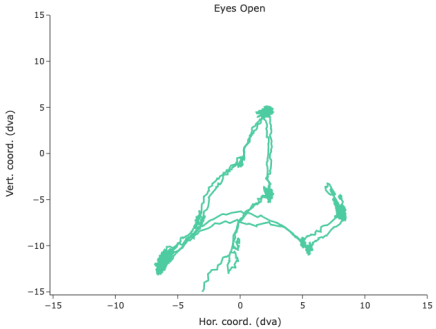

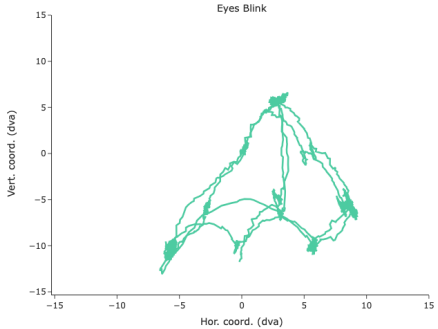

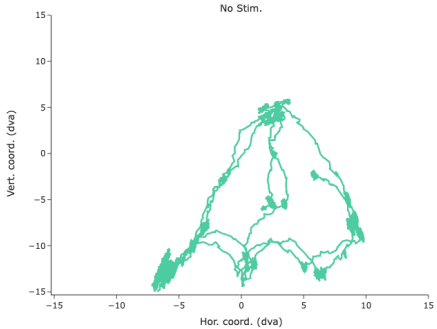

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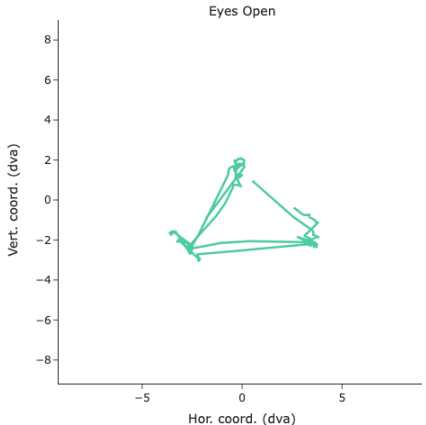

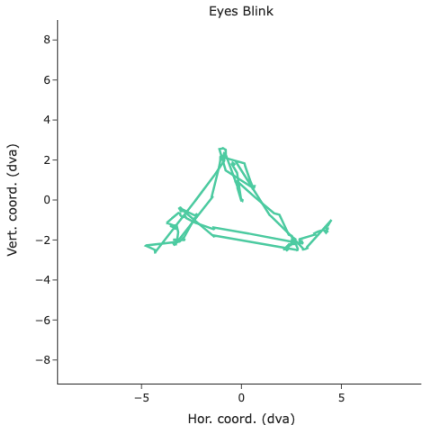

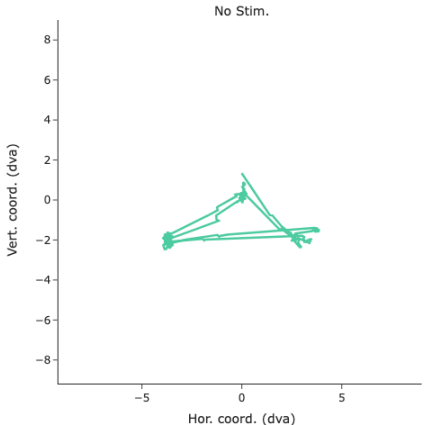

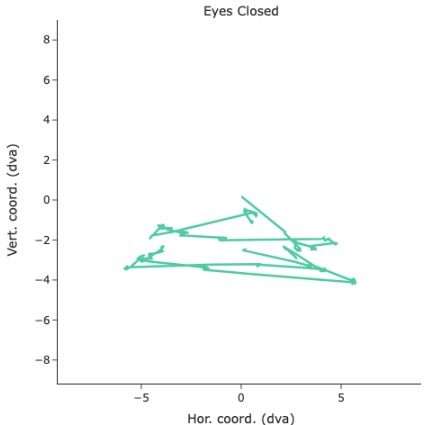

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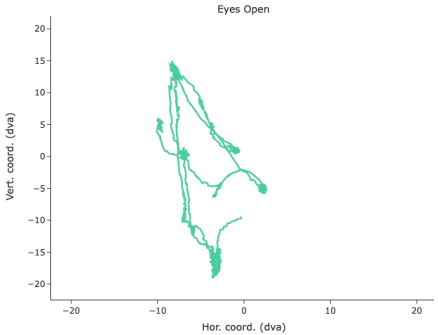

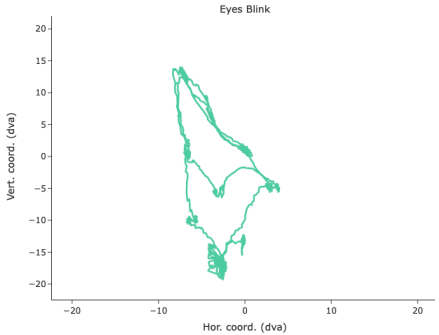

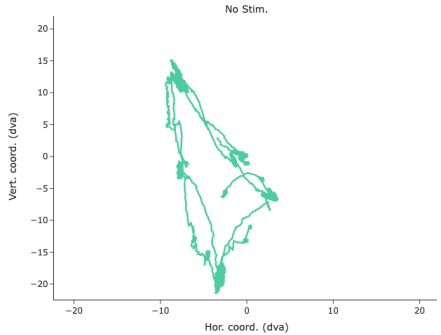

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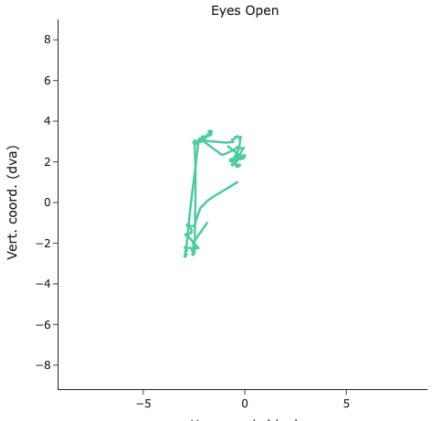
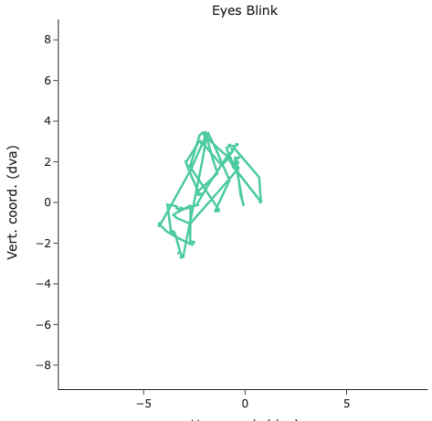
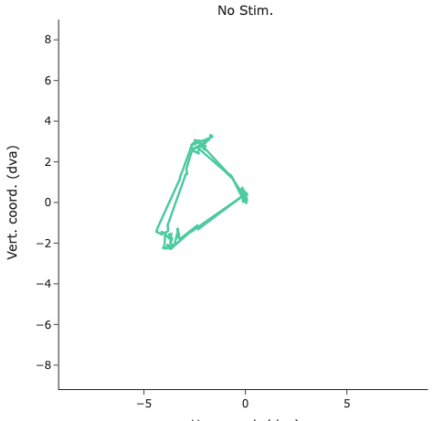
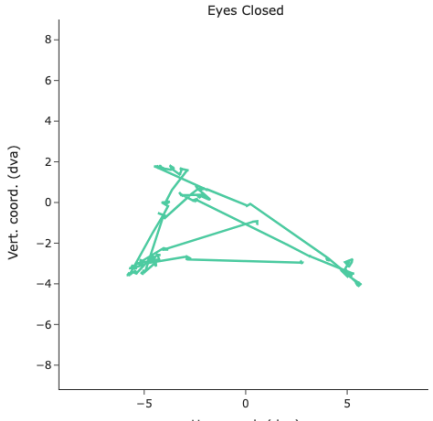
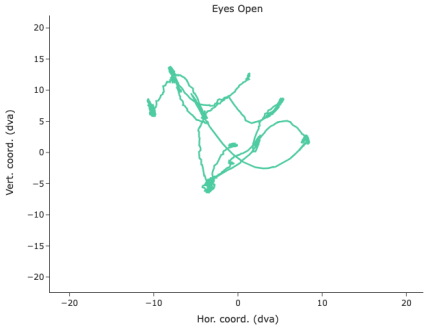


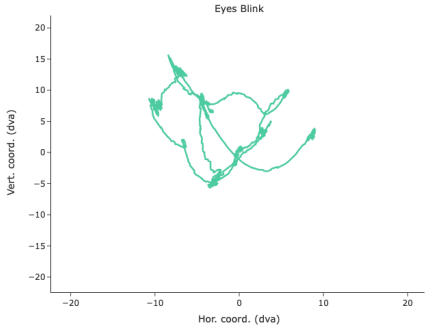


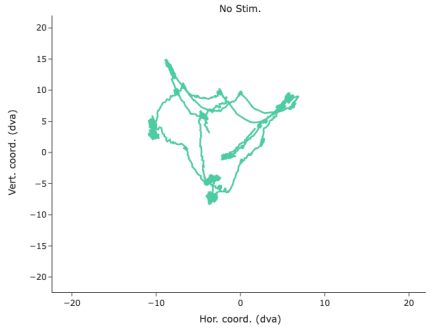




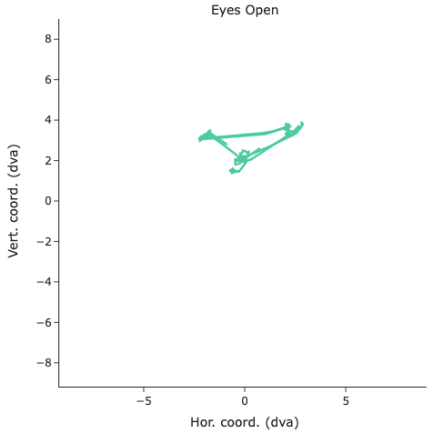
Scanner eye tracker

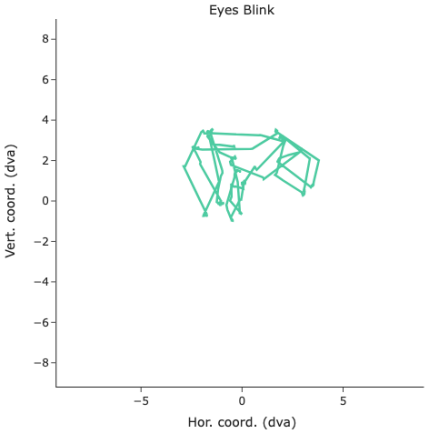


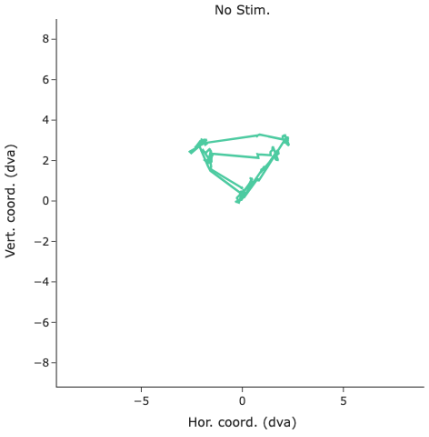


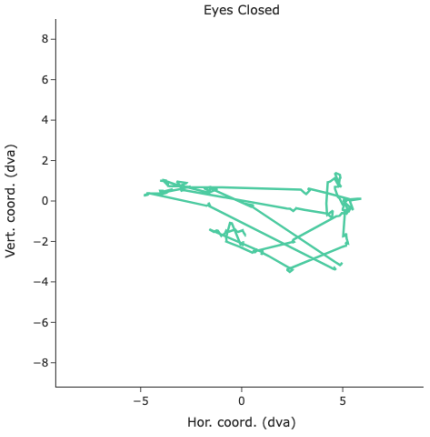


Pretrained DeepMReye

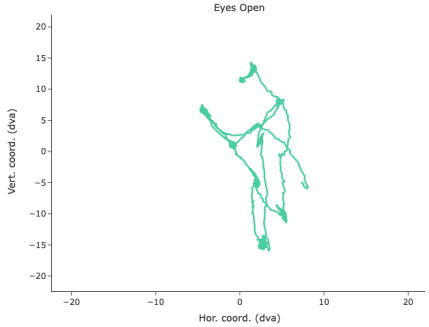


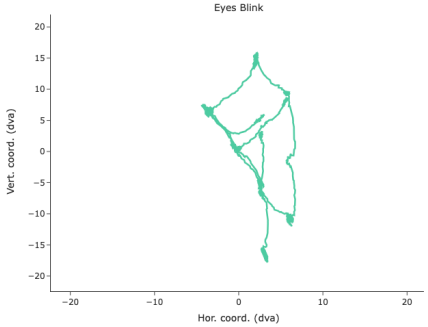


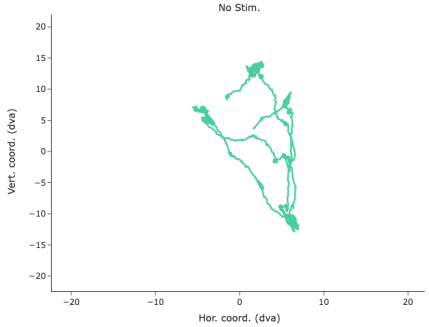




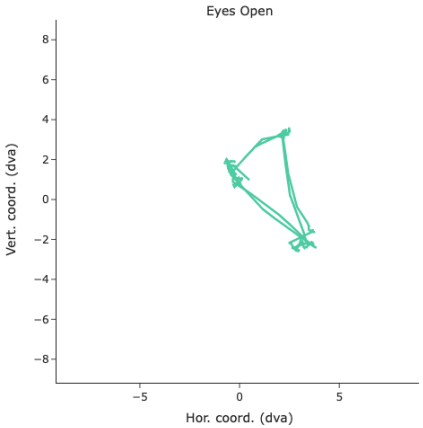
Scanner eye tracker

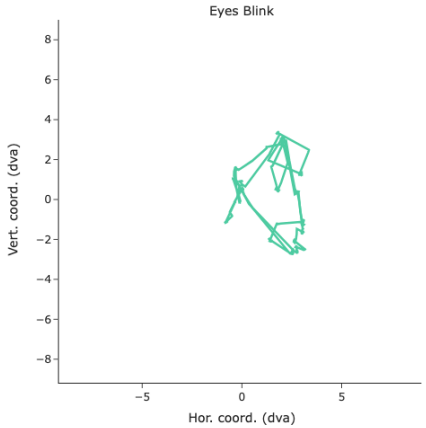


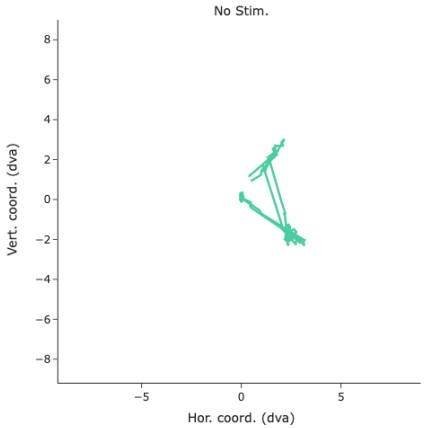


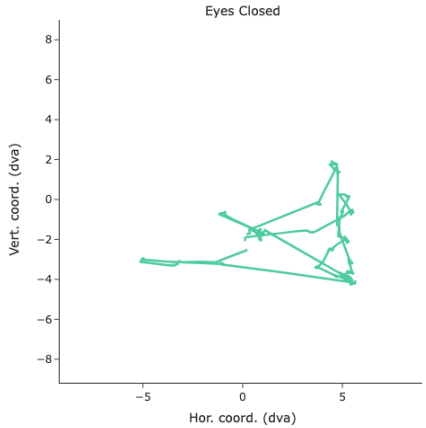


Pretrained DeepMReye









DeepMReyeClosed

How well can pretrained and trained DeepMReye decode images in total darkness or when the eyes are closed?

Can we use the pretrained DeepMReye model for eyes closed eyetracking?

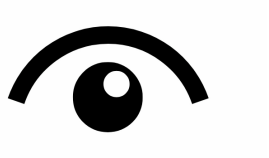
Yes we can!

Next steps

- Train classifier to recognise triangles (up, down, left, right)
- Gather data from 8 more participants
- Train DeepMReye with new data
- Evaluate DeepMReye performace

Implications of DeepMReye beyond this project

- Compatible with any fMRI dataset of the same sequence: past or future
- Easily identify and exclude trials with fixation failures, even without eye-tracking setup
- Integration of viewing behaviour data in studies using naturalistic stimuli
- Discrepancies in viewing behaviour across conditions and imaging artifacts are mitigated by precise gaze position tracking
- Analysis of eye movement patterns unveils underlying cognitive mechanisms



Thank you for your attention

References

[1] Kubota, Y., Hayakawa, T., & Ishikawa, M. (2021). Dnamic perceptive compensation for the rotating snakes illusion with eye tracking. PloS one, 16(3), e0247937.

[2] Bridgeman, B. R. U. C. E. (2010). Space constancy: The rise and fall of perceptual compensation. Space and time in perception and action, 94–108.

[3] Frey, M., Nau, M., & Doeller, C. F. (2021). Magnetic resonance–based eye tracking using deep neural networks. Nature neuroscience, 24(12), 1772–1779.