Simulation of eye movement artefacts in EEG

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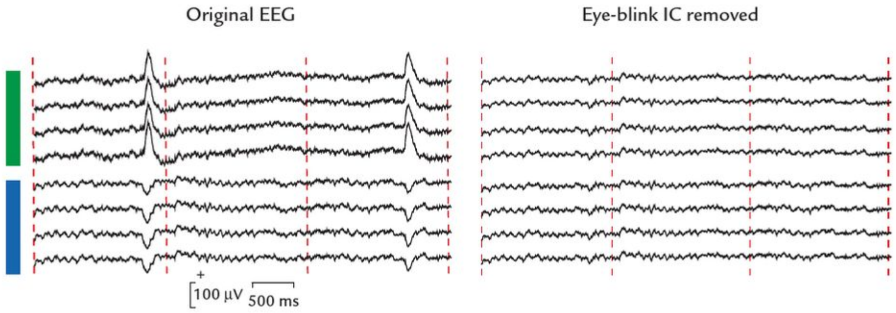
Motivation

- Understanding the artefact
- Make simulated data more similar to real EEG data
- Improving analysis & artefact removal toolboxes



Eye blink artefact. Source: Hari, R., & Puce, A. (2017)

Research Questions 👀

1. What is the origin of the measured EEG potentials during eye movements, and how can we simulate these?
2. Does our simulation match recorded data? - qualitative: topoplot

Proof of concept: eye movements, pure horizontal and vertical.

- Simpler to understand
- Simulating blinks ➜ future scope

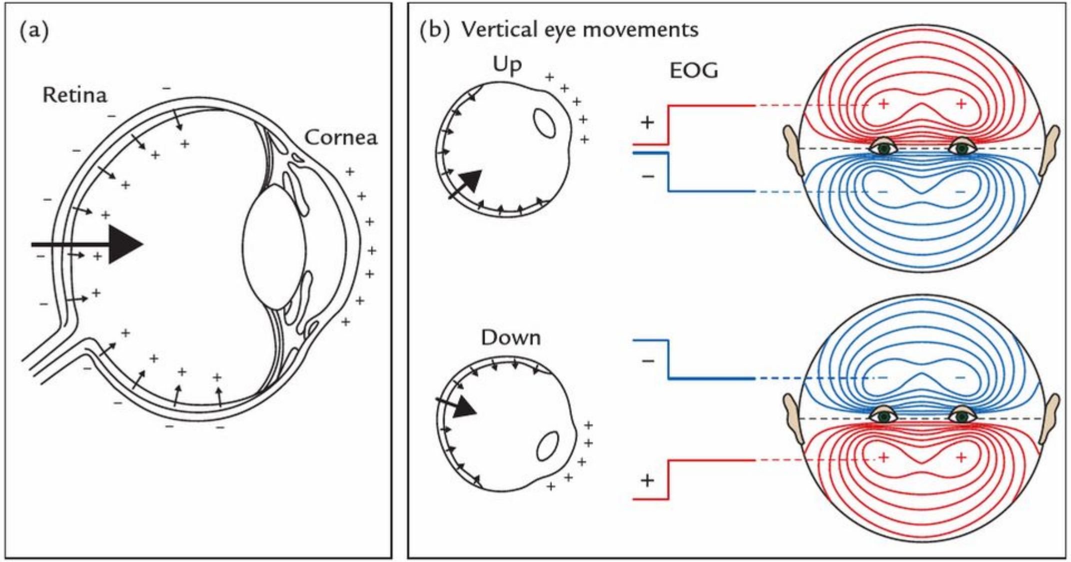
Origin of potentials from eye movements

- Eyeball - electrically charged.
- Eyelid movements - modifying the effect from the eyeball.
- Muscles - used to move the eyeball.

Our current focus is on the eyeball charges.

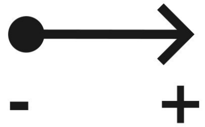
Eye structure

- Potential difference across retina, cornea surfaces
- Eye movement: charges' physical locations change.
- Electrodes closer to positive cornea measure higher voltage
- Overall, "Corneo-retinal" dipole (CRD)



Source: Hari, R., & Puce, A. (2017)

Representing the eye charges



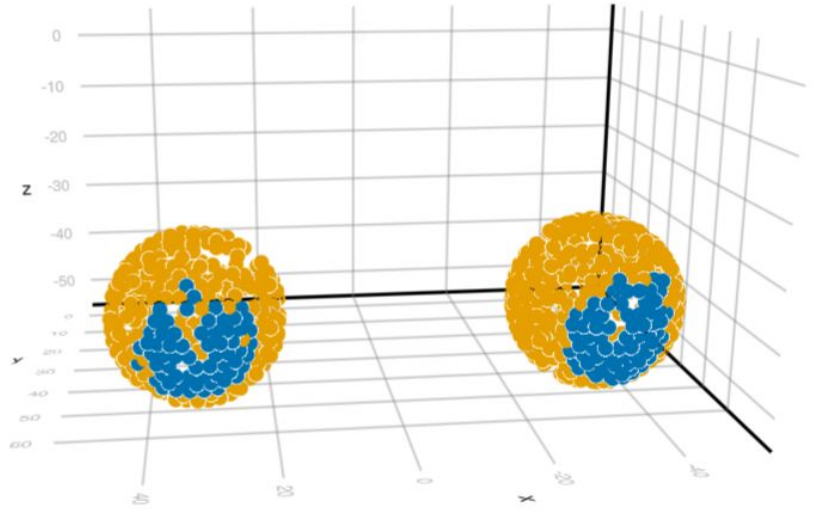
- Source dipole
  - Tiny current to represent an electrical potential difference.
  - Has a **position** and an **orientation**.

- Orientation: by convention, from the negative end of the dipole to the positive end.

Concept: Head model

- Head model - describes how the head conducts electric potentials.
    - Different tissue conductivities
    - “Lead field”: electric potential measured at the scalp

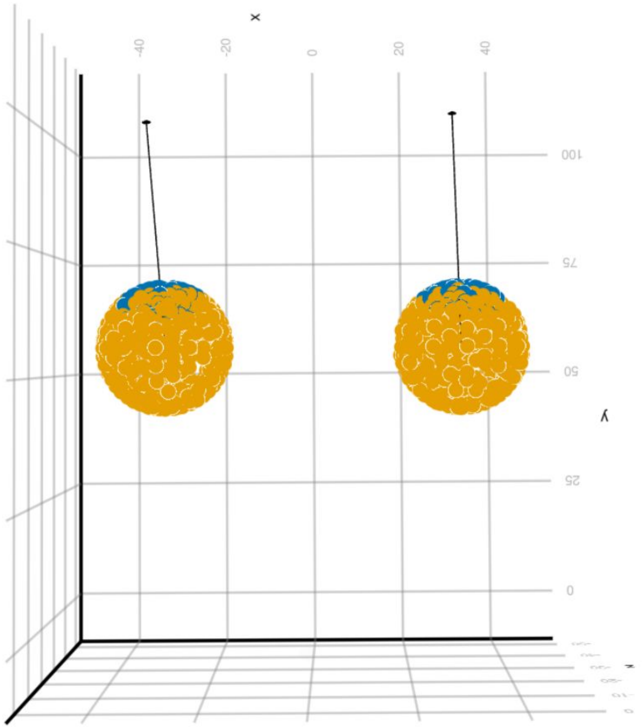
- We use the HArtMuT head model (Harmening et al. 2022)
- Eye model: source points on eye surface.



Source points on the eyeball surface.
View from the front showing retina (yellow) and cornea (blue).
Source: Harmening et al., 2022.

Concept: Gaze direction

- “Gaze direction” vector:
  - From center of eye in the direction of viewed object, through the cornea.
  - ‘Point’ the eye in a certain direction.



Eye gaze directions: from eyeball centre to cornea centre.
View from the top showing retina (yellow) and cornea (blue).
Source: Harmening et al., 2022.

Back to the research questions 👀

1. What physically creates the measured EEG potentials during eye movements, and can we simulate this? - let's try some simulations..

- Simulation
    - Movement: from viewing point A to point B
    - Input: Gaze direction, Output: scalp topography
    - Topoplot: difference between end (B) and start (A)

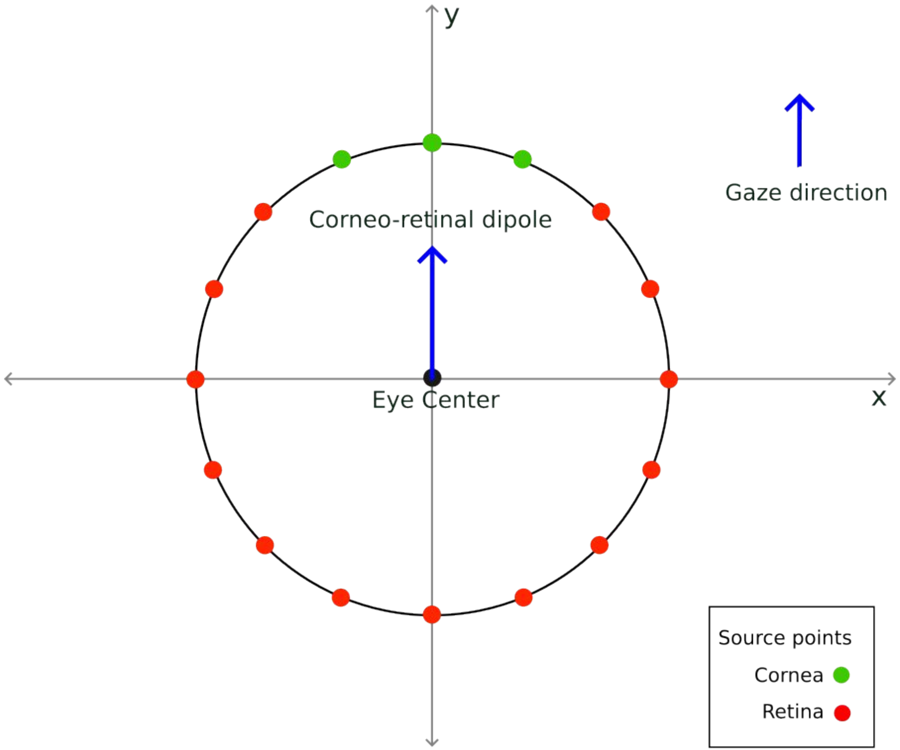
- What do we expect?
    - Positive near new cornea location
    - Negative near new retina location

Our assumptions

- Perfectly spherical eye
- Cornea symmetric around axis of gaze
- Only rotation, no translation of the eye within its socket
- Viewed target is very far away from subject - eye gaze directions are parallel.

Corneo-retinal Dipole method

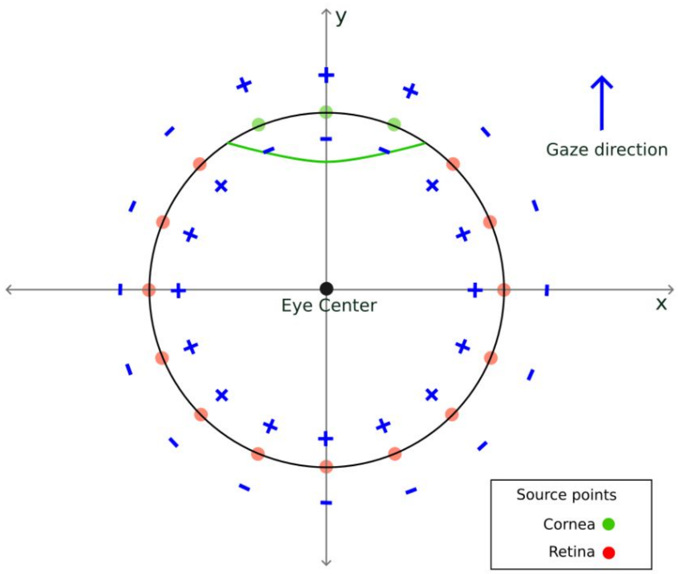
- One source dipole per eye
- Placed at the eye centre, oriented parallel to gaze direction.



Corneo-Retinal Dipole: Top-down view of the eye

Ensemble method - our approach

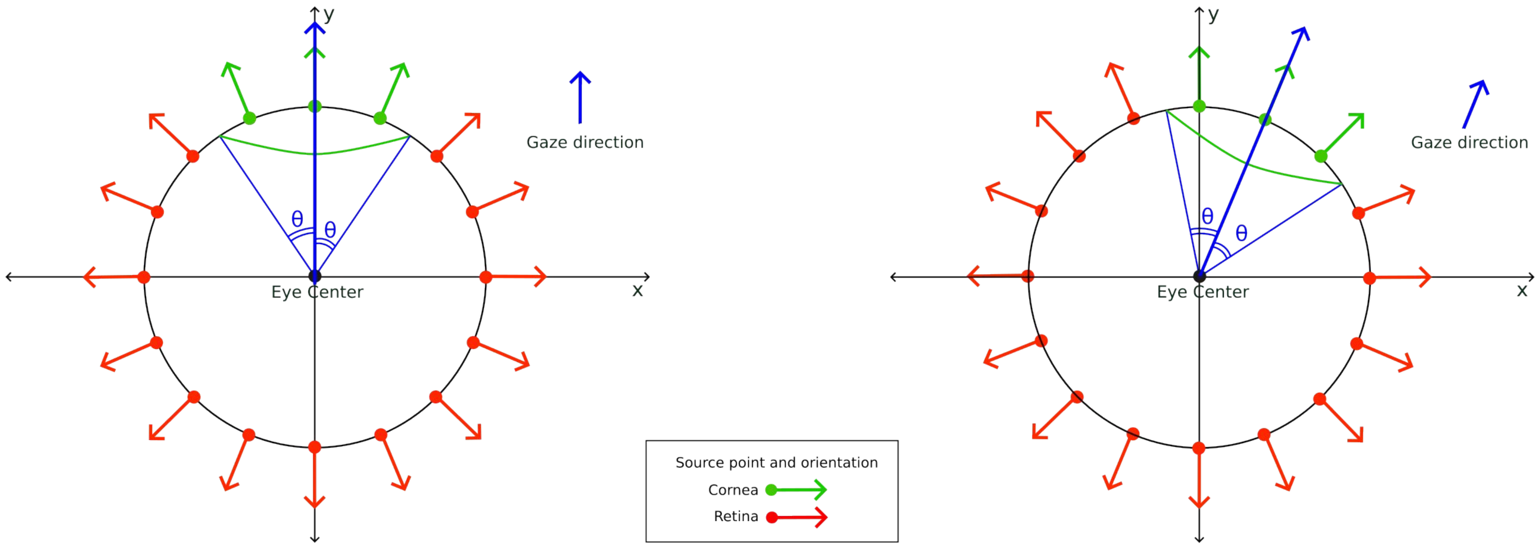
- Many source dipoles to represent the charges in the eye - closer to real-world
- Why?
  - More control: specify exact gaze direction, simulate any gaze trajectory



Charge distribution in the cornea and retina

Ensemble method

- Cornea always within a certain angle range away from gaze direction
  - use gaze direction and angle to find cornea



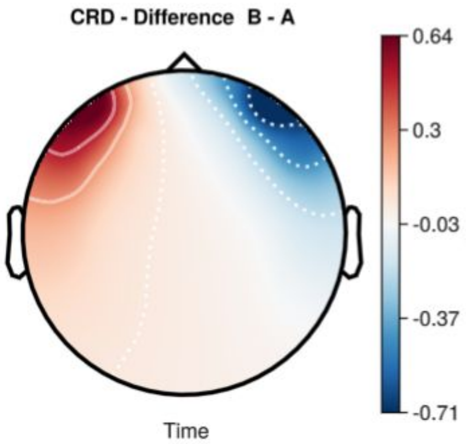
Position A: Start of the movement

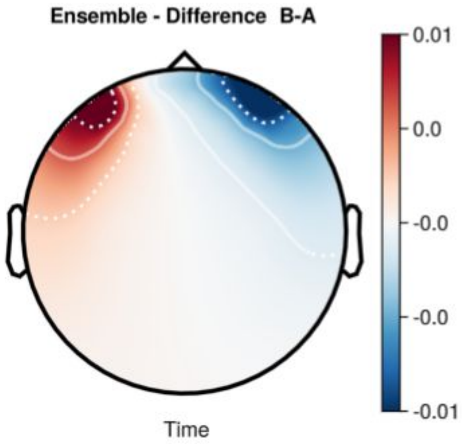
Position B: End of the movement

Simulation

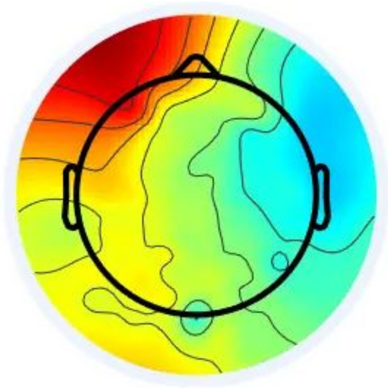
- Horizontal saccade: from centre (0°) to 15° to the left
- Vertical saccade: from centre (0°) to 15° upwards
- Real data:
    - Saccades of similar size from Gert et al. (2022)
    - Indicative plots: difficult to find pure horizontal/vertical saccades.

Results: Horizontal saccade



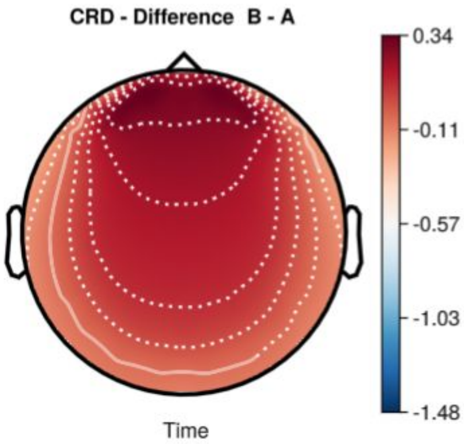


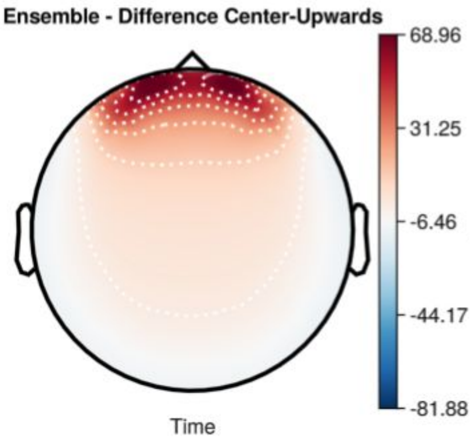
Real data: similar saccade



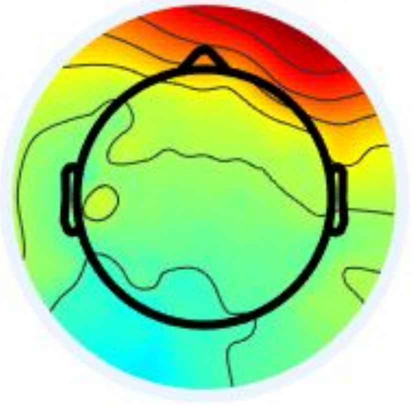
- Real data plot: saccade starts slightly to the right of centre, amplitude 9.63°, includes slight vertical movement. Source: Gert et al. (2022)

Results: Vertical saccade





Real data: similar saccade



- Real data plot: saccade starts slightly below centre, amplitude 10.69°, also includes some left-right movement. Source: Gert et al. (2022)

Evaluation

- Qualitatively - matches what we expected - more positive towards the left/upwards respectively.

- Quantitatively - not evaluated at the moment.
    - Cannot yet compare magnitudes - some scaling required.
    - Electrode positions differ
    - Difficult to find purely horizontal saccades with this exact magnitude and starting point.

Back to the research questions 👀

1. What physically creates the measured EEG potentials during eye movements, and can we simulate this?

   - Eyeball charges, eyelid, muscles;

   - We simulated eyeball movement: (1) single dipole, (2) ensemble of dipoles.

2. Does our simulation match the real recorded data?

   - Topography looks similar to expectations

   - Need to explore further

Limitations

- Current head model: eye tissue conductivity is still ‘skin’.
- Only pure horizontal/vertical saccades simulated. (unlikely in real data)
- Only the start and end positions; full trajectory not yet simulated.
- Cornea and retina relative magnitude - also, debated whether the cornea contributes at all.
- Not modelled here: accompanying eyelid motion, muscle activations.

Recap and Outlook

★ "Ensemble" method - charge distribution simulation - proof of concept

- New head model - updated conductivities
- Scaling - magnitudes for cornea & retina sources, and overall result
- Eyelid movement simulation
- Blinks - putting together eyelid movement and eye movement
- Muscle movements
- Package it up - UnfoldArtefacts.jl?

🕵️ Questions?

References

- Hari, R., & Puce, A. (2017). Meg-eeg primer. Oxford University Press, Incorporated. https://ebookcentral.proquest.com/lib/uni-stuttgart/detail.action?docID=5746005.
- Harmening, N., Klug, M., Gramann, K., & Miklody, D. (2022). HArtMuT—modeling eye and muscle contributors in neuroelectric imaging. Journal of Neural Engineering, 19(6), 066041–066041. https://doi.org/10.1088/1741-2552/aca8ce
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References

- Gert, A. L., Ehinger, B. V., Timm, S., Kietzmann, T. C., & König, P. (2022). WildLab: A naturalistic free viewing experiment reveals previously unknown electroencephalography signatures of face processing. European Journal of Neuroscience, 56(11), 6022–6038. https://doi.org/10.1111/ejn.15824