Club MEG:
Eye Tracking Discussion

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September 9, 2022

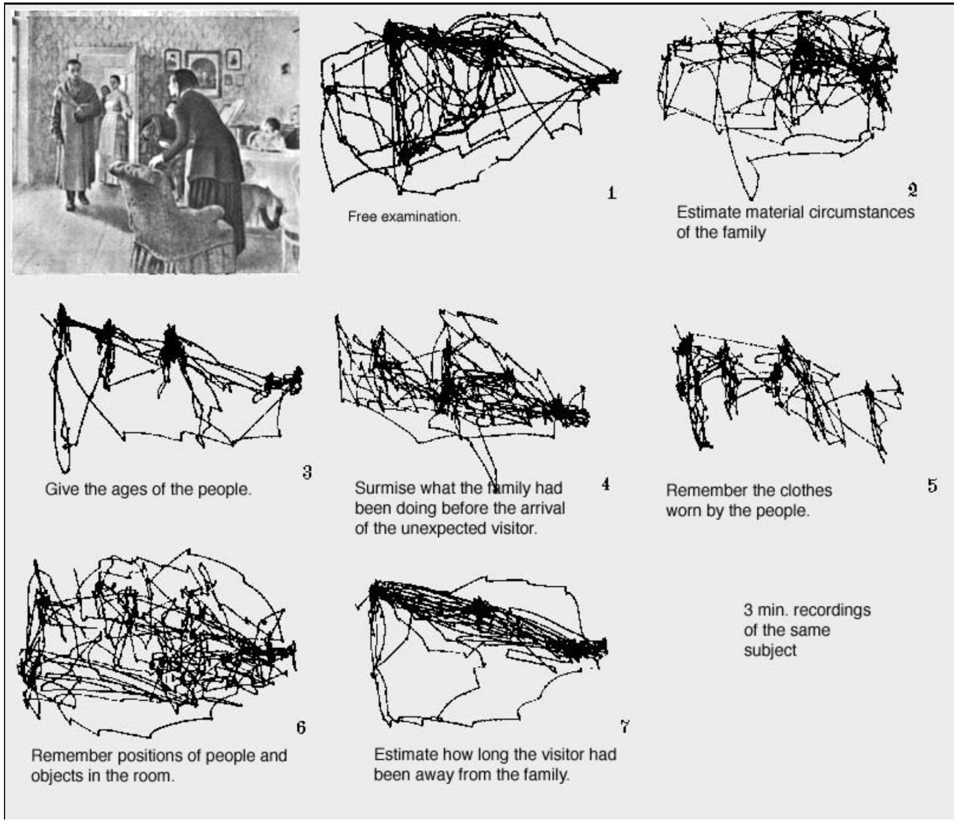
Overview

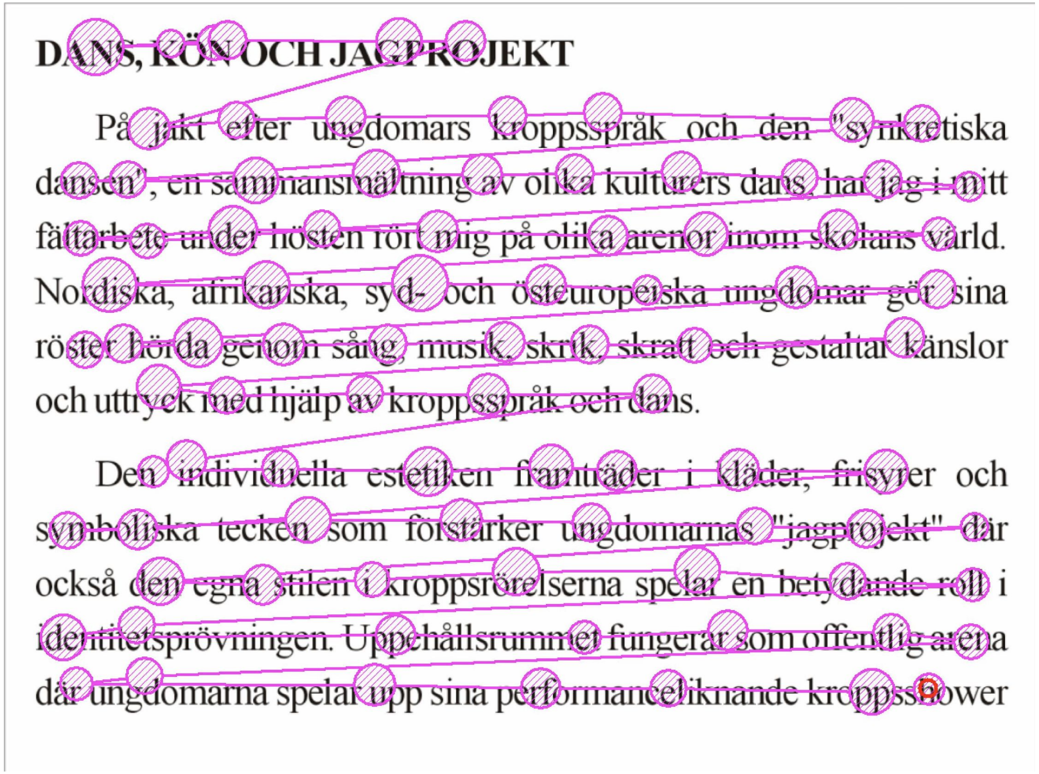
- Eye movements
- Eye tracking background
  - System
  - Setup/ Method
- Code Description
- Stimulus Integration
- Papers for natural viewing tasks

Eye Movements

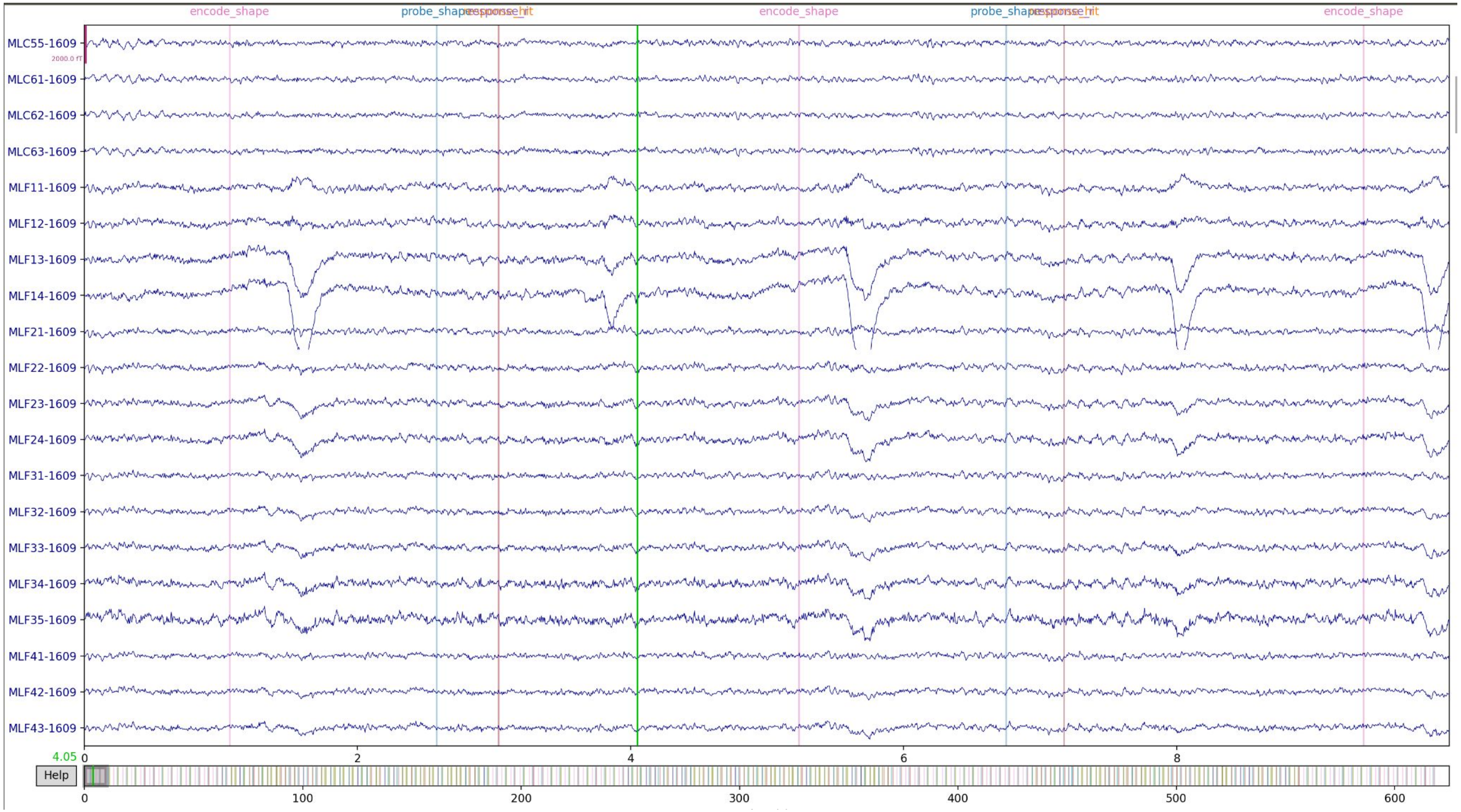
- Fixations:
  - Stopping on a visual item to collection information
- Saccade:
  - Rapid jump between fixations
  - Lack/lower information intake
- Micro saccade (<1 degree)
- Exploratory saccade - feature investigation
- Smooth Pursuit:
  - Tracking of an object in motion
  - Eye is fixated relative to moving object
    - Information intake

Given a task the eyes will move to gain information about the task at hand

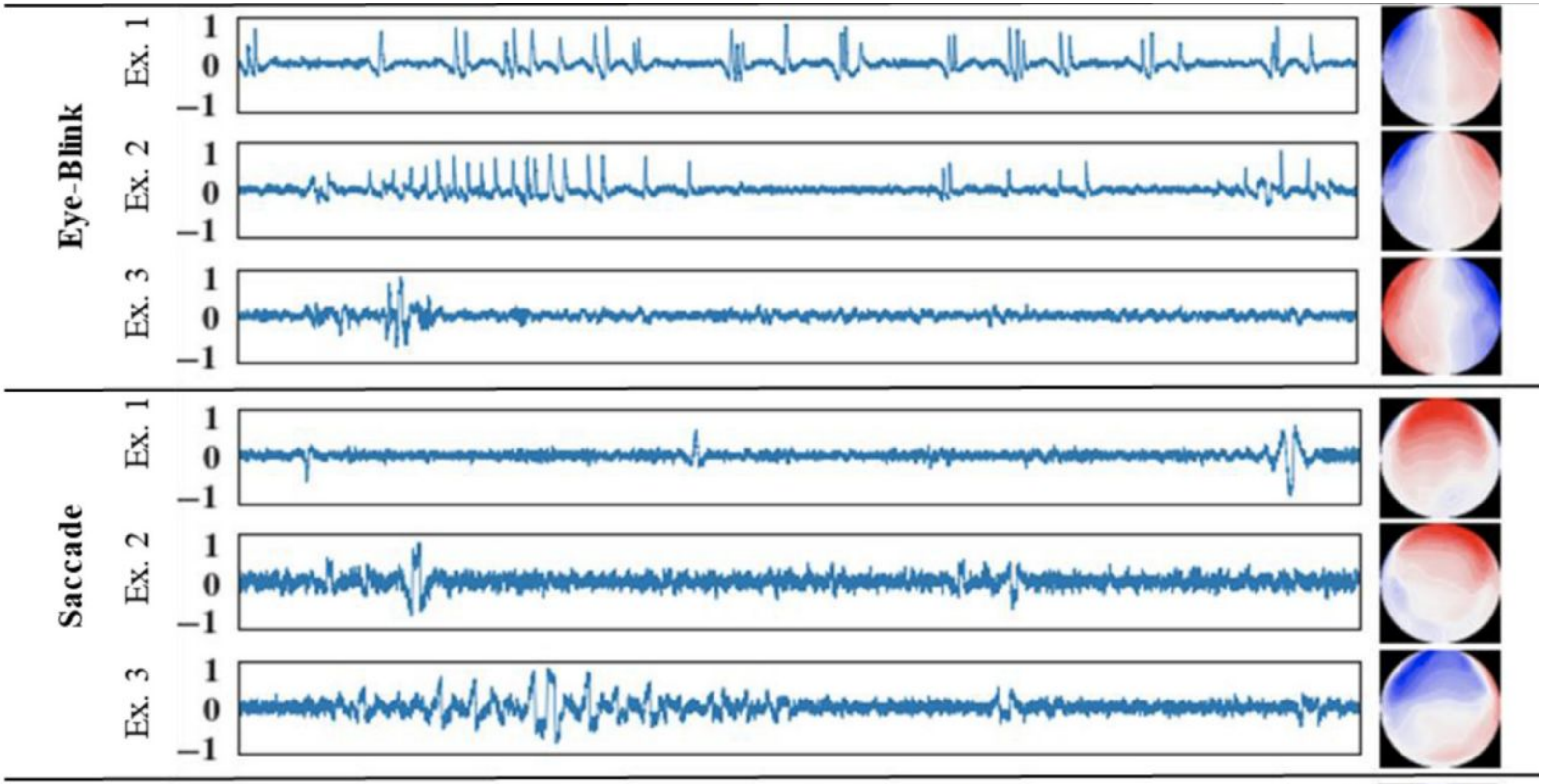




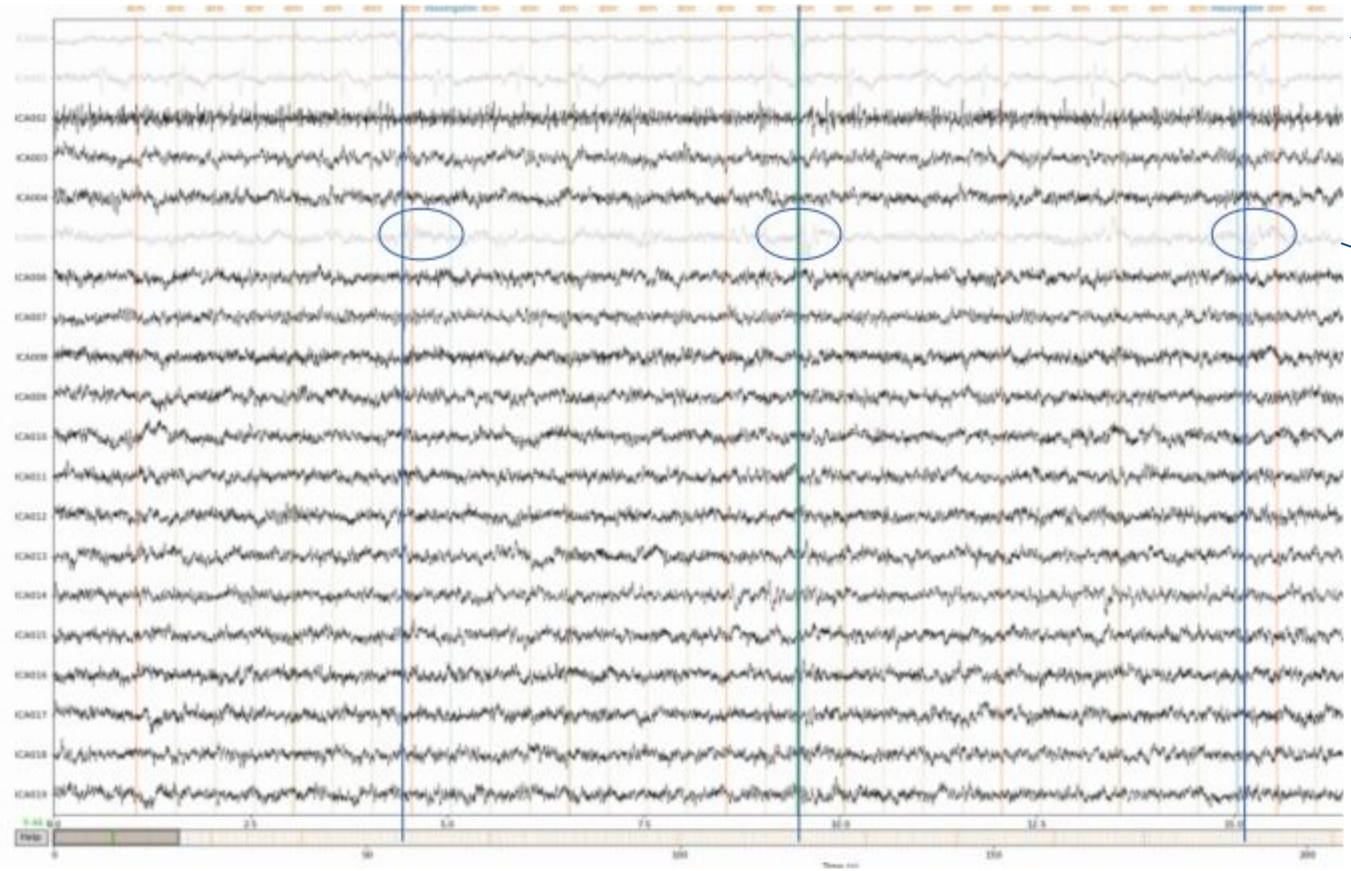
Eye movement in the MEG produces artifact

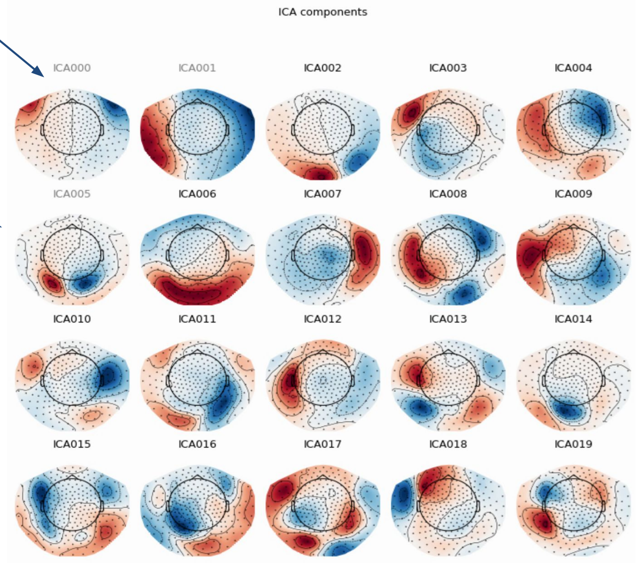


ICA can be used to isolate and remove eye-related artifact



Eyeblinks have both an ocular component and can also produce brain signal





Eyeblink consistently preceding an occipital burst, demonstrating eye activity can induce neurophysiological signal.

https://www.sr-research.com/about-eye-tracking/

Click to learn more!!

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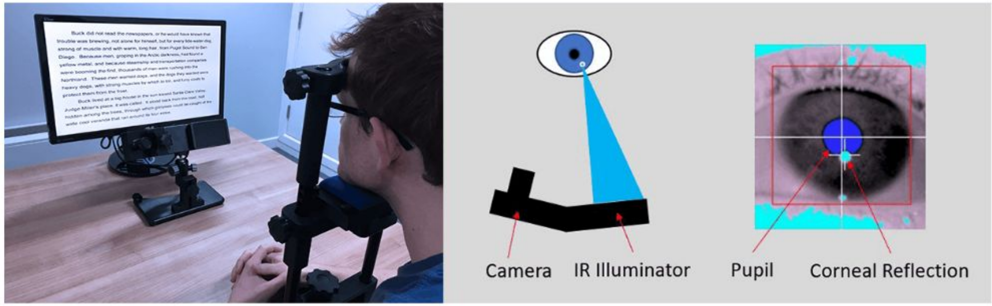
How Do Eye Trackers Work?

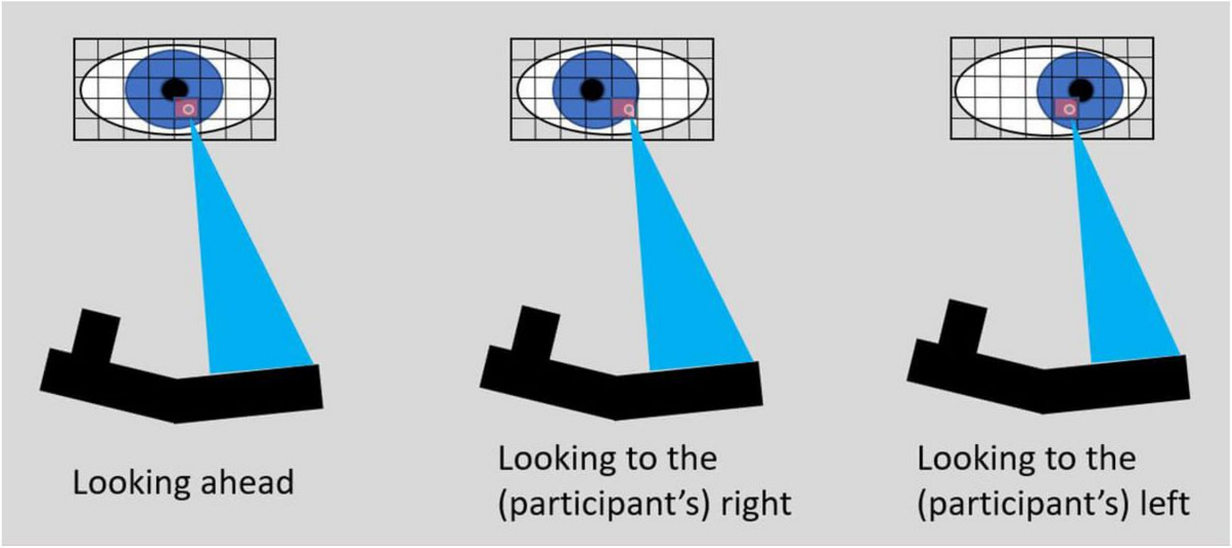
One of the biggest technological changes over the last couple of decades has been the near-universal adoption of video-based eye tracking as the technique of choice. All SR Research EyeLink systems employ video-based eye-tracking, as do most other commercially available eye trackers. So how do video-based eye trackers actually work?

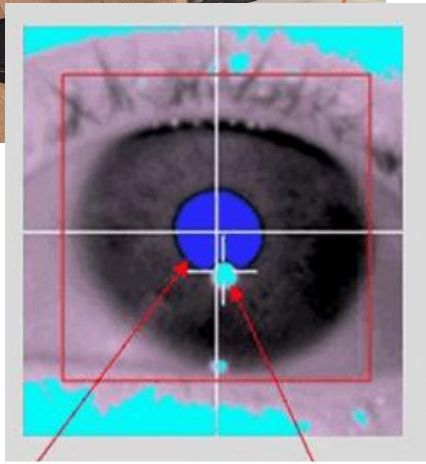
At the heart of all video-based eye tracking is a camera (or cameras) that takes a series of images of the eye. Both the **EyeLink 1000 Plus** and **EyeLink Portable Duo** use single cameras that are capable of taking up to 2000 images of both eyes every second. Within 3 ms from the image of the eye being taken, EyeLink systems work out where on the screen the participant is looking, and relay this information back to the computer controlling stimulus presentation. So how is this done? The eye-tracking software uses image processing algorithms to identify two key locations on each of the images sent by the eye-tracking camera – the center of the pupil, and the center of the corneal reflection. The corneal reflection is simply the reflection of a fixed light source (the infrared illuminator) that sits next to the camera, as illustrated below.



Eye tracking Basics

- **Key Components: Pupil** and **Corneal Reflection**
- Without identifying and maintaining these two locations, eyetracking cannot be done accurately/precisely.





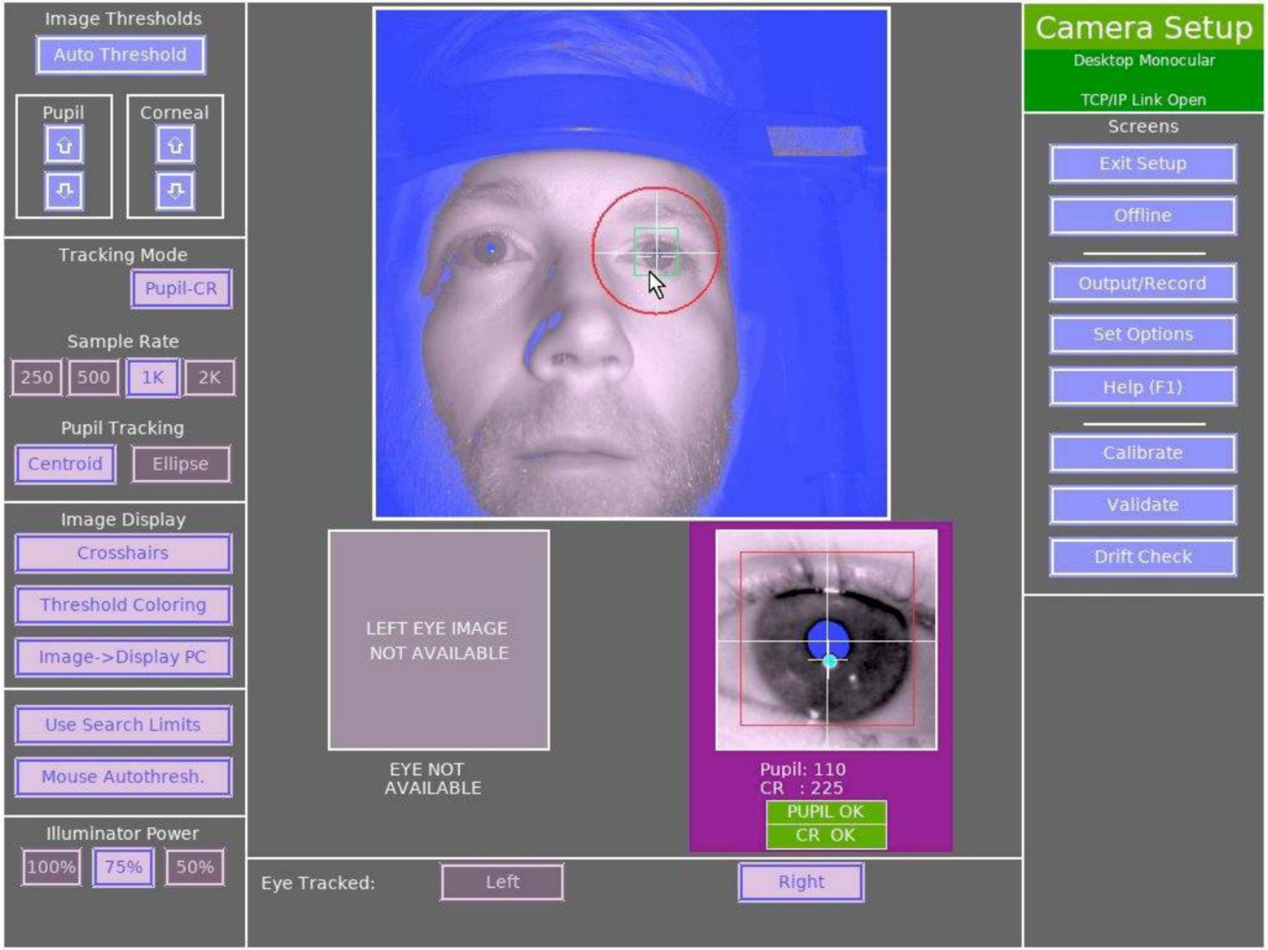
Our System –
SR Research Eyelink 1000 Plus

- Configured for MEG and MR use
- Equipped with a long-range mount.

- Minor challenges:
  - No permanent fixture (currently).
  - Poor illumination due to dewar helmet constraints and angle if not positioned appropriately.

These challenges are easily overcome with familiarity to the system.

Setup



- Identify the center of the pupil and the corneal reflection.
- Autothreshold can help adjust the illumination, but threshold bias can also be manually adjusted.
- If these target circles become frequently occluded (e.g. due to eye shape, angle, position, etc.), an **ellipse** can be fitted instead.

Calibration

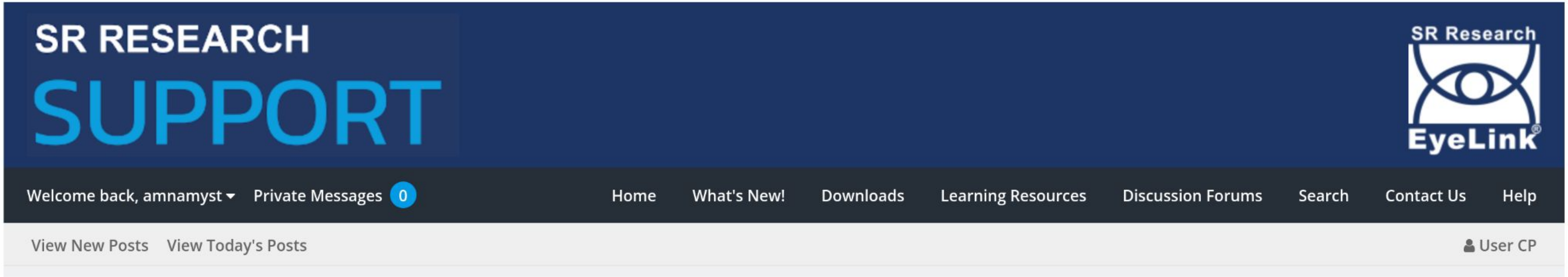
- Calibration grid can be 5, 9, 13, or a custom layout.
- Target points are displayed one at a time and participant fixations are recorded.
- Validation confirms the accuracy of each fixation – i.e. whether calibration was successful.
- If errors exceed acceptable levels (>0.5°avg., >1.0°max), adjust the setup and recalibrate.

SR Research – Resources

SR Research maintains a support forum and has prepared numerous tutorials, webinars, and troubleshooting materials for self-study.

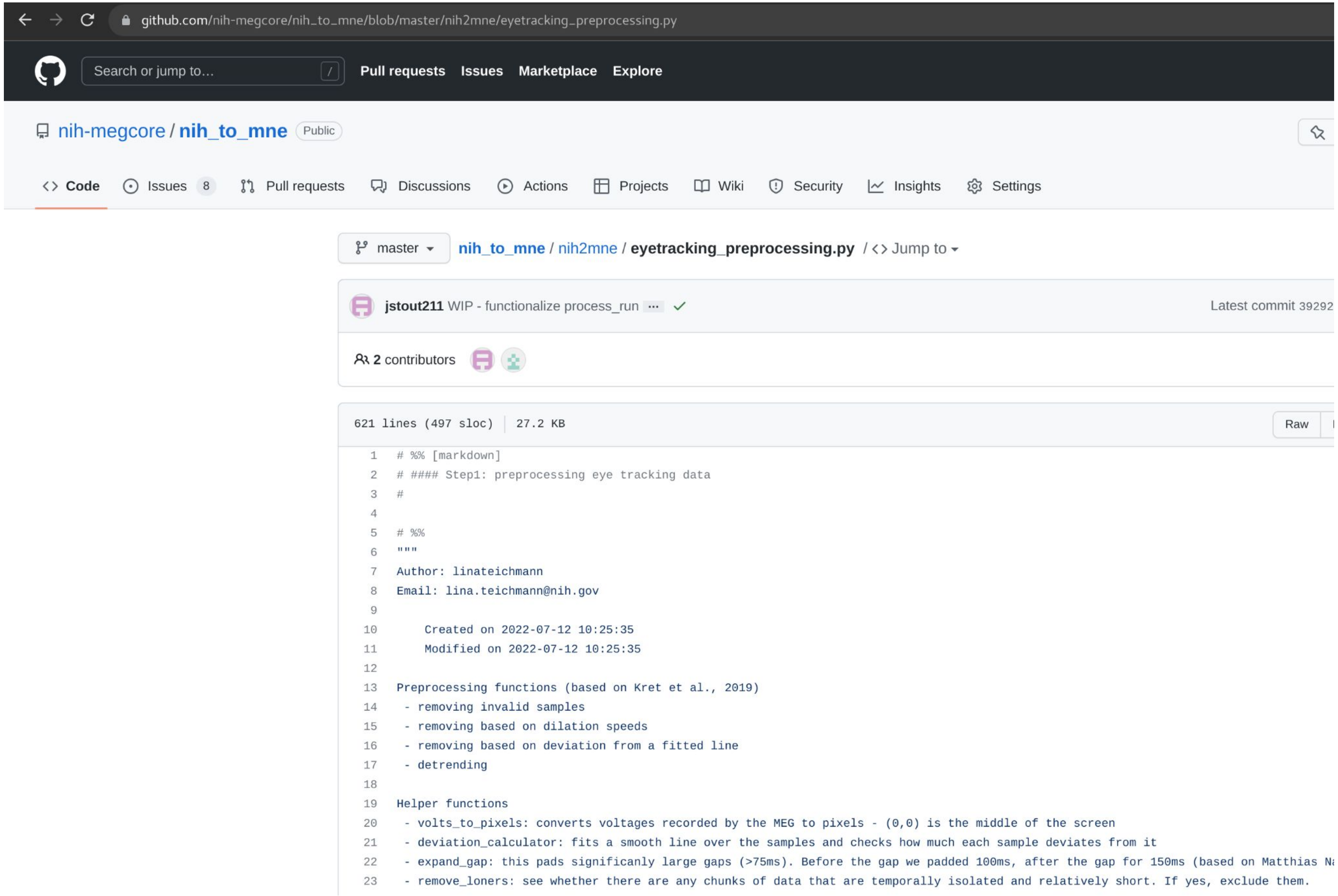
- SR Support Forum - Video Tutorials
- SR Support Forum - Getting Started
- SR Support Forum - FAQs

**(Registration is required for access, but accounts are typically approved within 24 hours.)*



Eye Tracking Code for NIH

Author: Lina Teichmann, Available on Github



Overview and Processing Steps

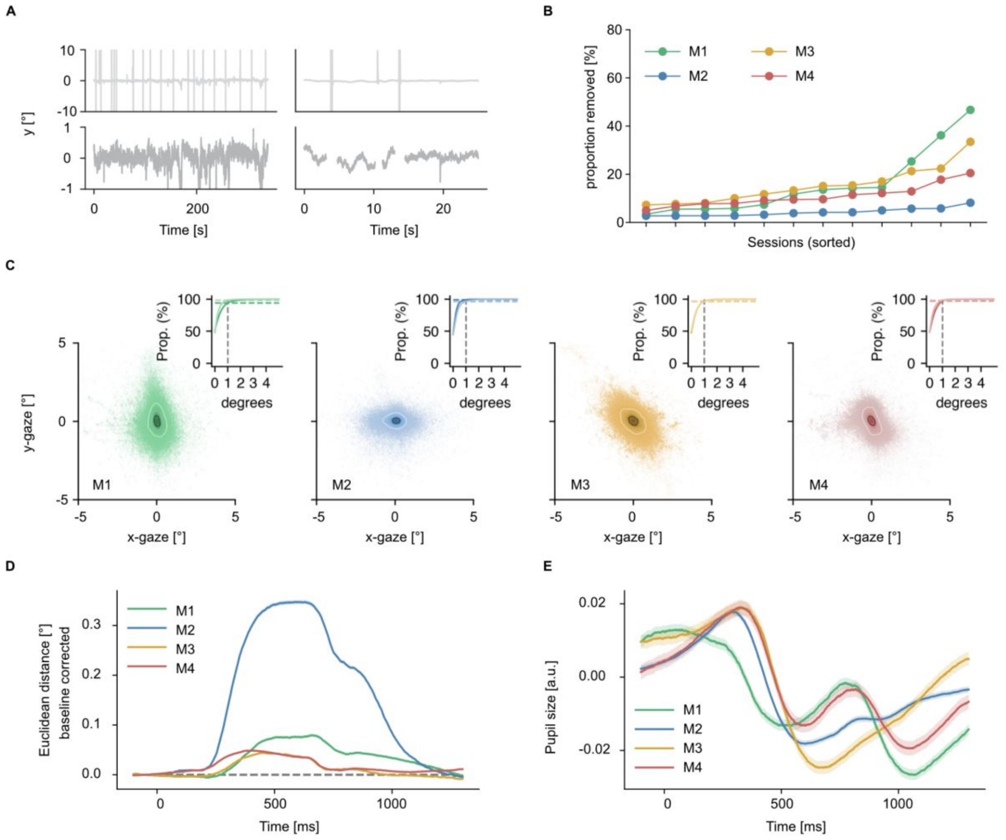
- EyeTracking outputs are sampled with the MEG on channels in Volts:
  - UADC009 - [X deviation] / UADC010 - [Y deviation] / UADC013 - [Pupil size]
- Preprocessing functions (based on Kret et al., 2019)
  - removing invalid samples - outside of visual angle of the screen
  - removing based on dilation speeds
  - removing based on deviation from a fitted line
    - Median filter data and fit trend line
    - Identify outliers and remove - iterate
  - detrending
- Helper functions
  - volts_to_pixels: converts voltages recorded by the MEG to pixels - (0,0) is the middle of the screen
  - deviation_calculator: fits a smooth line over the samples and checks how much each sample deviates from it
  - expand_gap: this pads significanly large gaps (>75ms). Before the gap we padded 100ms, after the gap for 150ms (based on Matthias Nau pipeline in NSD paper)
  - remove_loners: see whether there are any chunks of data that are temporally isolated and relatively short. If yes, exclude them.

Image provided by Lina Teichmann:

*THINGS-data: A multimodal collection of large-scale datasets for investigating object representations in brain and behavior Hebart, M.N.*1,2, Contier, O.*2,3, Teichmann, L.*1 , Rockter, A.H.1 , Zheng, C.Y.4 , Kidder, A.1 , Corriveau, A.1 , Vaziri-Pashkam, M.1 , & Baker, C.I.1*

Demonstrating gaze contingent processing.

Supplementary Figures



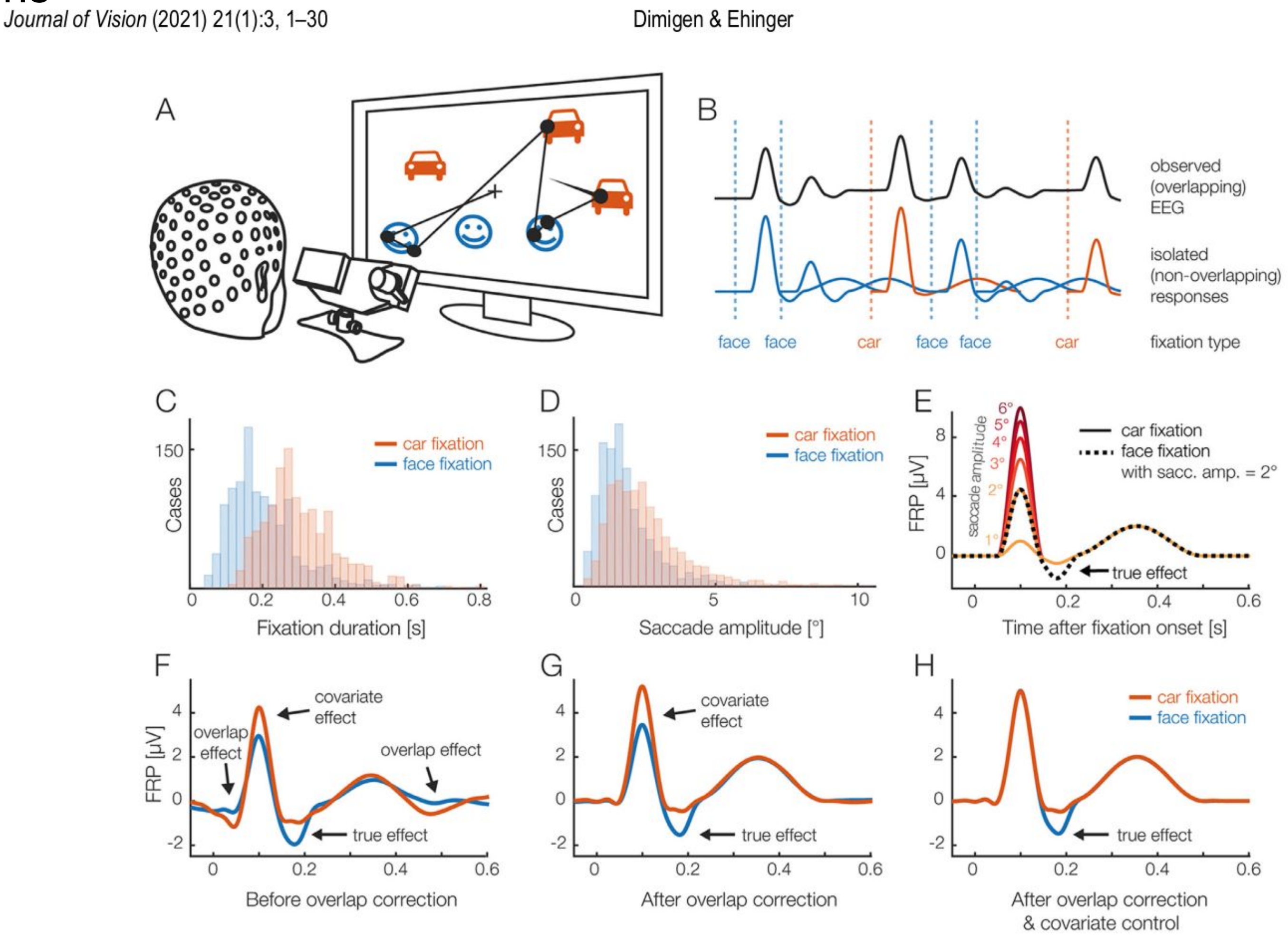
Articles for further consideration…

- Typical stimuli for neuroimaging / neurophysiology do not reflect typical human behavior.
  - Single word in center of screen
  - Repeated stimuli
  - Stim frequency set by experimenter
- Using analysis techniques from the following papers, more natural task designs can be utilized

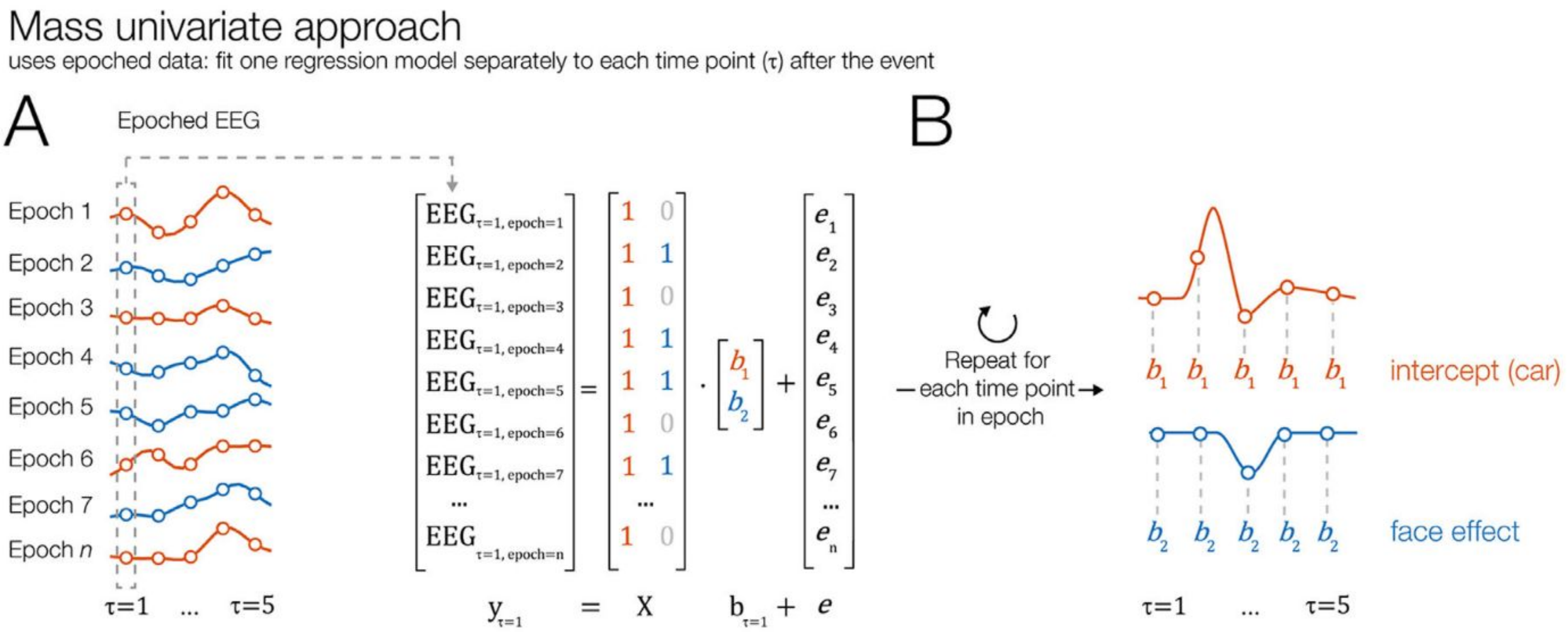
- https://jov.arvojournals.org/article.aspx?articleid=2772164
- https://www.biorxiv.org/content/10.1101/2021.07.09.451139v1.full.pdf

Regression-based analysis of combined EEG and eye-tracking data: Theory and applications

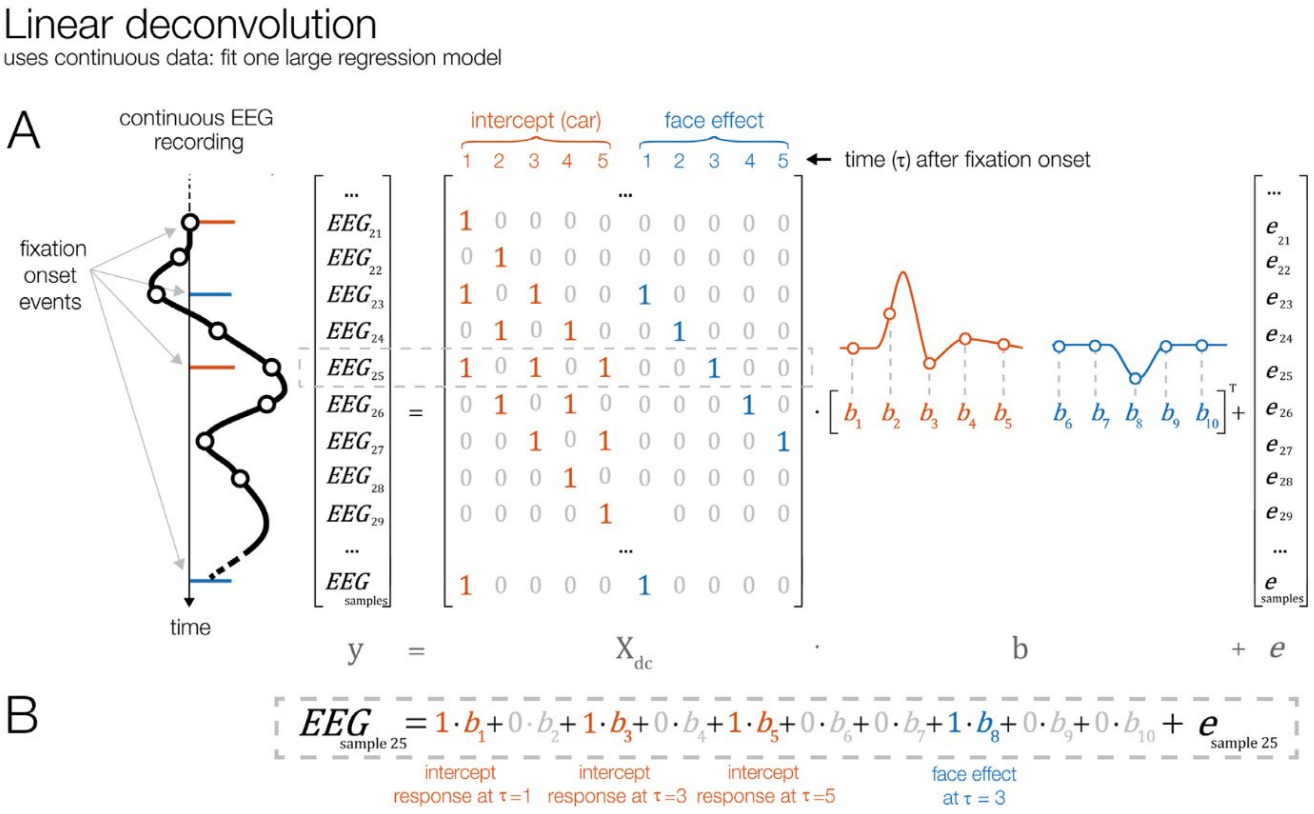
Olaf Dimigen*
Benedikt V. Ehinger



General linear model to extract conditional effects

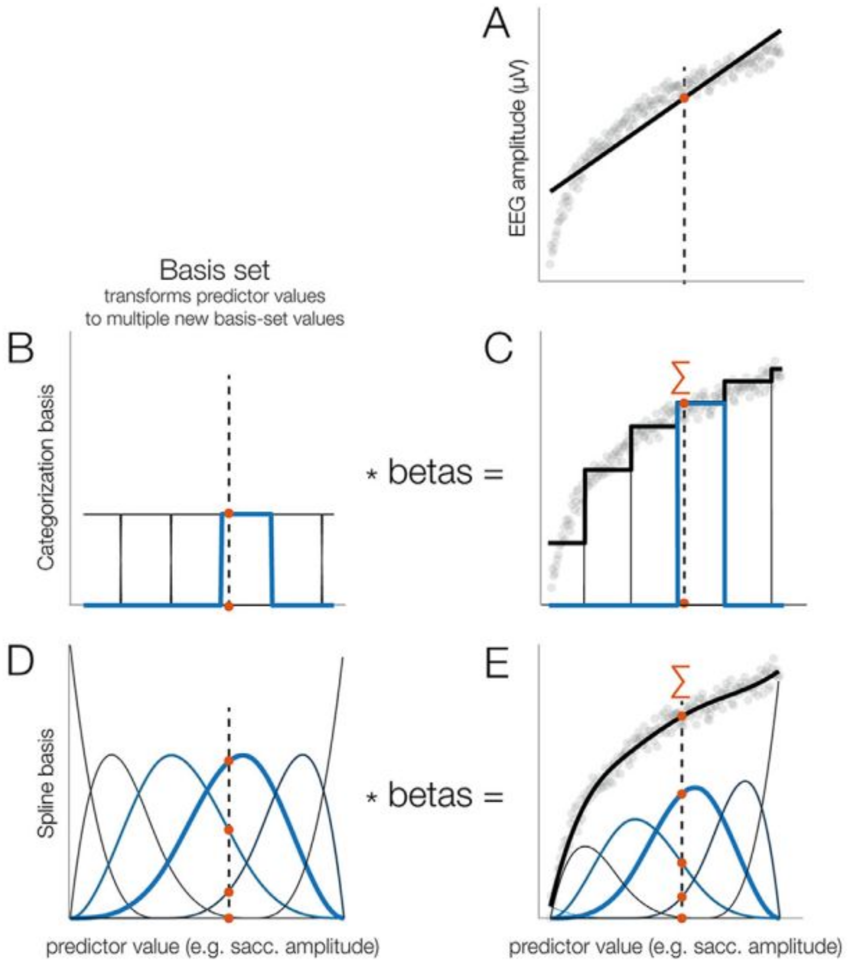


Adds time deltas to the general linear model to account for overlapping stimuli



Modeling Nonlinear effects
(see task 2)

Figure 5. Using splines to model nonlinear effects, illustrated here for simulated data. (A) Example of a relationship between a predictor (e.g., saccade amplitude) and a dependent variable (e.g., fixation-related P1). As can be seen, a linear function (black line) fits the data poorly. The dashed vertical line indicates some example value of the independent variable (IV) (e.g., a saccade amplitude of 3.1°). (B) Categorization basis set. Here, the range of the IV is split up into non-overlapping subranges, each coded by a different predictor that is coded as 1 if the IV value is inside the range and as 0 otherwise. The IV is evaluated at all functions, meaning that, in this case, the respective row of the design matrix would be coded as [0 0 0 1 0 0]. (C) After computing the betas and weighting the basis set by the estimated beta values, we obtained a staircase-like fit, clearly better than the linear predictor, but still poor. (D) Spline basis set. The range of the IV is covered by several spline functions that overlap with each other. Note that the example value of the IV (3.1°) produces non-zero values at several of the spline predictors (e.g., [0 0 0.5 0.8 0.15 0]). (E) After computing the betas and weighting the spline set by the betas, we obtain a smooth fit.



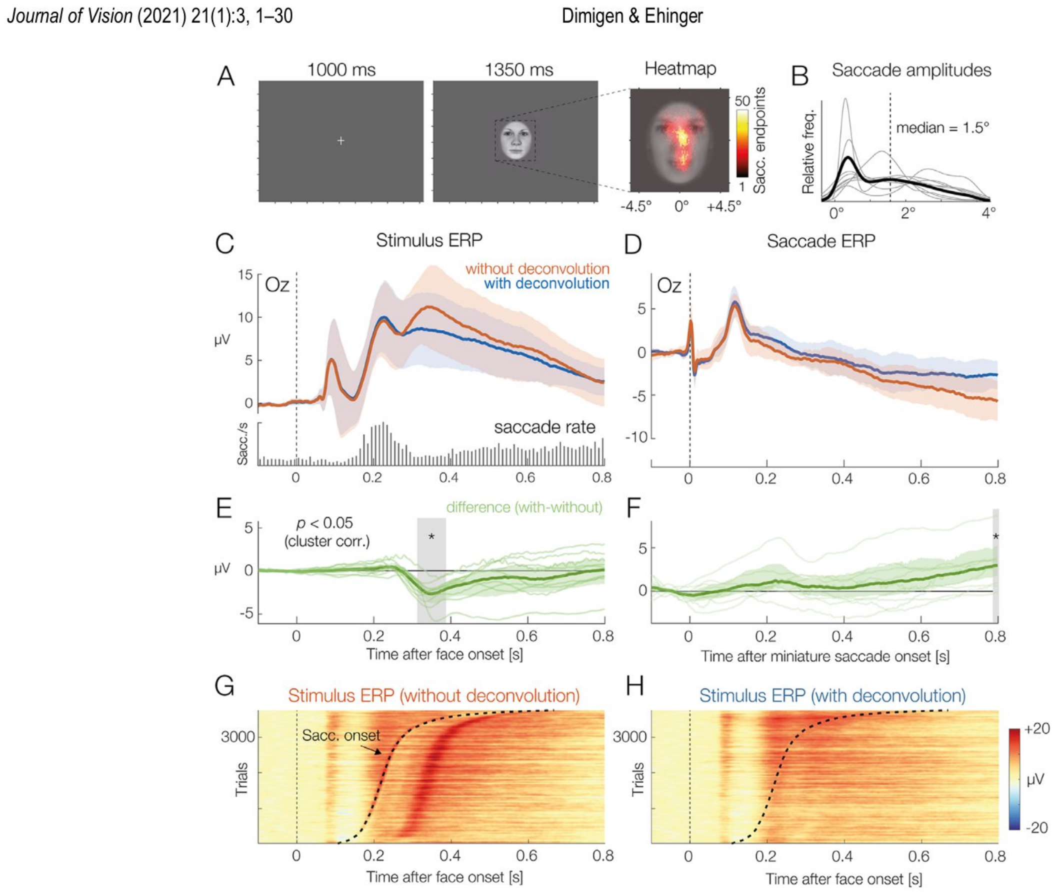
Task 1 - Facial Processing

- Subjects instructed to fixate at the center of the screen
- Images of faces (happy/sad/neutral) were presented in the center of the screen

"Eye-tracking revealed that participants made at least one miniature saccade in the vast majority (99%) of trials. With a median amplitude of 1.5° (Figure 6B), most of these saccades were not genuine microsaccades but rather small exploratory saccades aimed at the eyes or at the mouth region (Figure 6A), the parts of the face most informative for the emotion classification task."

"Each miniature saccade elicits its own visually evoked lambda response (Dimigen et al., 2009), which peaks around 110 ms after saccade onset."

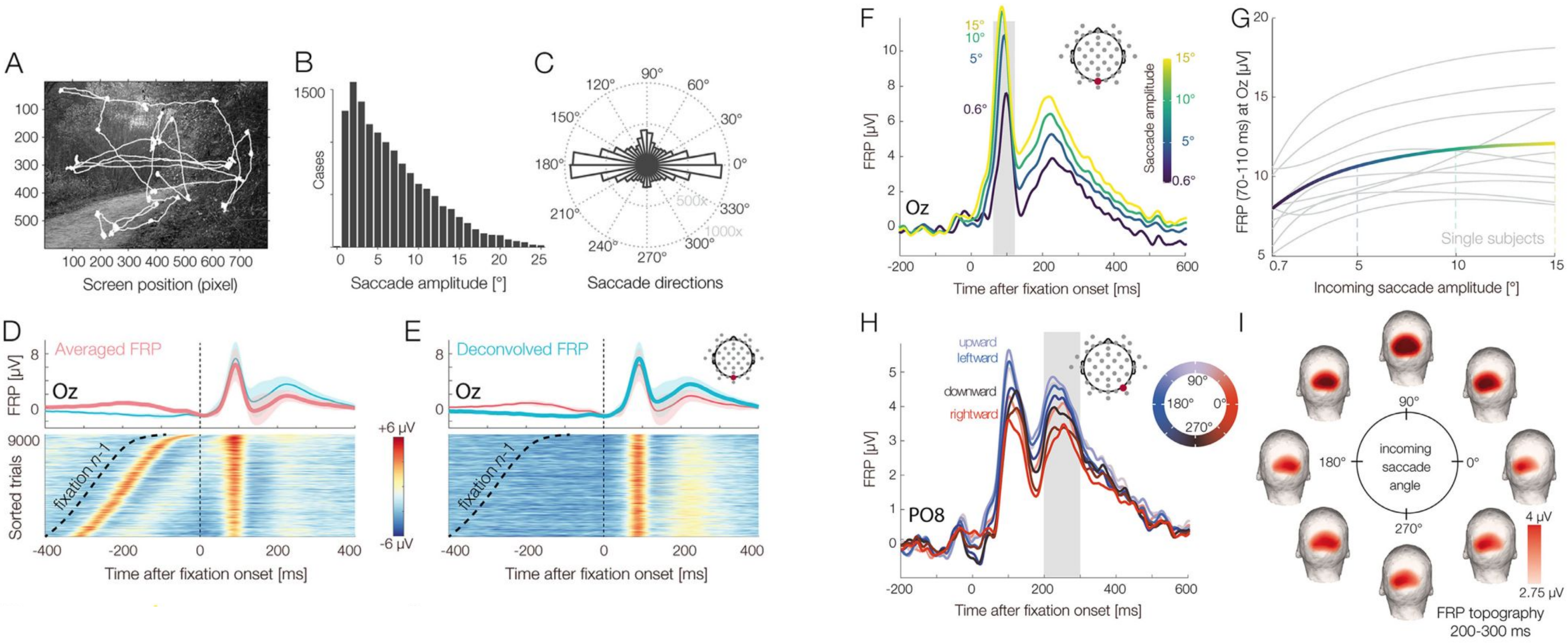
Accounting for microsacade effects



Task 2 - Scene Viewing

What is clear, however, is that, in addition to local stimulus features, properties of the incoming saccade strongly influence neural responses following fixation onset (Armington & Bloom, 1974; Thickbroom et al., 1991). This means that even a slight mismatch in oculomotor behavior between two conditions will produce spurious differences between the respective brain signals.

Results also confirm that this effect is indeed highly nonlinear. The increase in P1 amplitude with saccade size was steep for smaller saccades (< 6°) but then slowly leveled off for larger saccades.

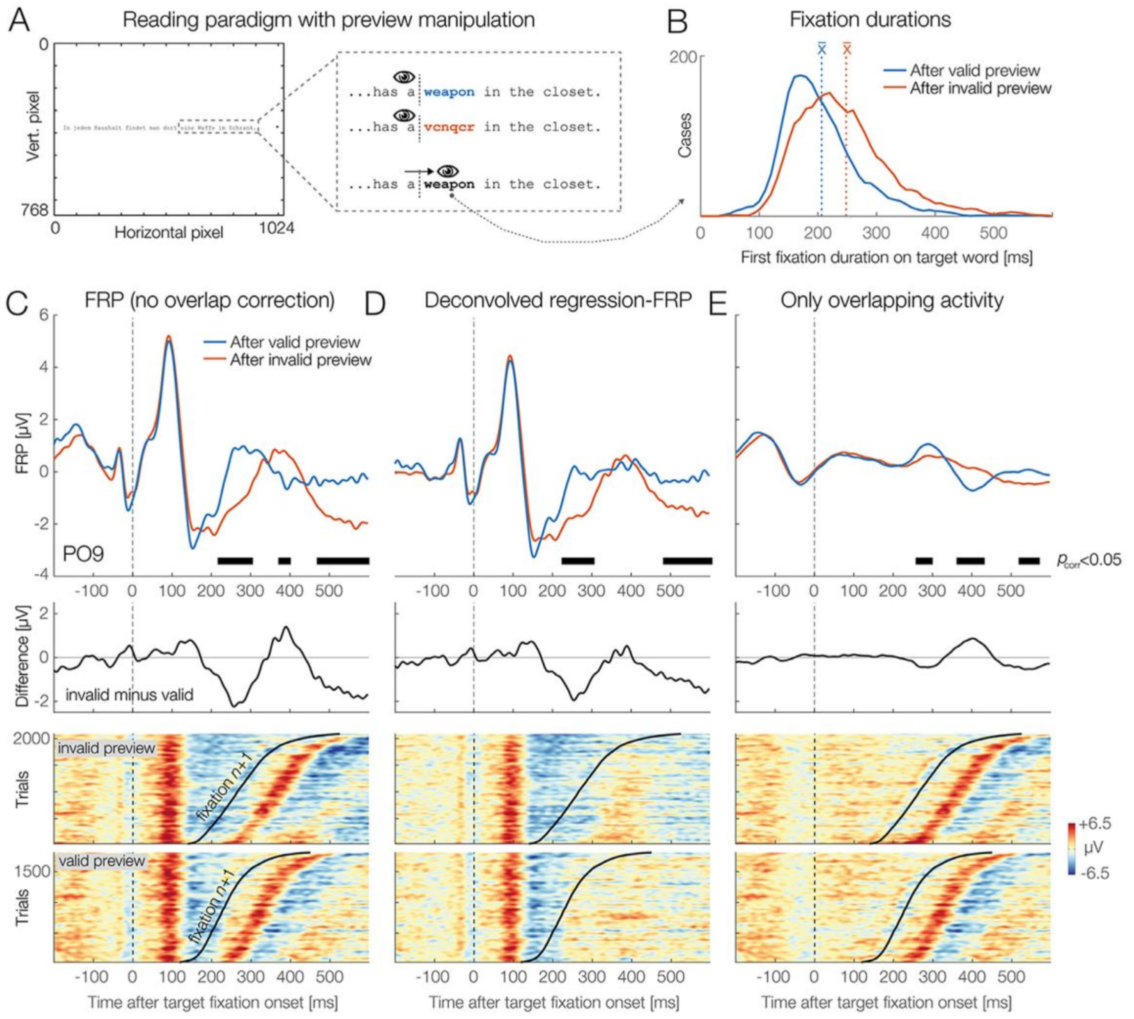

A
100
200
300
400
500
100 200 300 400 500 600 700
Screen position (pixel)
B
1500
Cases
0 5 10 15 20 25
Saccade amplitude [°]
C
90°
120°
60°
150°
30°
180°
0°
210°
330°
240°
270°
300°
500x
1000x
Saccade directions
D
Averaged FRP
FRP [µV]
8
0
Oz
9000
Sorted trials
fixation n-1
-400 -200 0 200 400
Time after fixation onset [ms]
+6 µV
-6 µV
E
Deconvolved FRP
8
0
Oz
fixation n-1
-400 -200 0 200 400
Time after fixation onset [ms]
F
15°
10°
5°
0.6°
FRP [µV]
Oz
-200 0 200 400 600
Time after fixation onset [ms]
Saccade amplitude
G
FRP (70-110 ms) at Oz [µV]
20
15
10
5
Single subjects
0.7 5 10 15
Incoming saccade amplitude [°]
H
upward
leftward
downward
rightward
FRP [µV]
PO8
-200 0 200 400 600
Time after fixation onset [ms]
90°
180°
0°
270°
I
incoming
saccade
angle
4 µV
2.75 µV
FRP topography
200-300 ms

Experiment 3: Natural Reading

One key property of visual word recognition that is neglected by serial presentation procedures is that the upcoming word in a sentence is usually previewed in parafoveal
vision (eccentricity 2° to 5°) before the reader look at it

The parafoveal preprocessing then facilitates recognition of the word when the word has been fixated. This facilitation is evident in the classic preview benefit (Rayner, 1975) in behavior, such that words that were visible during preceding fixations receive 20- to 40-ms shorter fixations (Vasilev & Angele, 2017)

Participants read 144 pairs of German sentences belonging to the Potsdam Sentence Corpus 3, a set of materials previously used in psycholinguistic ERP research and described in detail in Dambacher et al. (2012). On each trial, two sentences were successively presented as single lines of text on the monitor (Figure 8A). Participants read the sentences at their own pace and answered occasional multiple-choice comprehension questions presented randomly after one third of the trials.


A
Reading paradigm with preview manipulation
Vert. pixel
Horizontal pixel
...has a weapon in the closet.
...has a vcnqcr in the closet.
...has a weapon in the closet.
B
Fixation durations
After valid preview
After invalid preview
Cases
First fixation duration on target word [ms]
C
FRP (no overlap correction)
D
Deconvolved regression-FRP
E
Only overlapping activity
FRP [µV]
PO9
Difference [µV]
invalid minus valid
invalid preview
valid preview
fixation n+1
Trials
µV
Time after target fixation onset [ms]

Fixation related potentials
How to extraction information about the brain state from semi-overlapping brain processes.
How to remove eye-related artifacts

Investigating brain mechanisms underlying natural reading by co-registering eye tracking with combined EEG and MEG

- Typical stimuli are presented in an unnatural way, eg single words at the center of the screen presented at regular intervals.
- This paper demonstrates natural reading in MEG

Task: 4 word sentences of either plausible or implausible final word

Table 1
Example Sentence Quadruple

Pronoun	Verb	Preposition	Noun	Plausibility
I	frighten	the	calf	Plausible
You	frighten	the	class	Plausible
They	frighten	the	towel	Implausible
We	frighten	the	corn	Implausible

Table 2: Stimulus parameters

	Number of letters	Word form frequency p/m	Orthographic neighborhood size	Cloze probability	Plausibility
Plausible	4.8	417	5.7	0.0	6.4
Implausible	5.0	383	5.7	0.0	1.9

Fixation duration is much shorter than processing speed of language

Table 4: Behavioural results for target words.			
Measure	**Plausible**	**Implausible**	**P**
Reading speed (words/s)	3.93	3.65	<0.001
Total number of saccades	436	463	<0.01
Percentage of regressive saccades (%)	3.65	5.71	<0.01
Saccade amplitude (vis. deg.)	2.92	2.94	<0.01
Fixation duration (s)	0.150	0.152	n. s.

Evoked response localized using minimum norm.

Initial activity is in the posterior occipital processing regions

Later activity is localized over left superior and middle temporal gyri, known for language processing

****Unfortunately this is only for target words at the end of the sentence and not all words.**

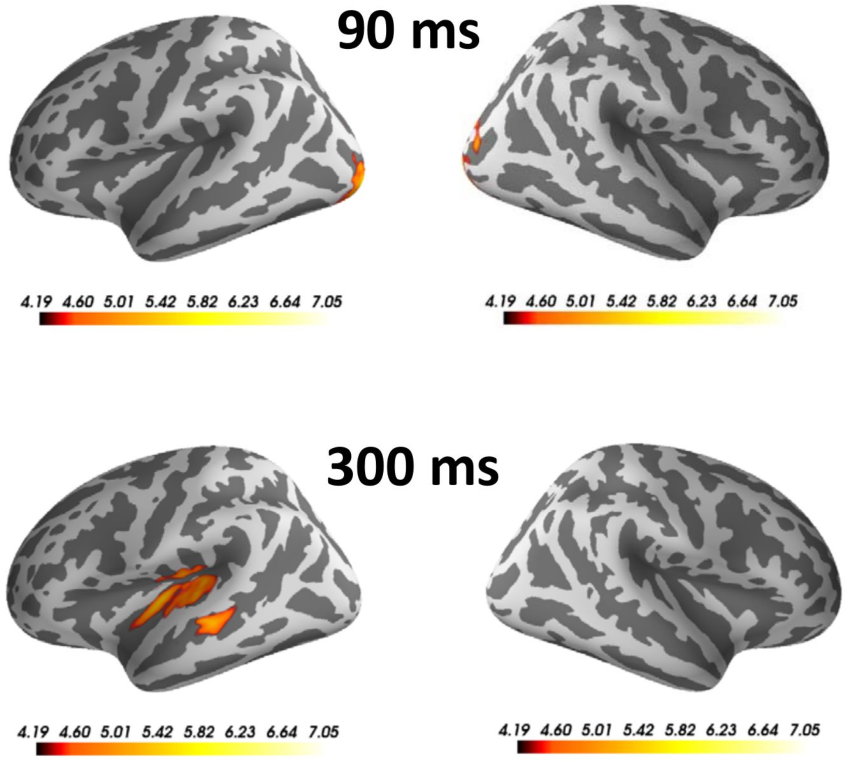


Figure 3: L2-minimum-norm source distributions from combined EEG and MEG data for the average across all target words, at different latencies.

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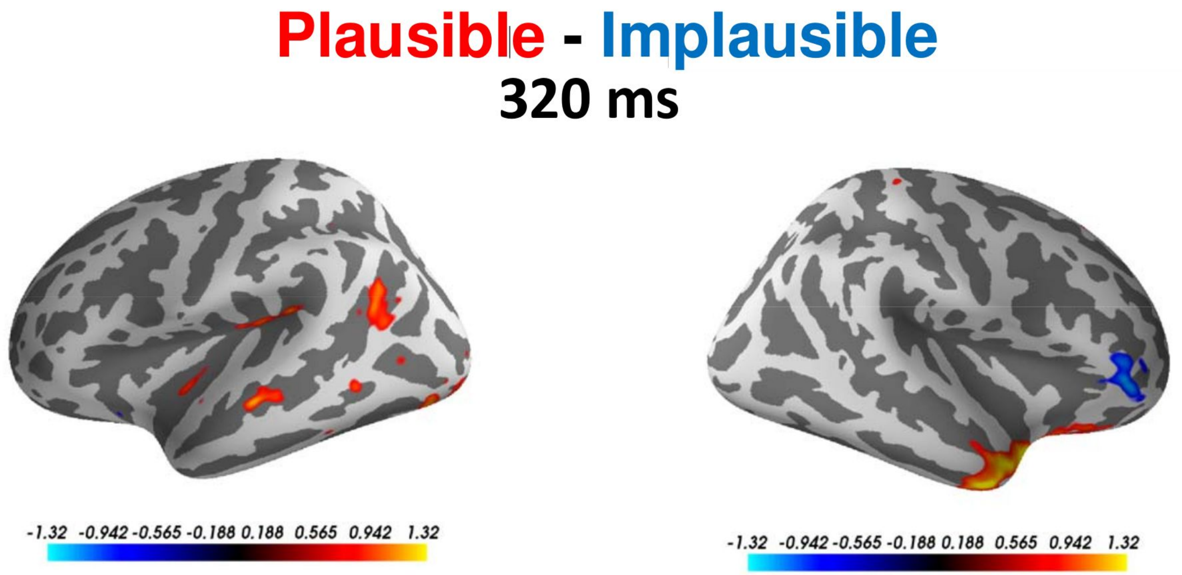

Figure 4: Difference between source distributions for Plausible and Implausible target words at 320 ms.