

Objectives

- Eye-Fixation / Saccade Related Potentials (EFRP / ESRP) : joint analysis of eye-tracking and EEG data.
 - ✓ Early visual potentials : Lambda response (λ -wave) $\rightarrow$ 3 sub-components (latency up to ≈ 150 ms).
 - ✓ The two first sub-components (λ_1 , λ_2) are saccade onset components, the third (λ_3 , the most prominent) is a fixation onset component (or a saccade offset component).
 - ✓ The λ -wave is a consequence of visual changes on the retina.
 - ✓ The λ -wave is modulated by features of incoming saccades [Yagi, 1981; Thickbroom, et al., 1991], but also by low level features of gazed area [Ossandon, et al., 2010].
 - ✓ Saccadic activities depending on amplitude and direction impact EFRP estimation [Nikolaëv, et al., 2016], during cognitive tasks, such as visual perception or reading for example.
- Linear models based on the General Linear Model (GLM) [Congedo, et al., 2016; Kristensen, et al., 2017] are efficient to deconvolve overlapping evoked potentials as EFRP and ESRP.

To that end :

- To differentiate the different sub-components, both Eye-Fixation Related Potentials and Eye-Saccade Related Potentials have to be take into account into an unique model :
 - ✓ Better understanding of the sub-components of the λ -wave.
 - ✓ Comparison of three models : the first with EFRP, the second with ESRP and the third with ESRP and EFRP estimations.

Co-registration: EEG and Eye-movements

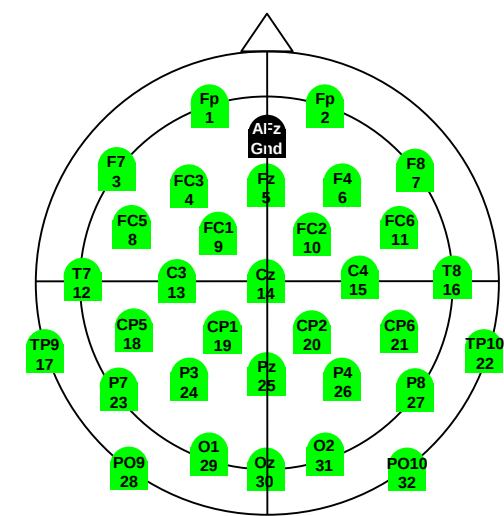
Materials

EEG

- Gtec - 32 active electrodes
- Referenced to the right mastoid - Ground AFz
- Sampled at 1000 Hz, filtered at 0.1 - 100 Hz

Eye-Tracker

- Eyelink 1000 (SR Research)
- Sampling at 1000 Hz



Data pre-processing

Synchronization

- Time-alignment with common hardware triggers

Artifacts rejection

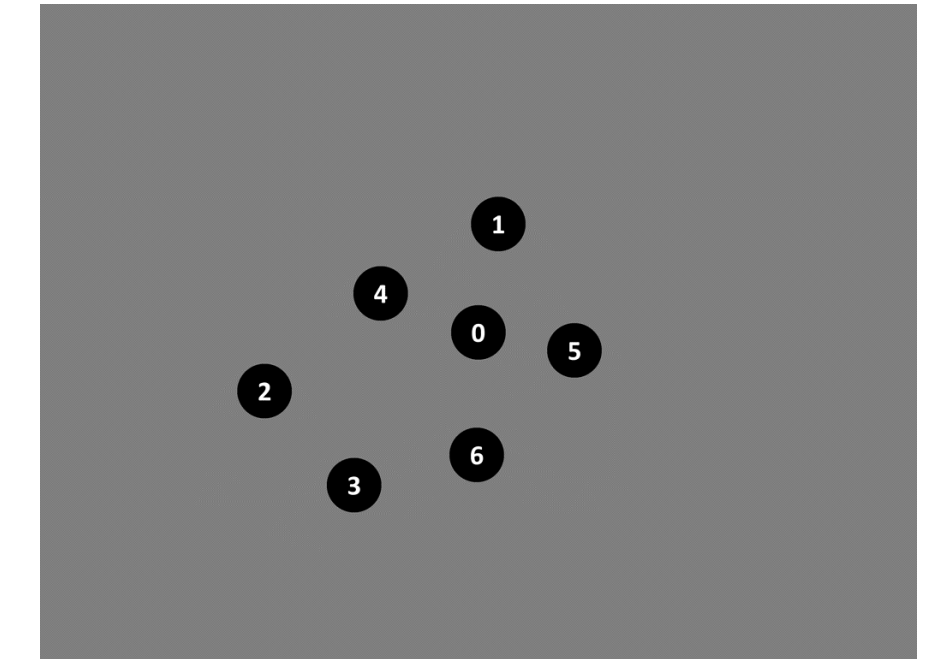
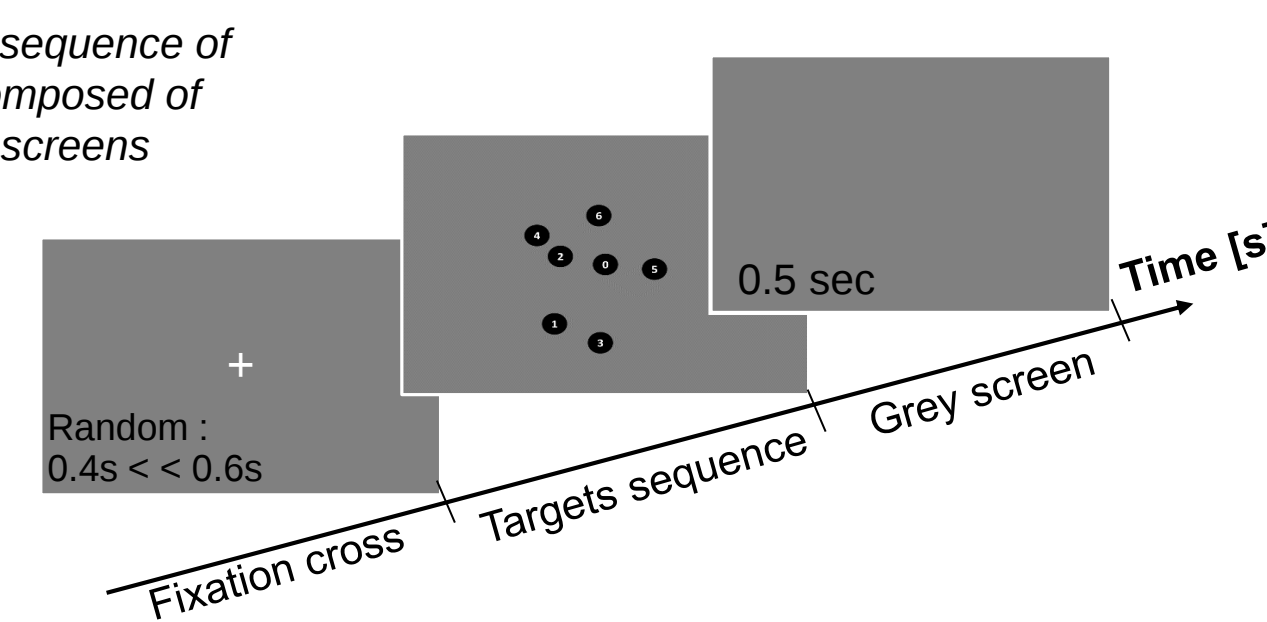
- Visual inspection (muscular activity or non-physiological artifacts)
- ICA (Sobi) correction for ocular artifacts (blinks)
- During saccades, linear regression correction for saccade artefacts

$$\text{Denoised EEG} = \text{EEG} - B * \text{Eye position}$$

Experiment

- 24 healthy participants
- 150 trials per participant : make a sequence of fixations / saccades to go from targets to targets, numbered from 0 (beginning of the sequence) to 6, and return to 0 (end of the sequence).
- The targets in the sequence are pseudo-randomly set in order to have :
 - ✓ A uniform distribution of the saccade orientations.
 - ✓ A typical distribution of incoming saccade amplitudes as for a free visual exploration.

Temporal sequence of a trial composed of three screens



Example of the spatial positions for the targets

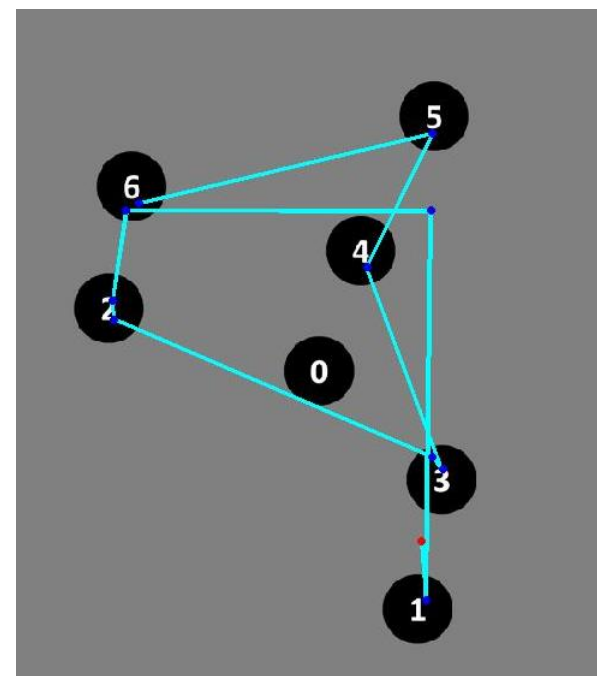
Incoming saccades: amplitude and orientation

After EEG data preprocessing

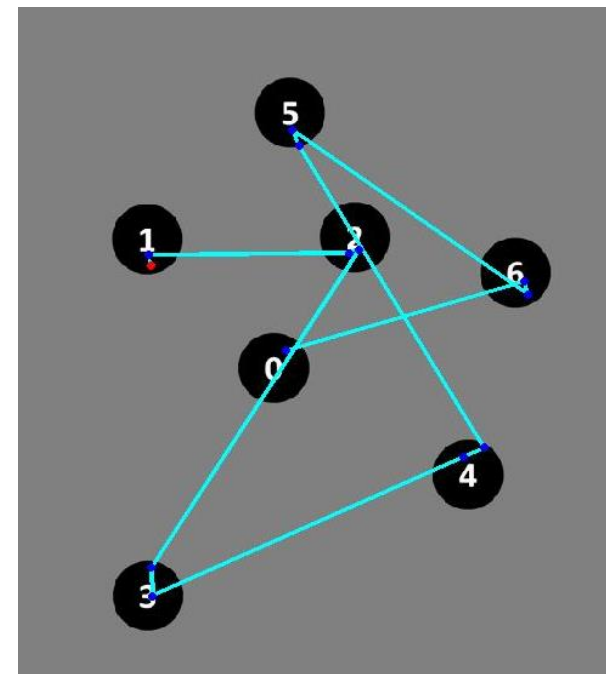
- 139.5 (10.7) trials per participant
- 10.8 (2.7) fixations per trial

Definition of the saccade classes (#6)

- Two directions $\rightarrow \leftarrow$
- Three amplitude classes :
 - ✓ Two thresholds : 4.1° ; 7.5°



Examples of scanpath



Distribution of incoming saccade : amplitudes and orientations

EFRP and ESRP estimations by GLM

Models "Fix Only" or "Sacc Only": six EFRP / ESRP $\{f_c(t), c = 1..6\}$ / $\{s_c(t), c = 1..6\}$

- EFRP or ESRP estimation taking into account responses overlap

Model « Fix Only »

$$x_i(t) = \text{stim}(t) + \sum_{c=1}^6 \sum_j f_c(t - \tau_{j(i)}^{(c)}) + n(t)$$

Model « Sacc Only »

$$x_i(t) = \text{stim}(t) + \sum_{c=1}^6 \sum_l s_c(t - \tau_{l(i)}^{(c)}) + n(t)$$

Model : "Fix & Sacc" : 6 EFRP $\{f_c(t), c = 1..6\}$ and six ESRP $\{s_c(t), c = 1..6\}$

- Estimation taking into account responses overlap and post-saccadic activities

$$x_i(t) = \text{stim}(t) + \sum_{c=1}^6 \sum_j f_c(t - \tau_{j(i)}^{(c)}) + \sum_{c=1}^6 \sum_l s_c(t - \tau_{l(i)}^{(c)}) + n(t)$$

Estimation by GLM

- Output: $\{f_c(t), c = 1..6\}$, $\{s_c(t), c = 1..6\}$

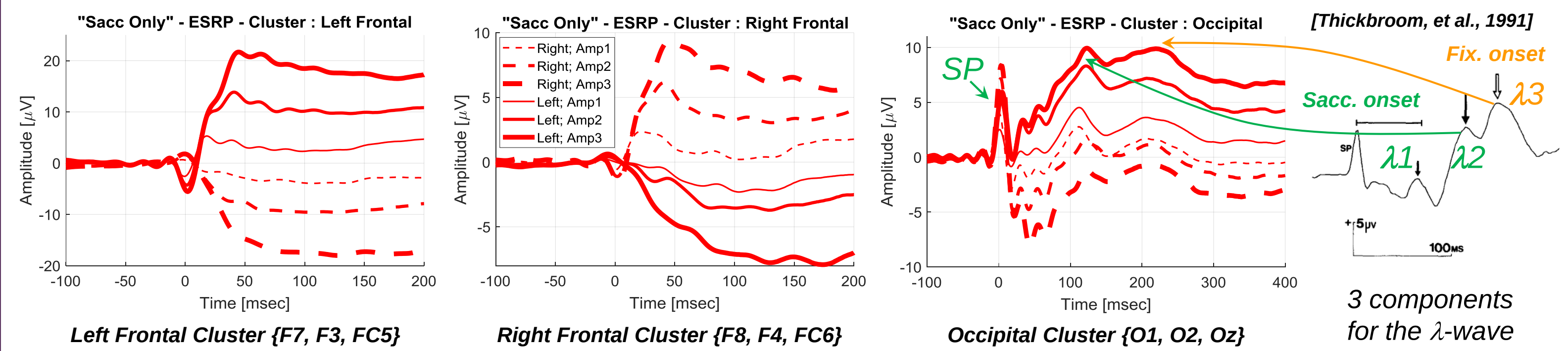
- Input : Epochs $\{x_i(t), i = 1..N\}$, Latencies $\{\tau_{j(i)}^{(c)}, \tau_{l(i)}^{(c)}\}$

$$\hat{a}^{GLM} = (D^T \cdot D)^{-1} \cdot D \cdot x$$

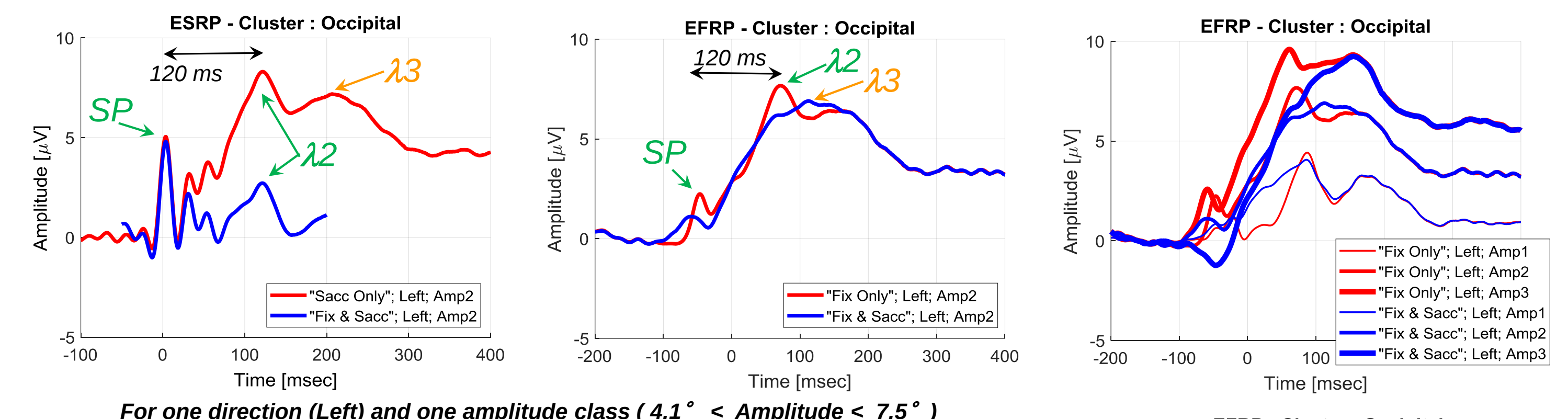
Eye-Fixation (Saccade)-Related Potentials

Model "Sacc Only": ESRP estimation on frontal sites (Left vs Right)

- $\rightarrow$ As expected, clear effect of amplitude and direction, on the right and left frontal site
- $\rightarrow$ Identification of the sub-components of the λ -wave on the occipital site

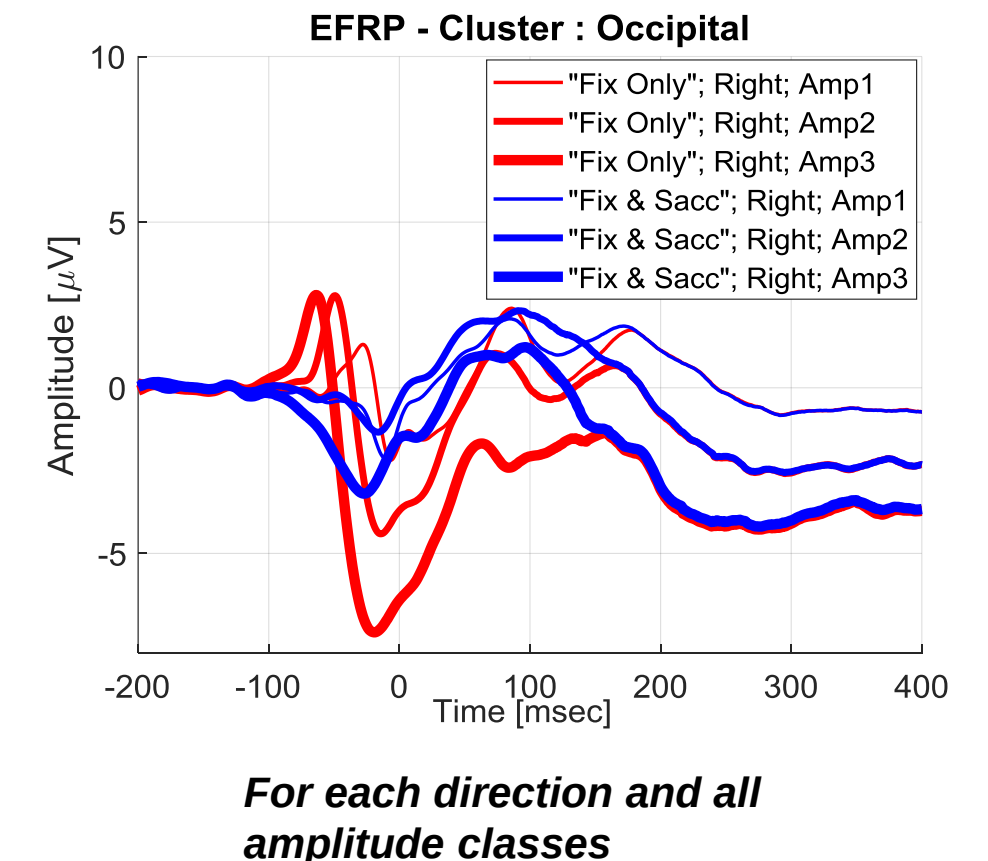


ESRP / EFRP estimation with the "Sacc Only" / "Fix Only" vs the "Fix & Sacc" model



Main Results

- ESRP
 - ✓ Spike potential (SP) modulated by saccade amplitude.
 - ✓ Sub-component of the λ -wave time locked on saccade onset (λ_2) modulated by saccade amplitude and direction.
- EFRP
 - ✓ Sub-component of the λ -wave time locked on fixation onset (λ_3) also modulated by saccade amplitude and direction.
 - ✓ Baseline impacted by saccade direction. This effect is amplified if the saccadic potential is not take into account for the EFRP estimation.



For each direction and all amplitude classes

Conclusions

- Fixation and saccade as predictors in the GLM were usually considered separately;
 - ✓ It better to include them in the This is the same model (Fix & Sacc).
- λ wave with two sub-components [Yagi, 1979; Thickbroom, et al., 1991] :
 - ✓ λ_2 at the saccade onset and λ_3 at the fixation onset, modulated by amplitude and orientation.
- Be careful on the possible confounding effects between the experimental conditions and the ocular features of the incoming saccades, especially for the λ_3 sub-component.
- The EEG correction for saccade artefacts isn't still efficiently resolved :
 - ✓ The λ_3 sub-component may be a marker to assess the efficiency of the correction.

References

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Acknowledgments

