

EEG & TMS: overview of opportunities and challenges

Mateusz Gola, PhD

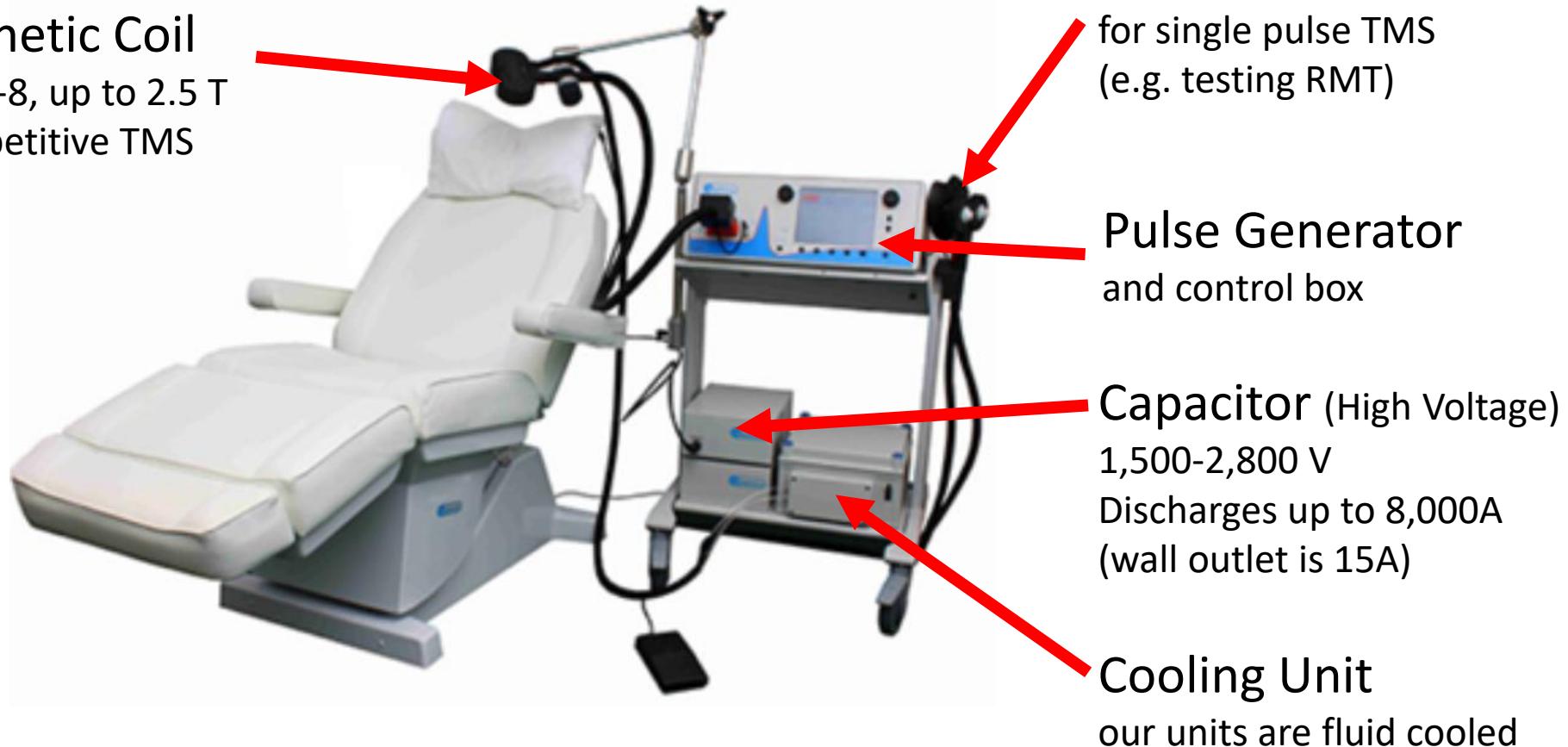
UC San Diego,
Swartz Center for Computational Neuroscience

Objectives:

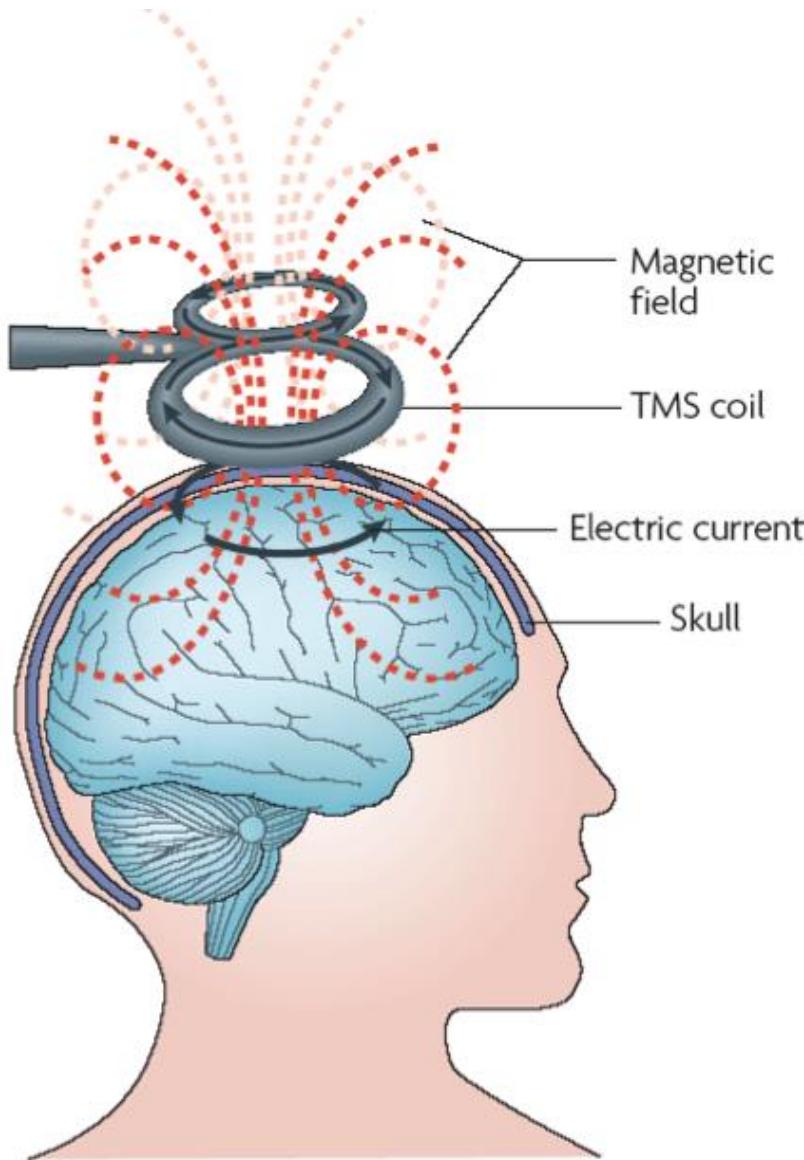
- 1. Quick introduction to TMS**
- 2. Opportunities enabled by combined TMS & EEG**
- 3. Characteristics of TMS Pulse and its impact on EEG signal**
- 4. Challenges of TMS-EEG signal analysis**
- 5. Available tools & new ideas**

Transcranial Magnetic Stimulation (TMS)

Magnetic Coil
Figure-8, up to 2.5 T
for repetitive TMS



Transcranial Magnetic Stimulation (TMS)

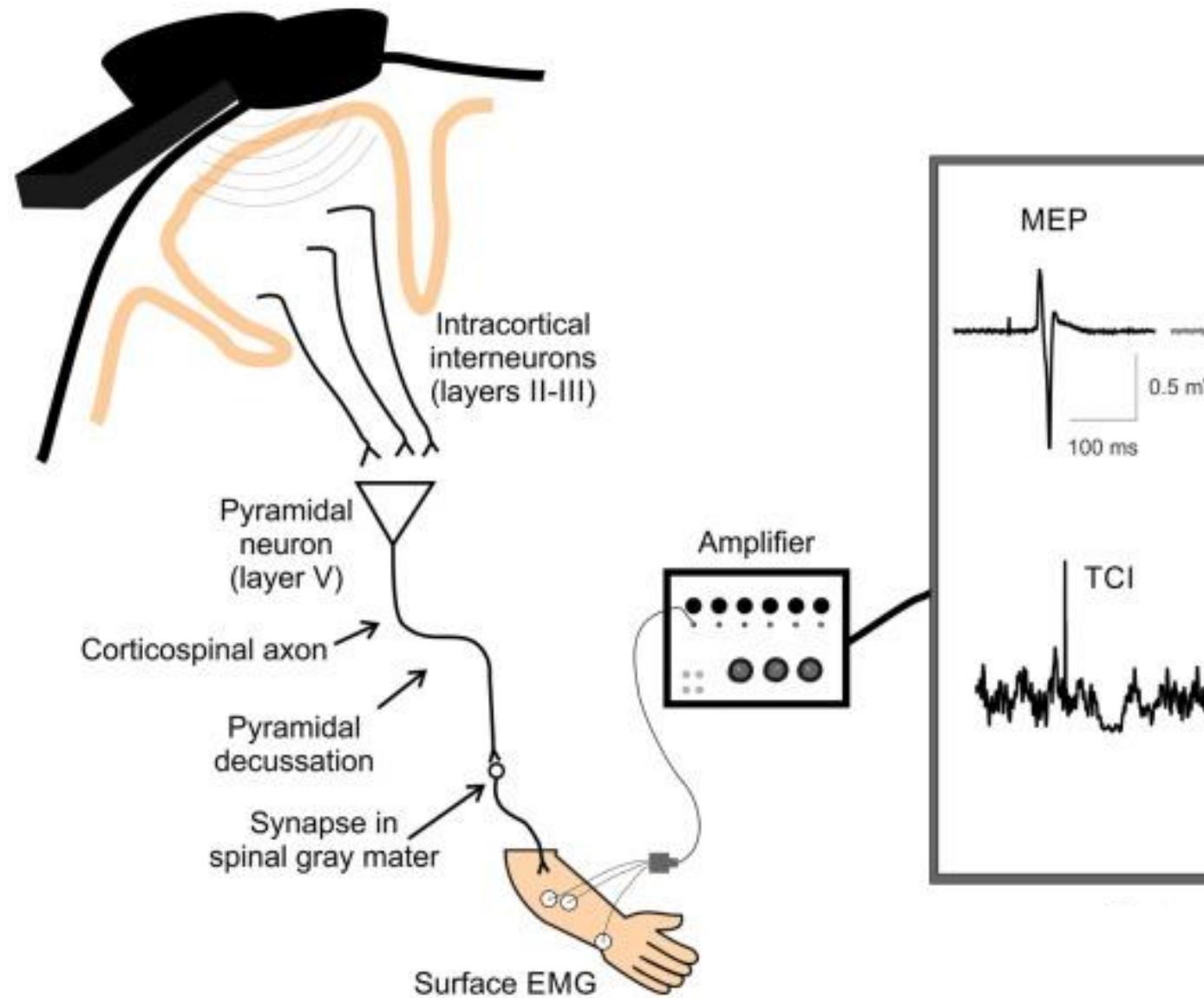


Electromagnetic Induction:

A changing magnetic field induces voltage across an electrical conductor (the brain)

Magnetic field not effected by scalp/skull as they conduct poorly

Transcranial Magnetic Stimulation (TMS)

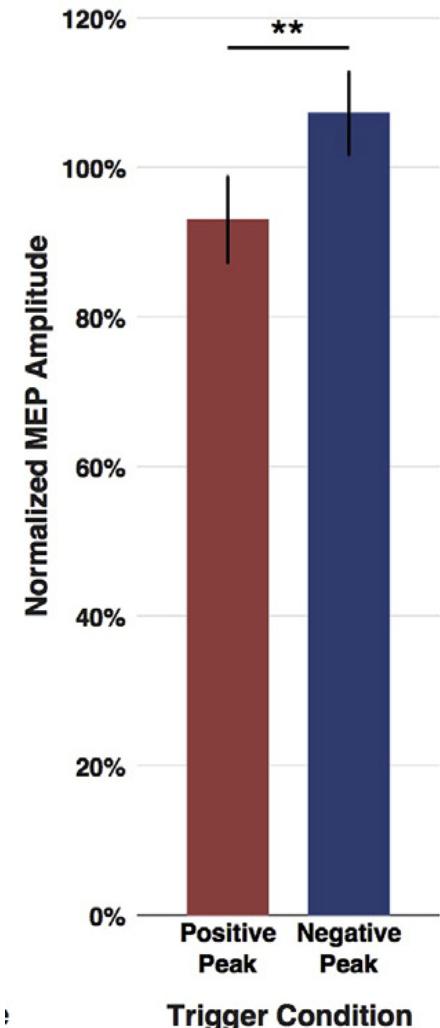
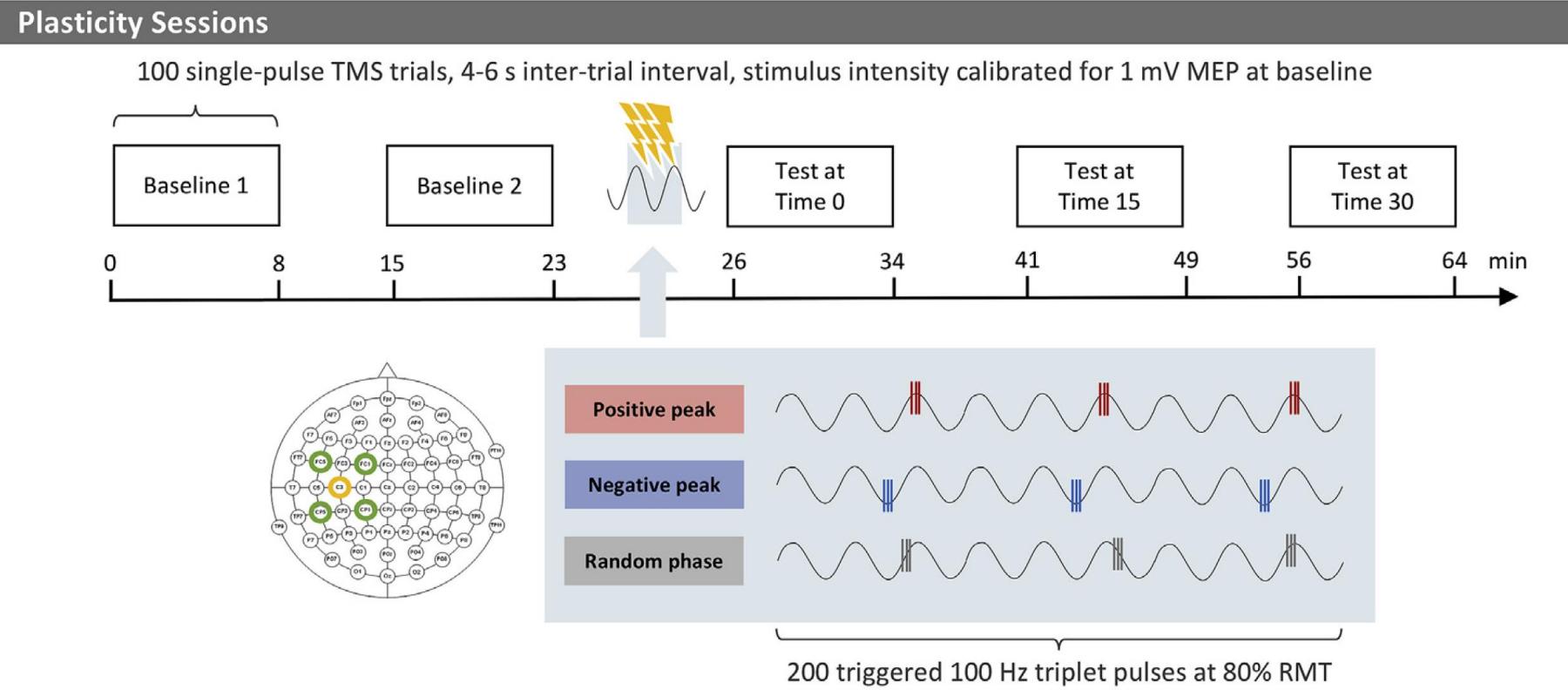


Transcranial Magnetic Stimulation (TMS)

Single Pulse TMS

- used for mapping of the central nervous system
- used clinically (e.g. in migraine headache)
- other applications (e.g. determining motor threshold for rTMS)

Motor potential & phase of ongoing EEG (Zrenner et al, 2018)

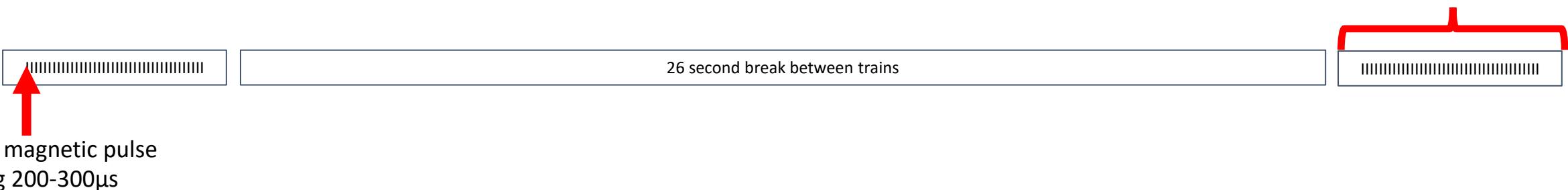


Transcranial Magnetic Stimulation (TMS)

Repetitive TMS (rTMS)

- multiple magnetic pulses are given in sequence
- used to treat a host of clinical conditions
- able to produce long-term neuromodulation
- pulses are repeated at defined intervals with defined breaks

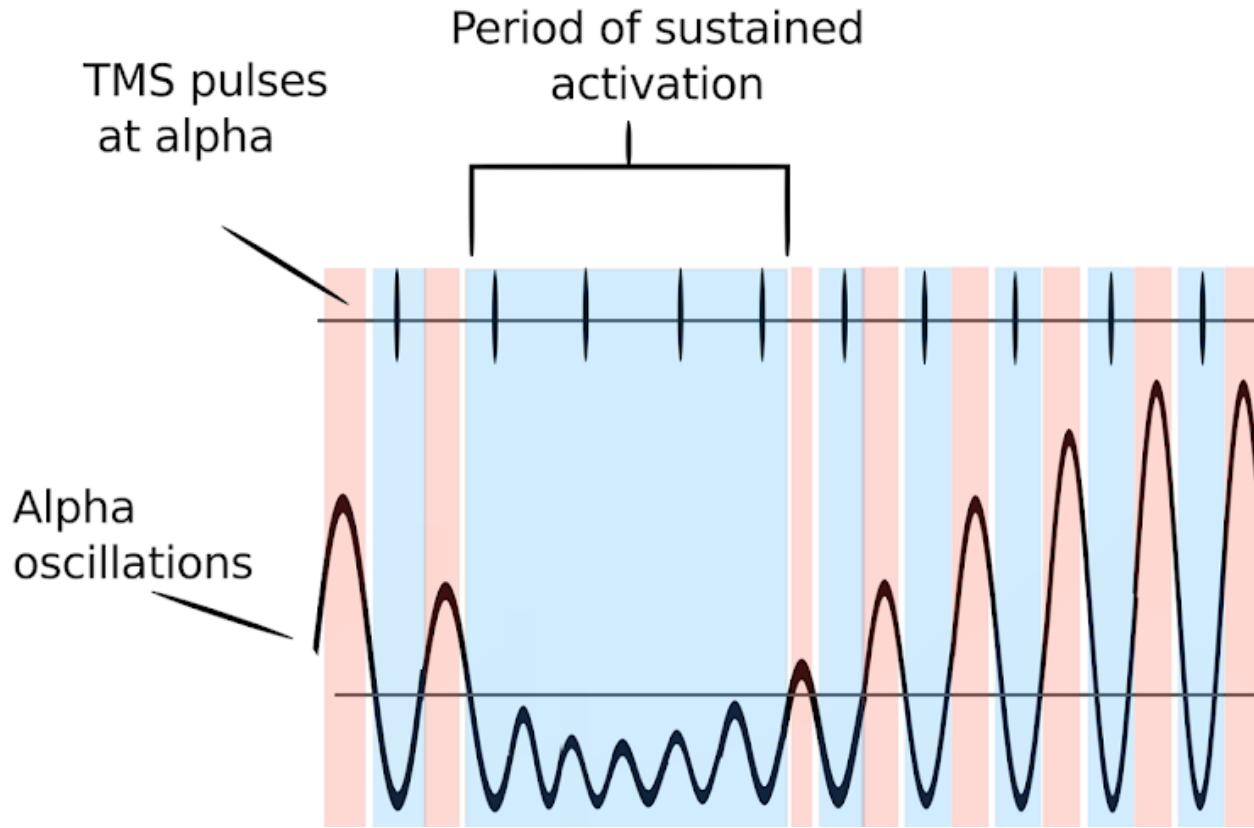
one “train” of magnetic pulses



Current Clinical Practice (FDA approved)

- rTMS for recurrent/refractory **Major Depressive Disorder (MDD)**
- neuromodulation (direct electrical and magnetic) for **Migraine Headache**
- rTMS for Obsessive Compulsive Disorder (OCD)

rTMS – enforcement of brain oscillations



Standard parameters for depression treatment:

Intensity

-FDA-approved depression treatments are at 80-120% RMT

Frequency

-FDA-approved depression rTMS is 1Hz, 5Hz, 10Hz, 15Hz or 20Hz

-New complex protocols includes changing frequency (iTBS 50Hz x 3 pulses then 5Hz x 10 pulses)

Train Duration

-FDA-approved depression treatments train durations 2-4 seconds

Location of Target/Stimulation Location

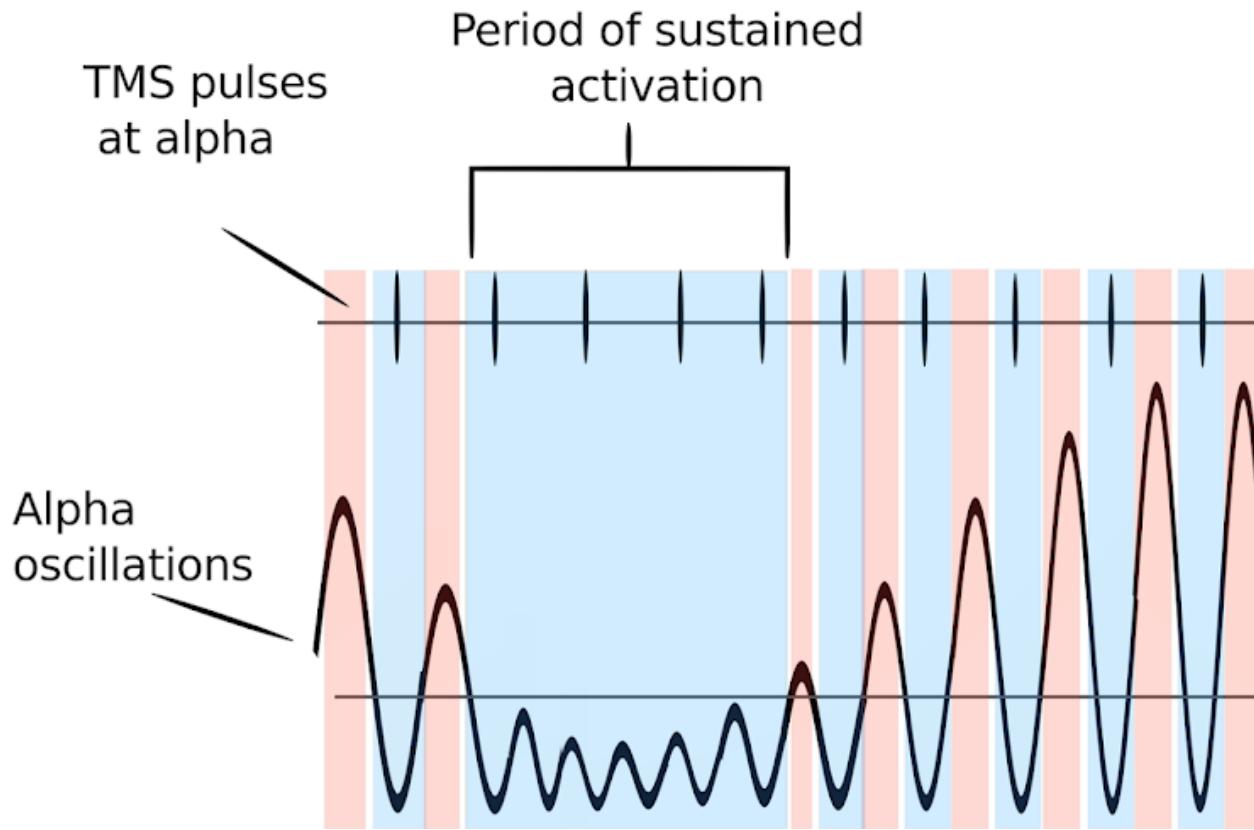
-FDA-approved depression stimulation is dorsolateral left prefrontal cortex (DLPFC)

Treatment Duration

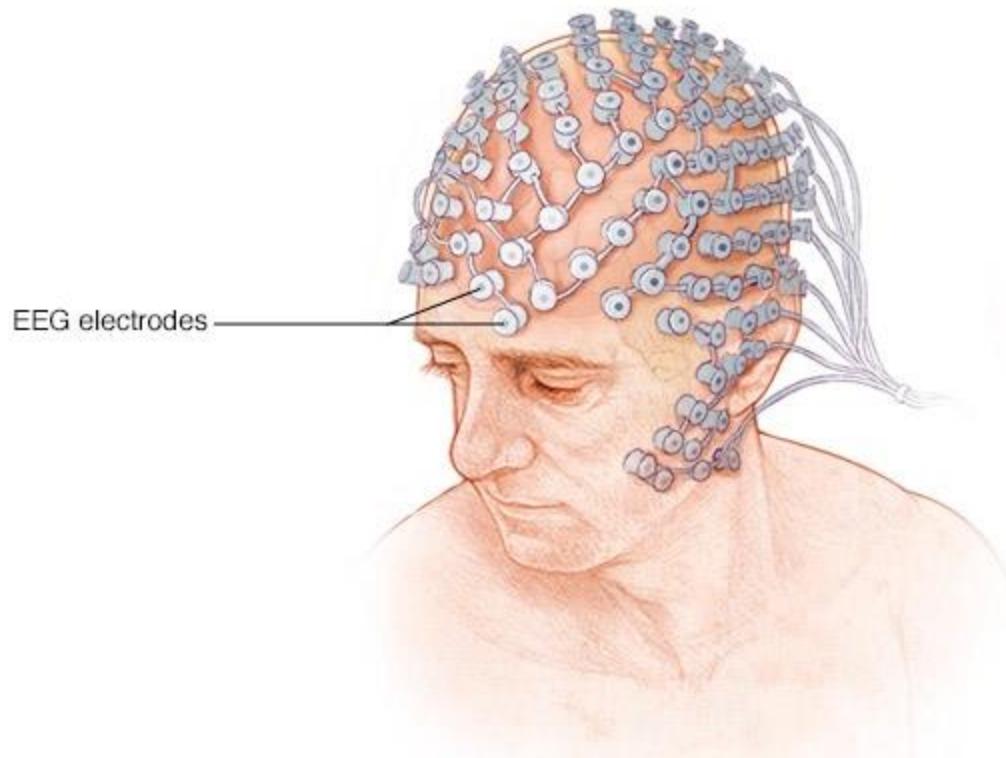
- 5 days a week for 6+ weeks



rTMS – enforcement of brain oscillations



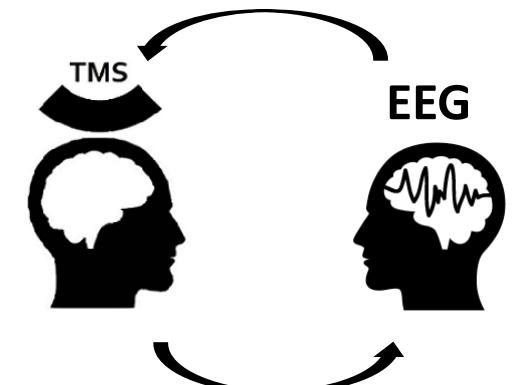
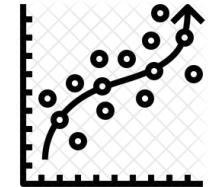
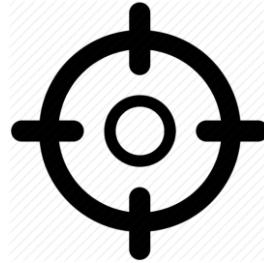




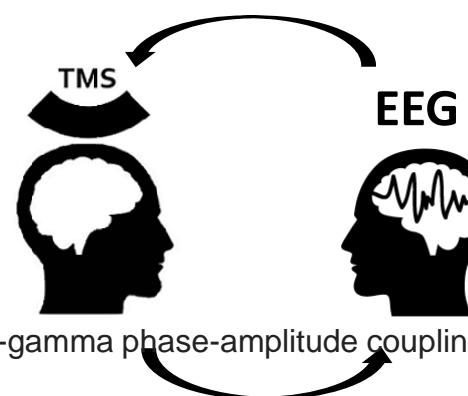
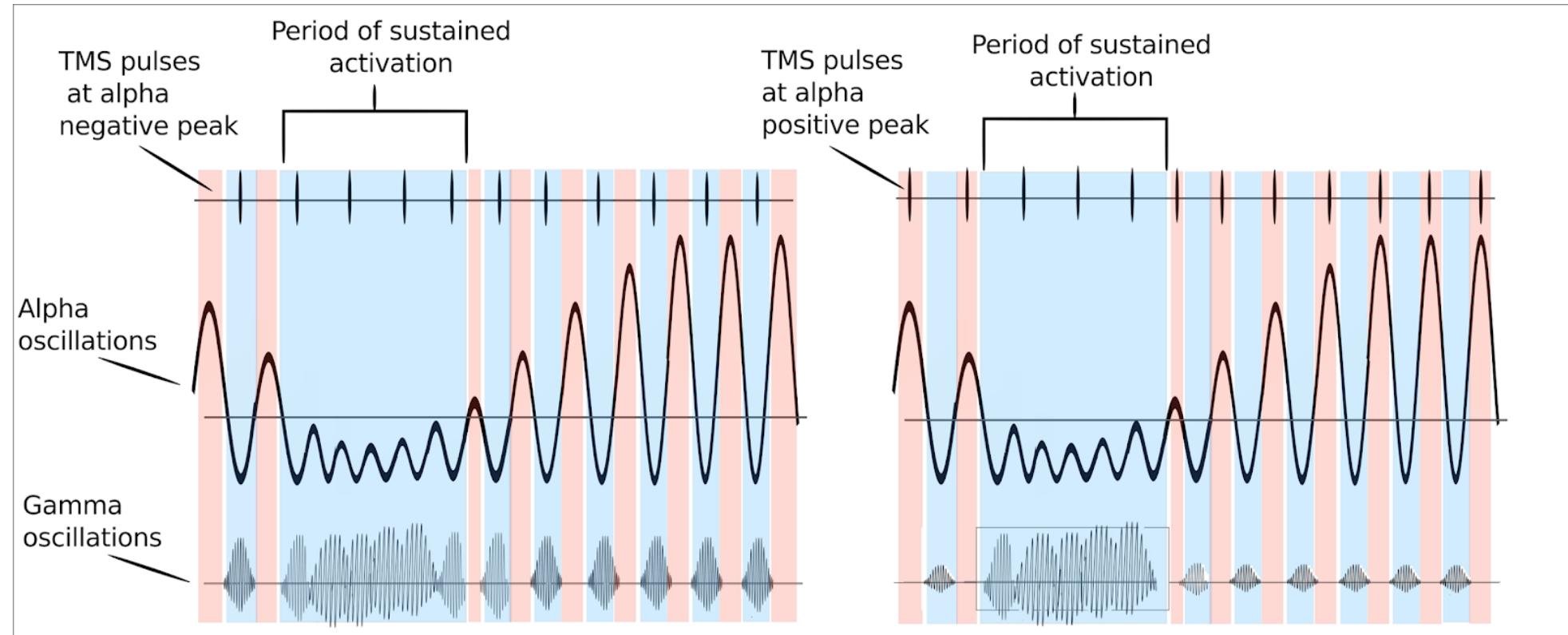
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Opportunities enabled by combined TMS & EEG

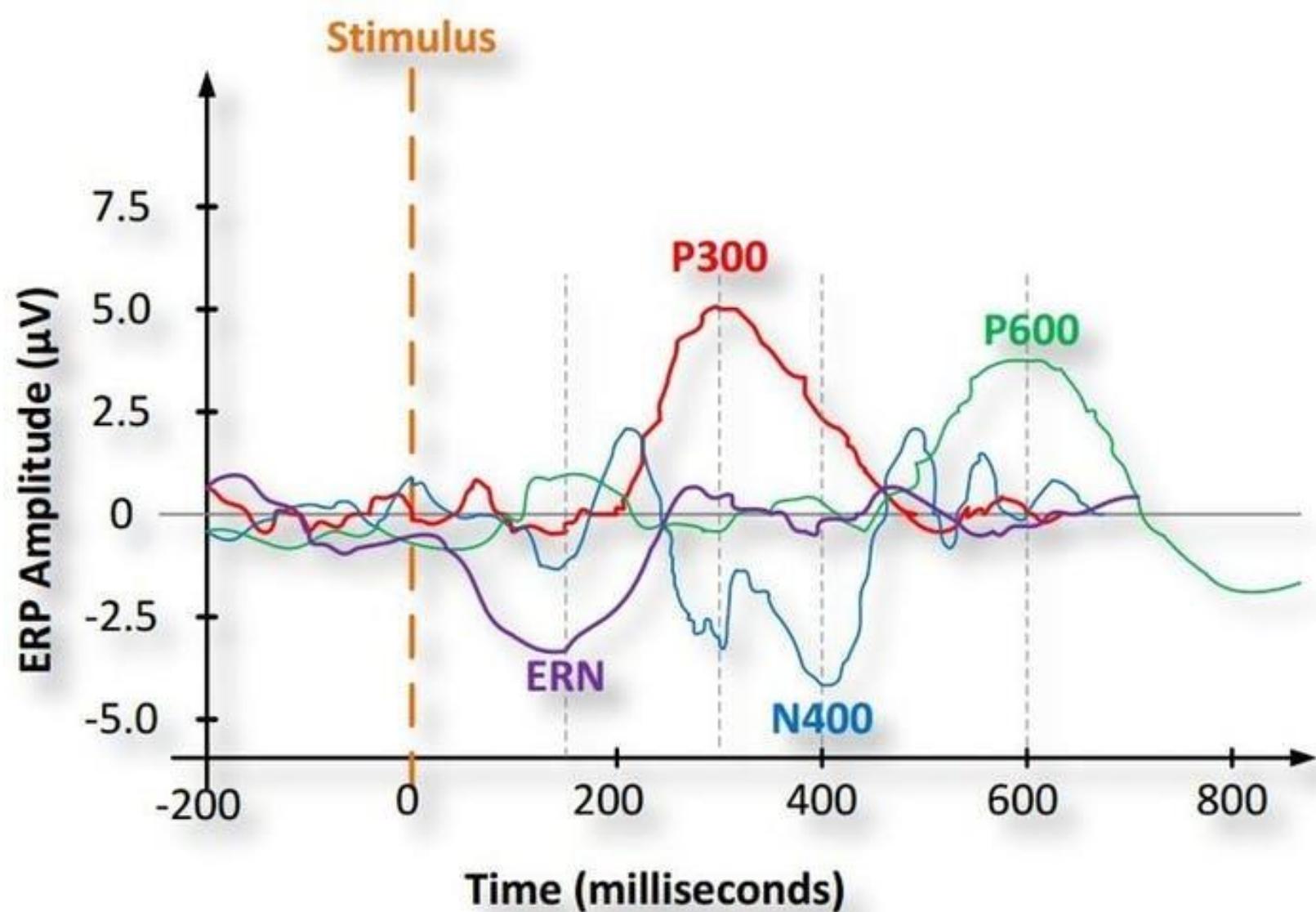
- EEG-based identification of target location (esp. for new applications)
- Advanced EEG signal processing for identification of individual target frequencies
- Real-time EEG signal processing for precise stimulation with closed EEG-TMS feedback loop



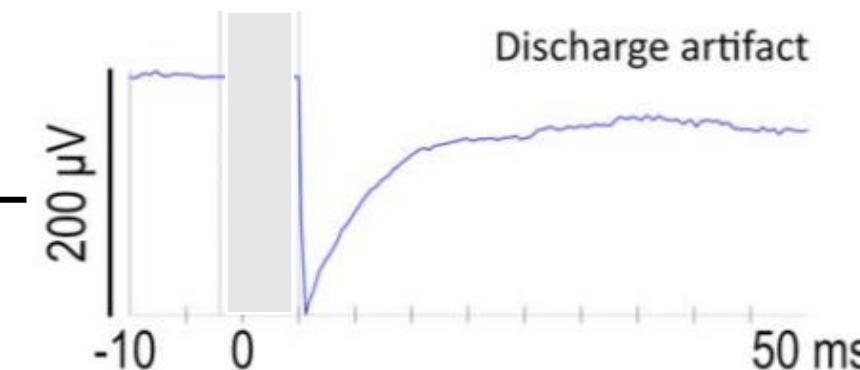
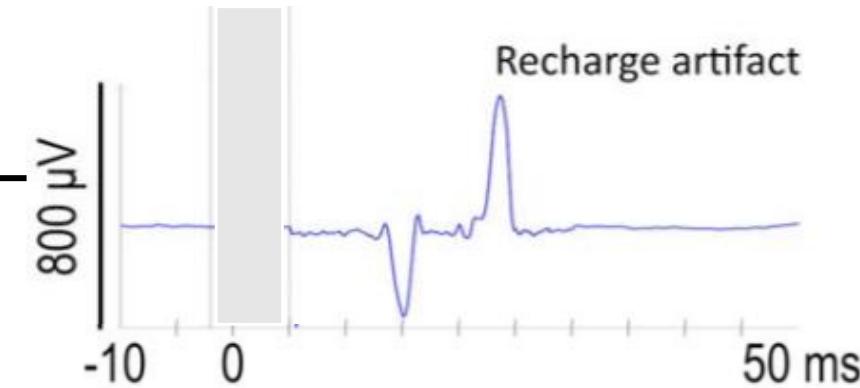
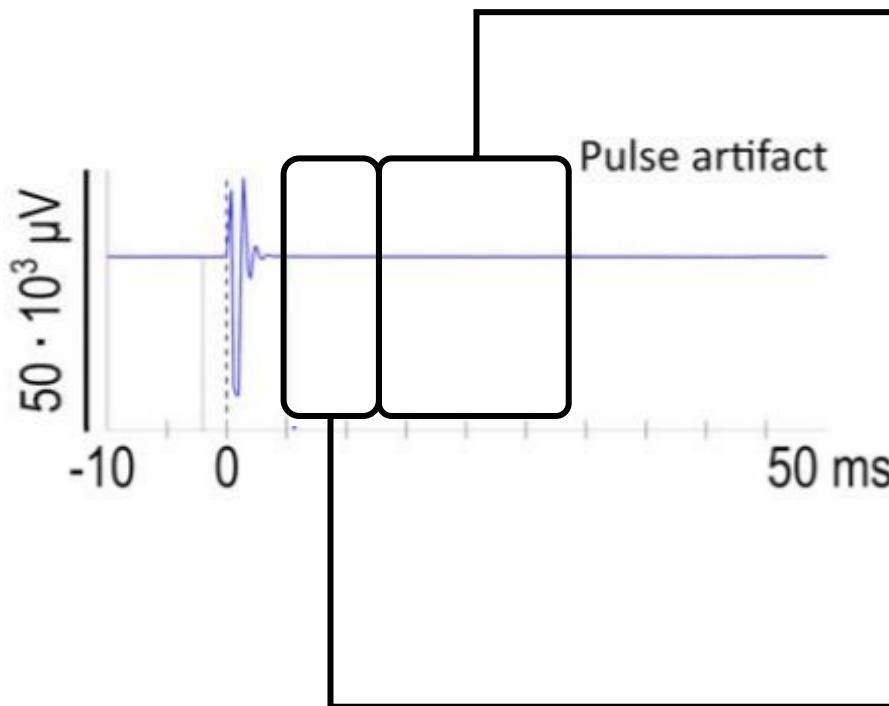
Individual frequency and phase



Characteristics of TMS Pulse

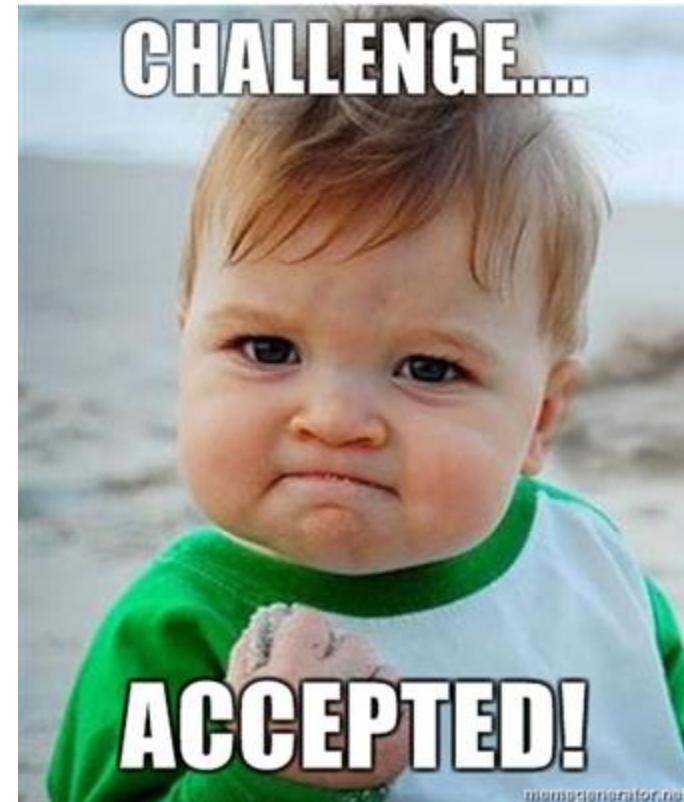


Characteristics of TMS Pulse



Technical challenges: TMS compatible EEG Amplifier

1. EEG Amplifier Saturation and sampling rate:
 1. Fast 24-bit analog digital converter
 2. High sampling rate (20+ kHZ) to capture full shape of TMS Pulse artifact
2. Electrodes heating
 1. Special electrodes (e.g. small Ag/AgCl pellet electrodes)
3. Muscle twitches
 1. High quality recording and postrecording artifact removal with ICA
4. Auditory evoked potentials and startle-related blinks (from TMS clicks)
 1. Noise canceling earphones / earplugs
 2. Active sham conditions (with the same sound)



Research challenges

- 1. Can we effectively remove rTMS artifacts?**
- 2. Can we see rTMS evoked potentials ?**
- 3. Can we evoke rTMS potentials with subthreshold intensity of stimulation?**

Mental Rotation

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Timeline practice:

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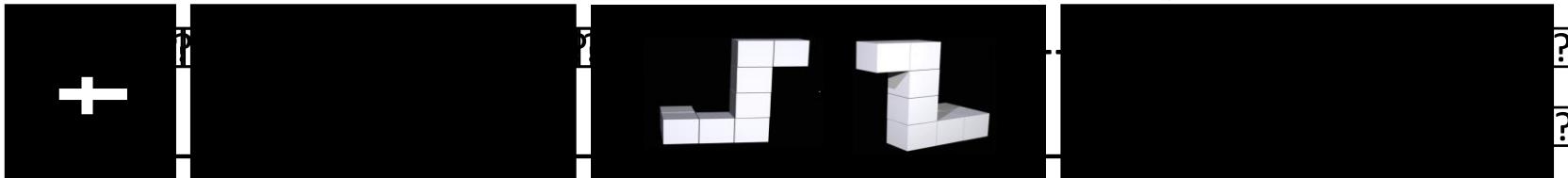
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Presentation

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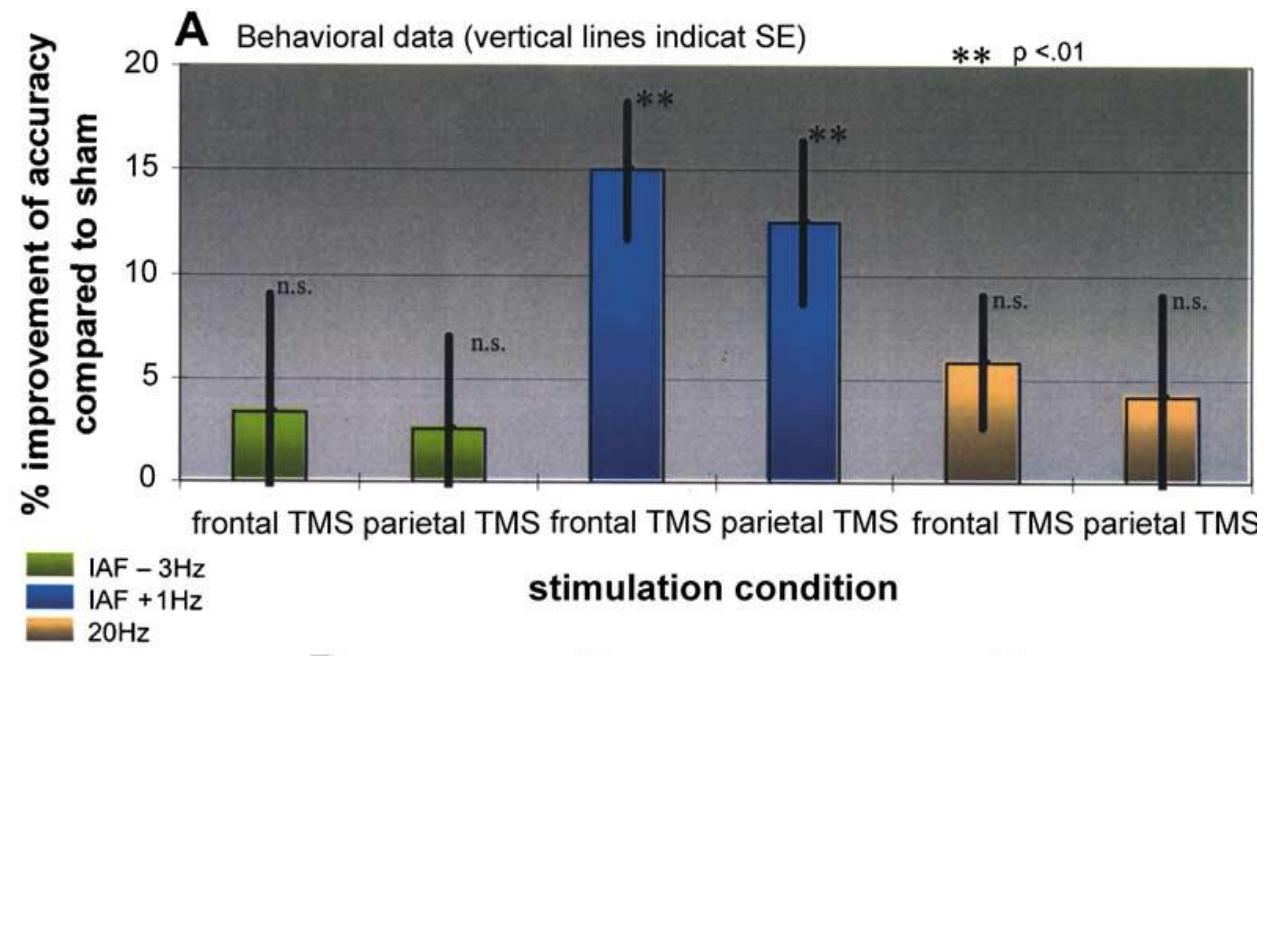
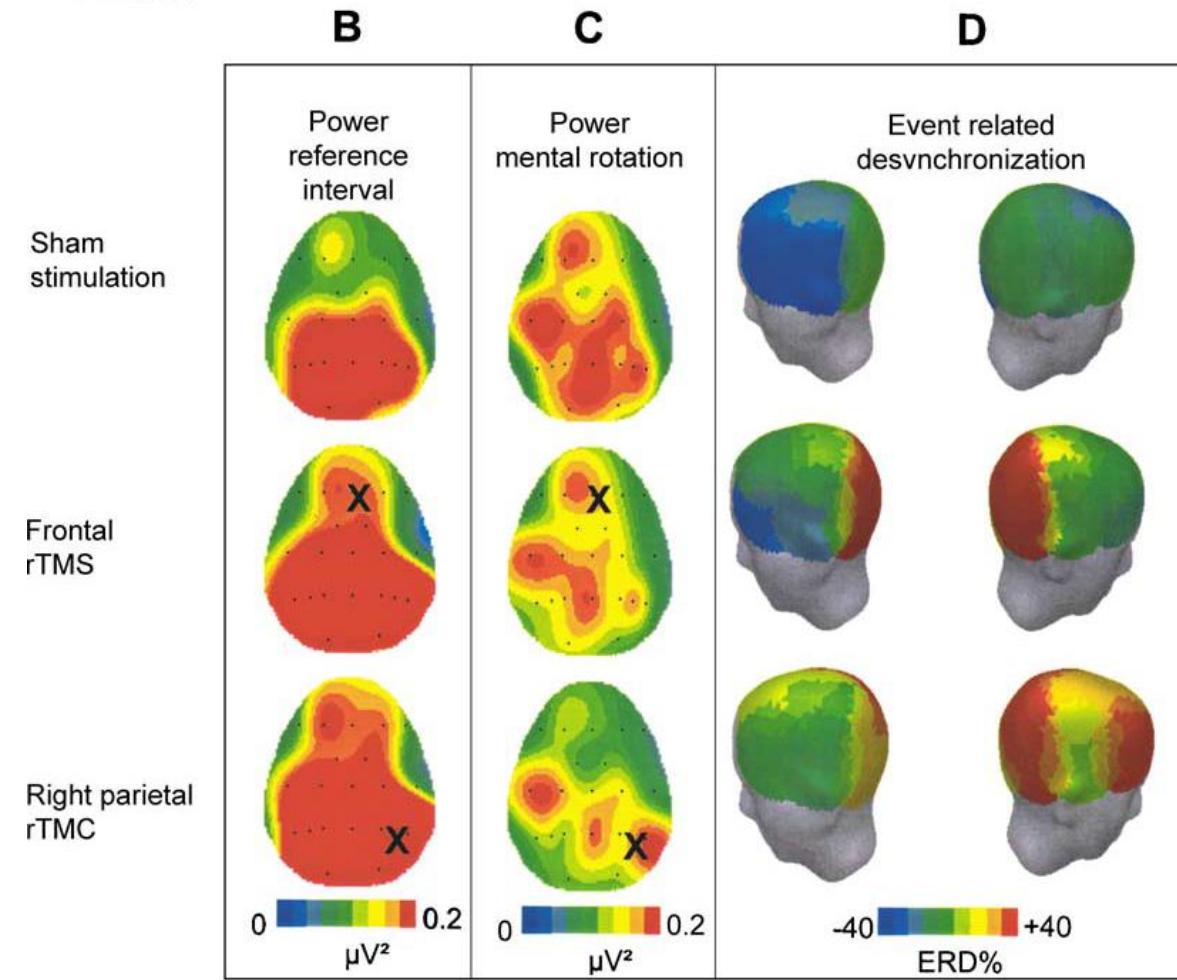
1sec 2.4sec 4.5sec 500ms 4sec

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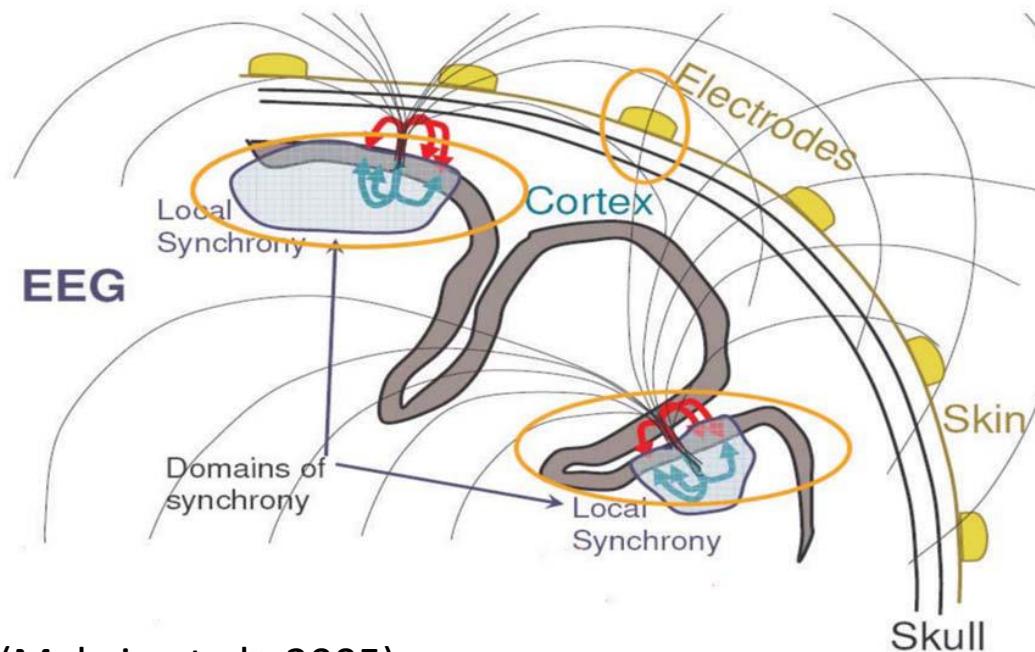
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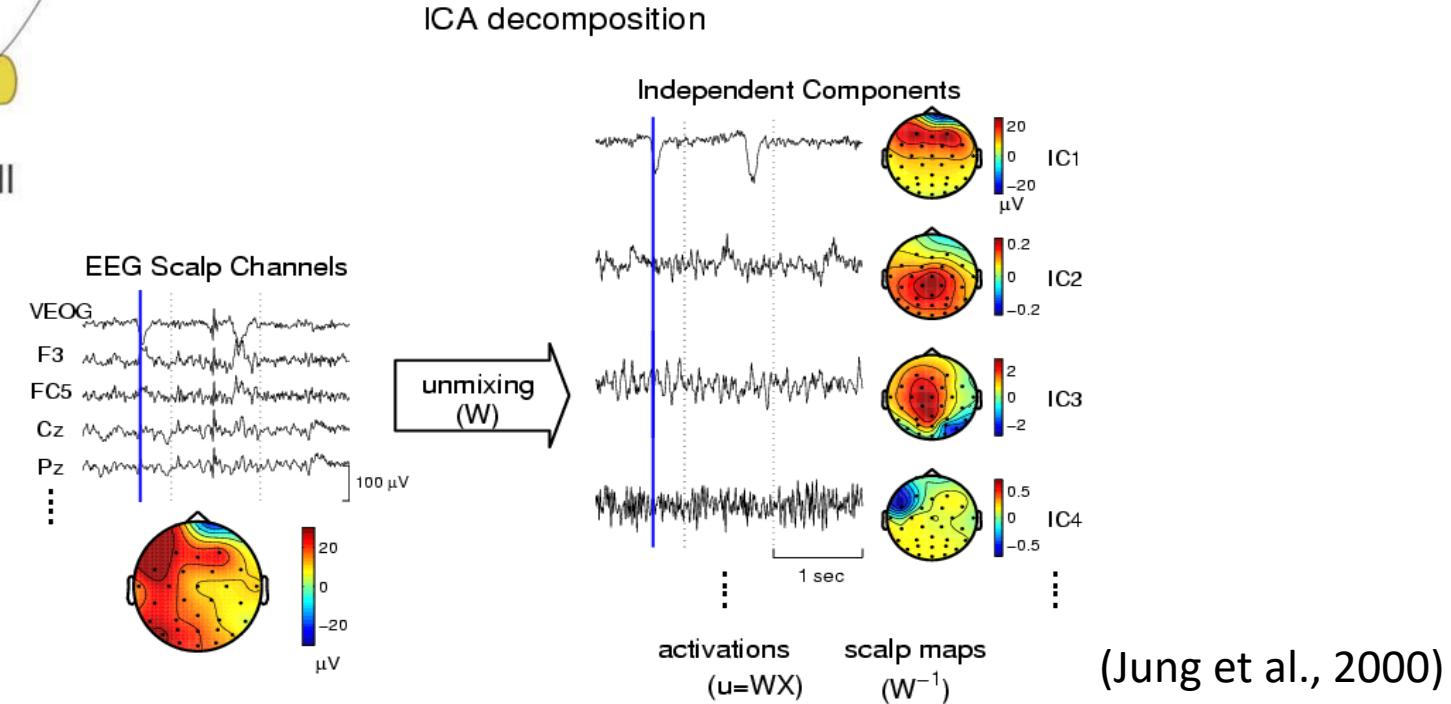


Independent Component Analysis

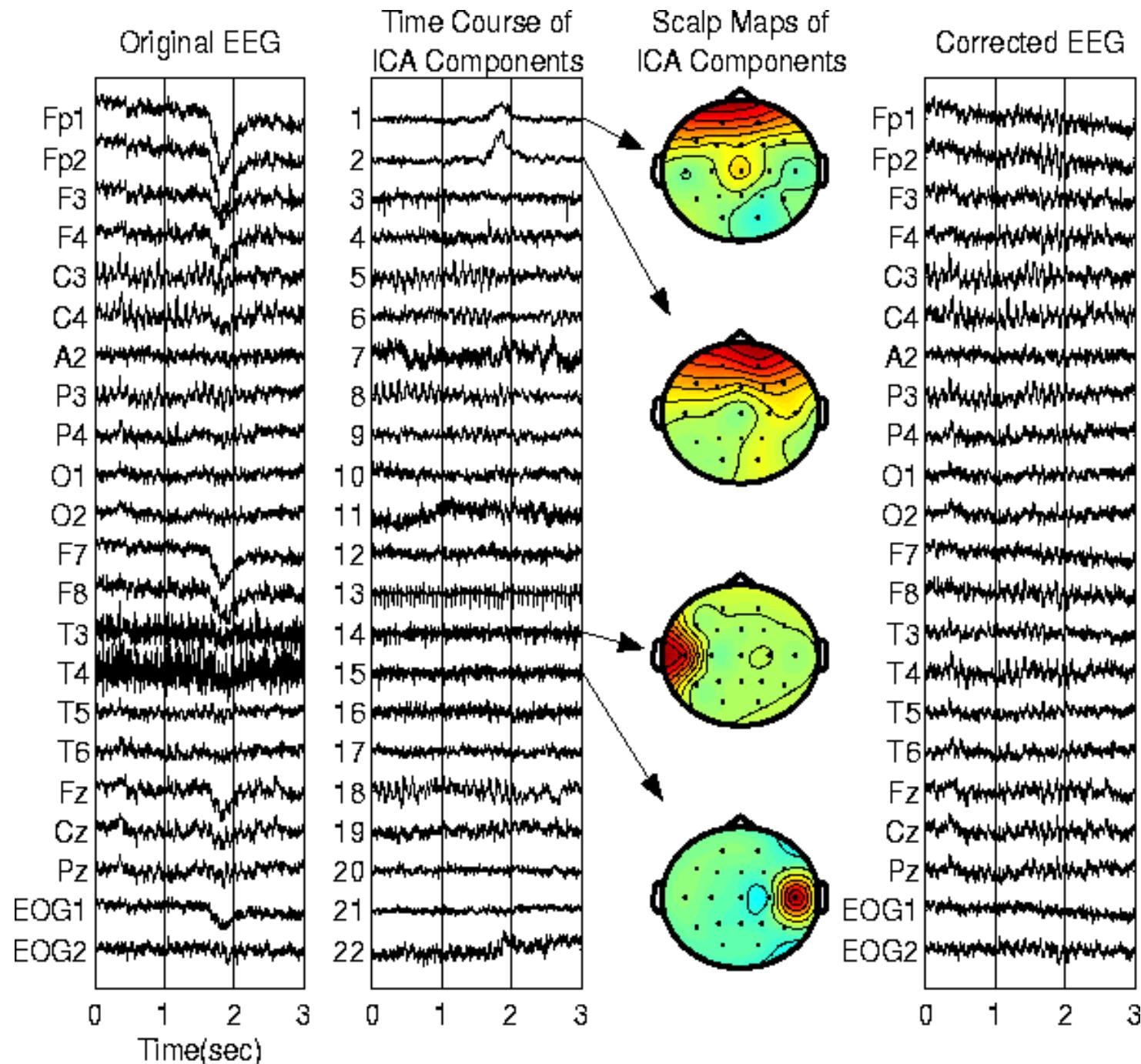


(Makeig et al., 2005)

ICA – separates the EEG into temporally independent source signals (Makeig, 1996)

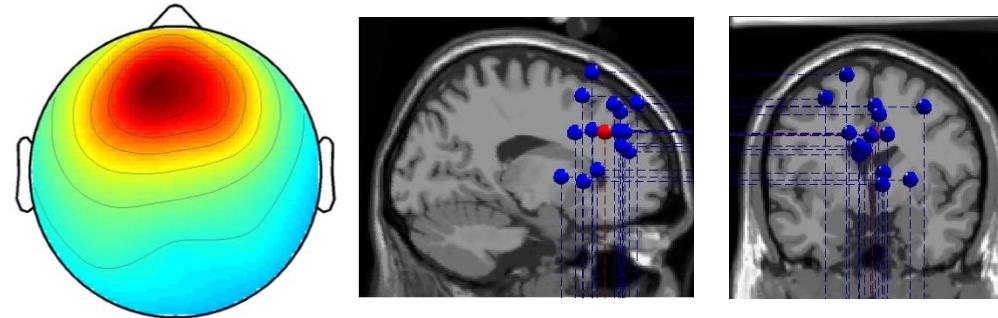


(Jung et al., 2000)



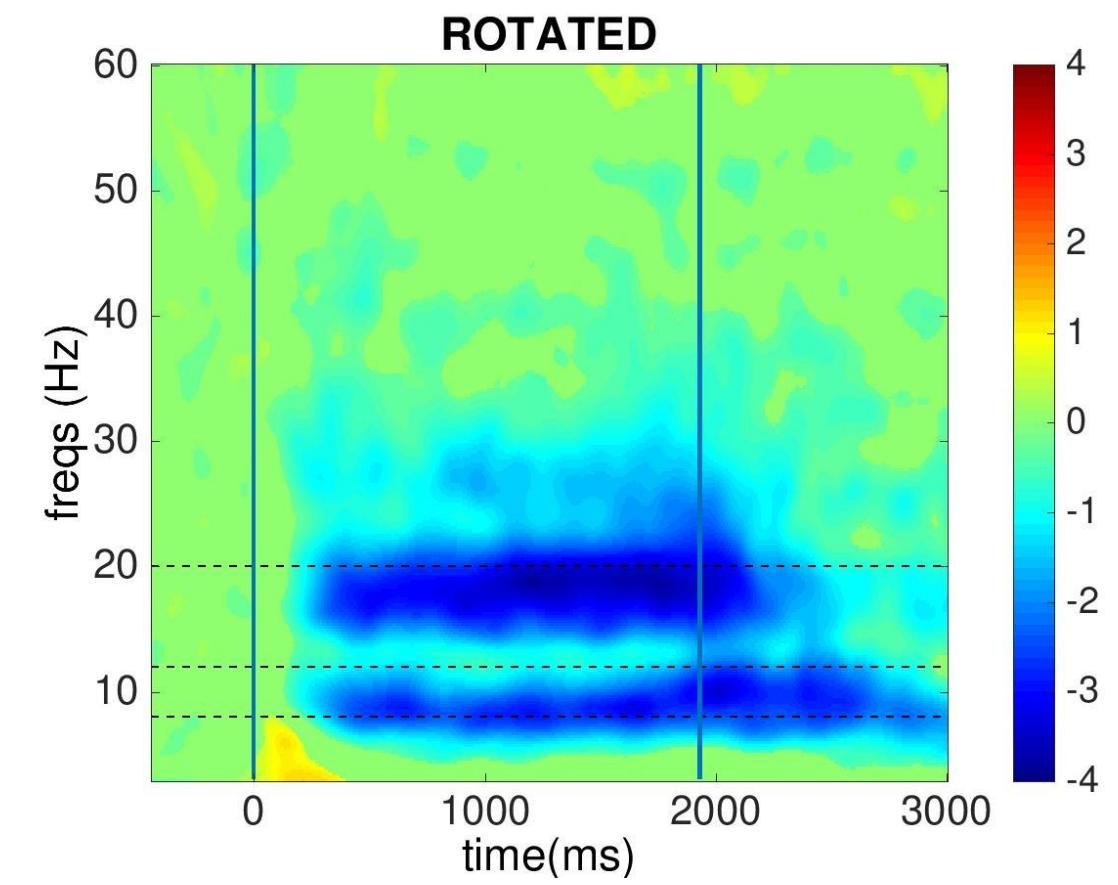
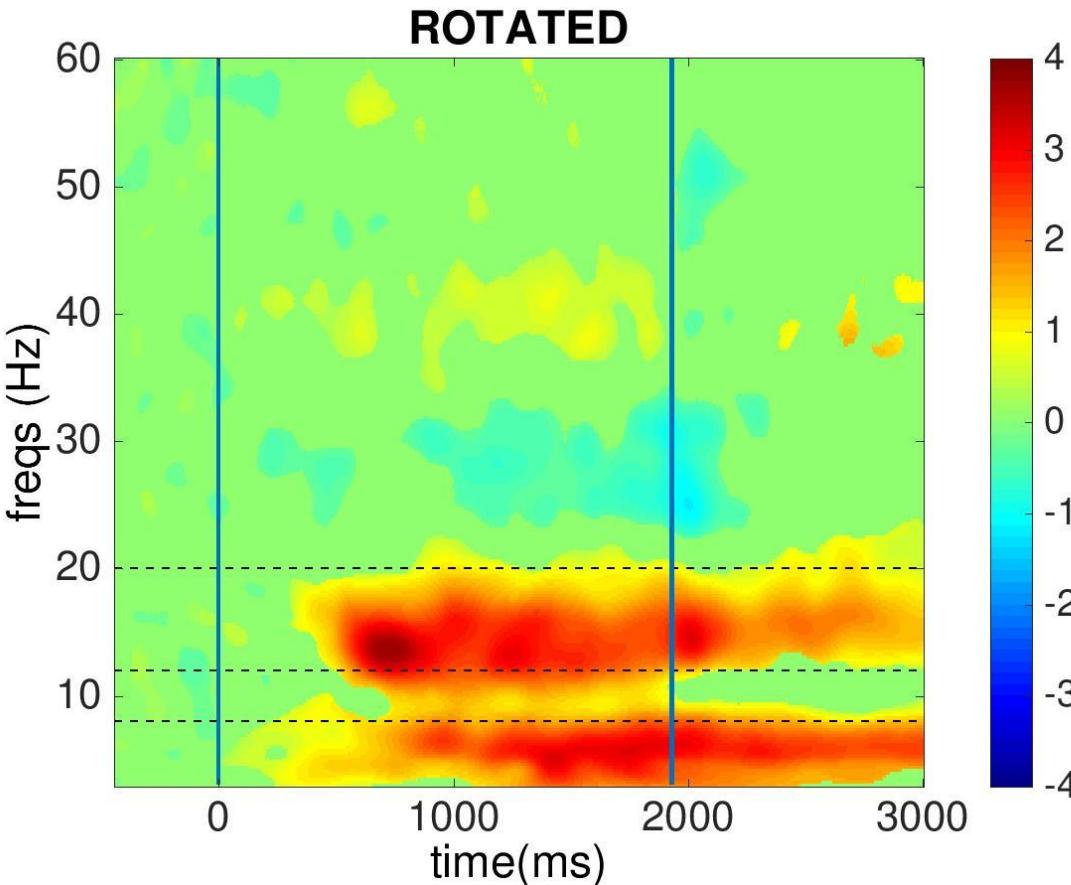
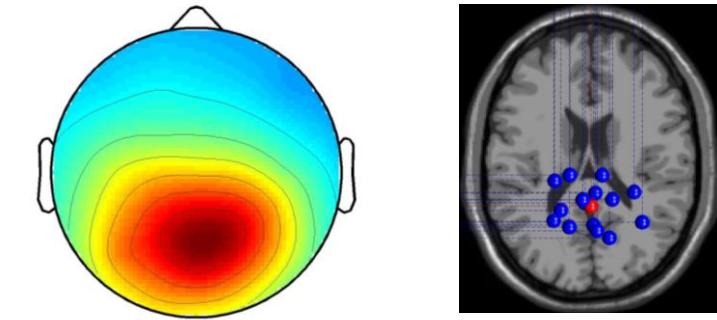
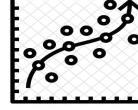


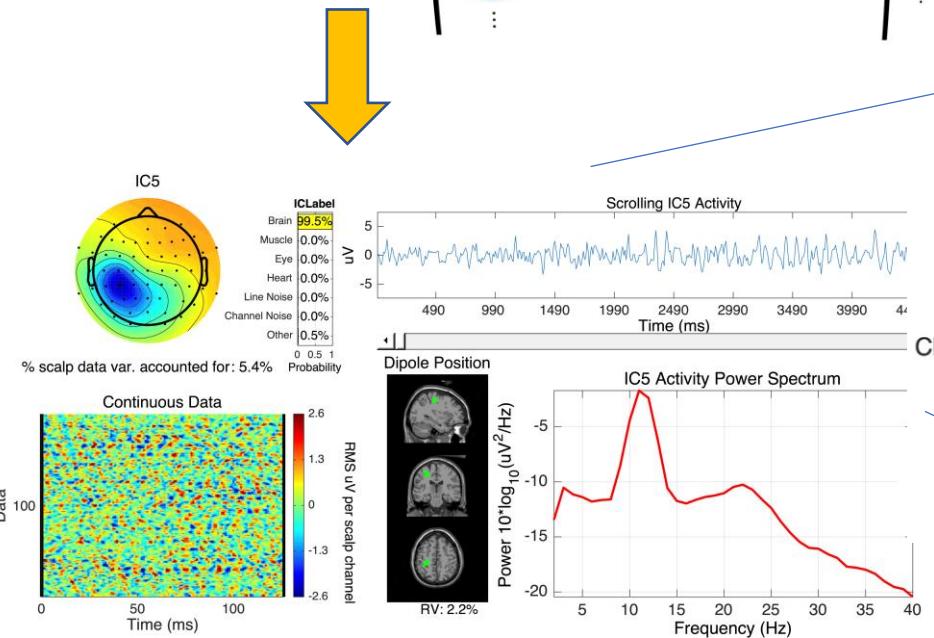
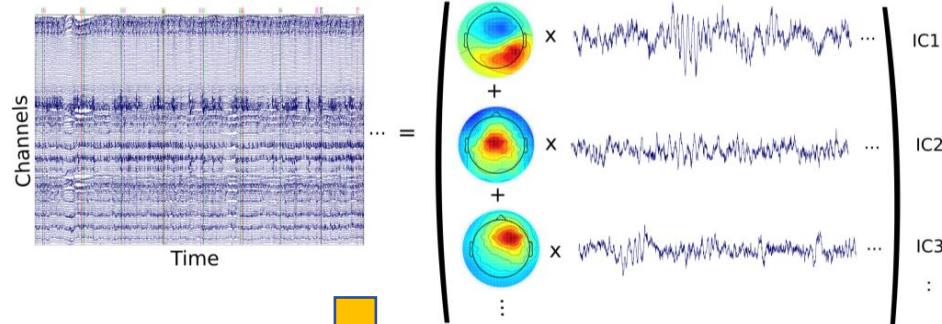
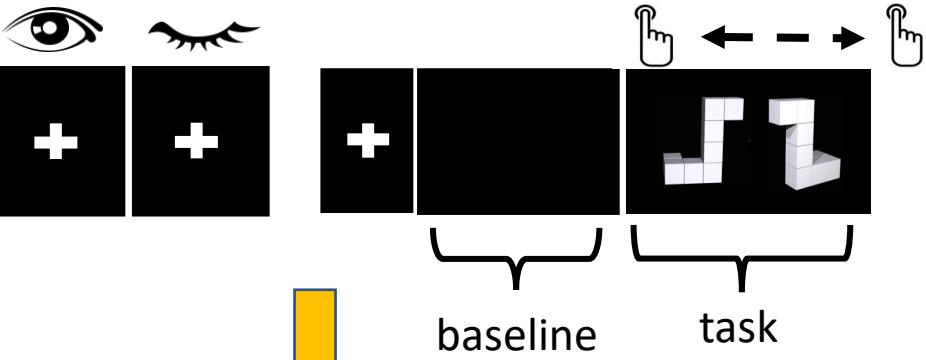
Target location for TMS



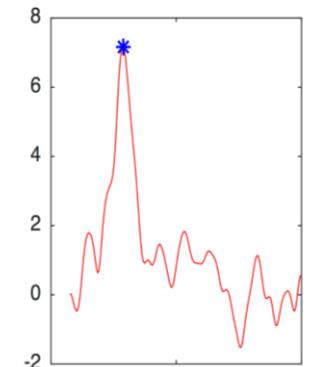
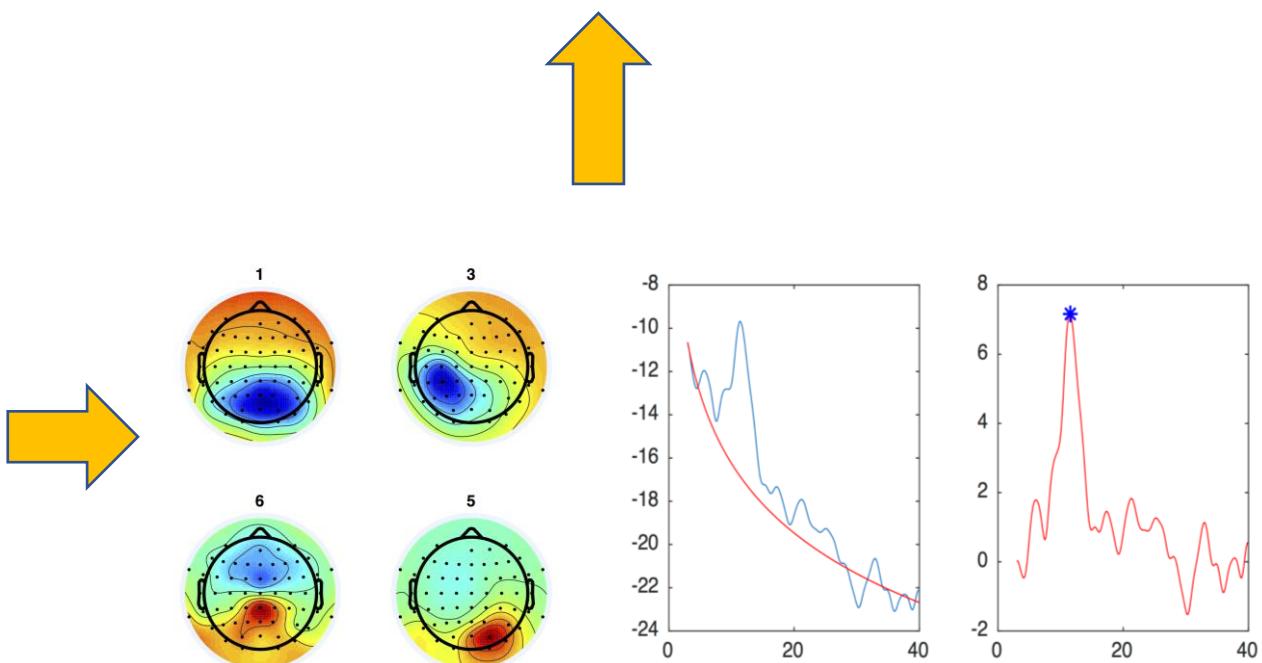
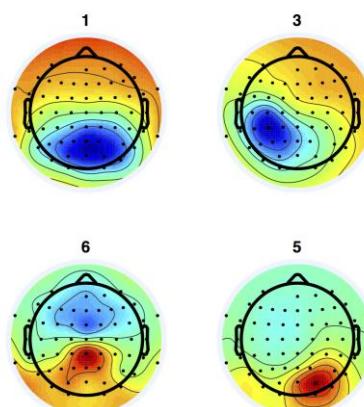
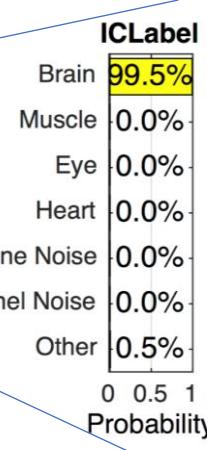
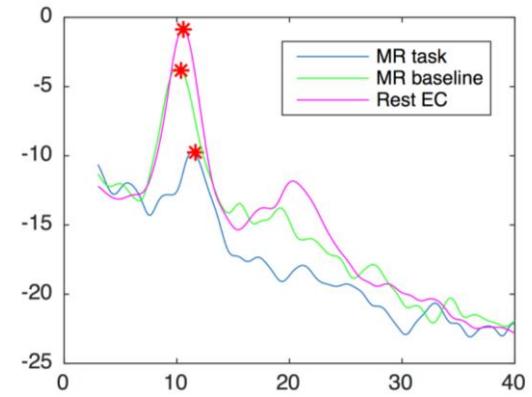
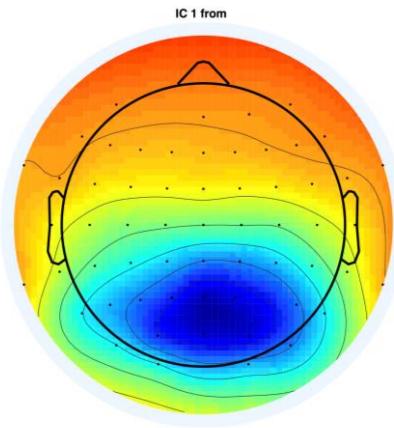
Results

Frequency of TMS





Method for selecting alpha peak



Mental Rotation

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Timeline
practice:

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?

PPPPPPPPPPPP

Presentation PPP

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?

PPPPPPPPPPPP

of cubes PPP

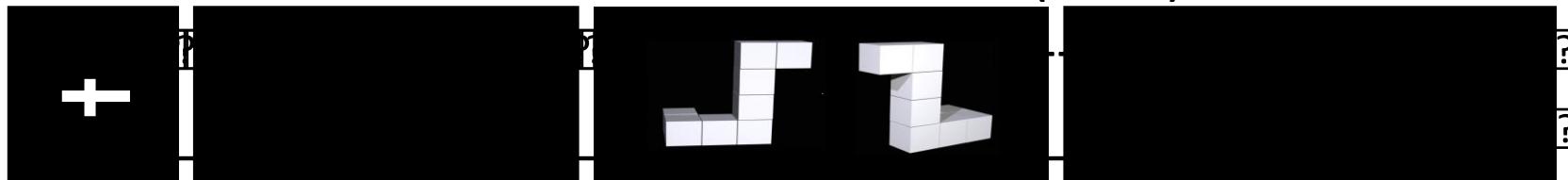
PPPPPPPPPPPP

PPPPPPPPPPPP

PPPPPPPPPPPP

PPPPPPPPPPPP

Button Press (5sec) ?



?

PP 1 sec PPPPPP

PP 2.4 sec PPPPPP



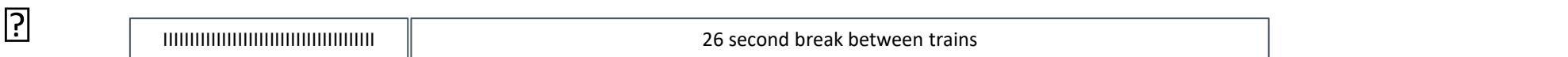
PP 2.4 sec PPPPPP

PP 4.5 sec PPPPPP



PP 500ms PPPPPP

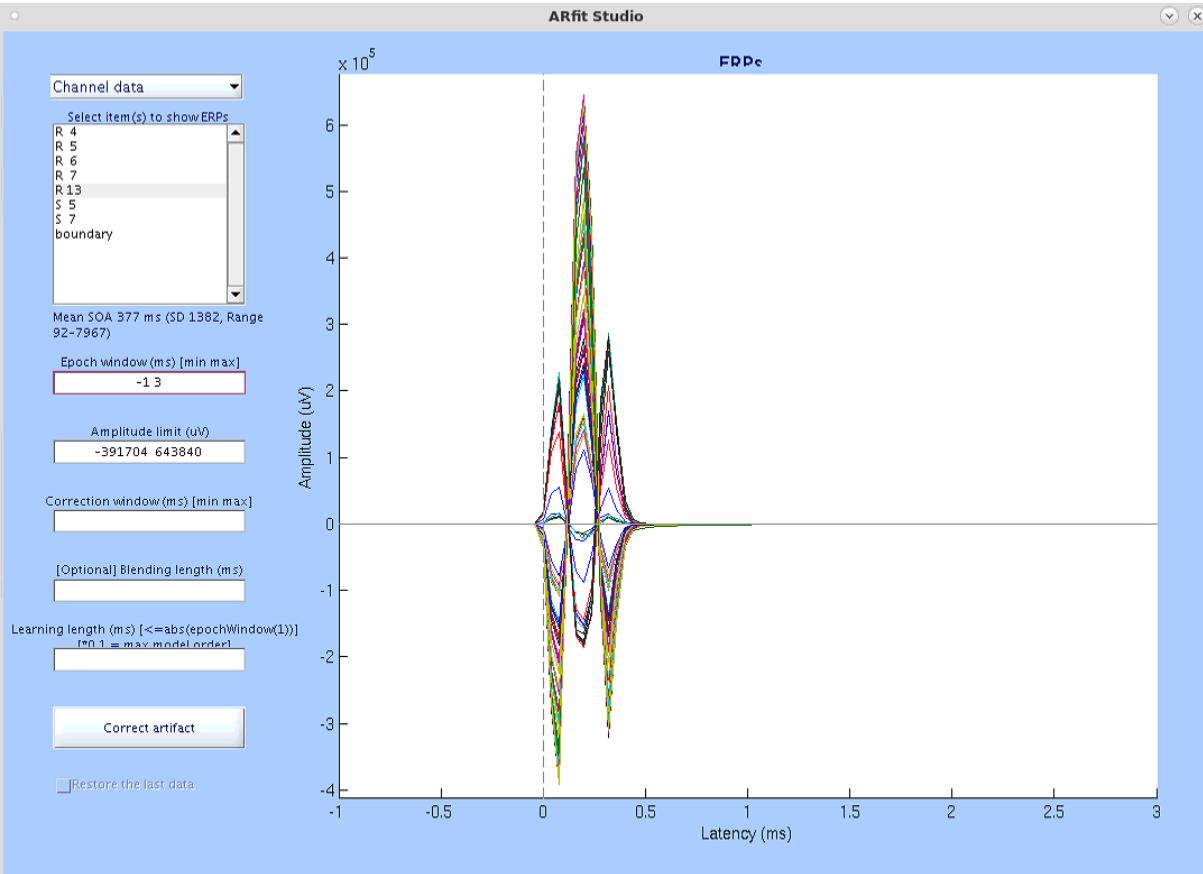
PP 4 sec PPPPPP



26 second break between trains

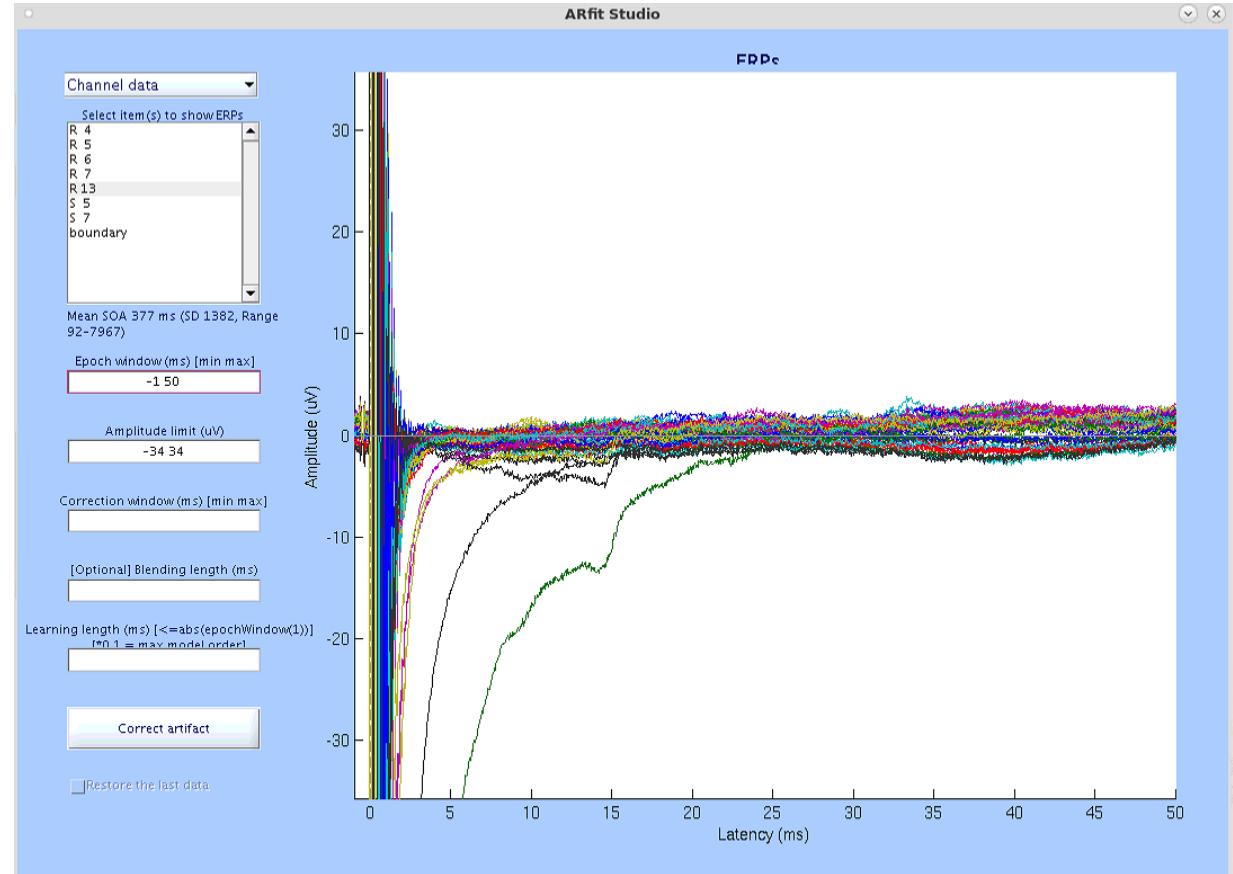
Example of TMS artifacts removal

TMS pulse (EEG: 25 kHz rate)
– artifact less than 1ms



Interpolation

Muscle and other artifacts
- up to 25 ms

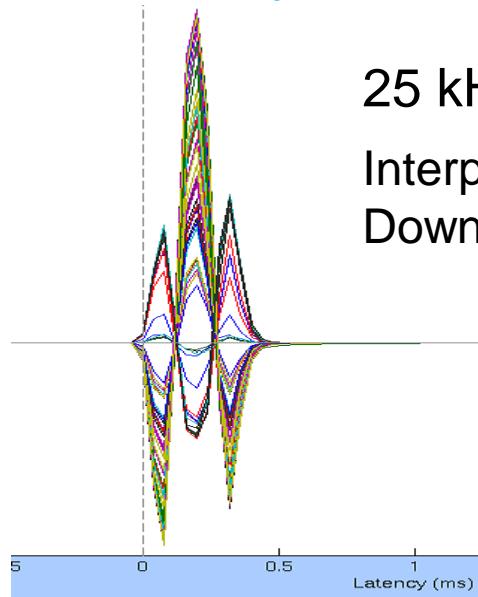


Independent Component Analysis

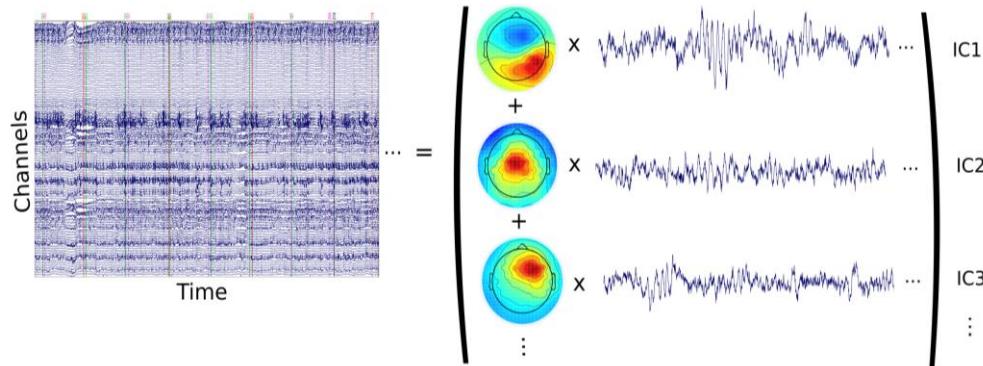
Gola & Wagner., in prep

EEG processing

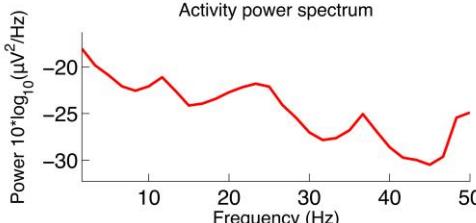
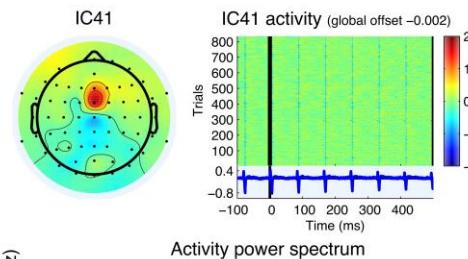
Gola & Wagner., in prep



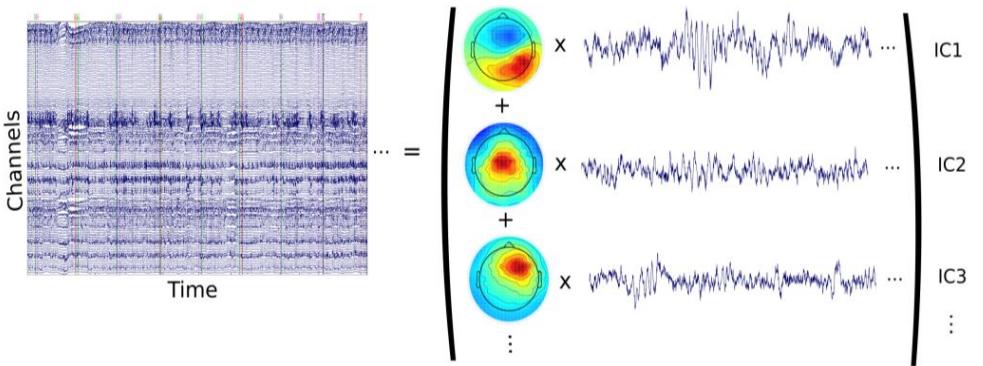
1st ICA at 5kHz



Apply ICA weights to 25kHz EEG,
Remove prominent TMS artifacts,
Downsample to 500 Hz



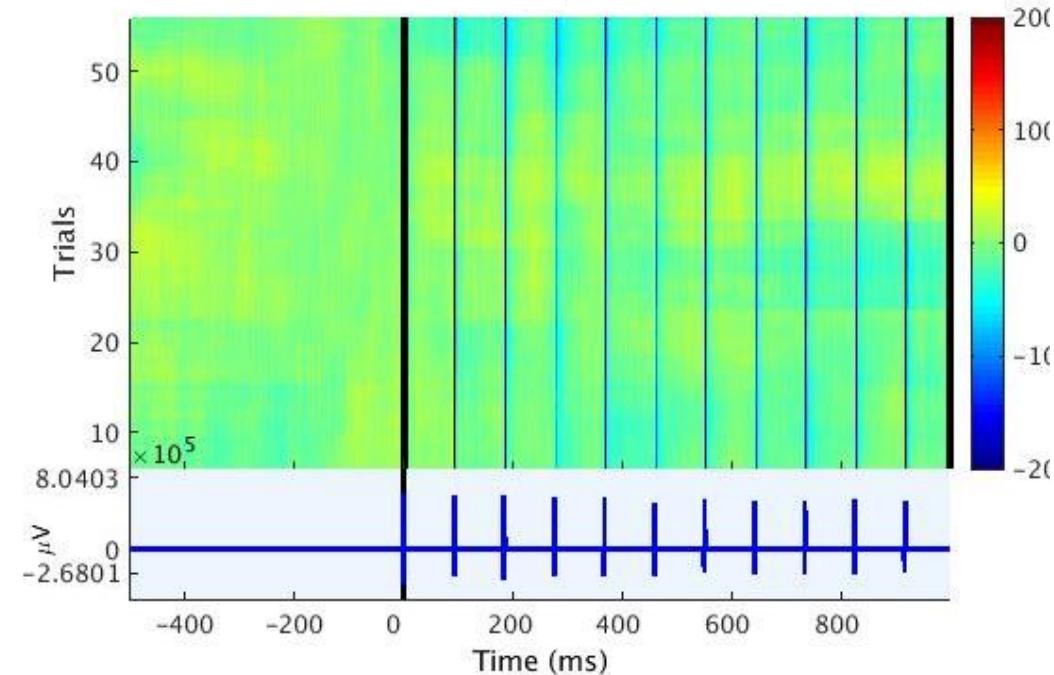
2nd ICA at 500 Hz



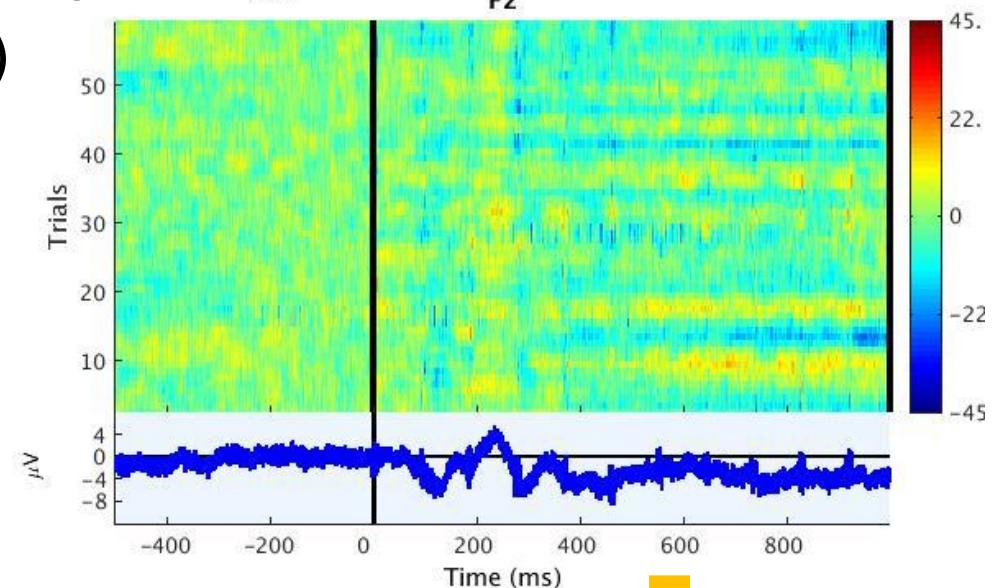
Apply ICA weights to 25kHz data,
Remove all non brain ICs,
Interpolate residual artefacts (~10ms)

EEG processing

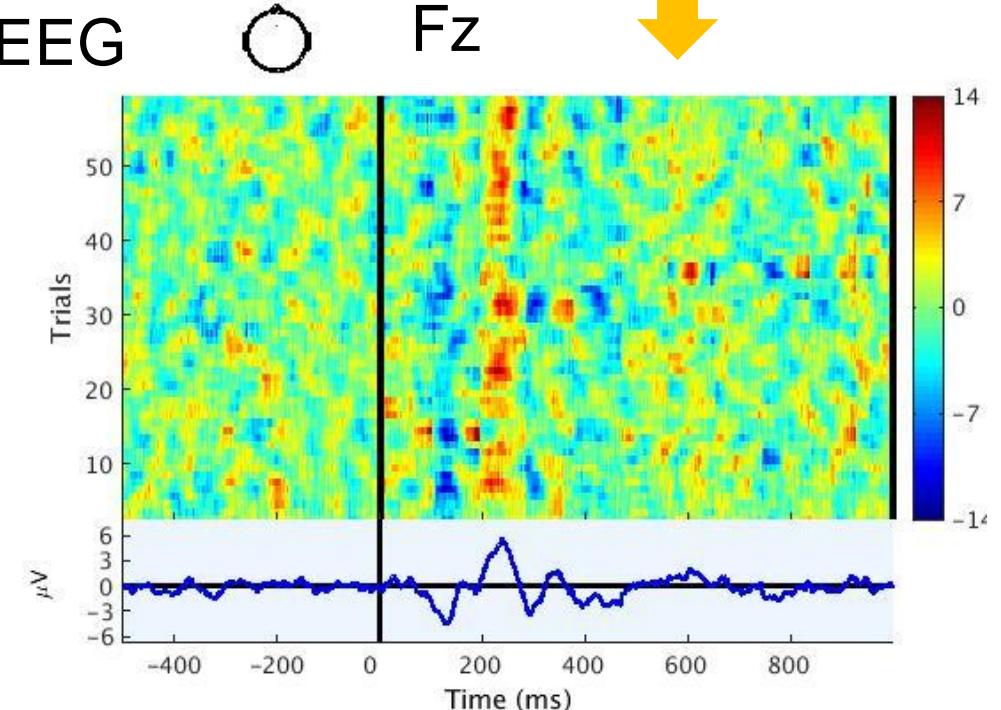
Raw EEG 25kHz Fz

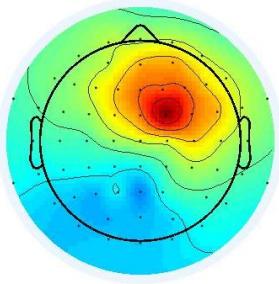


Cleaned EEG 25kHz Fz
(after 2nd ICA)

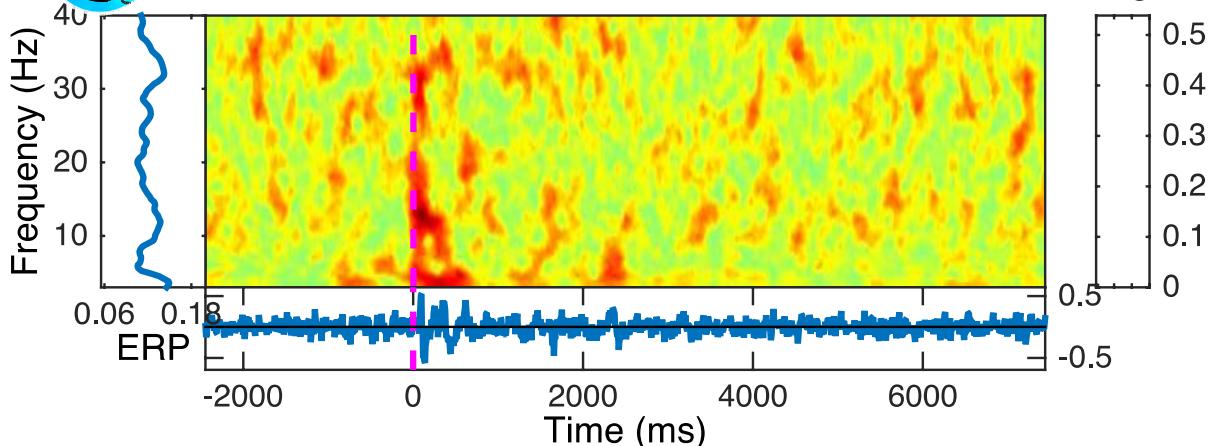
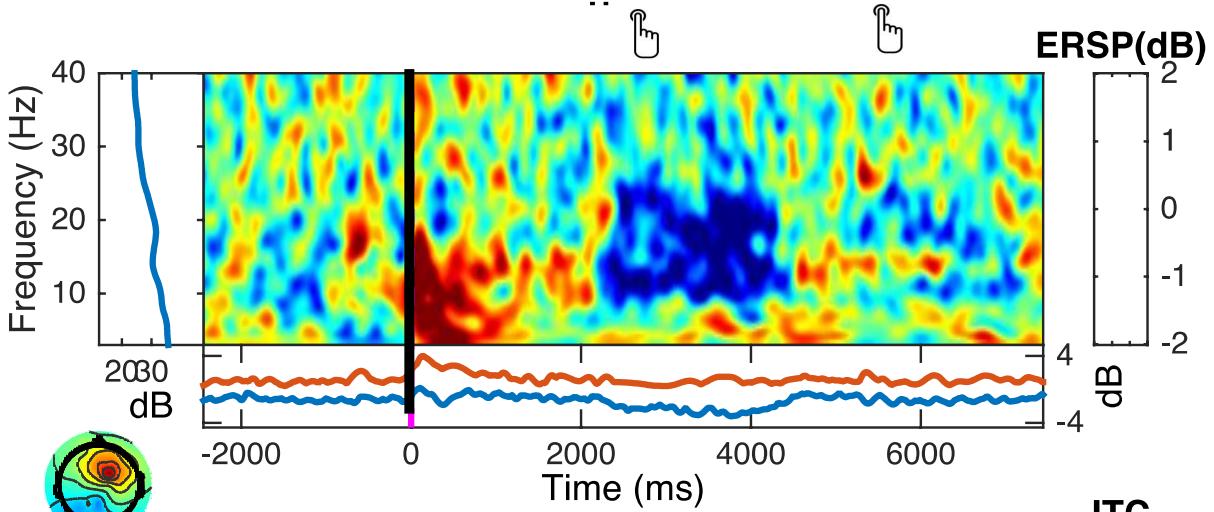
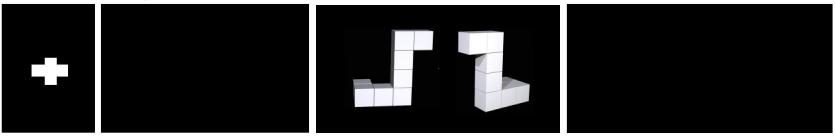


Cleaned EEG
500Hz

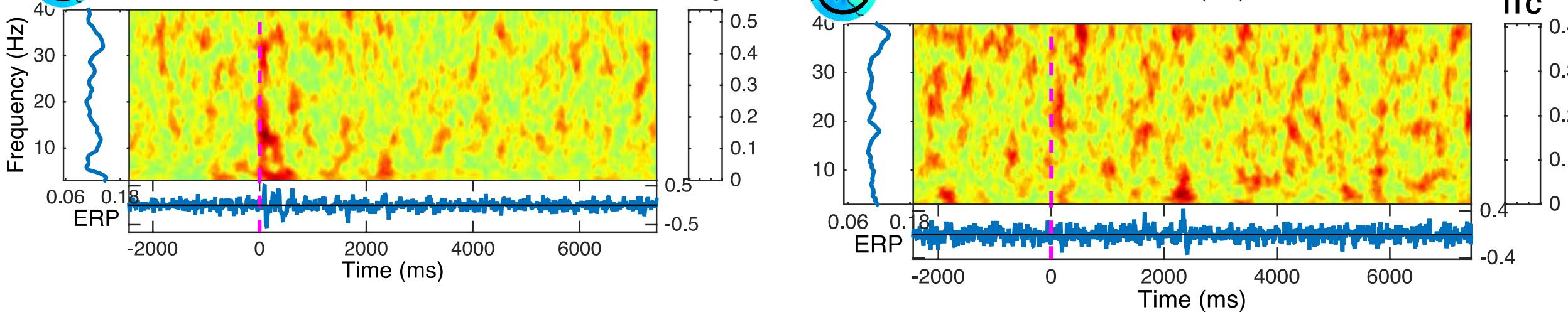
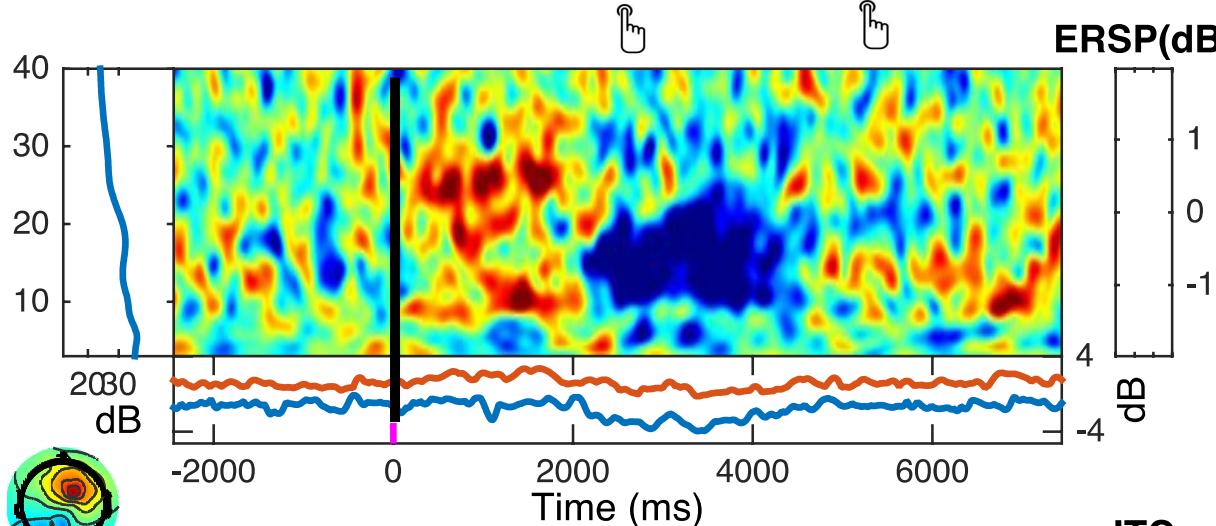
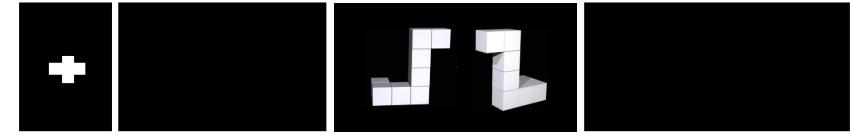


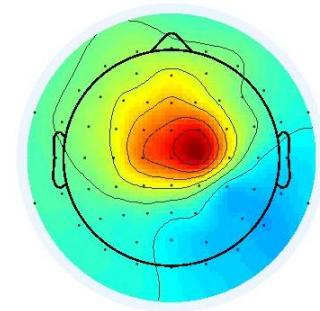


110% MT

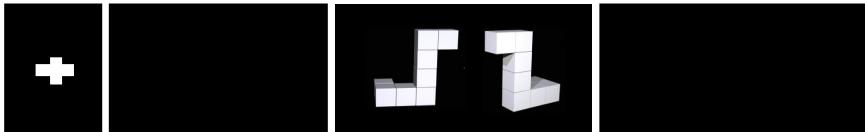


60% MT

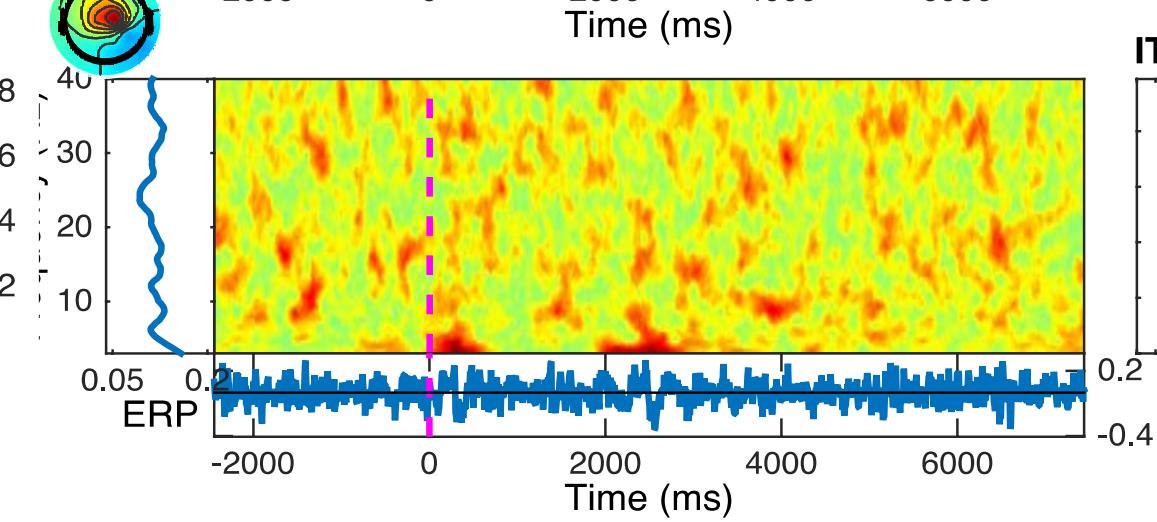
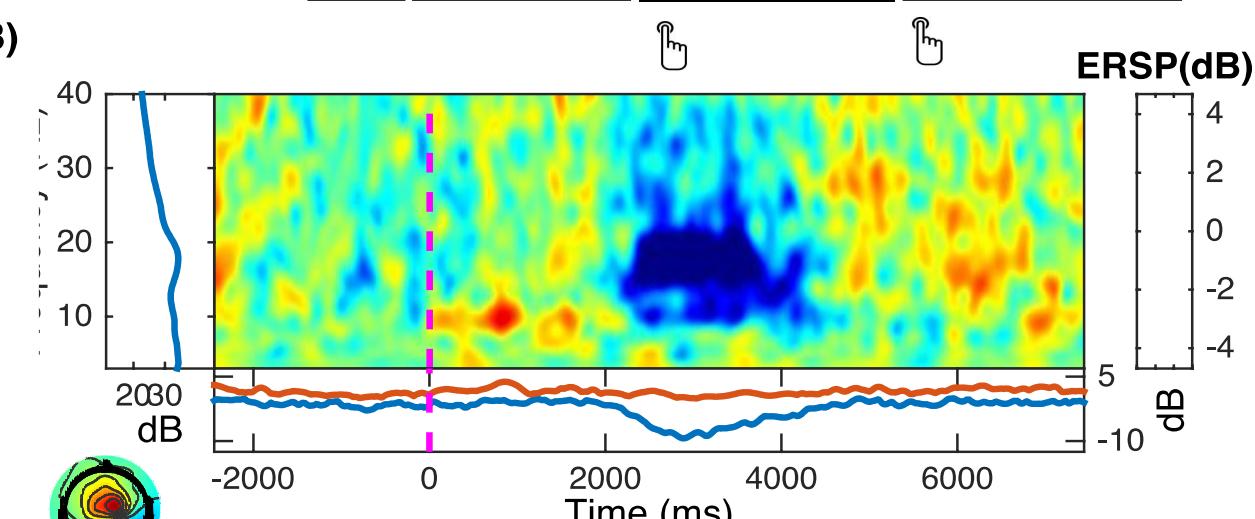
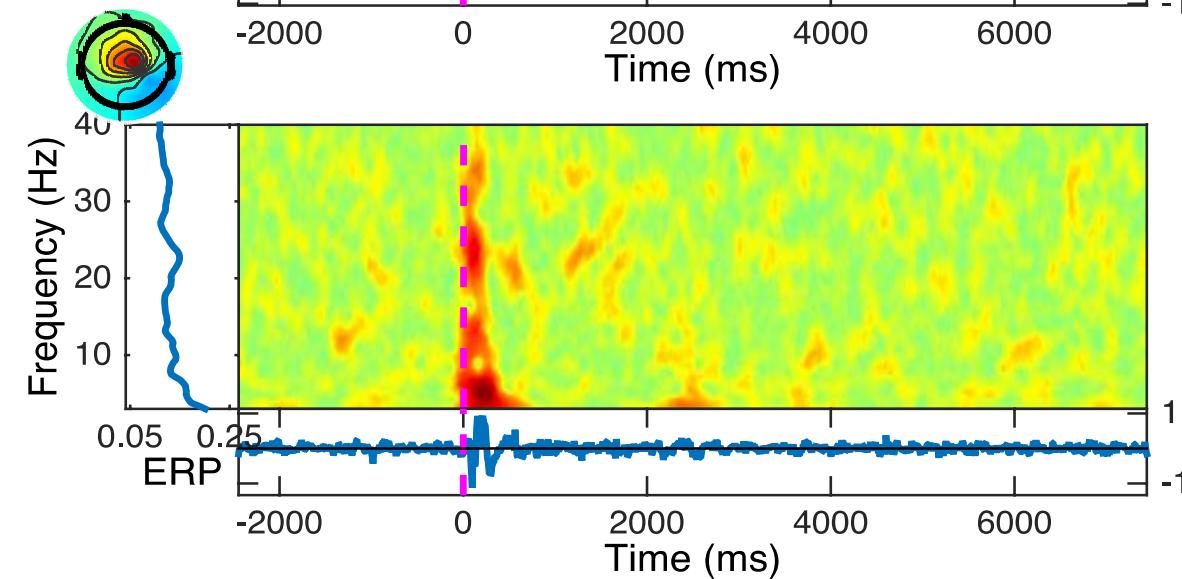
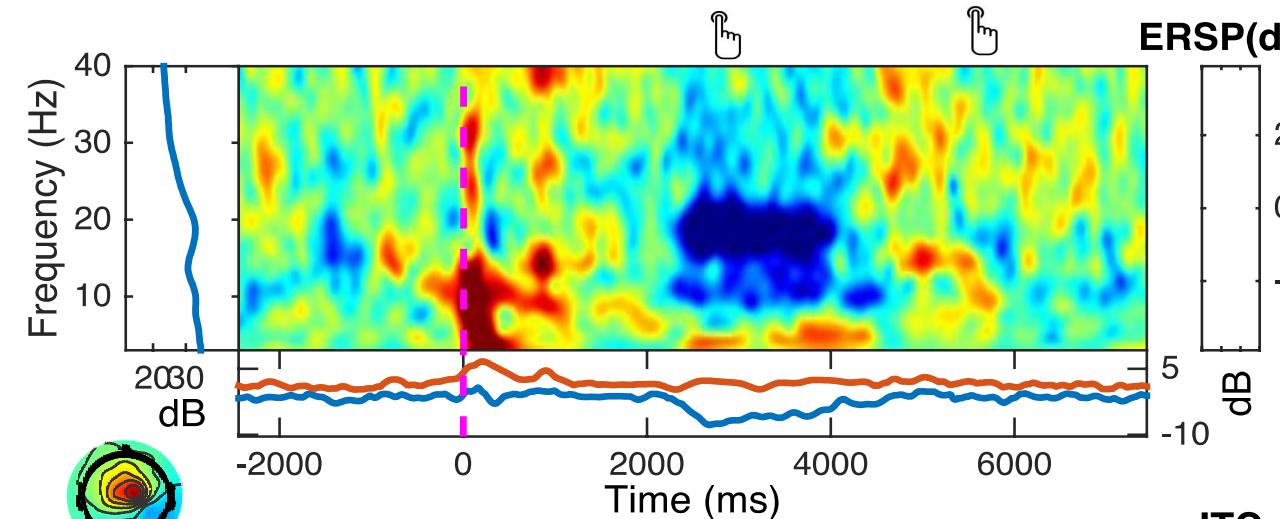


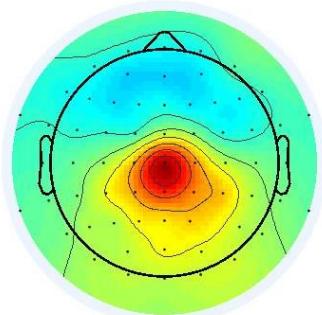


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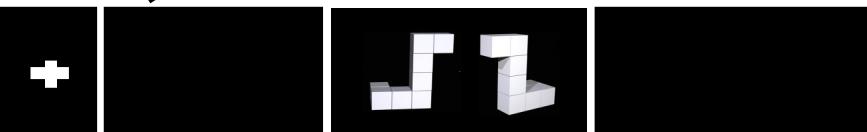


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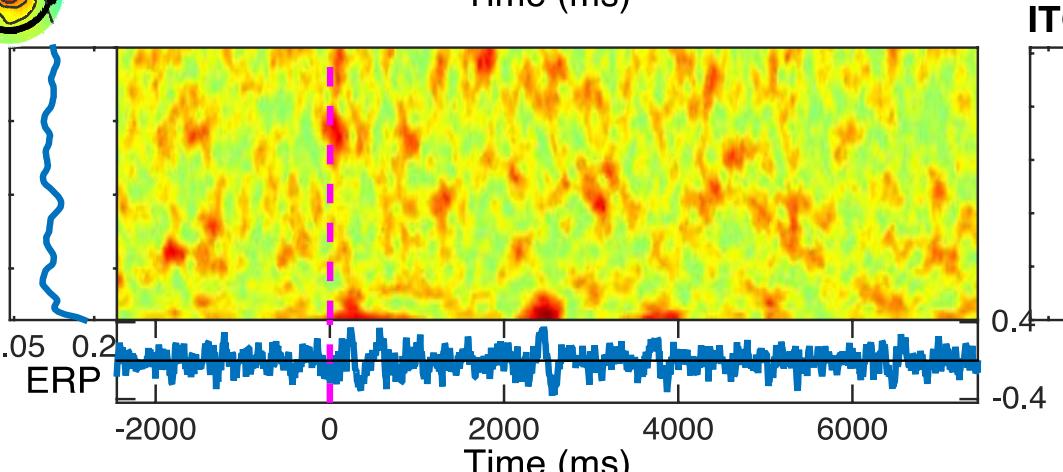
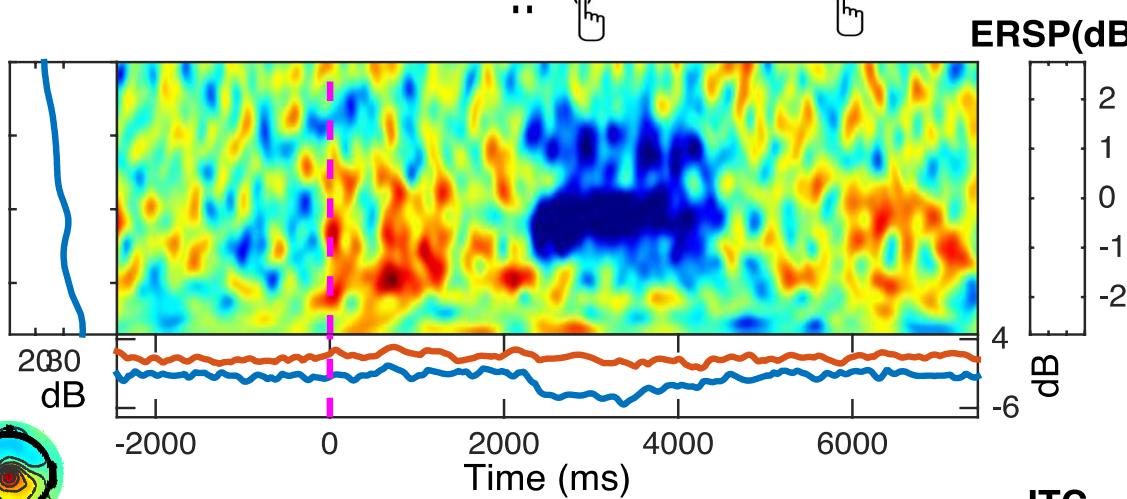
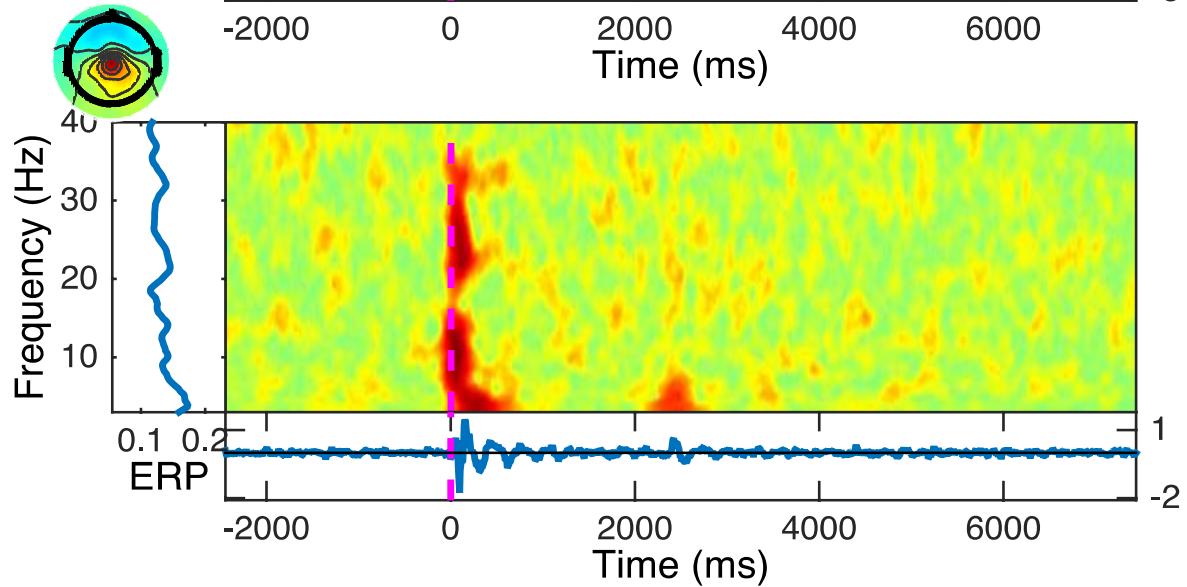
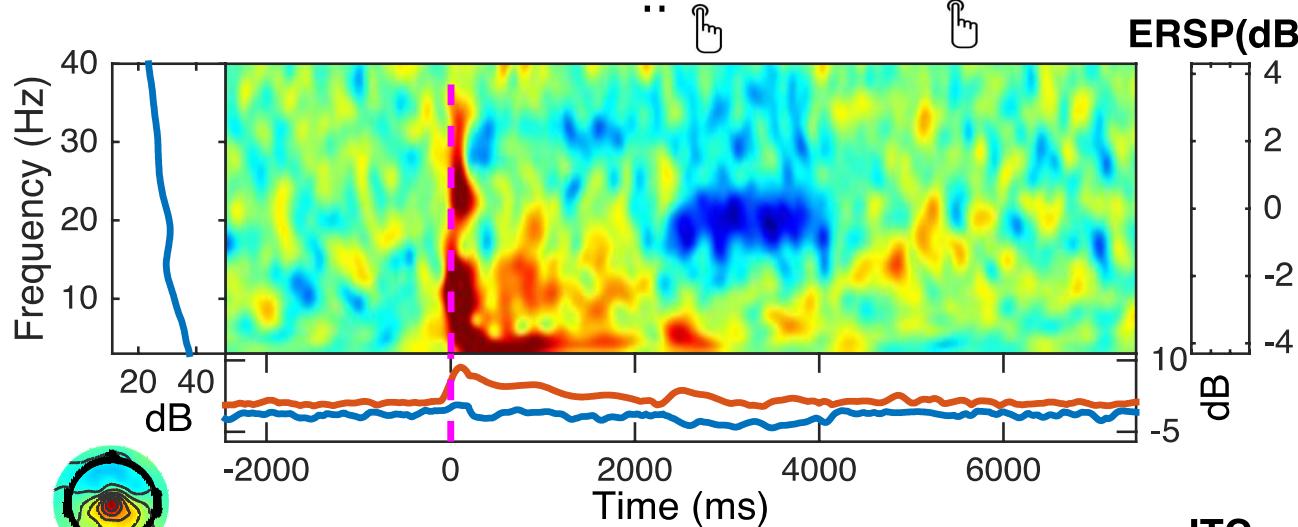
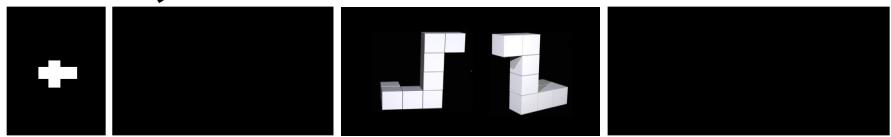




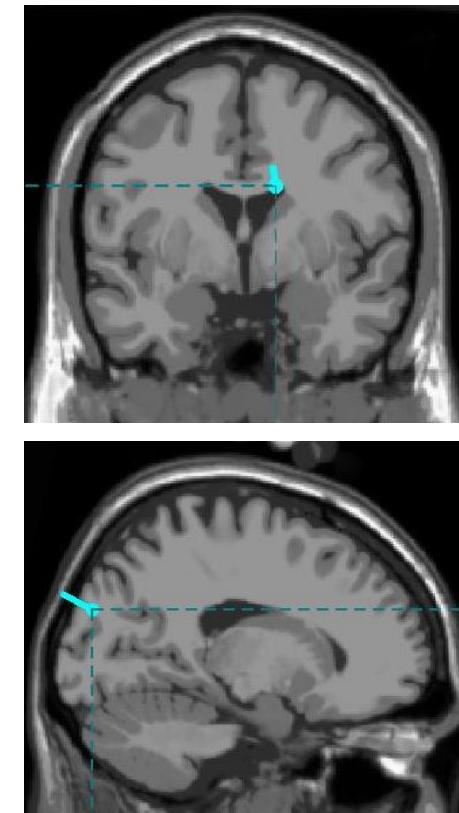
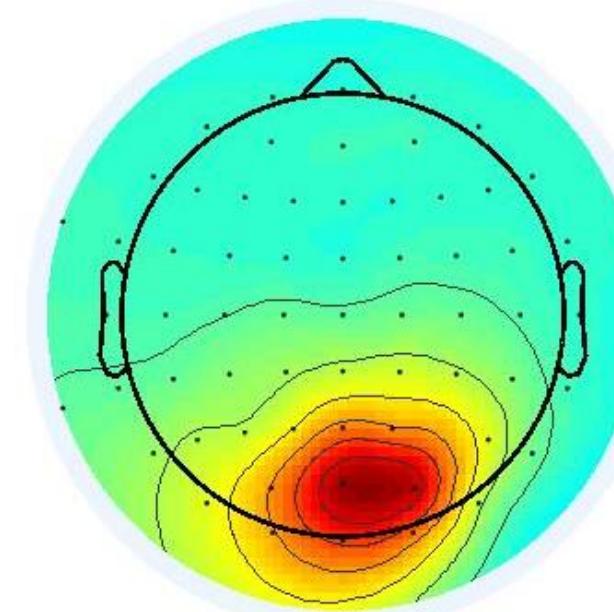
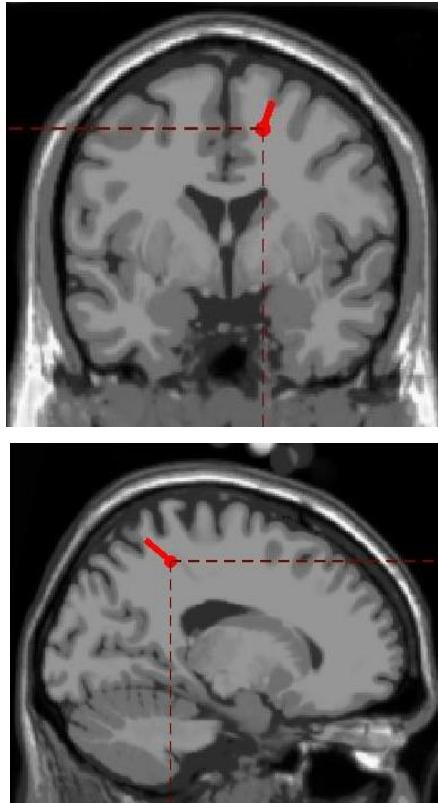
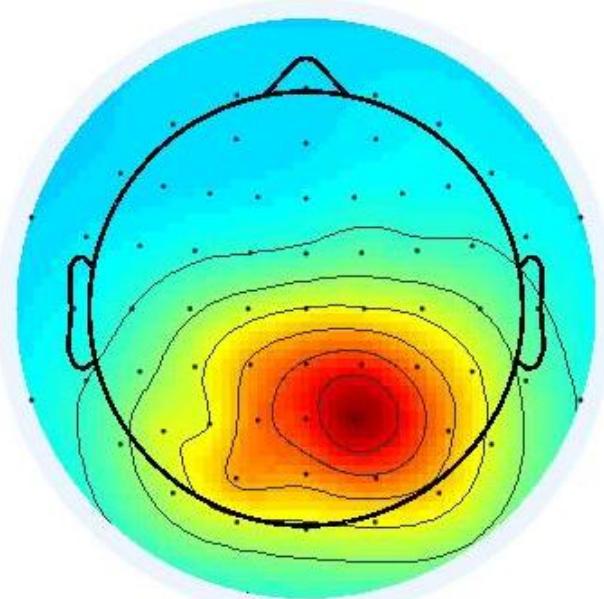
110% MT

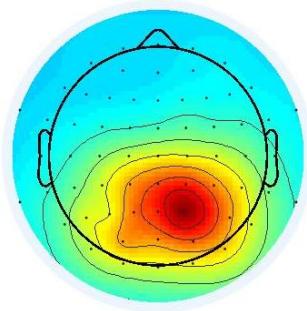


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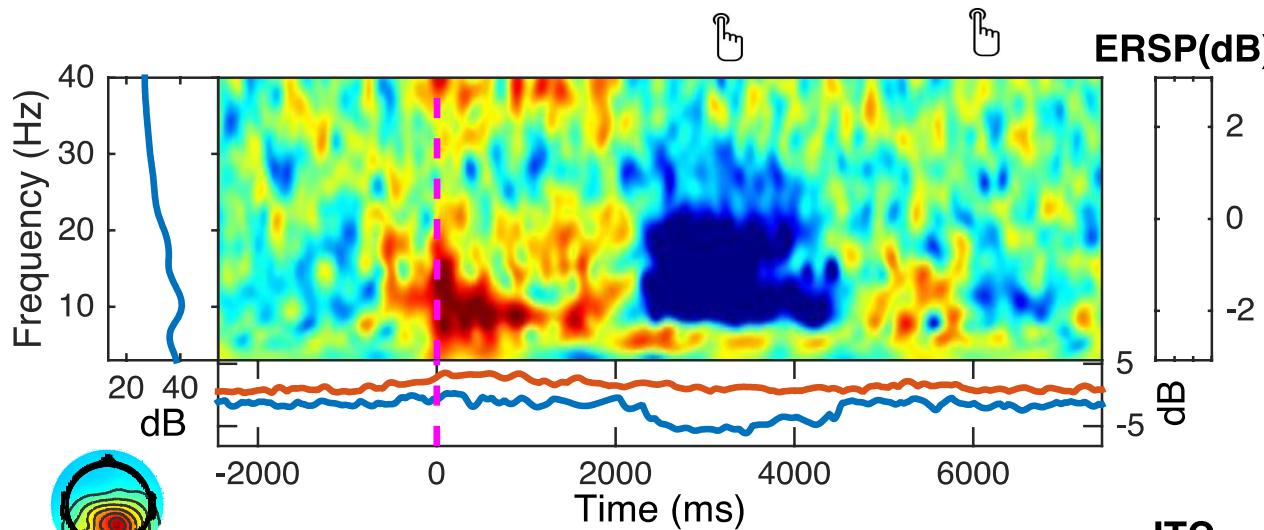
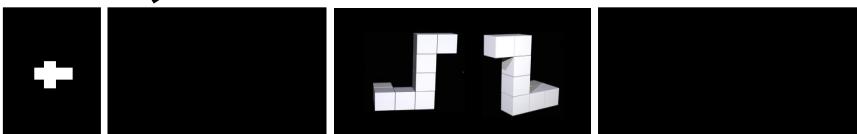


Parietal/occipital components

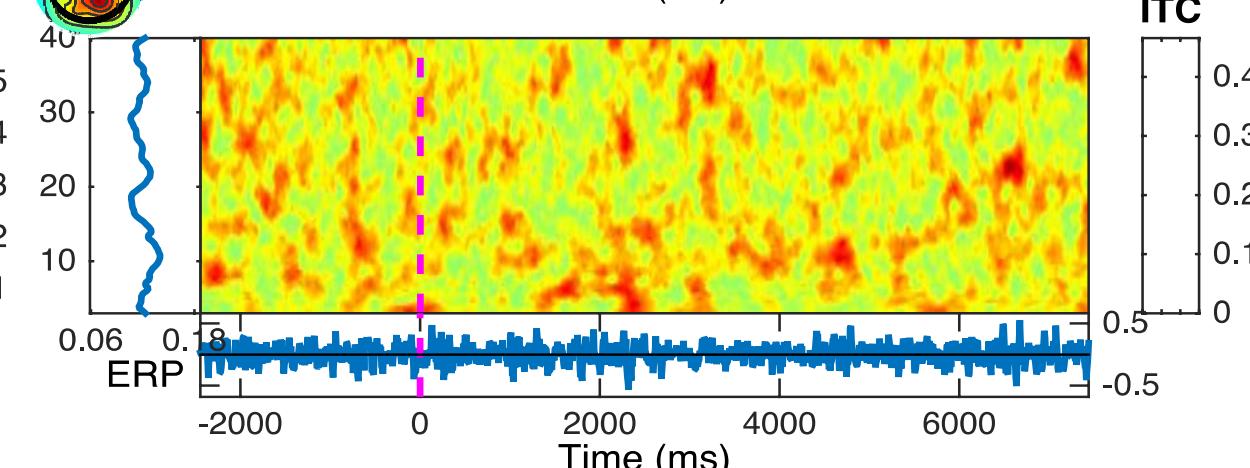
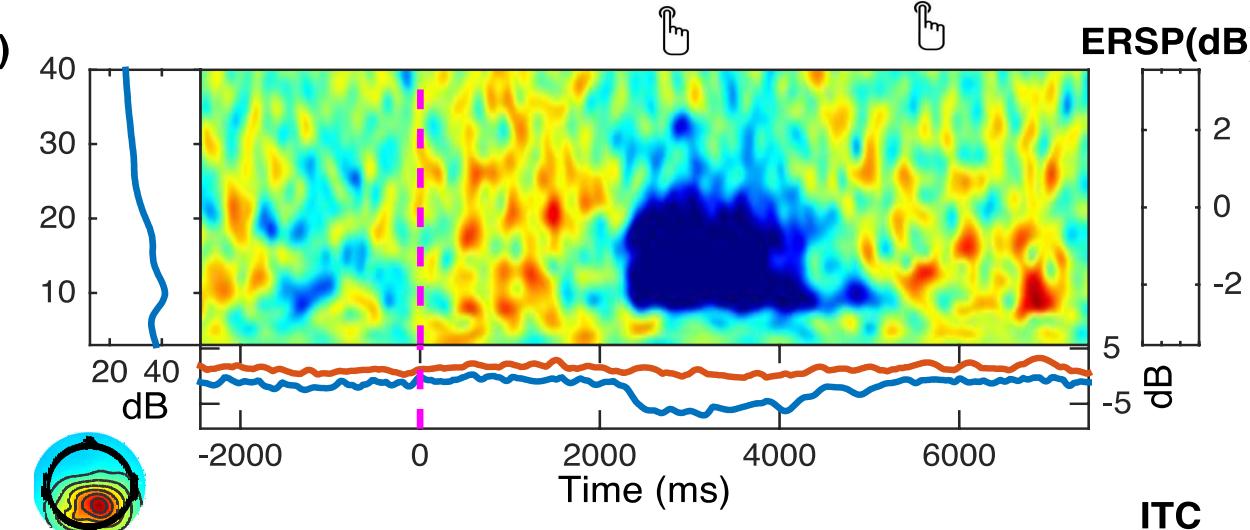
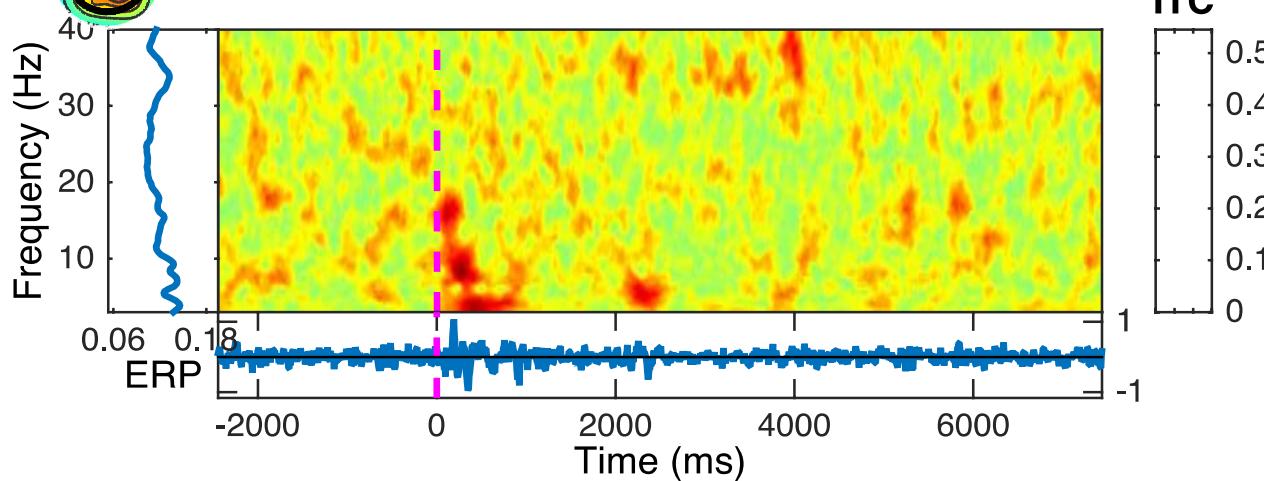
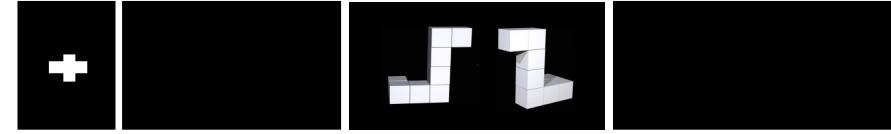


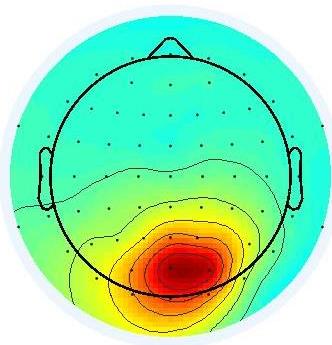


110% MT

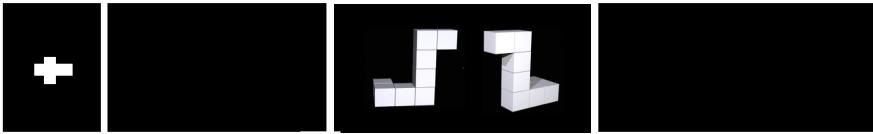


60% MT

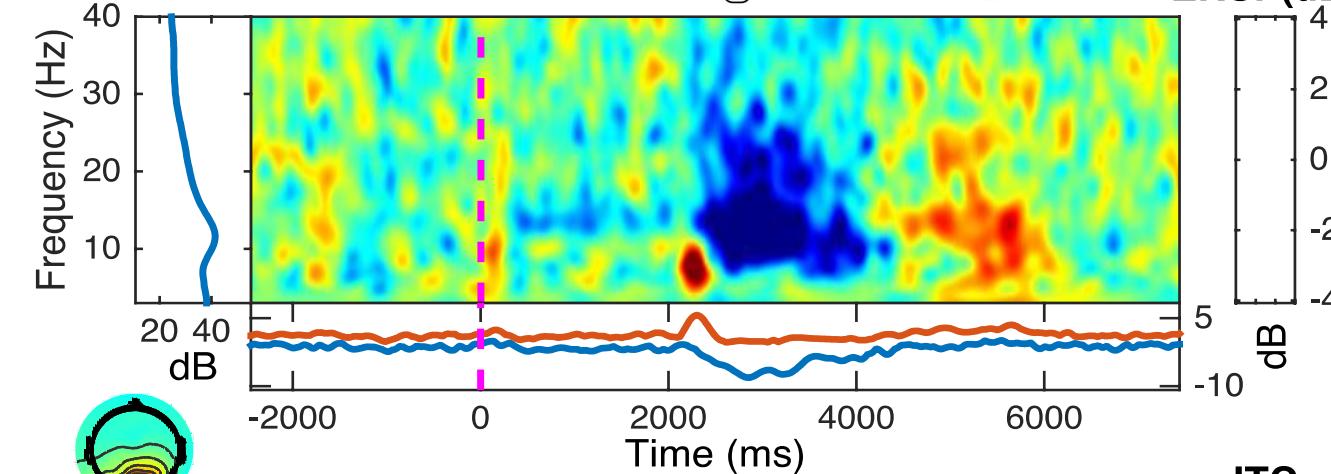




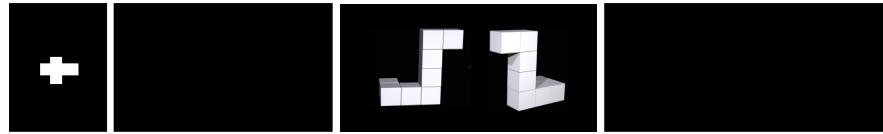
110% MT



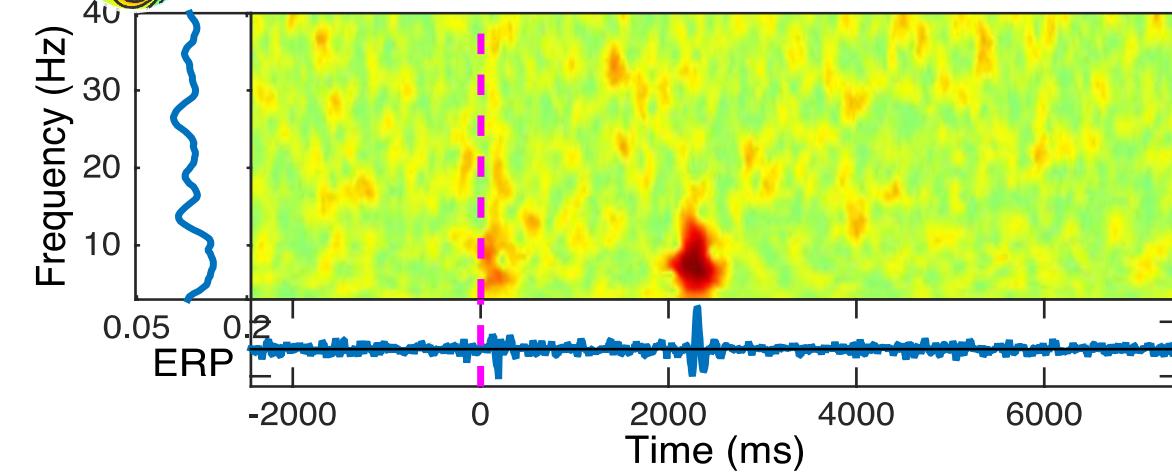
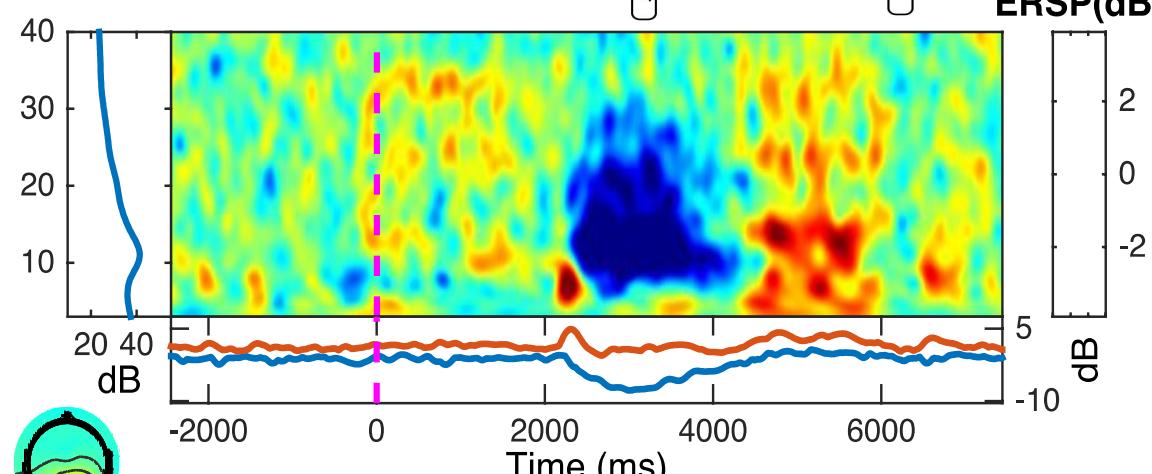
ERSP(dB)



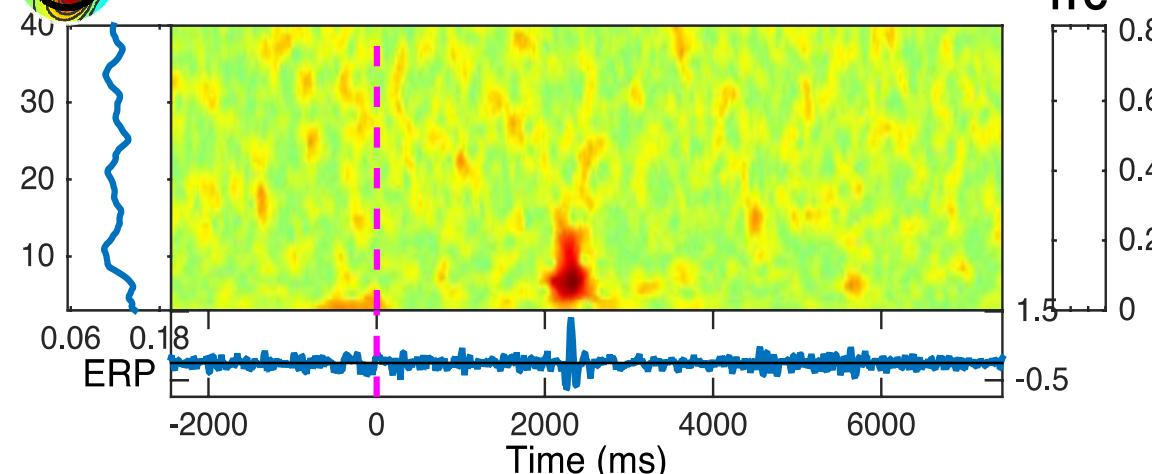
60% MT



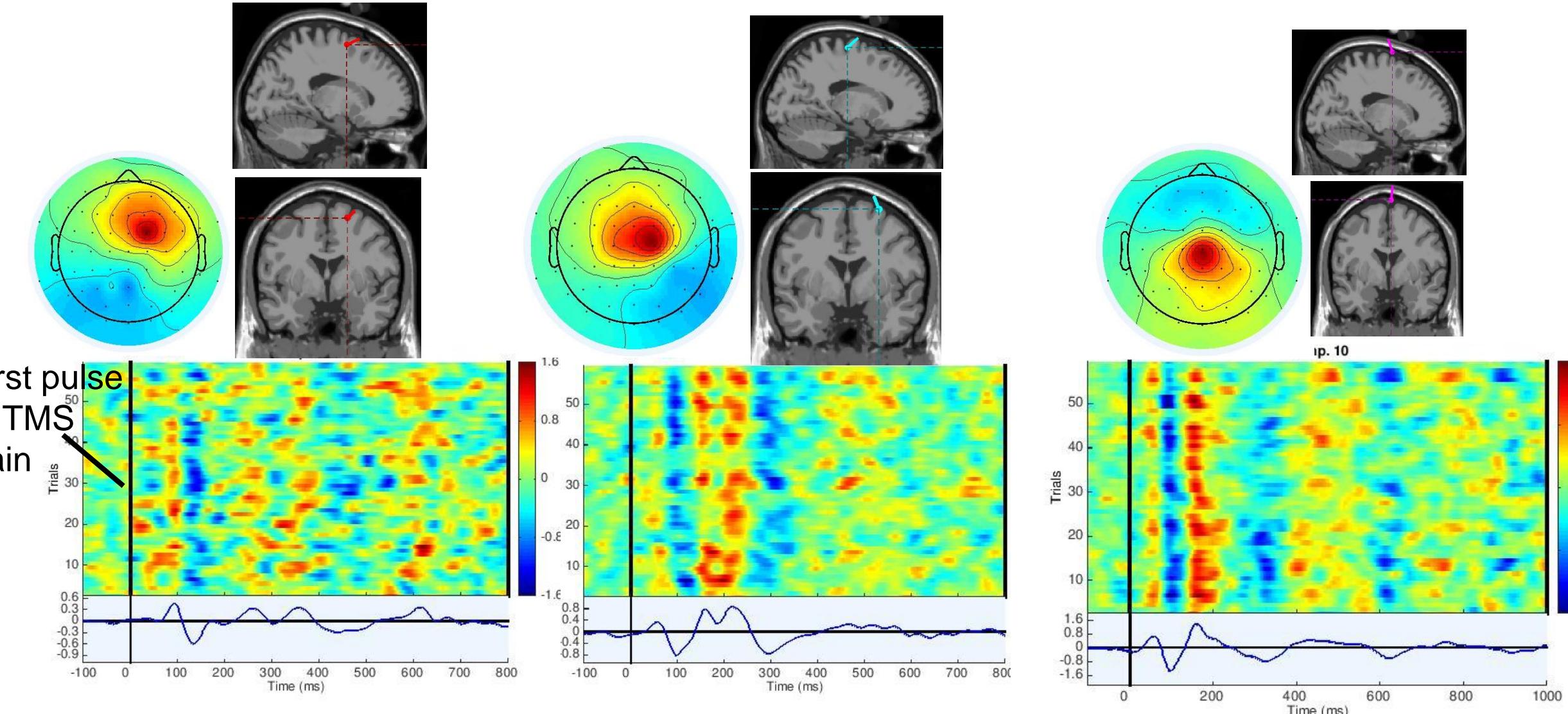
ERSP(dB)



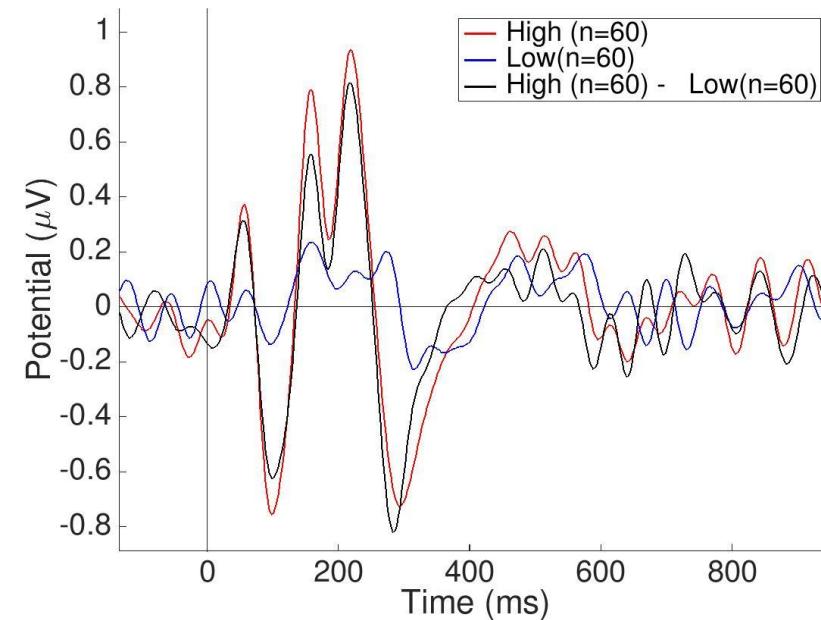
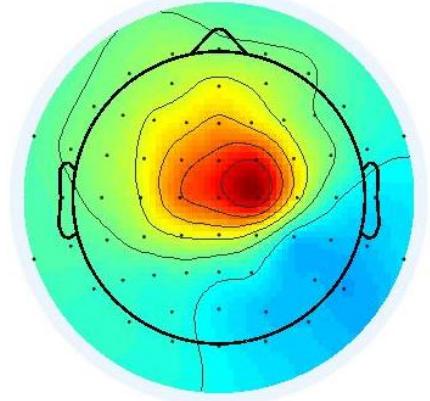
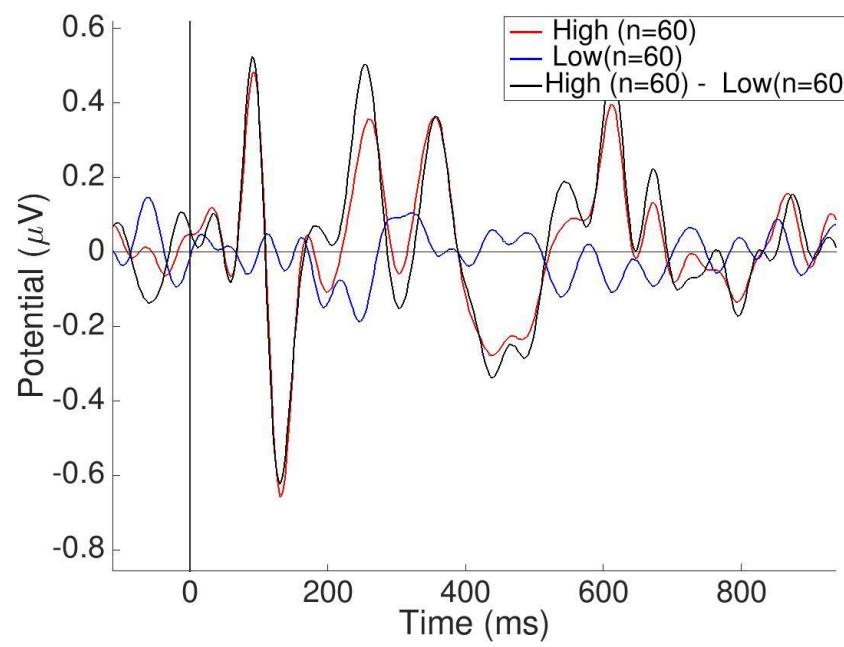
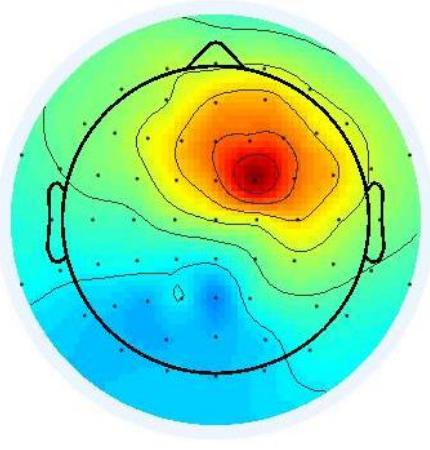
ITC



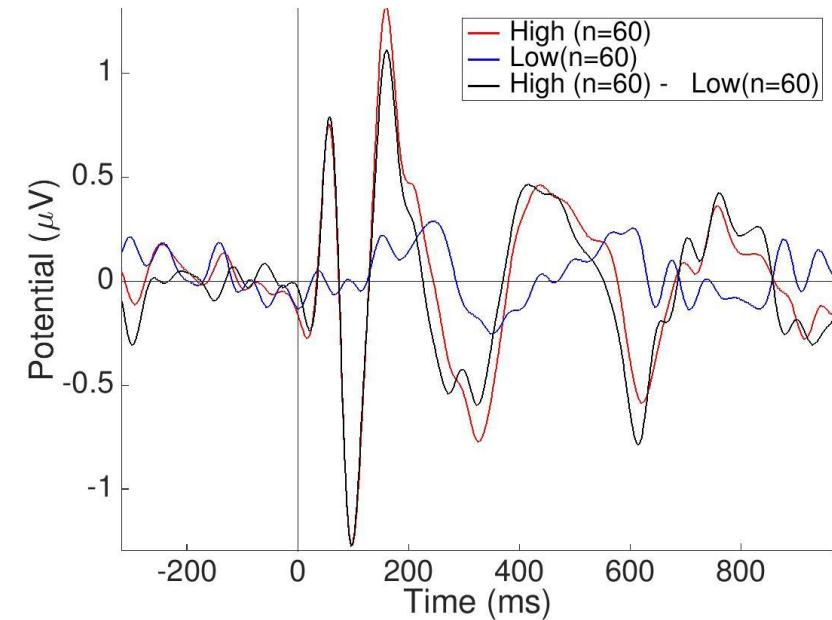
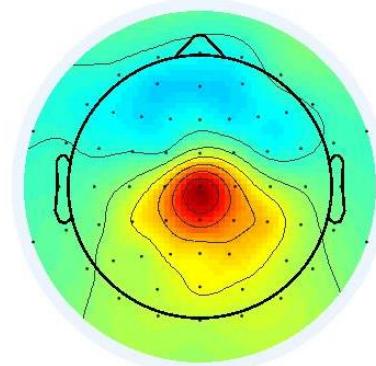
Frontal ICs located close to the stimulation site show TMS evoked potentials!



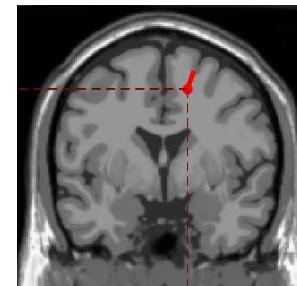
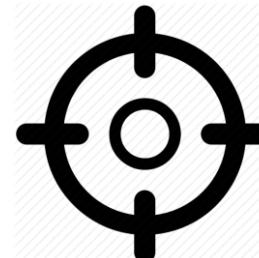
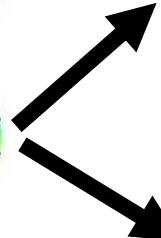
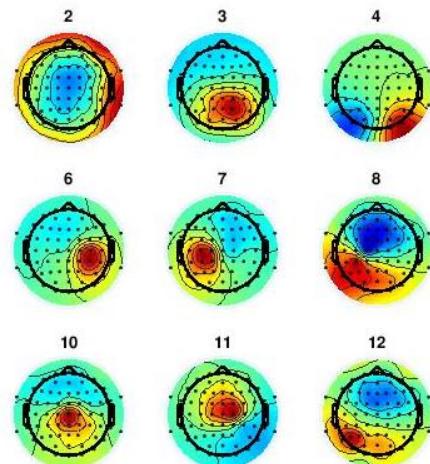
All 3 ICs are located in or close to Brodman area 6



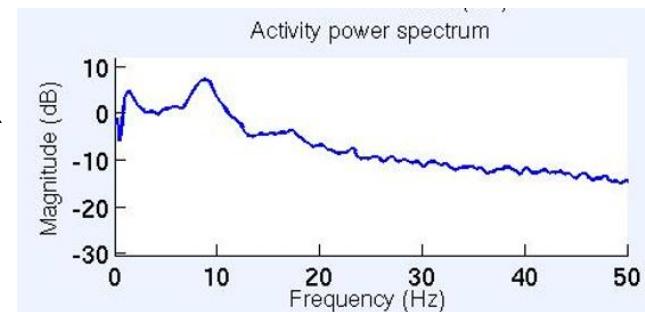
High vs. Low intensity stimulation 110% MT vs 60% MT



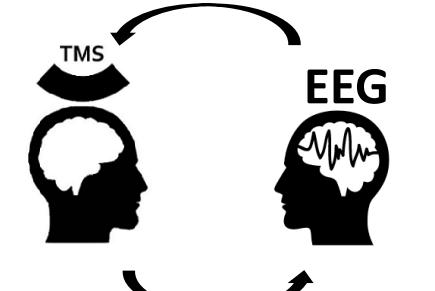
Summary: Opportunities enabled by combined TMS & EEG



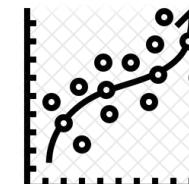
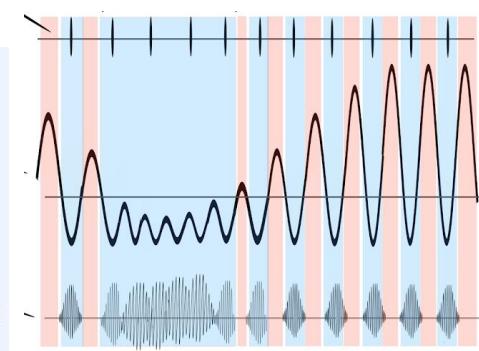
Location



Frequency



Phase



Available Tools for single pulse TMS artifact removal for EEG signal

Received: 14 February 2017

Revised: 29 October 2017

Accepted: 14 December 2017

DOI: 10.1002/hbm.23938

RESEARCH ARTICLE

WILEY

ARTIST: A fully automated artifact rejection algorithm for single-pulse TMS-EEG data

Wei Wu^{1,2,3,4}  | Corey J. Keller^{1,2,3}  | Nigel C. Rogasch⁵ | Parker Longwell^{1,2,3} |
Emmanuel Shpigel^{1,2,3} | Camarin E. Rolle^{1,2,3} | Amit Etkin^{1,2,3}

New Results

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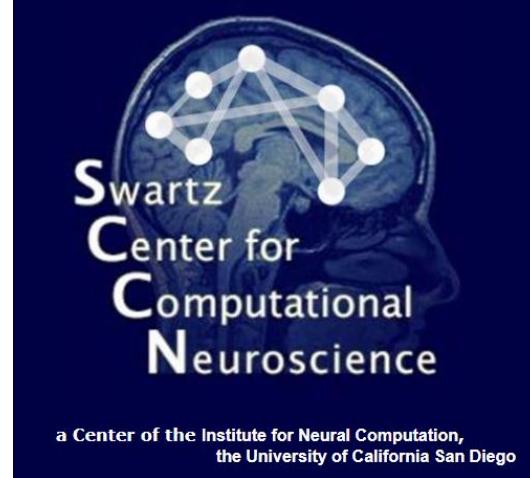
The rt-TEP tool: real-time visualization of TMS-Evoked Potential to maximize cortical activation and minimize artifacts

 S Casarotto,  M Fecchio, M Rosanova, G Varone, S D'Ambrosio,  S Sarasso, A Pigorini, S Russo, A Comanducci, R Ilmoniemi, M Massimini

doi: <https://doi.org/10.1101/2021.09.15.460488>



Johanna
Wagner



Thank you for attention