

Cortical Responses to Transcranial Magnetic Stimulation during Non-Rapid Eye Movement Sleep

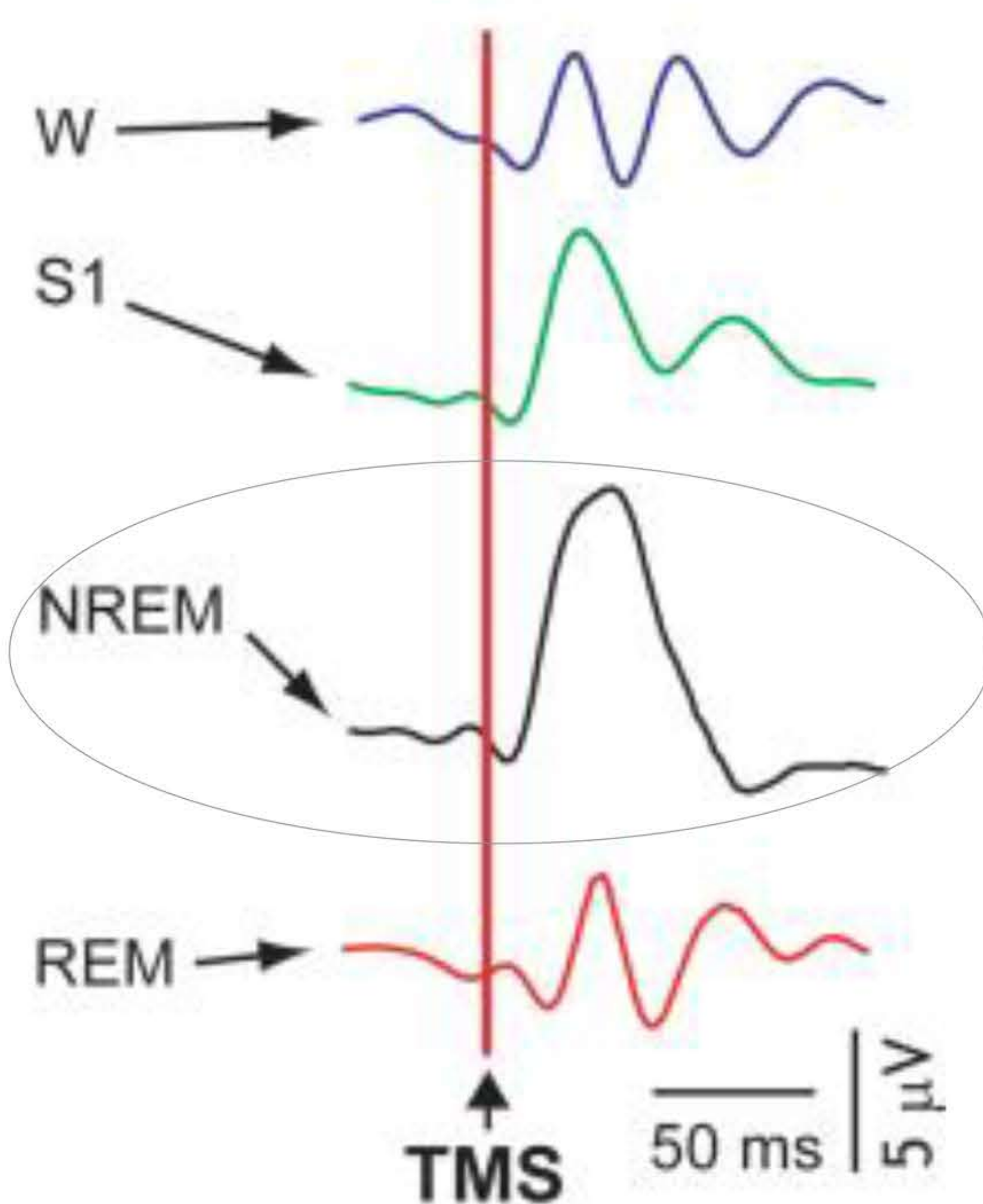
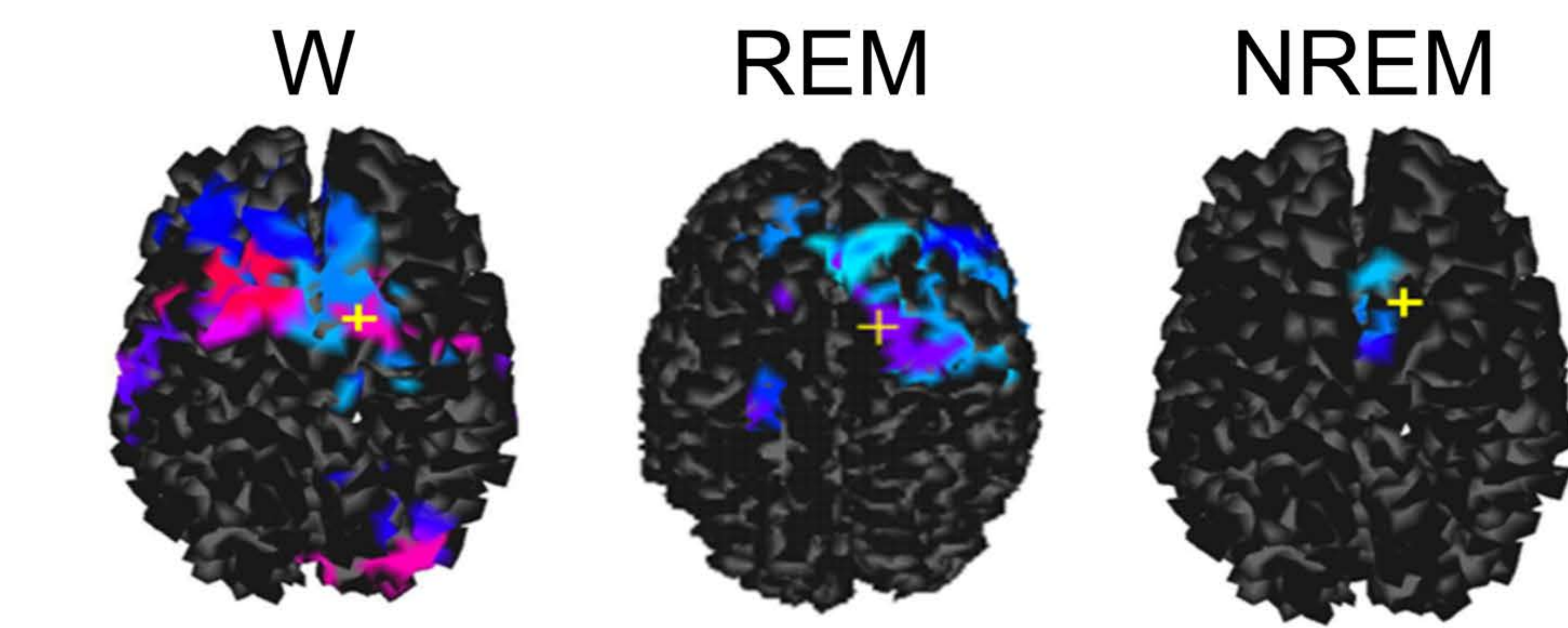
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Background

Combined transcranial magnetic stimulation and high-density electroencephalography (TMS–EEG) allows assessing changes in brain activity after noninvasive stimulation of the cortex. Previous studies^{1–3} showed differences in TMS–EEG responses between wakefulness (W), rapid eye movement (REM) and non-REM (NREM) sleep. It still remains unclear whether TMS–EEG is sensitive to variations in the level of consciousness within the same physiological state, as for example, subjects awakened from NREM sleep report having conscious dream-like experiences about half of the time⁴.



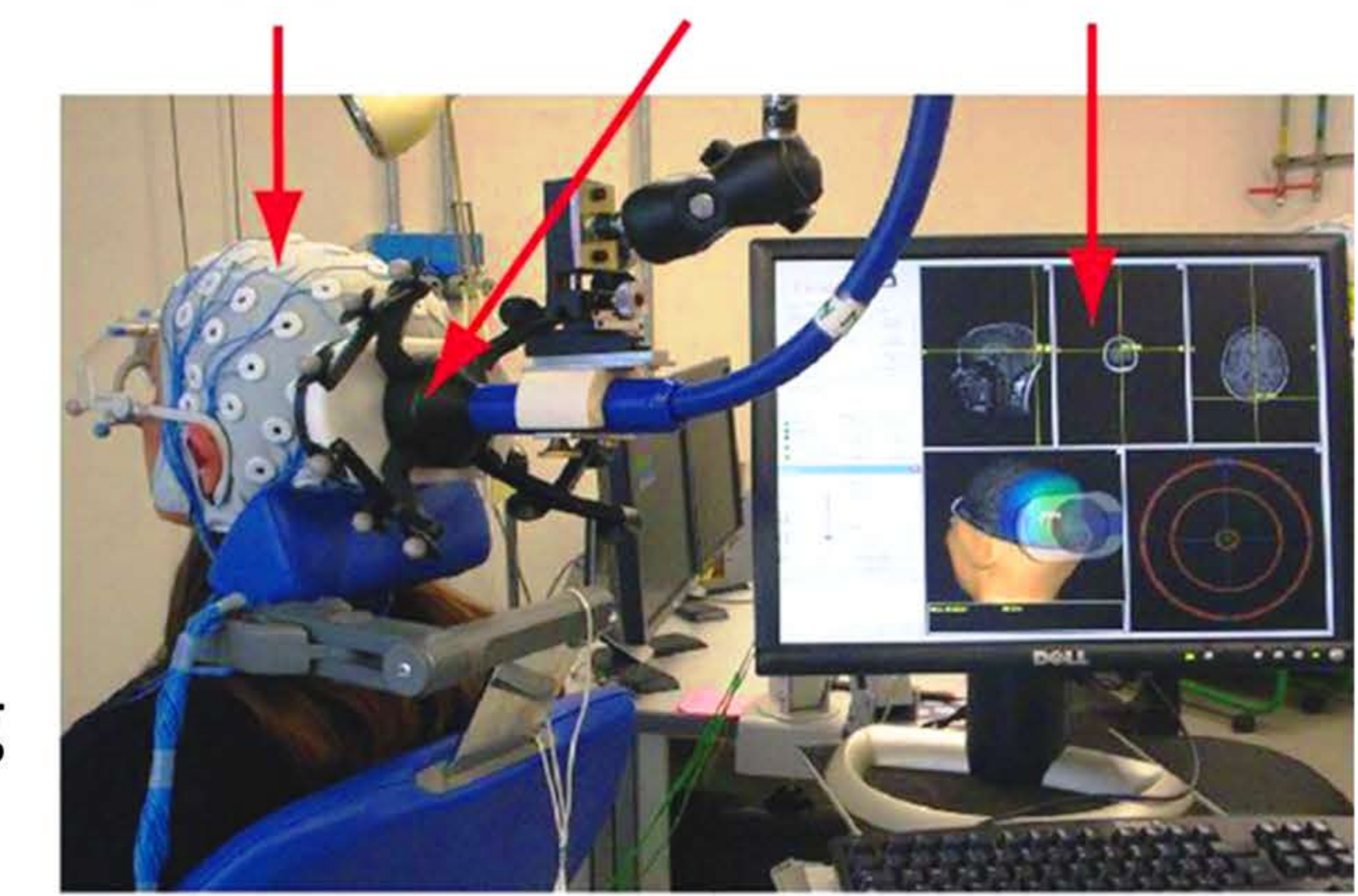
Does NREM sleep differ when subjects report a conscious experience versus when they don't?

TMS–EEG cortical activation and TMS–EEG responses under the coil in wakefulness and sleep

Methods

- 10 healthy participants (5 included in the analyses, 19–31 years old).
- 38 overnight TMS–EEG recordings (Nexstim eXimia, 60-channel EEG, navigated TMS using individual MRIs of the subjects) targeting the median superior parietal lobule.
- 151 awakenings in NREM sleep (based on AASM) with questionnaire to assess consciousness.
- Up to 16 TMS sessions (10–284 single pulses per session) were recorded in one night.
- Artifact-free filtered data (1.5–45 Hz) of the last 15 s before the awakenings were analyzed using global mean field amplitude (GMFA) and phase-locking factor (PLF). Statistical analyses were performed and differences between conditions were thresholded at cluster-level $p < 0.05$.

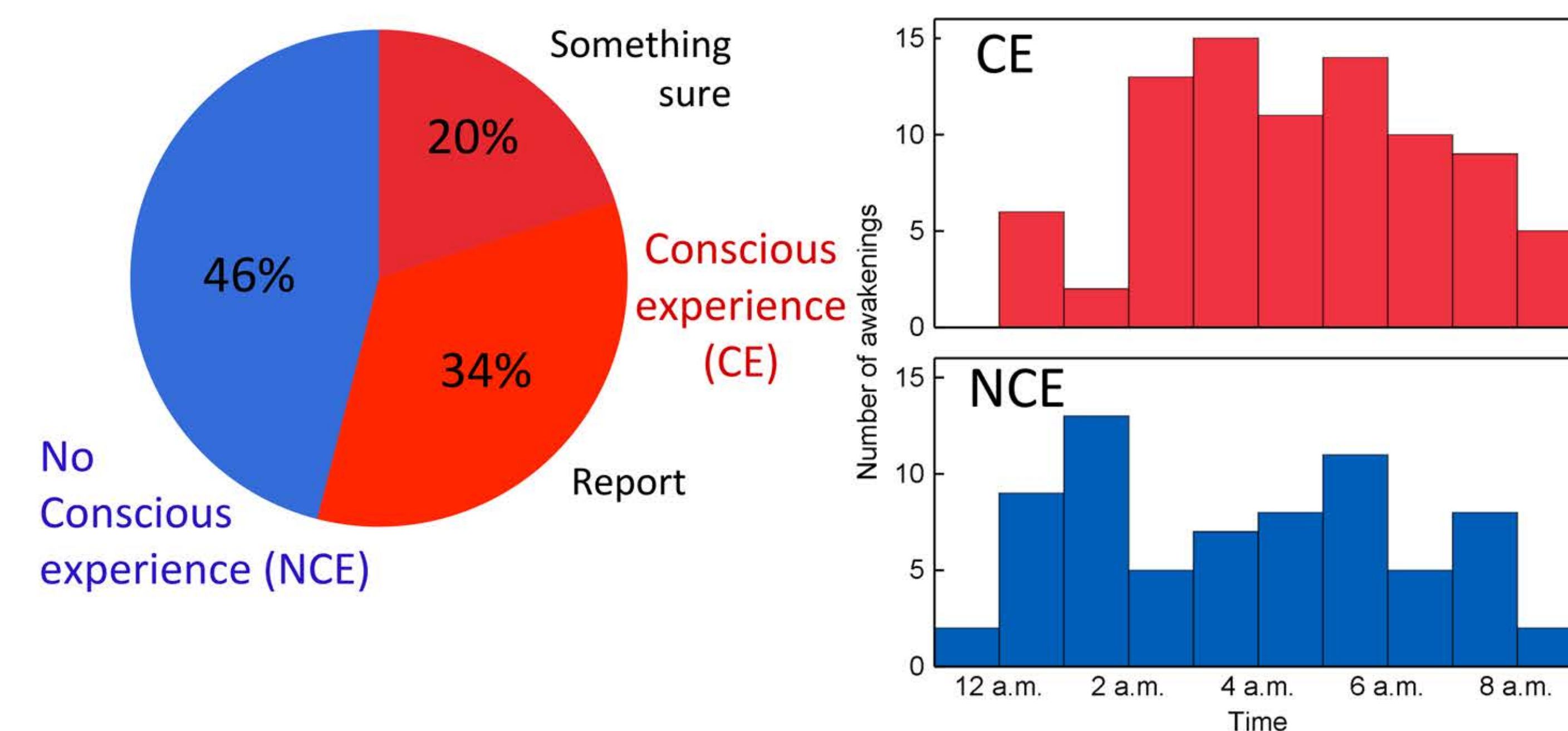
hd-EEG TMS NBS



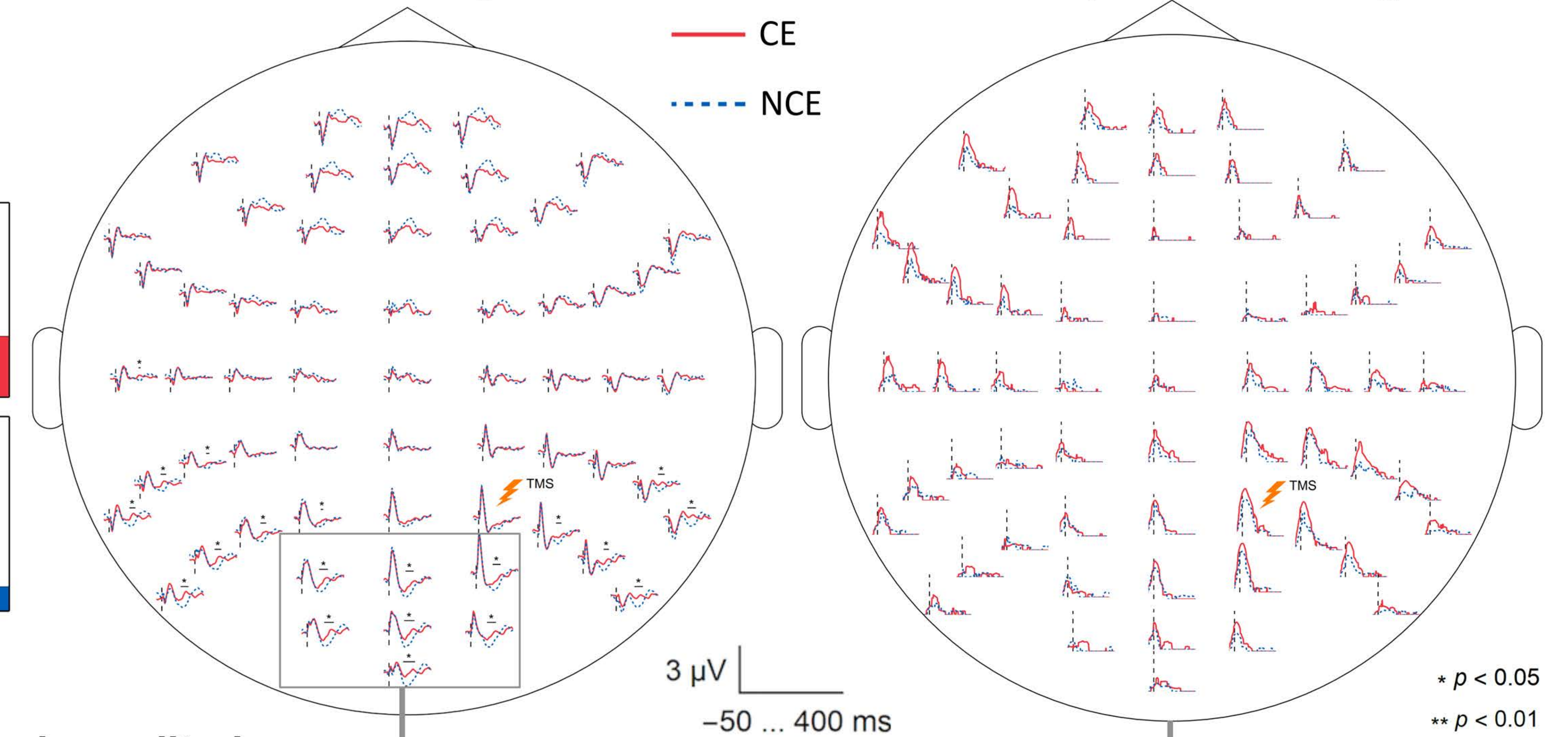
TMS–EEG set-up

Results

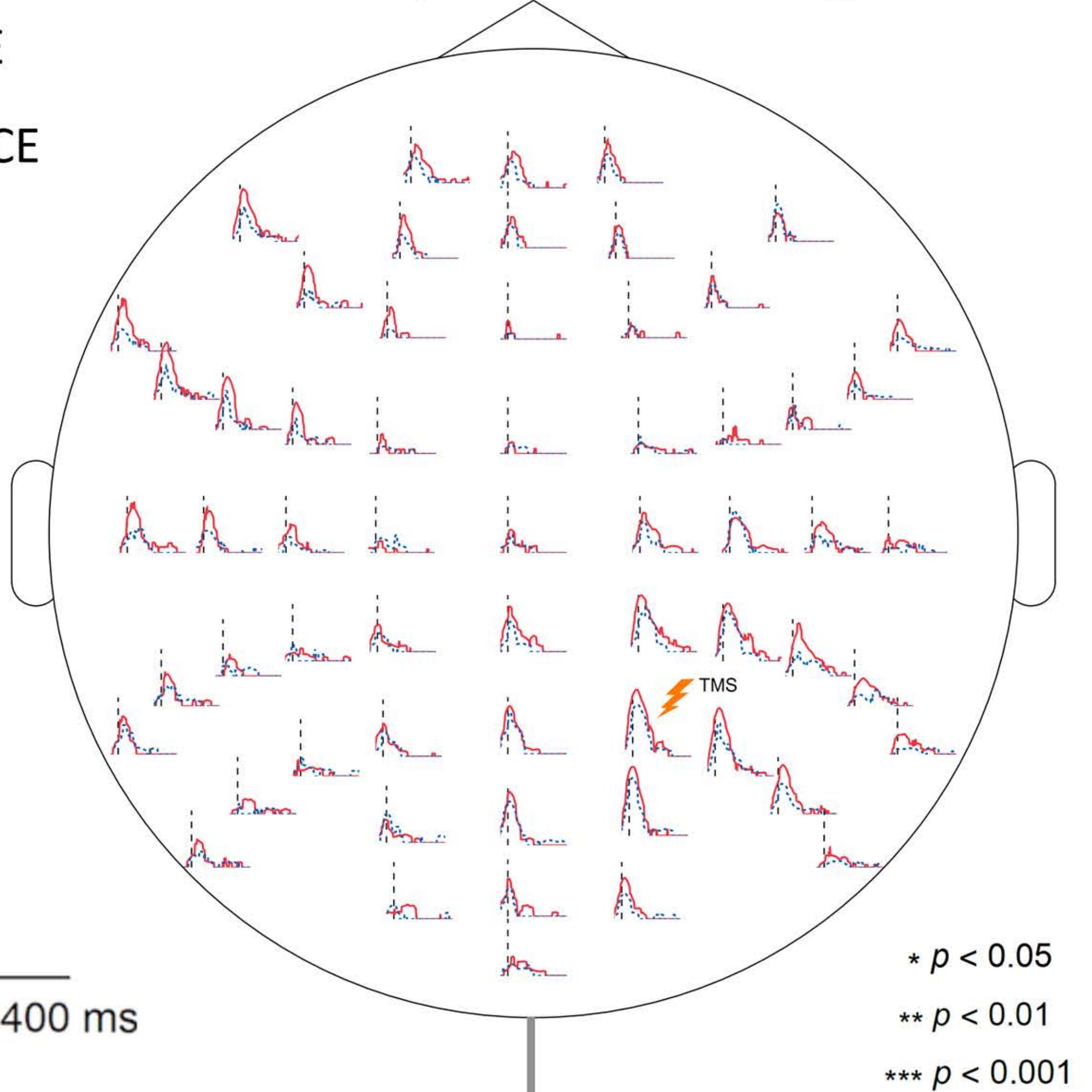
1. Behavioral responses



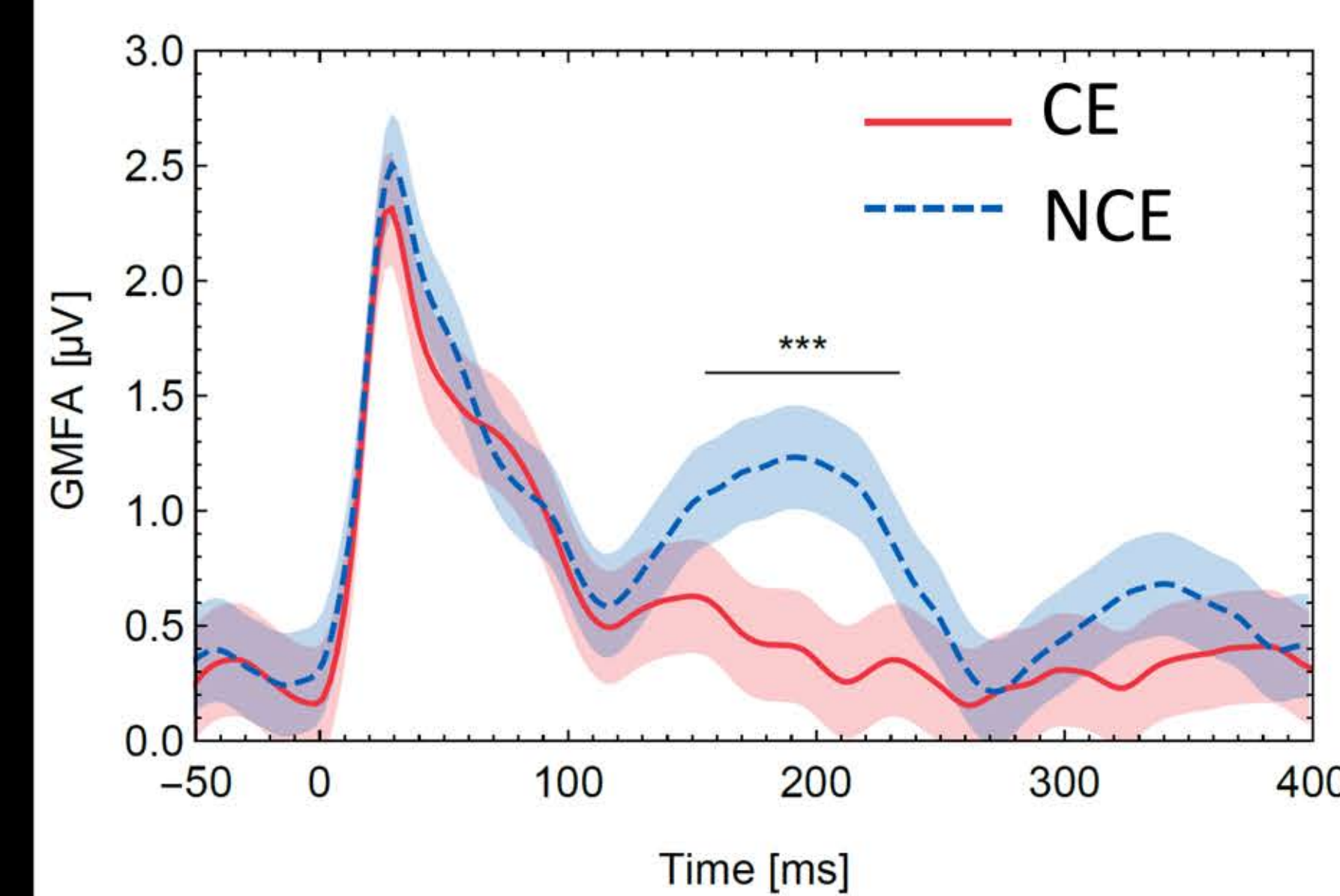
2. TMS–EEG responses



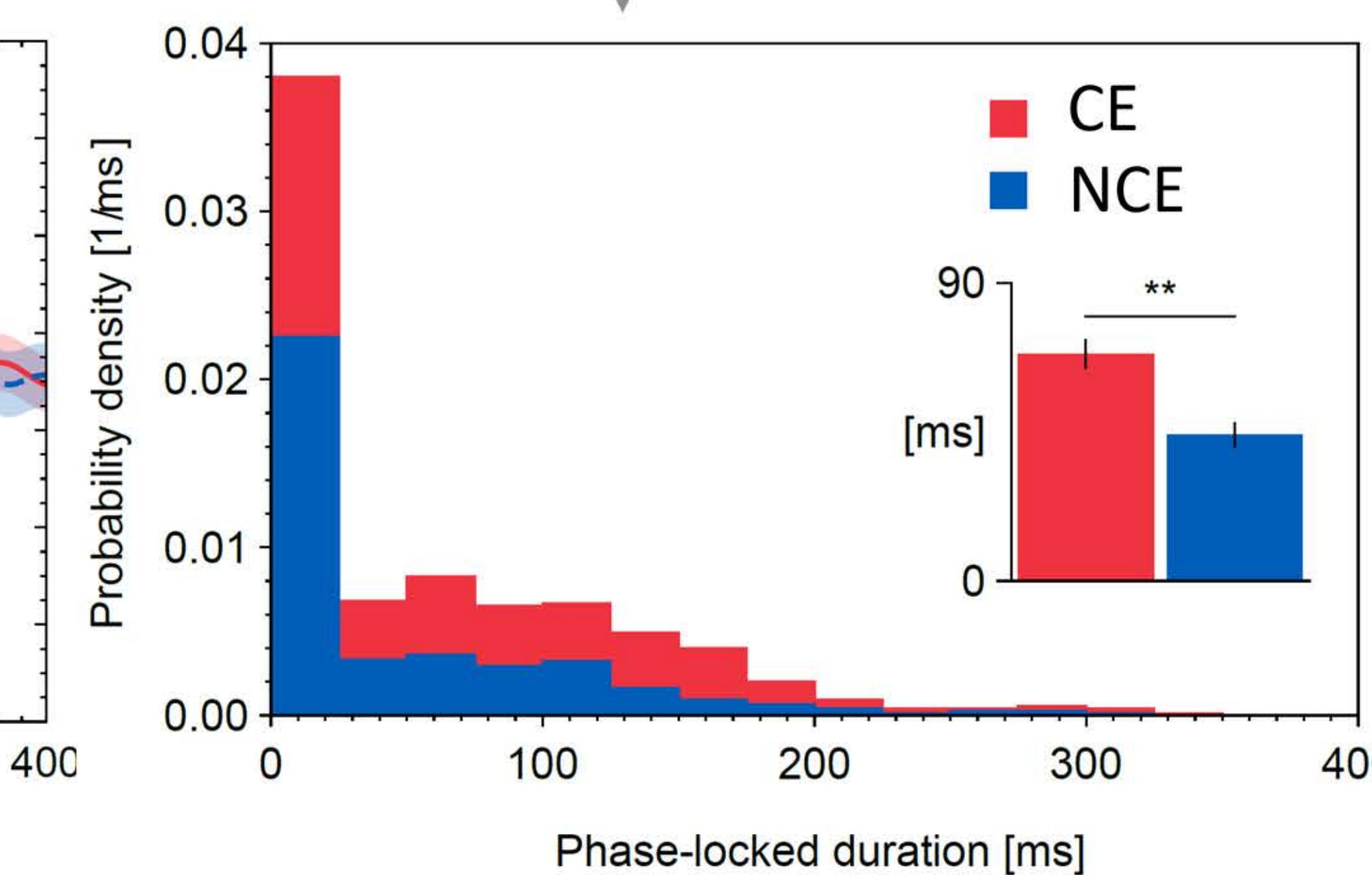
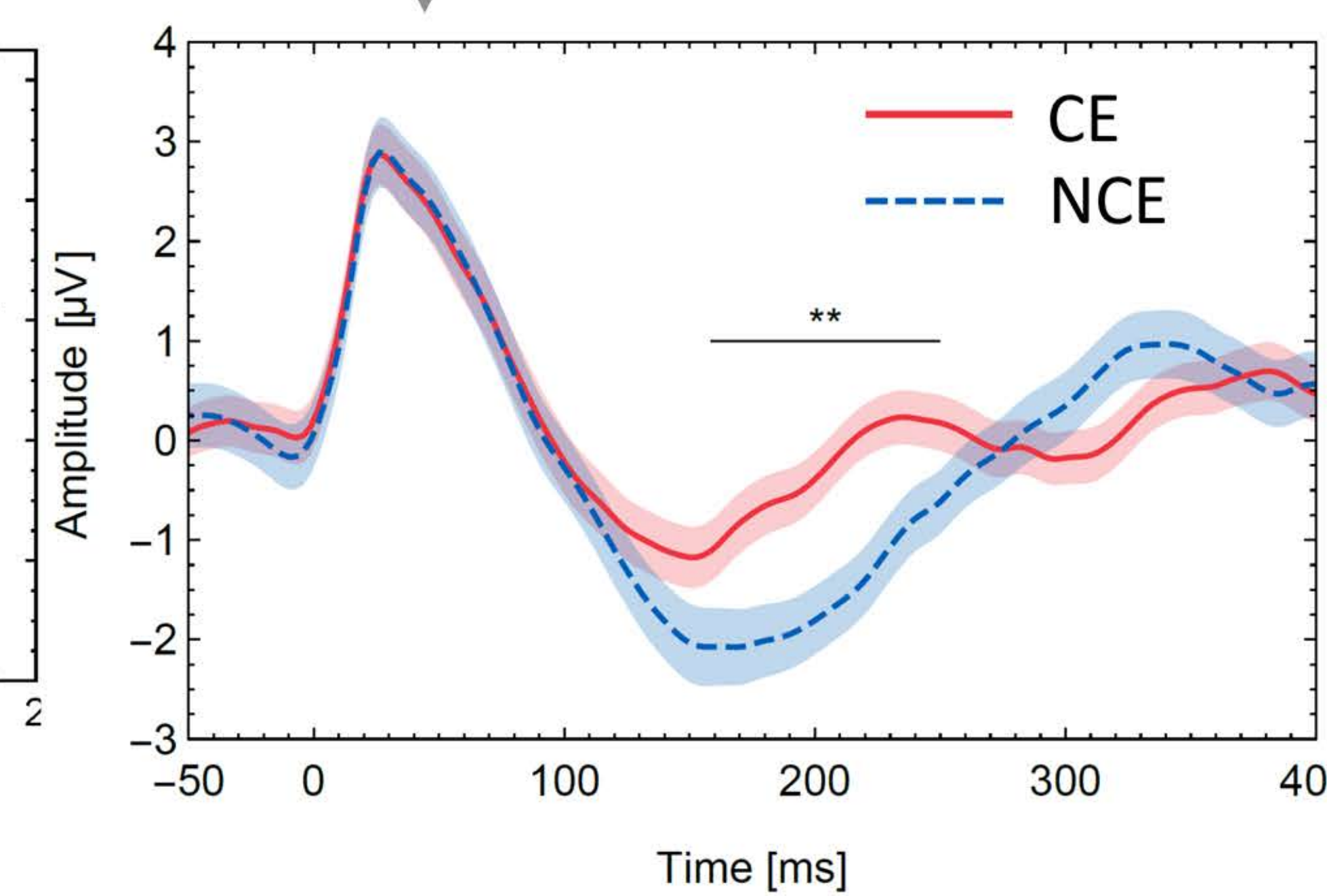
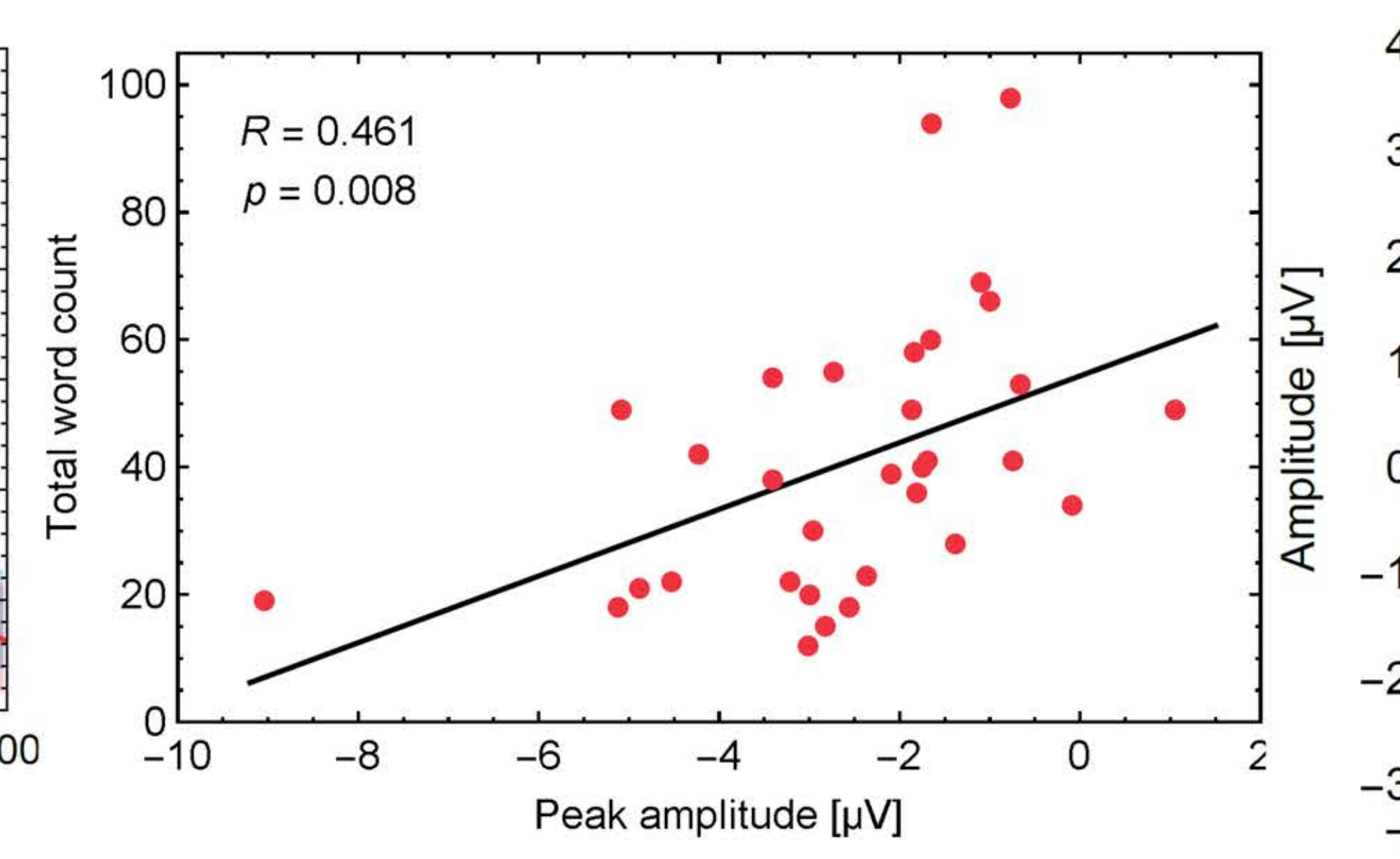
3. Global phase-locking (8–20Hz)



4. Global mean field amplitude



5. Word count & peak amplitude



In NREM sleep, subjects report conscious experiences (CE) as often as they do not, except early in the night. When subjects do not report any conscious experience (NCE), the negative peak amplitude of the TMS–EEG response (at 150–200 ms) is larger than when they do report one. This reflects the putative downstate and increased bistability when subject do not experience conscious experience. GMFA (a measure of the overall amount of synchronous electrical activity induced by TMS) is higher for the NCE condition whereas PLF (a measure of the duration of the deterministic effect of TMS) is higher for the CE condition. Additionally, the length of the reports negatively correlates with the peak amplitude of the TMS–EEG responses in stage N2 of NREM sleep.

References

¹Massimini et al. Cogn Neurosci. 2010 1:176–183. ²Massimini et al. Science. 2005 309:2228–32. ³Massimini et al. Proc Natl Acad Sci USA. 2007 104:8496–501. ⁴Siclari et al. Front Psychol. 2013 4:542

Acknowledgement

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Conclusion

Our findings suggest that variations in the level of consciousness within the same physiological state (here NREM sleep) are predicted by changes in the bistability of cortical networks revealed by TMS–EEG responses. This study shows that TMS–EEG is able to differentiate consciousness from unconsciousness within the same physiological state.