Hippocampal ripples during offline periods predict motor sequence learning

Pin-Chun Chen[1]; Jenny Stritzelberger[2]; Hajo Hamer[2]; Bernhard Staresina[1]
1 - Department of Experimental Psychology, University of Oxford; 2 - Department of Neurology of the University Hospital Erlangen
Contact: pin-chun.chen@psy.ox.ac.uk

Marie Skłodowska-Curie Actions

UNIVERSITY OF OXFORD

Uniklinikum Erlangen

Introduction

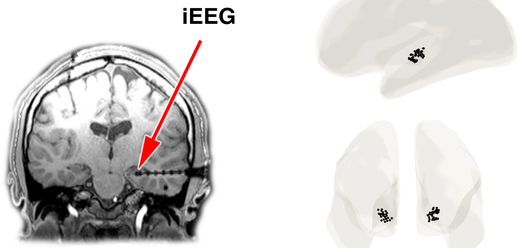
- Offline rest periods are critical for motor skill learning and the hippocampus might be involved[1-3].
- Hippocampal ripples (80–120 Hz in humans) as a key mechanism for offline memory reactivation and consolidation in declarative memory[4].

Question

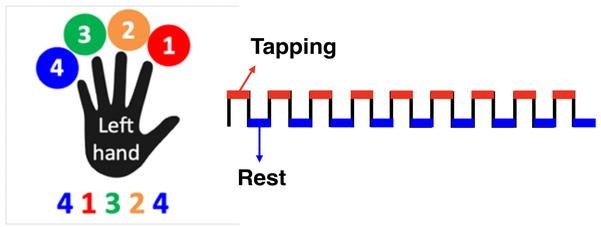
- Are hippocampal ripples involved in human memories of motor skills?

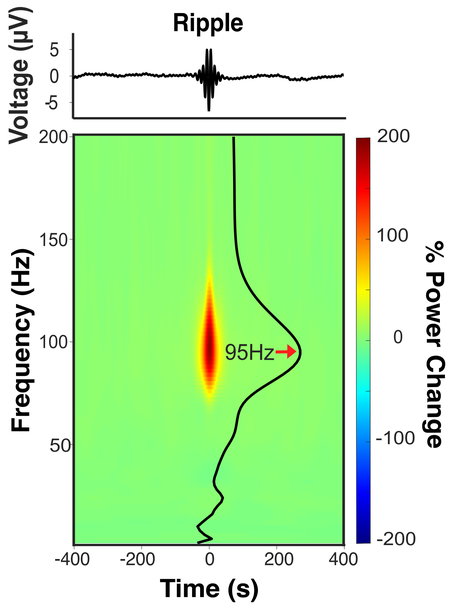
Methods

- 17 human epilepsy patients implanted with iEEG depth electrodes
- 9 male; age: 31.3 ± 10.2 years old
- 34 bipolar hippocampal contacts were visually identified on the post-implantation MRI.
- Statistical tests were modeld using Linear-Mixed Effects Models with participant and contact as random effects.



Motor sequence learning (MSL) task



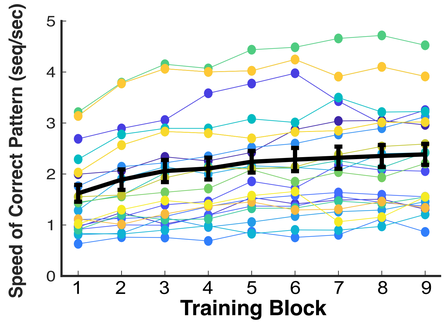


iEEG data preprocessing and ripple detection

- Signals were recorded at 4096Hz and downsampled to 1024Hz.
- Medial two hippocampal contacts were bipolar referenced.
- Interictal epileptic discharges (IEDs) were identified following previously established automated methods[5], prior to ripple detection.
- Ripple detection criteria were based on prior human hippocampal ripple studies[6,7], with an envelope of 80-120 Hz activity exceeding 1.5 S.D. from the mean.
- Ripple Rate (Hz) = # detected ripples divided by artifact-free recording time in seconds.

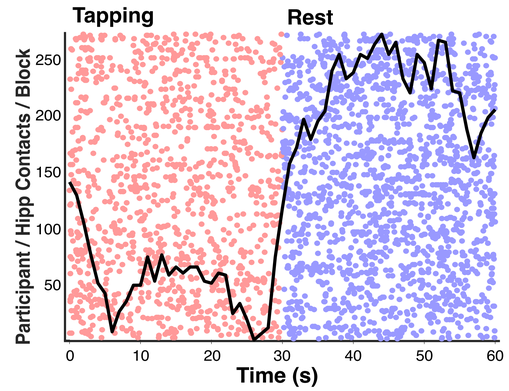
Results

Tapping speed increase

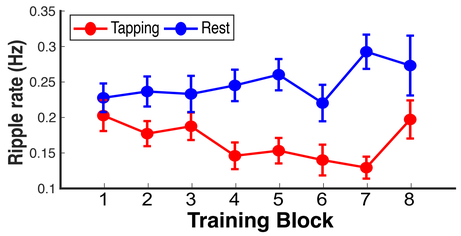


- With one block increase, the speed of correct sequence tapping increases by 0.09 on average (keypress/sec; $p < 0.001$).

Ripple rates: Rest > Tapping

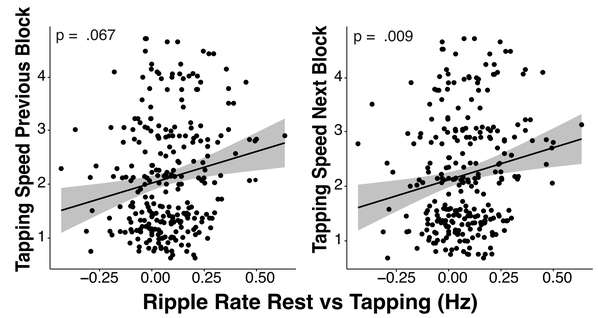


Rest ripple rates increase across training



- With one block increase, the difference of ripple rates b/w rest vs tapping increases by 0.01 on average ($p = 0.010$).

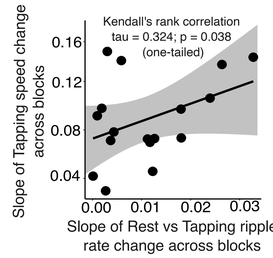
Rest ripple rates linked to tapping speed



- With one unit increase in ripple rate difference, tapping speed increases by 0.16 (previous block) and 0.21 (next block).

Conclusions

- Ripple rates increase during rest periods following finger tapping, which tracks learning behaviour across participants and across training blocks.
- The hippocampus may be involved in offline learning beyond the declarative memory domain.



- Participants with greater ripple rate increase during rest (compared to tapping) showed greater slope of improvement in tapping speed.

References

1. Bönstrup et al. (2019). A rapid form of offline consolidation in skill learning. Current Biology, 29(8), 1346-1351.
2. Jacobacci et al. (2020). Rapid hippocampal plasticity supports 3. motor sequence learning. Proceedings of the National Academy of Sciences, 117(38), 23898-23903.
3. Buch et al. (2021). Consolidation of human skill linked to waking hippocampo-neocortical replay. Cell reports, 35(10).
4. Buzsáki (1996). The hippocampo-neocortical dialogue. Cerebral cortex, 6(2), 81-92.
5. Janca et al. (2015) Detection of Interictal Epileptiform Discharges Using Signal Envelope Distribution Modelling: Application to Epileptic and Non-Epileptic Intracranial Recordings. Brain Topogr 28, 172–183
6. Staresina et al. (2015). Hierarchical nesting of slow oscillations, spindles and ripples in the human hippocampus during sleep. Nat. Neurosci. 18, 1679–1686.
7. Chen et al. (2021). Stability of ripple events during task engagement in human hippocampus. Cell reports, 35(13).