CORTICAL REPLAY OF TEMPORAL MEMORY DURING INTER- AND INTRA- HIPPOCAMPAL RIPPLES

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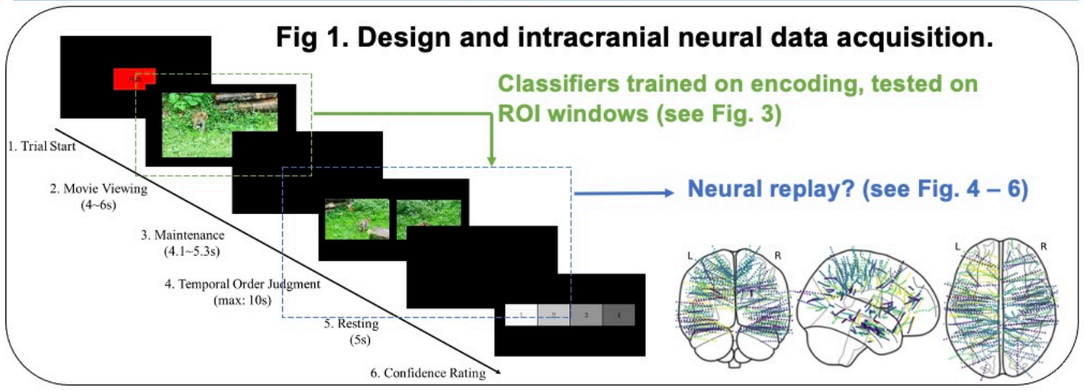
INTRODUCTION

- Replay has emerged as a pivotal mechanism in understanding how episodic memory is retrieved and consolidated.
- Neural activity patterns can either recapitulate past experiences or anticipate future events.
- Evidence exists for replay of "where" (location) and "what" (object) sequences in rodents (Macdonald et al. Neuron 2011) and humans, the "when" (time) aspect remains understudied.
- To address this gap by isolating temporal information independently of visual content.
- Intracranial electroencephalography (iEEG) data from epileptic humans in a temporal order judgment task (Fig.1), to test for replay that is attributed to temporal structure rather than specific visual elements.

METHODS

Fig 1. Design and intracranial neural data acquisition.

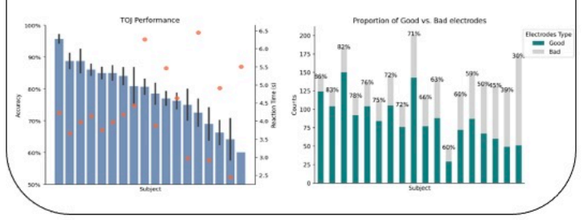


RESULTS (behavior)

Fig 2. Memory performance & summary of electrodes.

Accuracy: 82.82±9.87%

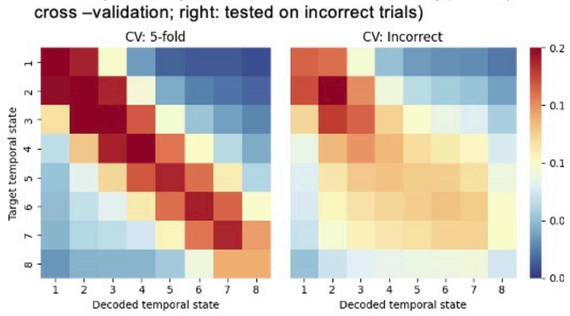
Electrode inclusion: 64.80 ± 15.24 %



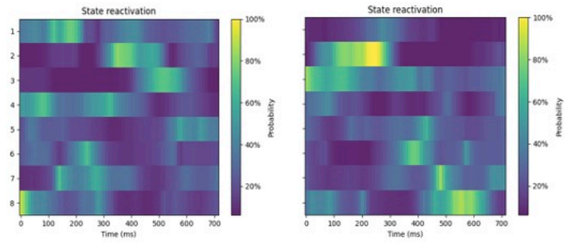
RESULTS (neural)

Fig 3. Content-invariant time decoder from whole-brain neural representations and replay detection using TDLM framework (Liu et al. Cell 2021).

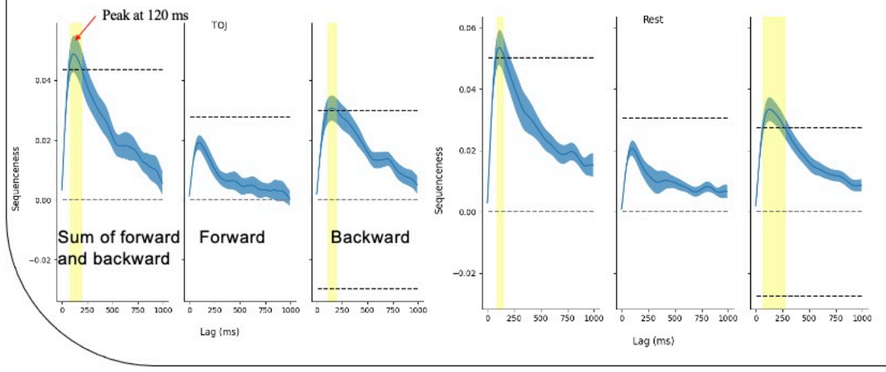
Decoding accuracy for temporal states of encoding period (left: 5-fold cross –validation; right: tested on incorrect trials)



Example matrices of predicted reactivation for each temporal state (left: forward; right: backward sequence-ness)



Forwards-and-backwards sequence-ness of temporal replay. Memory stage (TOJ, left three panels: sum of forward and backward, forward, backward): Significant replay at state-to-state intervals of 90-170ms, whereas during rest (right three panels) it occurred at intervals of 80-160ms; both peaking at 120 ms.



Temporal context drift during replay: State dissimilarity increases as temporal state distance increases

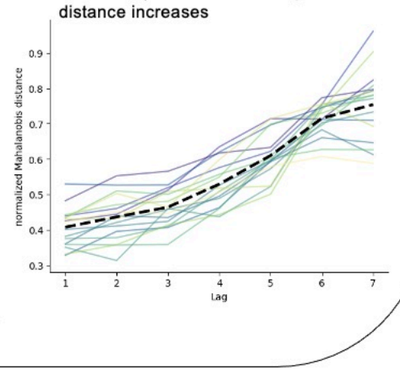


Fig 4. Stronger replay sequence-ness (TOJ, Fig. 3 bottom left) → faster temporal-order memory judgement speed.

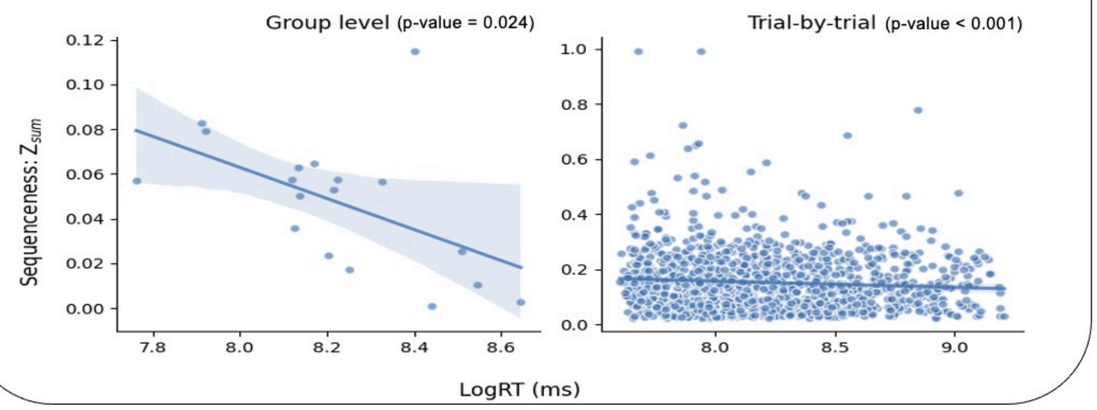
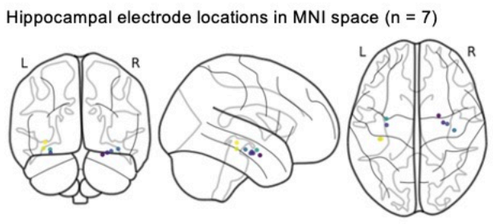
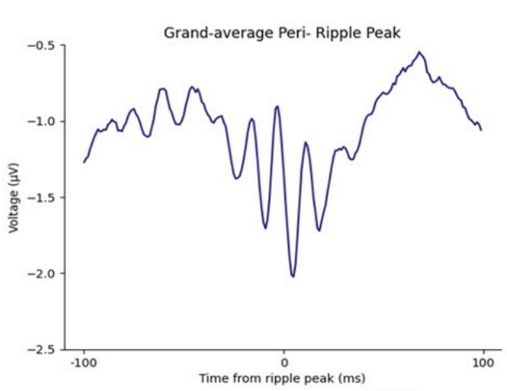


Fig 5. Hippocampal SWR detection (Norman et al. Science 2019).

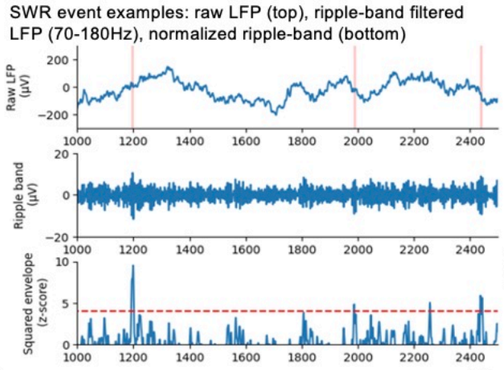
Hippocampal electrode locations in MNI space (n = 7)

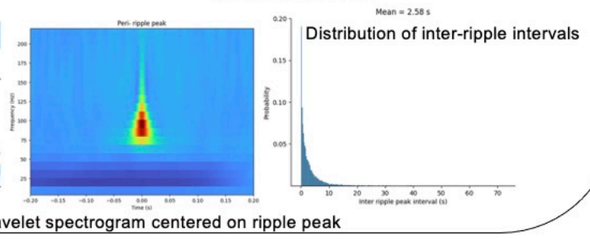


Grand-average Peri- Ripple Peak



SWR event examples: raw LFP (top), ripple-band filtered LFP (70-180Hz), normalized ripple-band (bottom)

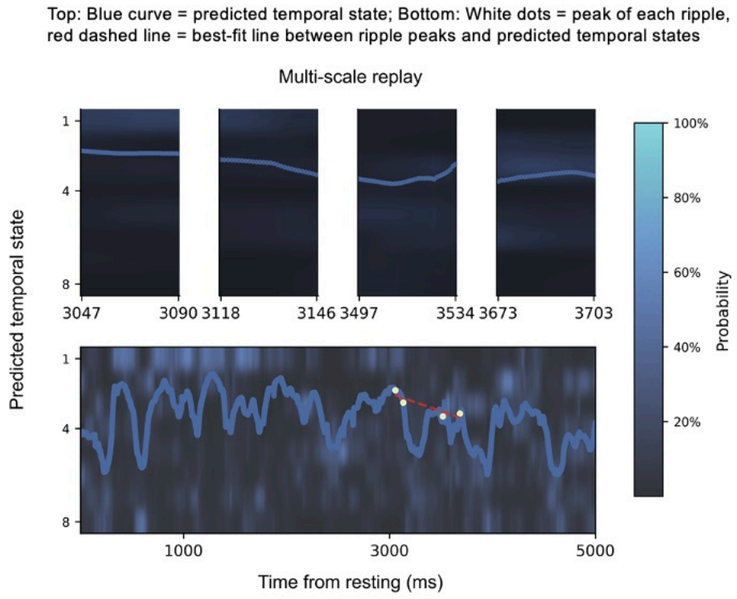


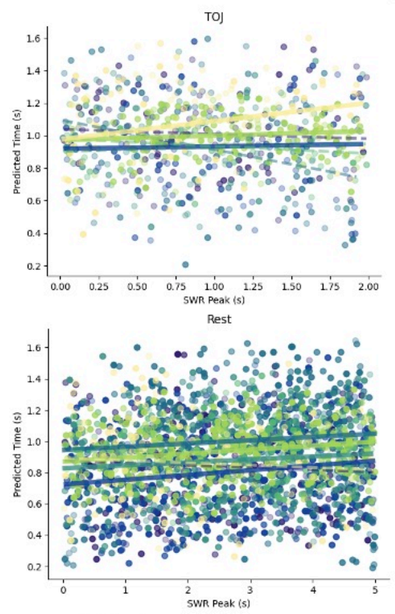


Wavelet spectrogram centered on ripple peak

Fig 6. Multi-scale intra- and inter-SWR neural replay evidence.

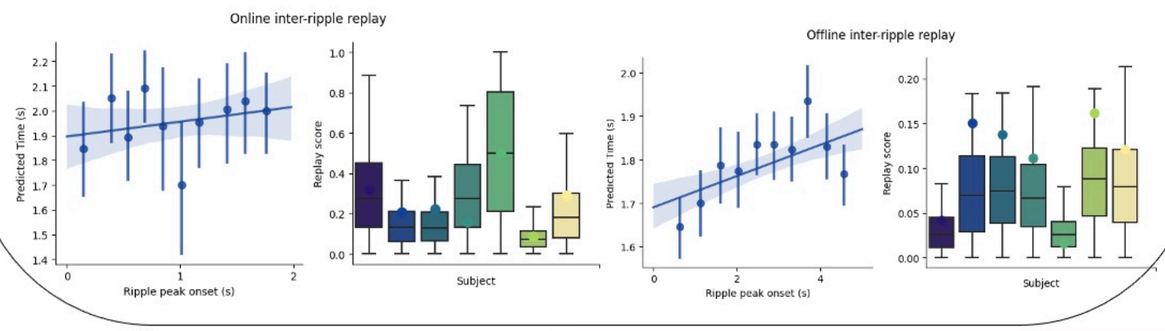
Top: Blue curve = predicted temporal state; Bottom: White dots = peak of each ripple, red dashed line = best-fit line between ripple peaks and predicted temporal states





At TOJ:
3 / 7 subj show sign. replay, p-value (Binomial test) = 0.003.

At Resting:
5 / 7 subj show sign. replay, p-value (Binomial test) < 0.001.



SUMMARY

- Rapid replay of temporal states during both memory retrieval and subsequent resting periods.
- Online replay accelerate the memory retrieval process at both trial-by-trial and group level.
- Hippocampal SWRs mark replay at different scales (i.e., intra- vs inter- SWR replay).
- Cortical extended replay occurring at a longer timescale (120ms x 7 states) than those with SWRs.

- Time in episodic memory, like "where" and "what", can be retrieved by a rapid replay mechanism.
- Memory recollection are not just holistic experiences but can be analyzed in terms of separate spatiotemporal components.

REFERENCES & FUNDERS

Liu et al. Cell 2021; Macdonald et al. Neuron 2011; Norman et al. Science 2019

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