Signal complexity of local field potentials during sleep reflects both sleep stage and learning

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INTRODUCTION

Brain signal complexity, measured using multiscale entropy (MSE), is thought to reflect information processing capacity [1]. Studies have shown an increase in the MSE of brain signals in humans performing cognitive tasks, and this change may support more accurate and stable behavior [2]. Studies have also shown a decrease in signal complexity with decreased wakefulness [2]. However, during slow-wave sleep, neuroplasticity is considered an essential mechanism for learning and memory consolidation [3]. Multiscale entropy, then, may be able to capture the effects of sleep-dependent neuroplasticity in brain signals.

Here, we tested the hypothesis that signal complexity varies as a function of sleep stage and learning.

METHODS // MATERIALS

- Preprocessed data from a study by Lemke and colleagues [4] were downloaded from Dryad (DOI: 10.7272/Q6KK9927) and used for this study.
- Data included local field potentials (LFPs) from 4 male rats implanted with either microwire electrodes or high-density silicon probes targeted to the forelimb area of M1 [10].
- Recordings were acquired during sleep that occurred prior to and following a motor skill learning session (see Figure 1). Rats were trained for between 6 and 17 days, with training ending once rats reached a performance asymptote.
- Preprocessing procedures included manual rejection of noisy electrodes and Z-scoring of each electrode's signal across the entire recording session.
- LFPs were grouped into the following conditions:
  - non-REM (NREM) and rapid eye movement (REM) stages of sleep
  - Pre- and post-training sleep sessions, and
  - First and last day of training
- For each condition, LFPs were epoched into 4000 ms durations and multiscale entropy (MSE [5]) was calculated for each epoch.
- A data-driven multivariate Partial Least Squares analysis [6,7] was used to compare multiscale entropy across sleep stages and conditions

METHODS // MATERIALS

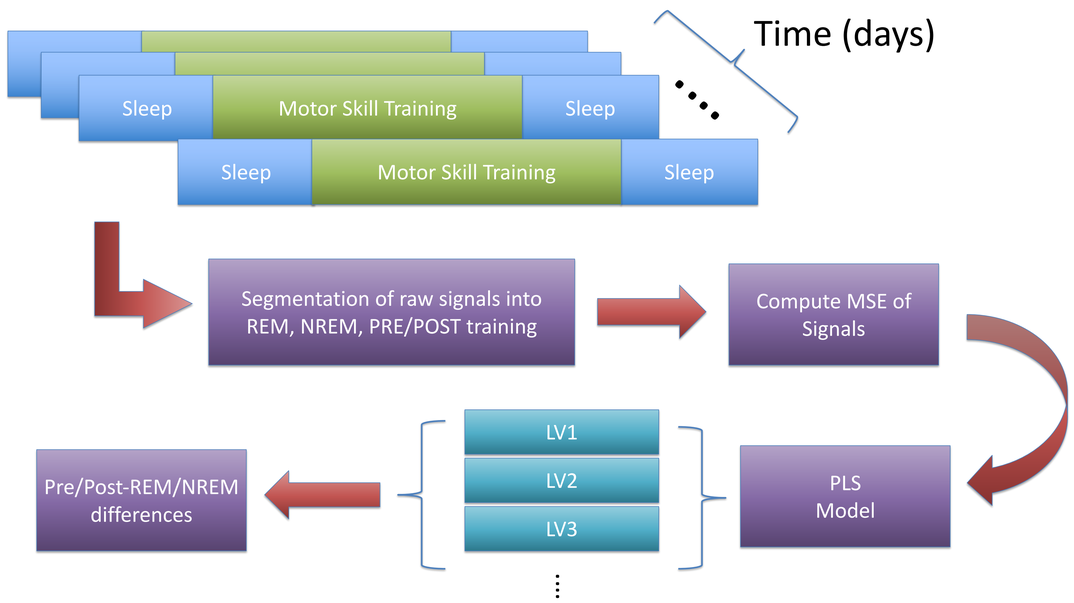

Fig 1. (top) Experimental design. (bottom) Workflow for segmenting LFP signals into REM/NREM, Pre/Post training sleep sessions. Multiscale entropy (MSE) of LFPs was computed, and a Partial Least Squares (PLS) statistical model applied to examine the differences between sleep stages, pre/post sessions, and days. The outputs of the model are a set of orthogonal latent variables that express the strongest differences across conditions.

RESULTS

a) Effect of sleep stage

b) Effect of training

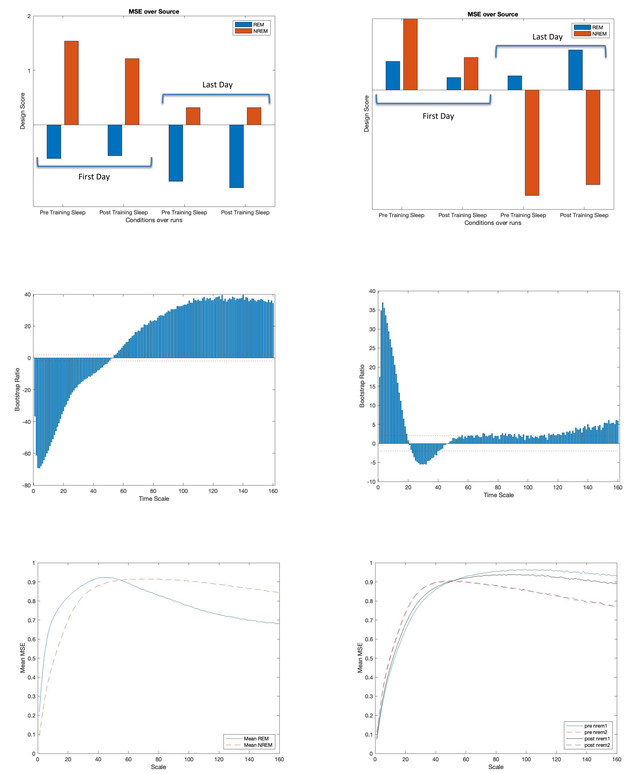

Fig 2. A Partial Least Squares analysis revealed two significant latent variables.

(a) The first latent variable showed a difference in MSE between REM and NREM conditions ($p<0.001$). This difference was apparent in both the finest and coarsest timescales, reflecting the crossover of MSE curves at mid-scales.

(b). The second latent variable showed a difference between the first and last day of training in the NREM conditions ($p<0.001$). This difference was reflected in the middle timescales.

Dashed lines (middle panels) indicate the threshold for reliable saliences, which is when the absolute value of the bootstrap ratio (akin to a Z-score) is >= 2.

DISCUSSION

- We found a main effect that differentiated sleep stages, where multiscale entropy was higher in finer scales and lower in coarser scales in REM sleep.
- We also found a main effect of learning, where multiscale entropy was lower in the middle timescales after learning.

Our scale-dependent findings suggest that brain signal complexity may be a useful measure of the neuroplasticity that occurs in sleep. Future work is needed to determine the effects of differences performance, as well as regional differences across the brain.

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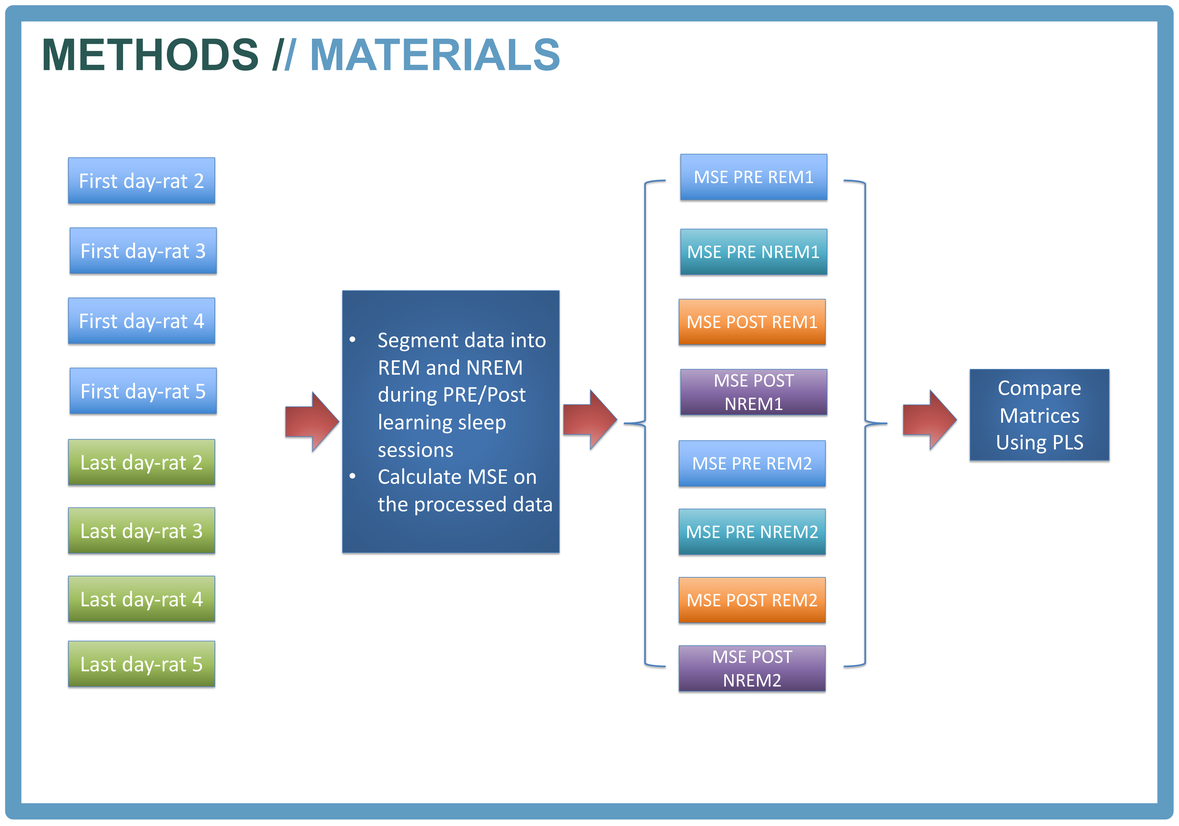
METHODS // MATERIALS



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