Napping to boost your brain:
Do sleep spindles enhance working memory?

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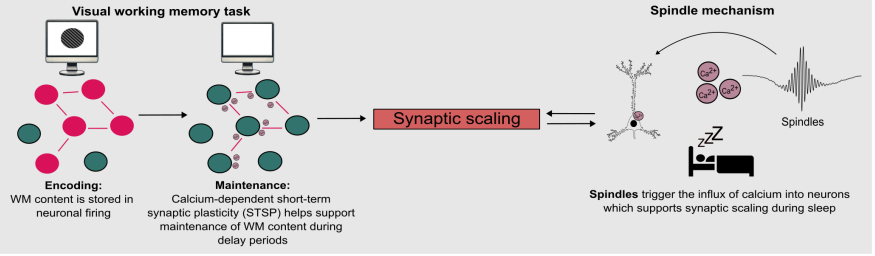
Background

Sleep has long been linked to long-term memory consolidation[1]. Specifically, the characteristics of **sleep spindles** during post-learning sleep have been linked to post-sleep memory retention. Mechanistically, spindles have shown to support **plasticity** mechanisms in the brain, for example by providing a window of opportunity for calcium to enter cells. However, these spindles do not only exist in isolation, but often couple within slow oscillations which further supports plasticity[2]. In recent years, it has been shown that **working memory** is also supported by synaptic plasticity[3]. We therefore set out to study if sleep, and specifically sleep spindles are important for post-sleep working memory functioning.

Do spindles and their role in synaptic modifications also promote working memory behaviour after sleep?



Methods

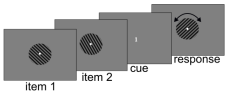
Experimental design

N = 30

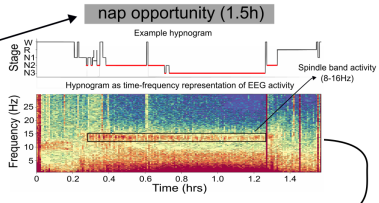
High-density EEG (64 channel) + polysomnography

working memory task 1

Task: clockwise or counterclockwise rotation?

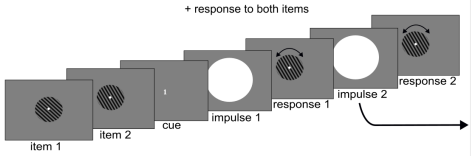


nap opportunity (1.5h)



working memory task 2

Task: clockwise or counterclockwise rotation? + response to both items

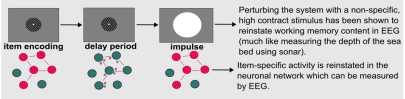


Using an impulse to measure silent (synaptic) states from EEG

Working memory items not in the centre of attention can be stored in an activity-silent (synaptic state) which makes it impossible to measure using non-invasive brain imaging.

Especially deprioritized items (item 2) in silent states have been hypothesized to be supported by residual calcium (STSP).

We hypothesize that especially these items should benefit from sleep spindles, and will follow up this hypothesis with decoding of "silent" items at the impulse in the future.

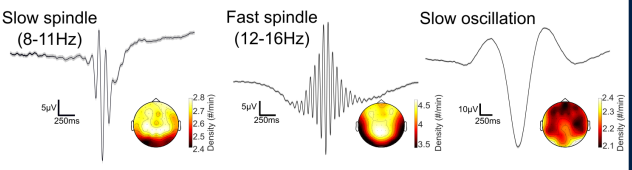


Perturbing the system with a non-specific, high contract stimulus has been shown to reinstate working memory content in EEG (much like measuring the depth of the sea bed using sonar).

Item-specific activity is reinstated in the neuronal network which can be measured by EEG.

Sleep scoring + event detection

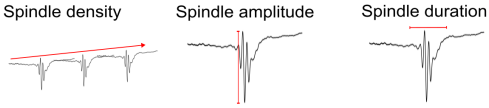
Semi-automated sleep staging → Automated spindle + SO detection



Average slow spindle, fast spindle and slow oscillation and their topographic density (left to right) across all participants. Density is calculated as the number of events per minute of N2 + N3 sleep.

Sleep matrices used for analyses

Matrices were seperately extracted for slow and fast spindles

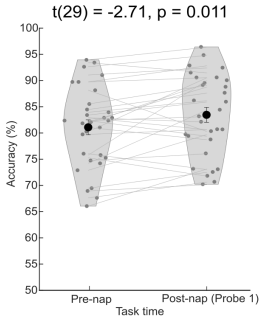


Spindle density	Spindle amplitude	Spindle duration
Spindle events per minute during N2 + N3 sleep	Mean maximum envelope amplitude across all spindle events	Mean duration across all spindle events

Results

Behavioural results

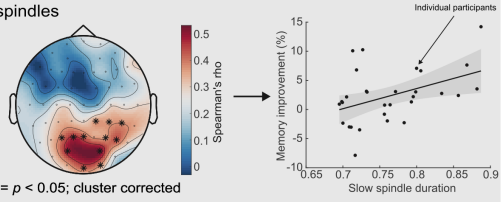
A day-time nap improves post nap working memory performance



Sleep spindle results

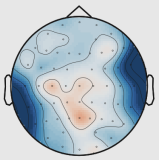
Correlation of spindle **duration** with working memory improvement

Slow spindles



* = $p < 0.05$; cluster corrected

Fast spindles

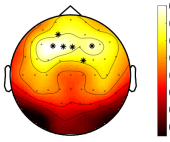


non-significant

Slow but not fast spindle duration predict working memory improvement

Phase-amplitude coupling (PAC) results

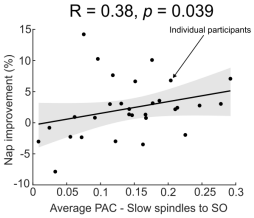
Slow spindle - slow oscillation coupling



* = $p < 0.05$; cluster corrected -> denotes electrodes significant PAC derived by testing coupling strength in real versus surrogate data

Correlation of electrodes with significant PAC with working memory improvement

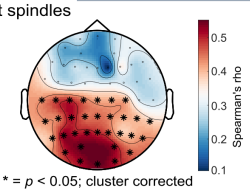
R = 0.38, $p = 0.039$



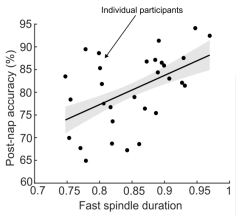
Postnap behaviour only

Fast spindles do predict post nap working memory behaviour

Fast spindles



* = $p < 0.05$; cluster corrected

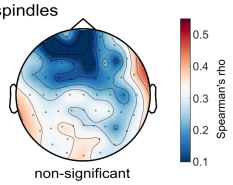


Slow spindles do not support working memory in isolation but their coupling to SOs also predicts working memory improvement

Control: Pre-nap behaviour only

No correlation between fast spindles and pre-nap behaviour

Fast spindles



non-significant

Summary

Slow spindle duration over the visual cortex positively correlates with visual working memory improvement

The **coupling of slow spindles into slow oscillations** positively correlates with working memory improvement

Fast spindle duration correlates with post-nap working memory behaviour. Importantly, fast spindle duration does not predict working memory behaviour prior to the nap.

Conclusion

Spindles play a role in working memory behaviour. Fast and slow spindles have distinct functional roles with slow spindles more specifically tracking working memory improvement whereas fast spindles could be more related to general post-sleep executive functioning.

References:
[1]Rasch, B., & Born, J. (2013). About sleep's role in memory. *Physiological reviews*.; 2 Staresina, B. P., Niediek, J., Borger, V., Surges, R., & Mormann, F. (2023). How coupled slow oscillations, spindles and ripples coordinate neuronal processing and communication during human sleep. *Nature Neuroscience*.; [3]Stokes, M. G. (2015). 'Activity-silent'working memory in prefrontal cortex: a dynamic coding framework. *Trends in cognitive sciences*.; Illustrations were generated using ChatGPT.