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Analyzing the Impact of Slow-Wave and Spindle Coupling on Memory Consolidation During Sleep
- MSc Project

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Analyzing the Impact of Slow-Wave and Spindle Coupling on Memory Consolidation During Sleep

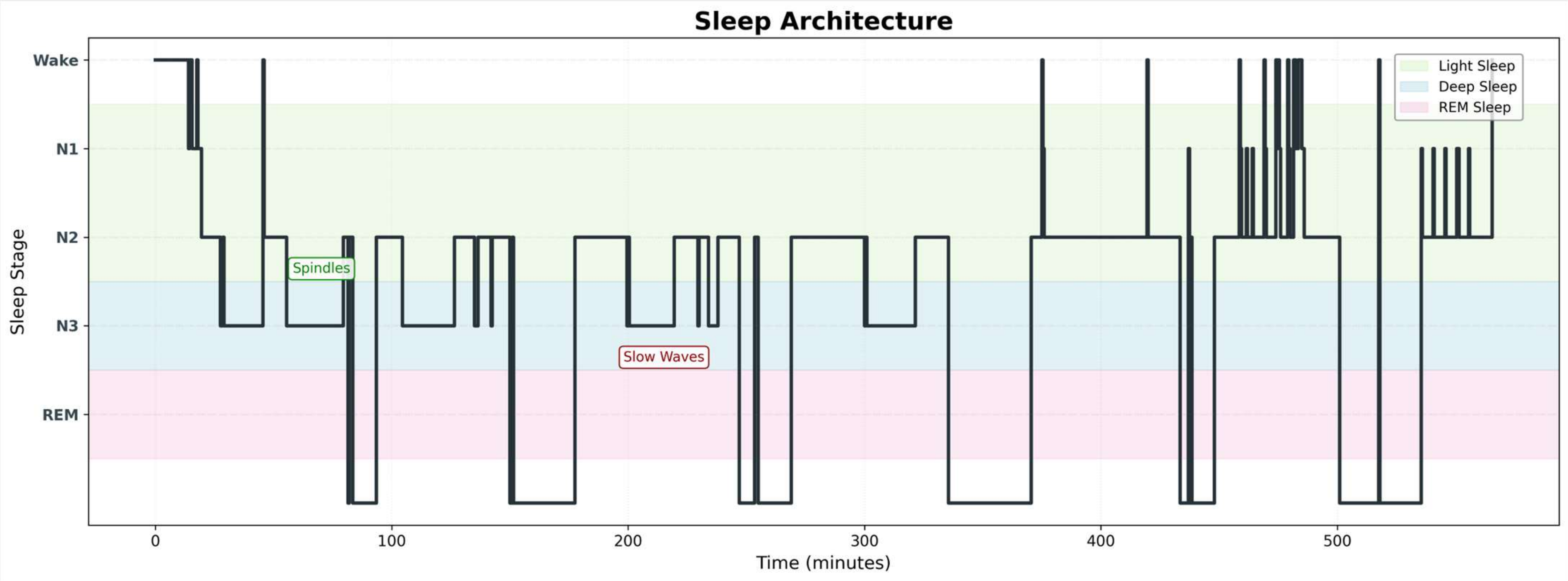
Introduction

EEG and Sleep Overview

Electroencephalography (EEG) records brain activity using scalp electrodes.

In sleep science, EEG helps track rhythmic patterns.

Sleep stages

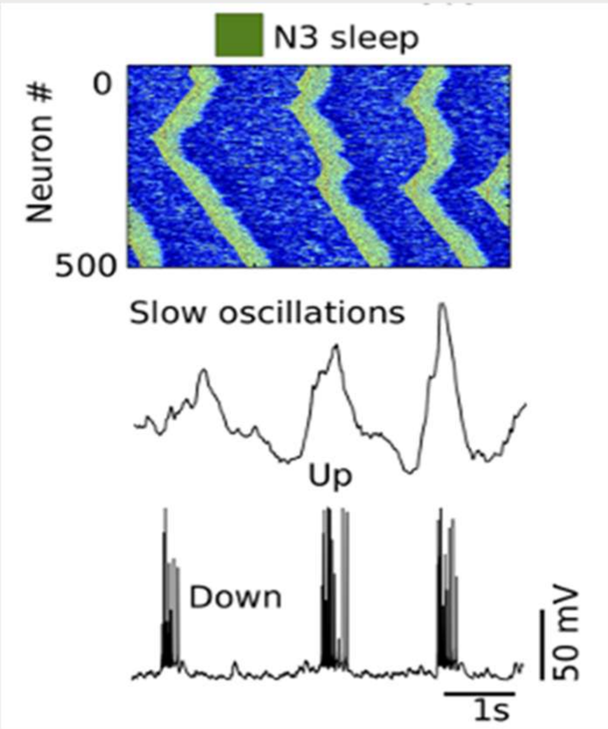


Slow Waves

Low-frequency, high-amplitude waves

Occur during N3 sleep stage

Each wave has a clear trough (peak), with onset and offset timing



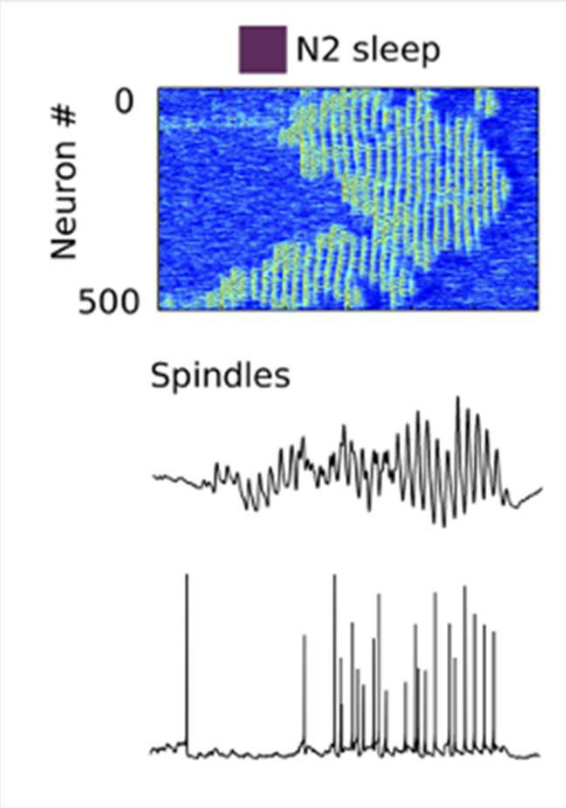
Adapted from Mölle et al. (2011), Trends in Cognitive Sciences.

Sleep Spindles

Short bursts of fast oscillations

Occurs primarily during N2 and N3 sleep stages

Each spindle has a start, peak, and end

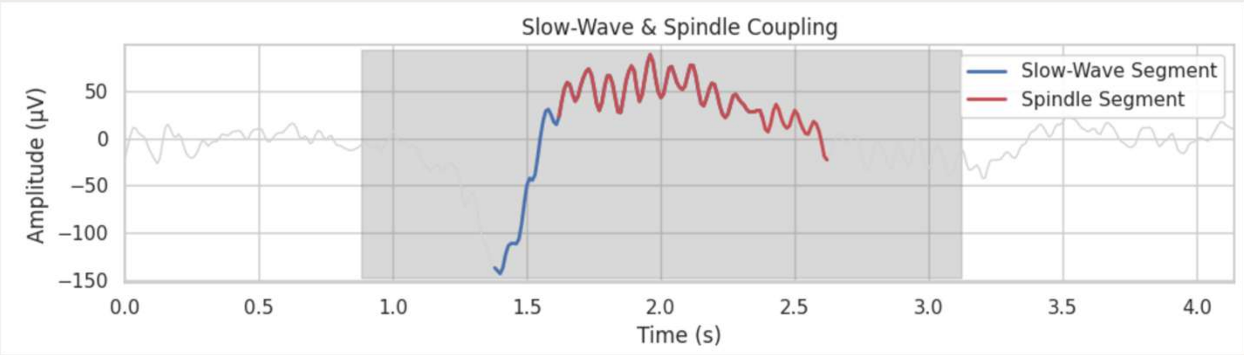


Adapted from Mölle et al. (2011), Trends in Cognitive Sciences.

Slow Wave & Spindle Coupling

How It Works:

- **Hippocampus**: Encodes and temporarily stores new memories during the day
- **Cortex**: Long-term memory storage center
- During deep NREM sleep, slow waves and spindles **help coordinate memory transfer**
- **Coupling** = rhythmic coordination between hippocampus and cortex



GU2

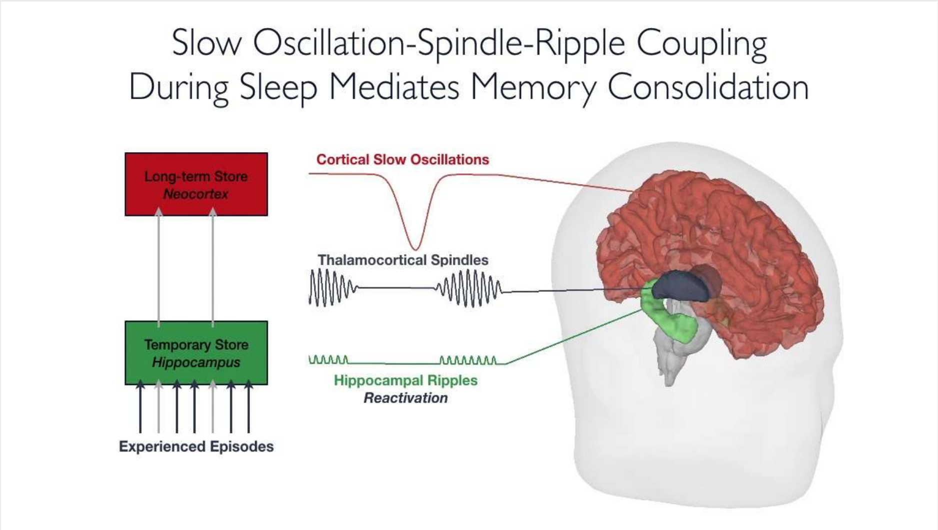
Why Sleep and Memory?

- We sleep to rest — but the brain remains active.
- During deep NREM sleep, the brain replays and reorganizes memories.
- This process involves slow waves and sleep spindles.
- Studies suggest that the precise timing between these rhythms boosts memory consolidation (Muehlroth et al. (2019)).
- Most findings linking sleep rhythms to memory come from small, controlled lab studies — how well do they generalize?

Slide 10

GU1	how can we do this slide. give ideas na Guest User, 2025-05-24T09:12:18.531
GU1 0	ayye i am not good at all this so i told u na Guest User, 2025-05-24T09:18:51.558
GU1 1	should we ask chat gpt Guest User, 2025-05-24T09:25:44.278
GU1 2	yes Guest User, 2025-05-24T09:25:59.743
GU1 3	then text on it Guest User, 2025-05-24T09:28:15.997
GU1 4	im thinking this grey background will look good on all slides Guest User, 2025-05-24T09:29:00.124
GU2	yeah Guest User, 2025-05-24T09:29:15.247
GU2 0	done Guest User, 2025-05-24T09:29:35.766
GU2 1	see this Guest User, 2025-05-24T09:33:28.026

How Sleep Supports Memory Consolidation



Adapted from Born & Wilhelm (2012), PNAS

- Slow waves provide a timing signal for memory transfer
- Spindles help organize when information gets sent
- This process is thought to stabilize and strengthen memory traces. (Diekelmann & Born, 2010)

Aim

Identify coupling between slow waves and spindles

Detect slow waves and sleep spindles from eeg recordings and quantify their coupling.

Test correlation between coupling and memory

Examine whether coupling metrics correlate with short-term recall and overnight memory retention across tasks.

Scale analysis across a large population

Use automated pipelines to process EEG and behavioral data from ~1900 participants.

Dataset and Experimental Setup

- ~1900 participants across two experimental days.

Day 1 Tasks:

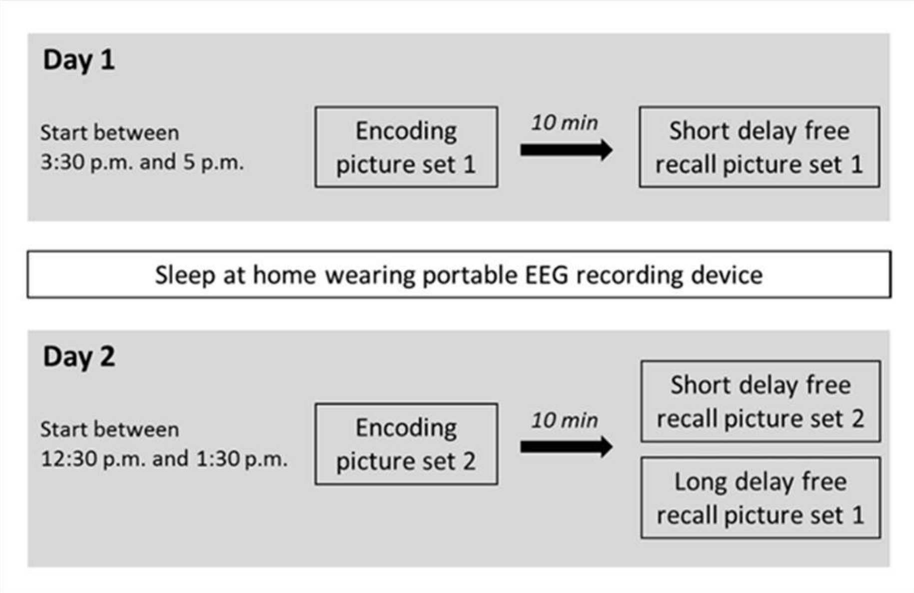
- Emotional and neutral picture recall (Set 1).
- Working memory task (n-back).
- Procedural memory task (finger tapping).

Day 2 Tasks:

- Recall of Set 1 and Set 2.
- Repeat of n-back and finger-tapping tasks.

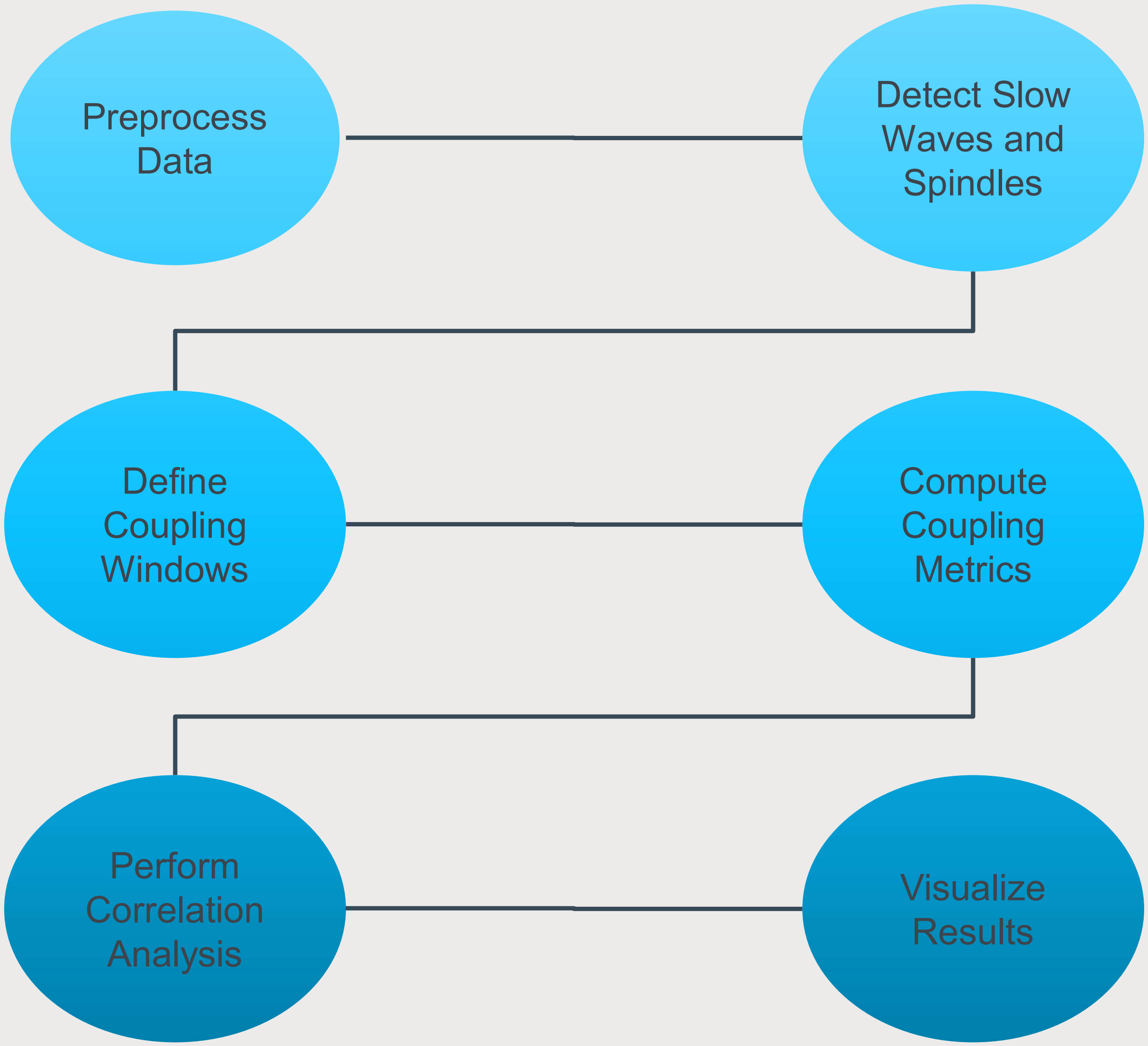
EEG Data:

- 4-channel EEG, EOG (eye movements), EMG (muscle activity).



Adapted from Ackermann et al. (2015).

Methodology


Preprocess Data
Detect Slow Waves and Spindles
Define Coupling Windows
Compute Coupling Metrics
Perform Correlation Analysis
Visualize Results

YASA: *Yet Another Spindle Algorithm*

What is YASA?

- **Open-source Python library** for analyzing sleep EEG
- Built on top of scientific Python tools like **MNE**
- Widely used in sleep research to **detect spindles, slow waves, etc.**
- Automatically identifies events using validated **amplitude, duration, and frequency** thresholds

Preprocessing & Detection

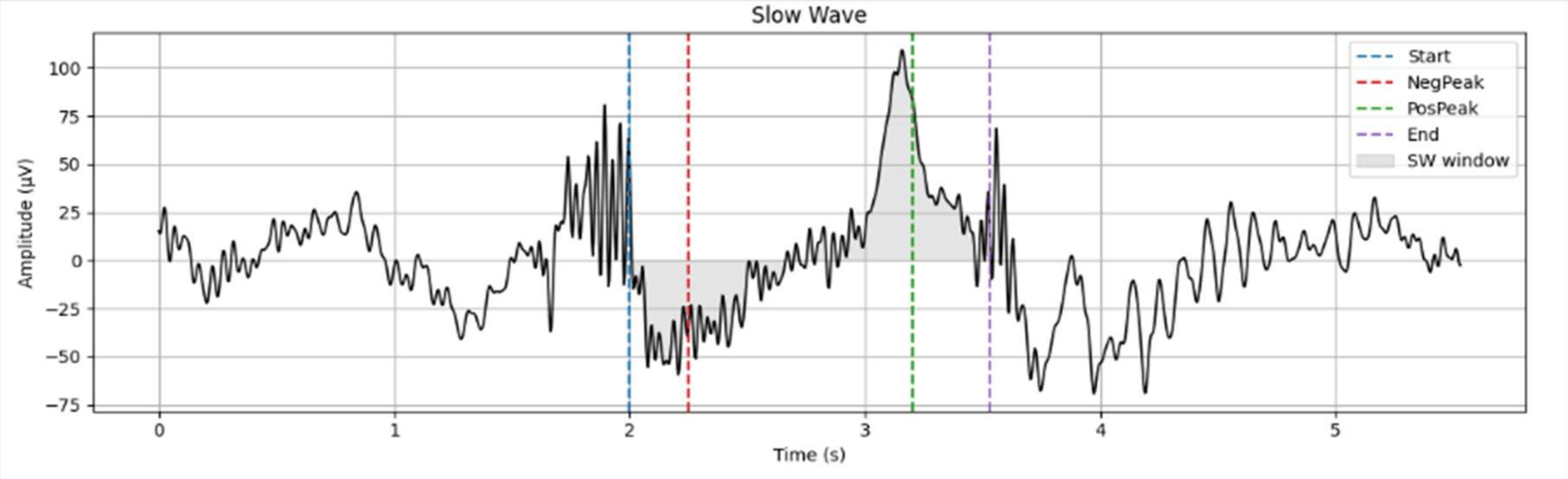
EEG was filtered (0.3–30 Hz) and downsampled to 100 Hz

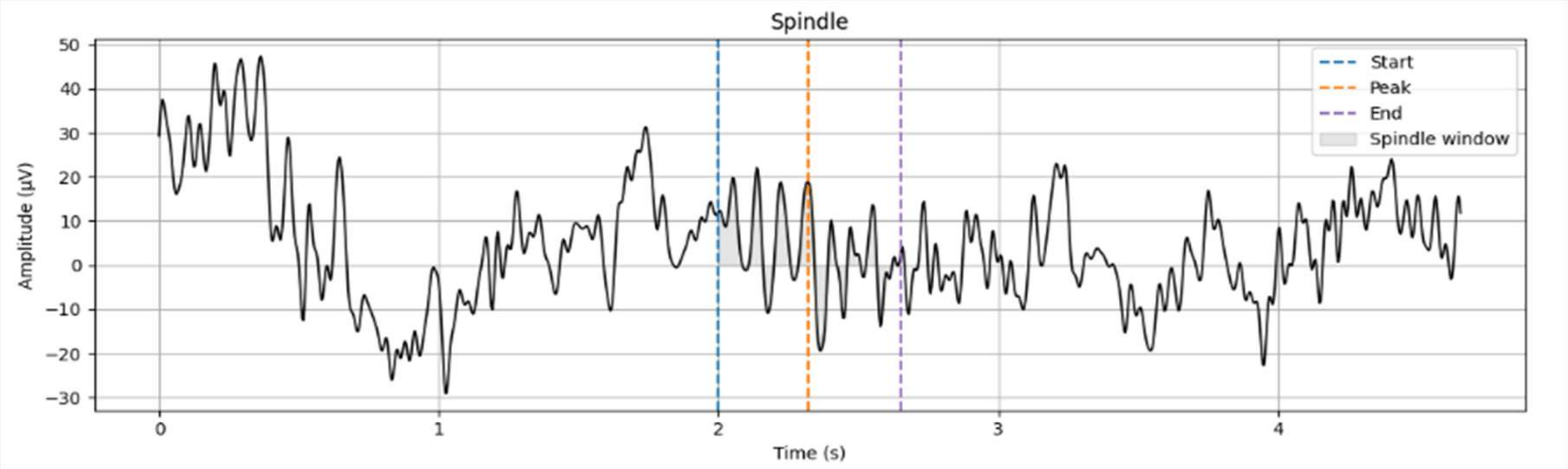
Event detection was done using YASA (Python-based)

Slow waves filtered to 0.3–1.5 Hz;

Spindles to 12–15 Hz using RMS threshold

YASA identified each event's onset, peak, offset — adaptively per person


Slow Wave
Amplitude (µV)
Time (s)
Start
NegPeak
PosPeak
End
SW window


Spindle
Amplitude (µV)
Time (s)
Start
Peak
End
Spindle window

Coupling Metrics

Coupling defined using a **±1 second** window around each slow wave trough ← **Coupling window**

Spindle Coupling Rate (%)

→ Percentage of all detected spindles whose peaks occur within the coupling window

Slow-Wave Coupling Rate (%)

→ Percentage of all detected slow waves that have at least one spindle peak within the coupling window.

Total Coupling Time (s)

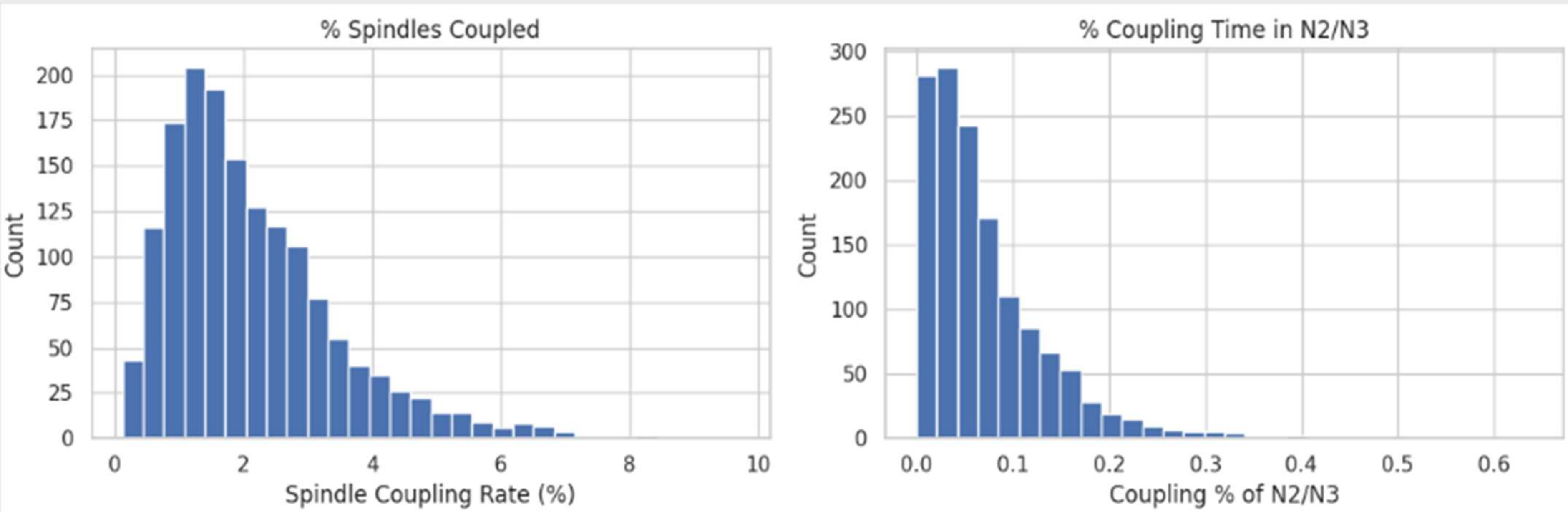
→ Sum of the durations of all coupled spindle events for a participant.

Coupling % of N2/N3

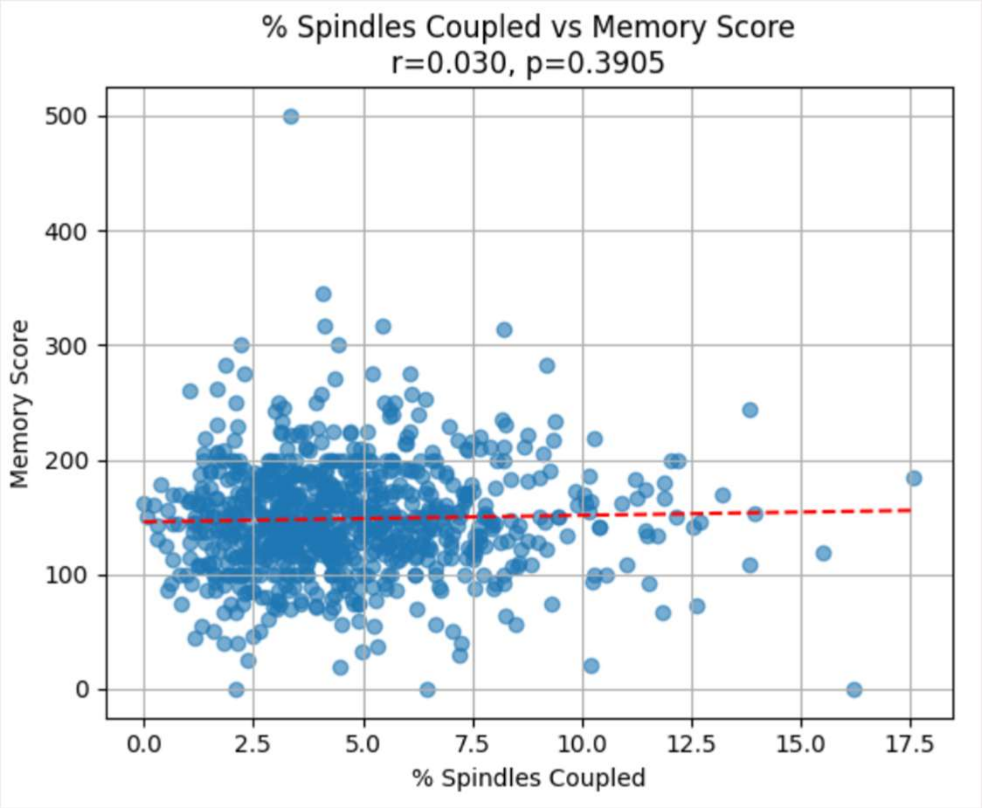
→ Total time spent in coupled spindles divided by total minutes of N2 and N3 sleep.

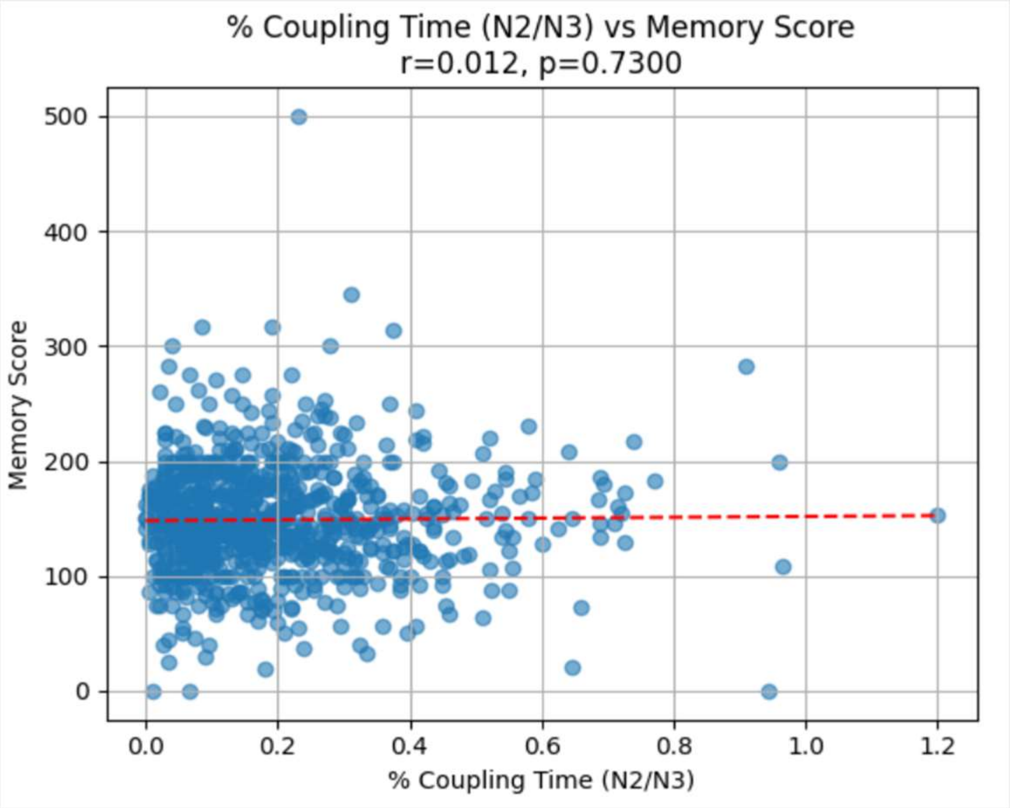
Results

Coupling Metrics Distribution



Statistical Methods: Pearson's Correlation

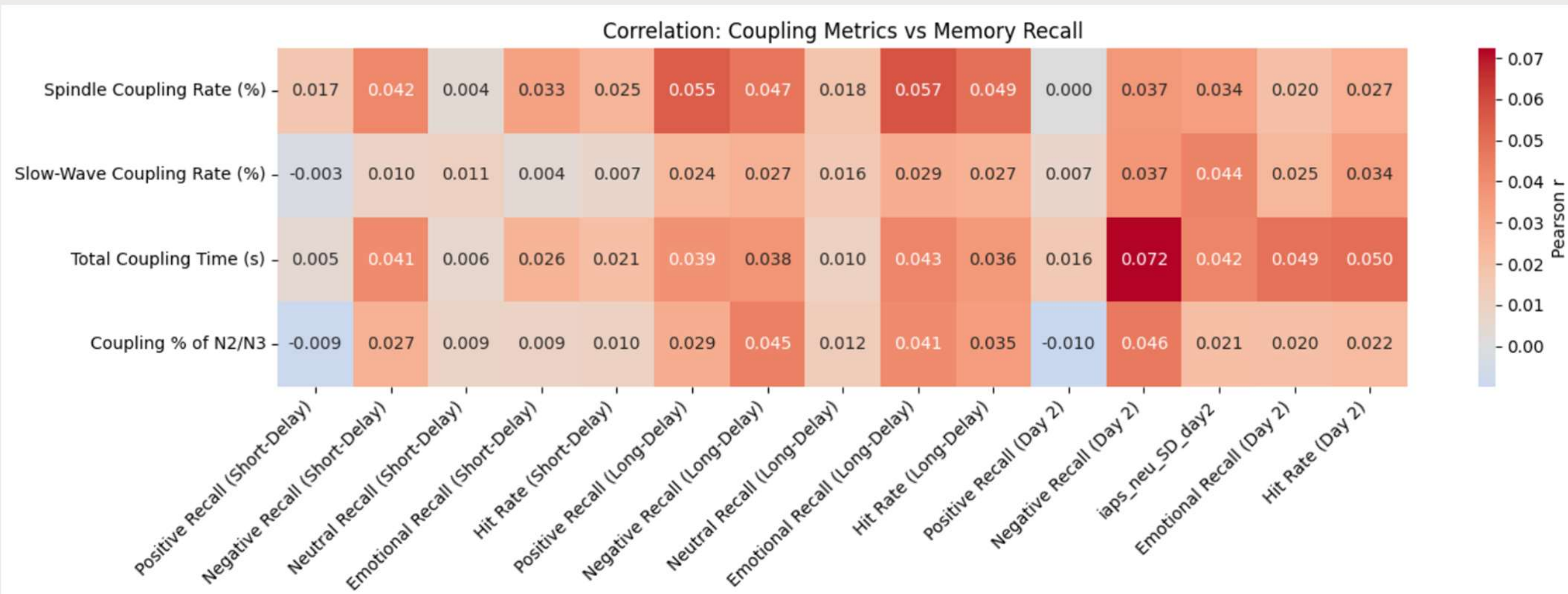




Memory score = Total correct recalls across both days

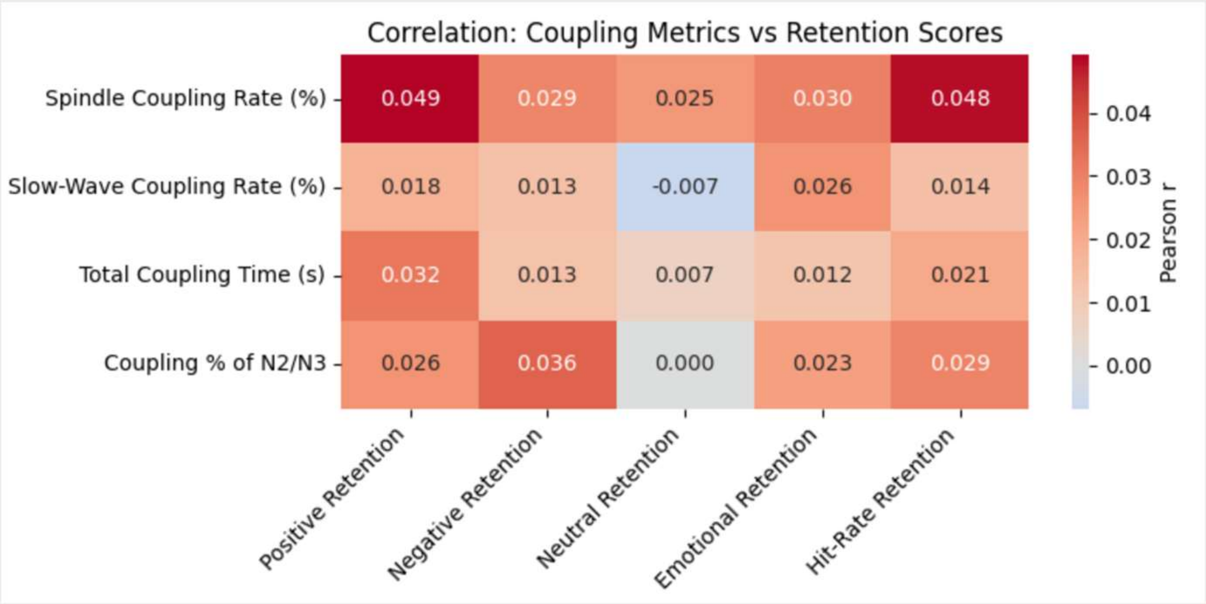
Correlation: Coupling Metrics Vs. Memory Scores

Tested whether slow wave–spindle coupling metrics were associated with memory performance. Metrics included coupling rate, total duration, and proportion of N2/N3 sleep in coupling.



Correlation: Coupling Metrics vs. Retention Scores

Tested whether SO–spindle coupling metrics were related to memory retention scores across different types (e.g., emotional, neutral).
Retention *= number of correctly recalled items on Day 2 that were also shown on Day 1.*



Limitations

Limitations

🧭 Spatial Resolution

- Only 4 EEG channels (Fz, Cz, C3, Pz)
- May miss where coupling is most meaningful

🛠️ Detection Simplicity

- Used fixed thresholds for amplitude and duration
- May ignore subtle or atypical events

⏱️ Coupling Metric Limitations

- Used a basic ±1s window around slow wave trough
- Treats all overlaps equally
- Ignores precise timing, phase-locking, or spindle patterns

👥 Sample Bias

- Only young, healthy adults (18-35 years), tested at home
- Results may not generalize to older adults, clinical populations, or other types of memory tasks.

Future Outlook

Future Outlook

🧪 **Improve Data Collection:**

Use more electrodes (especially frontal)
→ better spatial coverage and signal quality.

Study older adults, clinical groups, and more diverse memory tasks

💻 **Refine Analysis Techniques:**

Adaptive thresholds or machine learning
→ for personalized, more accurate event detection.

Analyze coupling using flexible, time-varying methods
→ instead of fixed windows, use phase-based alignment.

Combine EEG with fMRI/MEG
→ to capture deeper brain dynamics across modalities.

Conclusion

Conclusion

Simple coupling metrics don’t predict memory
– Neither coupling rate nor density showed meaningful correlations

Findings contrast prior small-scale studies
– Earlier lab-based results don’t generalize to large, real-world cohorts

Highlights the limits of basic overlap measures
– Fixed windows miss finer timing, phase relationships, and context

Demonstrates the complexity of sleep-memory dynamics
– Sleep rhythms work in more nuanced ways than simple co-occurrence

Calls for more advanced analysis methods
– Phase-based, multimodal, and personalized approaches are needed

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Thank you!

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