

Slow-Wave-Spindle Coupling and Sleep-Related Memory Consolidation in Mild Cognitive Impairment

Introduction

Non-rapid eye movement (NREM) sleep supports episodic memory consolidation through precise coupling of slow-waves and sleep spindles¹.

Spindle coupling closer to the slow-wave peak is associated with better overnight memory retention and is disrupted in healthy ageing².

Whether slow-wave-spindle coupling is further disrupted in mild cognitive impairment (MCI), and whether this relates to memory impairment, remains unclear

We examined slow-wave-spindle coupling and overnight memory consolidation in MCI, assessing both overall memory retention and selective consolidation (reinforced vs. non-reinforced memories).

We hypothesised that MCI would be characterised by slow-wave-spindle coupling further from the slow-wave peak and poorer overnight memory retention compared to cognitively healthy older adults, and that spindle coupling closer to the slow-wave peak would be associated with better overnight memory retention. We additionally explored whether slow-wave spindle coupling phase was associated with the preferential retention of reinforced relative to non-reinforced memories.

Methods

Participants

26 participants with MCI and 29 cognitively healthy controls. MCI participants were recruited from the Cognitive Disorders Clinic at Southmead Hospital, Bristol, UK, and via Join Dementia Research.

Sleep Monitoring

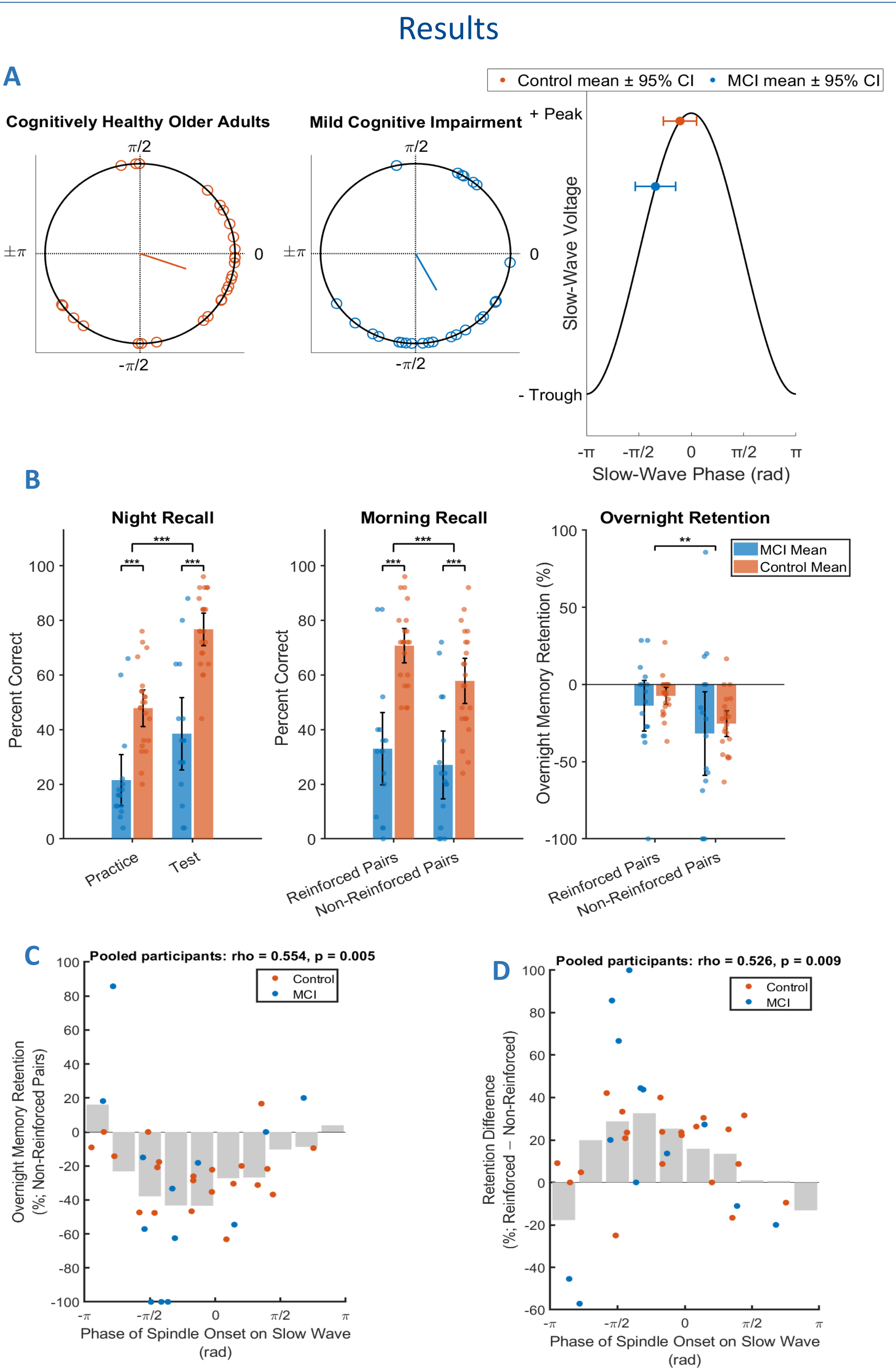
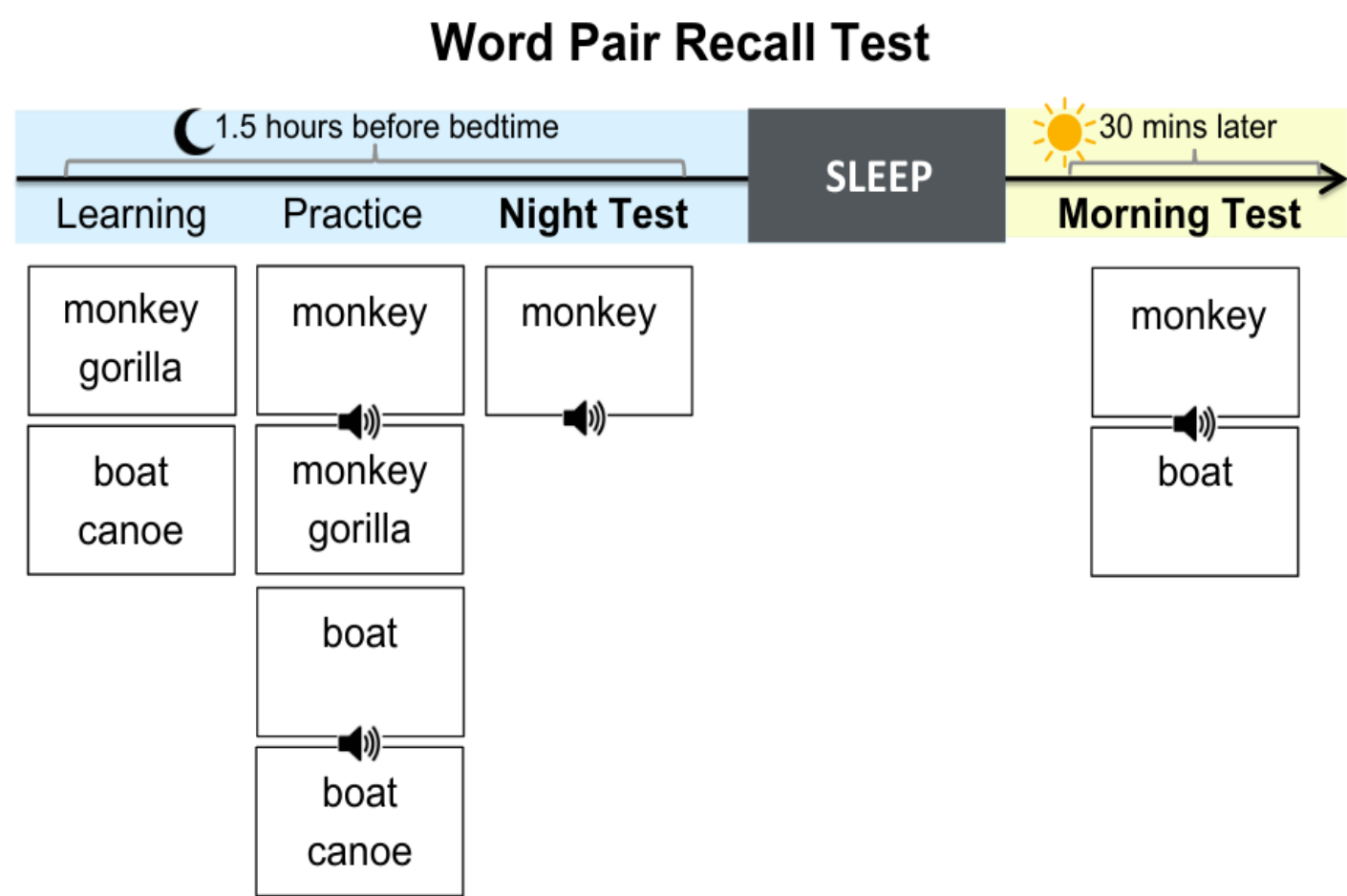
Participants underwent up to six consecutive nights of at-home sleep monitoring using the Sleep Profiler single-channel frontal EEG device. Sleep data were scored using the automated U-Sleep deep learning algorithm³.

Quantification of slow-wave-spindle coupling

Slow-waves and sleep spindles were automatically detected during NREM sleep using established algorithms^{4,5}. Slow-wave-spindle coupling was quantified as the instantaneous slow-wave phase at spindle onset for spindles occurring within detected slow-waves.

Overnight word-pair recall test

Participants learned 50 semantically related word pairs and completed an immediate practice recall task with feedback. Before sleep, cued recall was tested for 25 pairs (reinforced word pairs), whereas all 50 pairs were again tested the following morning, including the remaining 25 non-reinforced pairs. On each trial, one word was presented and participants had 10 s to verbally recall its pair. The primary outcome was overnight retention of non-reinforced pairs, with a retention difference score (reinforced – non-reinforced) also calculated to quantify the preferential retention of reinforced to non-reinforced memories.



- A) Mean coupling phase significantly differed between groups ($p = .041$): mean spindle onset occurred just before the slow-wave peak in controls but earlier on the ascending slope in MCI.
- B) Despite poorer recall before and after sleep, overnight memory retention did not significantly differ between individuals with MCI and cognitively healthy older adults ($ps \geq .388$).
- C) Across all participants, overnight retention of non-reinforced word pairs was significantly associated with slow-wave-spindle coupling phase, with individuals whose spindle onsets occurred closer to the slow-wave peak exhibiting poorer overnight retention. This relationship was directionally consistent in both controls ($p = .085$) and individuals with MCI ($p = .035$). Overnight retention of the reinforced word pairs was unrelated to slow-wave-spindle coupling ($p = .532$; not shown).
- D) Across all participants, the retention difference score was significantly associated with slow-wave-spindle coupling phase, with individuals whose spindle onsets occurred closer to the slow-wave peak showing better retention of reinforced relative to non-reinforced word pairs. This effect was directionally consistent in controls ($p = .137$) and MCI ($p = .053$).

Summary

Individuals with MCI exhibited altered slow-wave-spindle coupling, with spindles occurring earlier in the slow-wave cycle, closer to the trough, compared to cognitively healthy older adults.

Overnight memory retention was preserved in individuals with MCI.

Slow-wave-spindle coupling timing was functionally associated with overnight memory consolidation, with coupling closer the slow-wave peak predicting poorer retention of non-reinforced memories but better retention of reinforced relative to non-reinforced memories.

These findings suggest that slow-wave-spindle coupling may contribute to the selective prioritisation of memories during sleep, rather than uniformly strengthening all newly encoded memories.

Altered slow-wave-spindle coupling timing may represent a promising non-invasive biomarker of sleep-related memory processing in MCI and warrants further investigation in larger, longitudinal studies.