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Sleep, Memory, and Plasticity

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Key Words declarative memory, procedural memory, reconsolidation, REM sleep, learning

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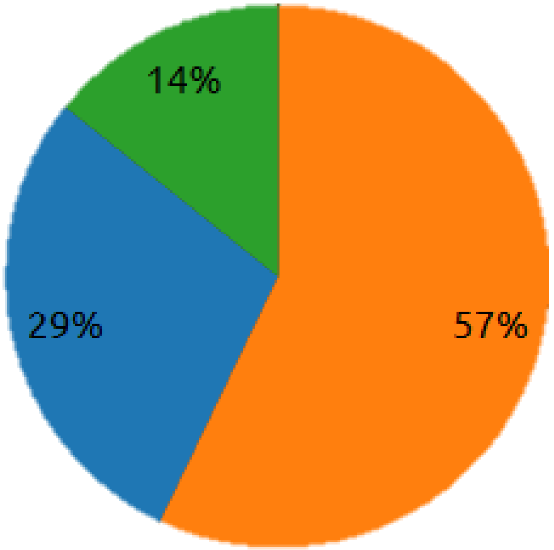

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Review focuses on

- Memory encoding
- Memory consolidation
- Brain plasticity
- Memory reconsolidation

SLEEP, MEMORY, AND PLASTICITY

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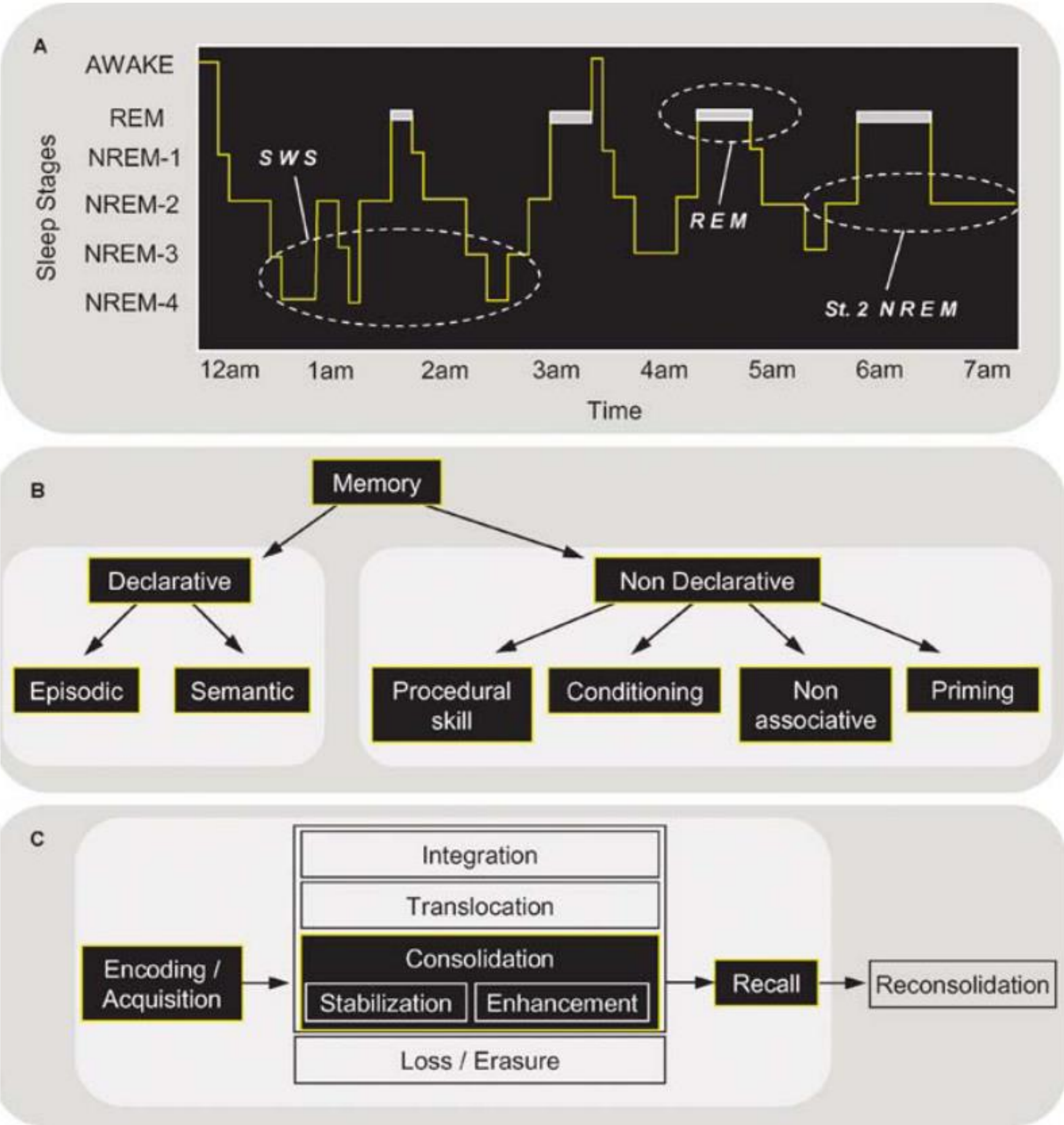
Glossary

Sleep states: Awake, Sleep (REM & NREM[1,2,3,4])

Memory categories: declarative and nondeclarative.

Memory stages: encoding, consolidation (stabilisation[awake], enhancement[sleep] , reconsolidation, postencoding[memory association, translocation, erasure])



Experimental design

- Generally, experiments involve control groups, consisting of individuals sleeping normally, and a test group, consisting of individuals being sleep deprived for some amount of time either before or after a task.

- Several investigation avenues can be pursued: **fMRI**, blood analysis, EEG, **behavioural**, heart rate, cellular and molecular analysis.

Sleep and memory encoding

Experiments in humans

- Sleep deprivation (36h) prior to **temporal memory task** (recency discrimination + confidence judgement) significantly impairs ability. (behaviour)
- Sleep deprivation prior to an **emotional task** significantly impairs memory encoding of emotionally-charged words 2 days later. (behaviour)
- Sleep deprivation (35h) significantly impacts ability measured on a verbal memory task. (fMRI)

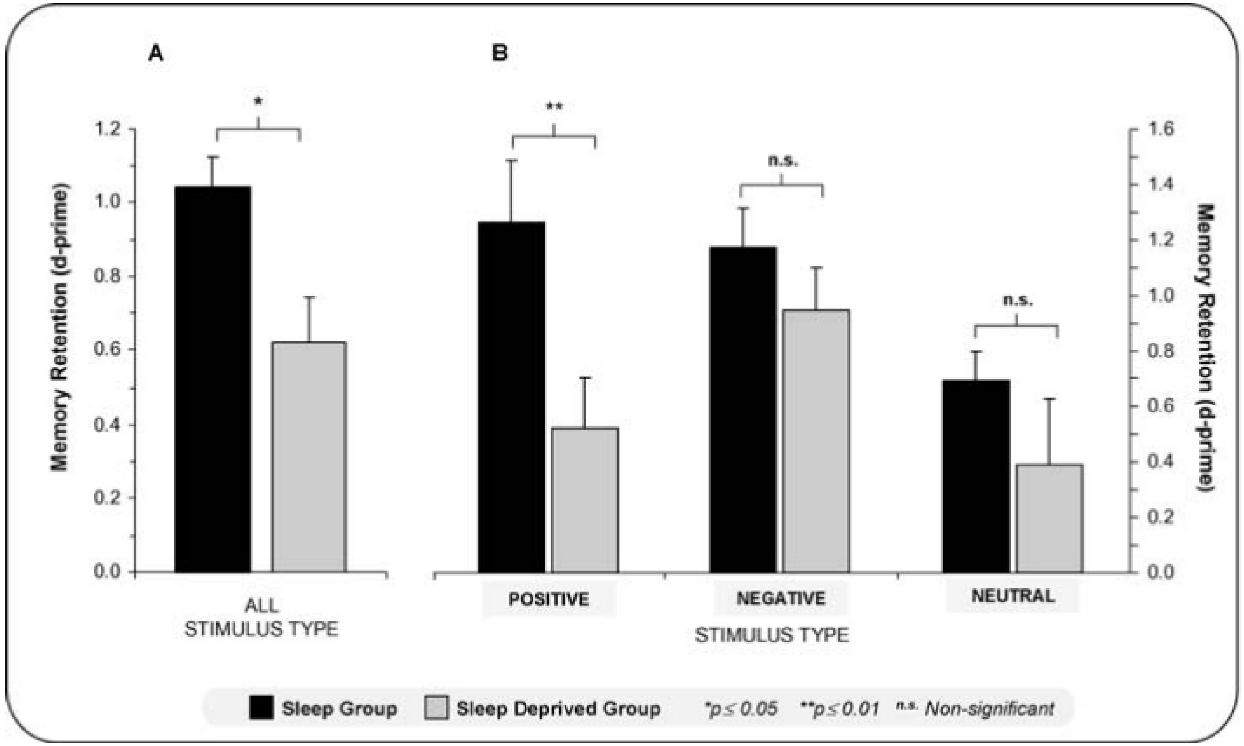


Figure 2 Sleep deprivation and encoding of emotional and nonemotional declarative memory. (*A*) Effects of 36 hours of total sleep deprivation on encoding of human declarative memory when combined across all emotional and nonemotional categories. (*B*) Effects when separated into emotional (positive and negative valence) and nonemotional (neutral valance) categories.

Experiments in (other) animals

- Sleep deprivation (6h) prior to **Hippocampally-dependent** Morris water maze (nonvisible platform) results in severe disruption of encoding. (behaviour)
- Sleep deprivation (6h) prior to **non-Hippocampally-dependent** Morris water maze (visible platform) did not impact ability as much. (behaviour)
- Selective deprivation (only **REM** deprived, 8h) prior is sufficient to impair encoding on the visible Morris water maze test. (behaviour)
- pretraining sleep deprivation (predominantly **REM**) profoundly impaired contextual memory encoding (>50%) measured 24 hours later, whereas cued learning was largely unaffected. (behaviour)
- REM sleep deprivation (24-72h) reduces the basic excitability of hippocampal neurons, significantly impairs long-term potentiation. The **LTP that does develop decays within 90 minutes**. (cellular)
- REM sleep deprivation (6h) significantly reduces nerve growth factor in the hippocampus and brain-derived neurotrophic factor is significantly decreased in the brain stem and cerebellum. (molecular)

Theories

- Theory from humans:
  - **memory encoding relies on integrity of PFC**, but baseline PFC reduction in cerebral metabolic rate is evident following one night of deprivation. However, overcompensation is seen by prefrontal regions combined with a failure of the medial temporal lobe to engage normally, leading to compensatory activation in the parietal lobes (Drummond & Brown 2001).
  - emotion facilitates memory encoding, however sleep deprivation shows a markedly smaller (19%) and nonsignificant impairment for **negative emotional memory.**
- Theory from animals
  - sleep deprivation may **selectively disrupt hippocampal-based encoding**
  - both basic **hippocampal spatial memory** and more **complex spatial learning (PFC mediated)** are susceptible to a lack of prior REM
  - REM sleep deprivation also has detrimental effects on the encoding of other hippocampally mediated tasks, including one-way and two-way avoidance learning, taste aversion, and passive avoidance tasks

Sleep and memory consolidation

Declarative memory -- Humans

- Potentially mixed evidence
- Significant increases in posttraining REM sleep after intensive foreign language learning – degree of successful learning correlates with extent of REM sleep increase.
- No evidence for verbal memory task.
- Consolidation of memories through sleep might be more subtle – emotion and task difficulty strongly influence degree of sleep dependency
- **Selective facilitation of weak associations** during REM sleep

Procedural memory -- Humans

- A robust and persistent finding spanning a wide variety of functional domains, including both **perceptual** (**visual** and **auditory**) and **motor** skills.
- Motor skills have been broadly classified into two forms— **motor adaptation** (e.g., learning to use a computer mouse) and **motor sequence learning** (e.g., learning a piano scale)
- Motor sequence learning: a night of sleep can trigger significant improvements in speed and accuracy*
- Learning of a visual texture discrimination task, which does not benefit from 4–12 hours of wake following training (Stickgold et al. 2000b), improves significantly following a night of sleep (Karni et al. 1994) and appears to require both SWS and REM sleep

Sejnowski, T. J., & Destexhe, A. (2000). Why do we sleep? 10.1016/S0006-8993(00)03007-9

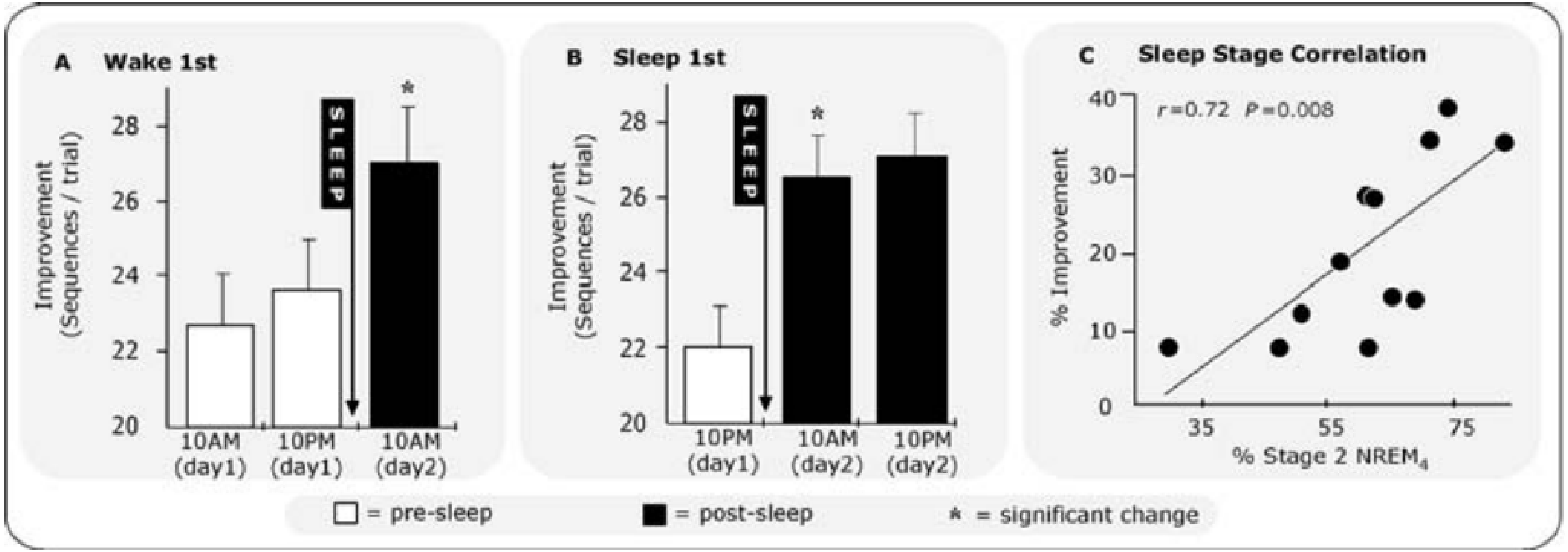


Figure 4 Sleep-dependent motor skill learning. (*A*) Wake first: After morning training (10 AM, *unfilled bar*), subjects showed no significant change in performance when tested after 12 hours of wake time (10 PM, *unfilled bar*). However, when tested again following a night of sleep (10 AM, *filled bar*), performance had improved significantly. (*B*) Sleep first: After evening training (10 PM, *unfilled bar*), subjects displayed significant performance improvements just 12 hours after training following a night of sleep (10 AM, *filled bar*), yet expressed no further significant change in performance following an additional 12 hours of wake time (10 PM, *filled bar*). (*C*) The amount of overnight improvement on the motor skill task correlated with the percentage of stage 2 non-rapid eye movement (NREM) sleep in the last (fourth) quarter of the night (stage 2 $NREM_4$). Asterisks indicate significant improvement relative to training, and error bars indicate standard error of the mean.

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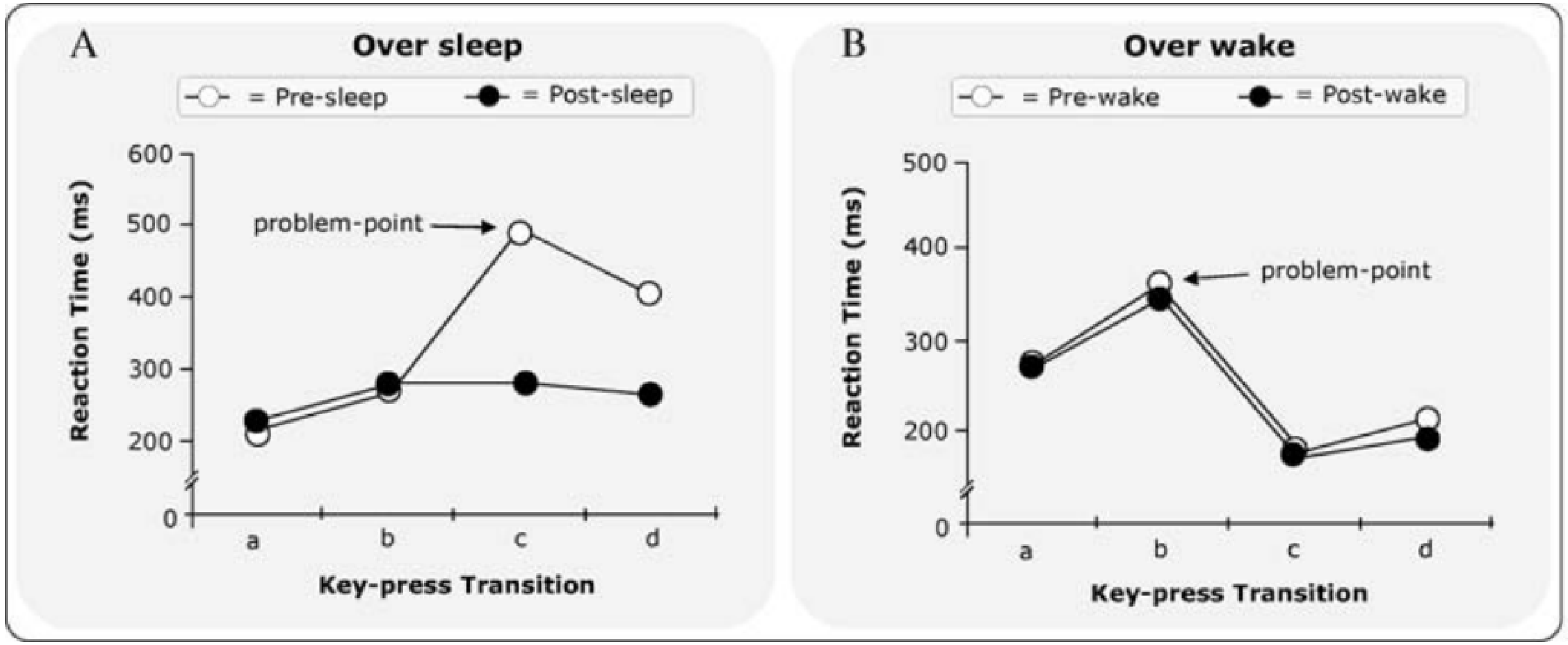

Figure 5 Single-subject examples of changes in transition speeds. Within a five-element motor sequence (e.g., 4-1-3-2-4), there are four unique key press transitions: (*a*) from 4 to 1, (*b*) from 1 to 3, (*c*) from 3 to 2, and (*d*) from 2 to 4. (*A*) The transition profile at the end of training before sleep (*unfilled circles*) demonstrated considerable variability, with certain transitions being particularly slow (most difficult; "problem points"), whereas other transitions appear to be relatively rapid (easy). Following a night of sleep (*filled circles*), there was a specific reduction (improvement) in the time required for the slowest problem point transition. (*B*) Similarly, at the end of training before a waking interval, transition profiles were uneven (*unfilled circles*), with some particularly slow transitions (problem points) and other relatively fast transitions (easy). However, in contrast to postsleep changes, no change in transition profile was observed following eight hours of wake (*filled circles*).

Sleep and brain plasticity

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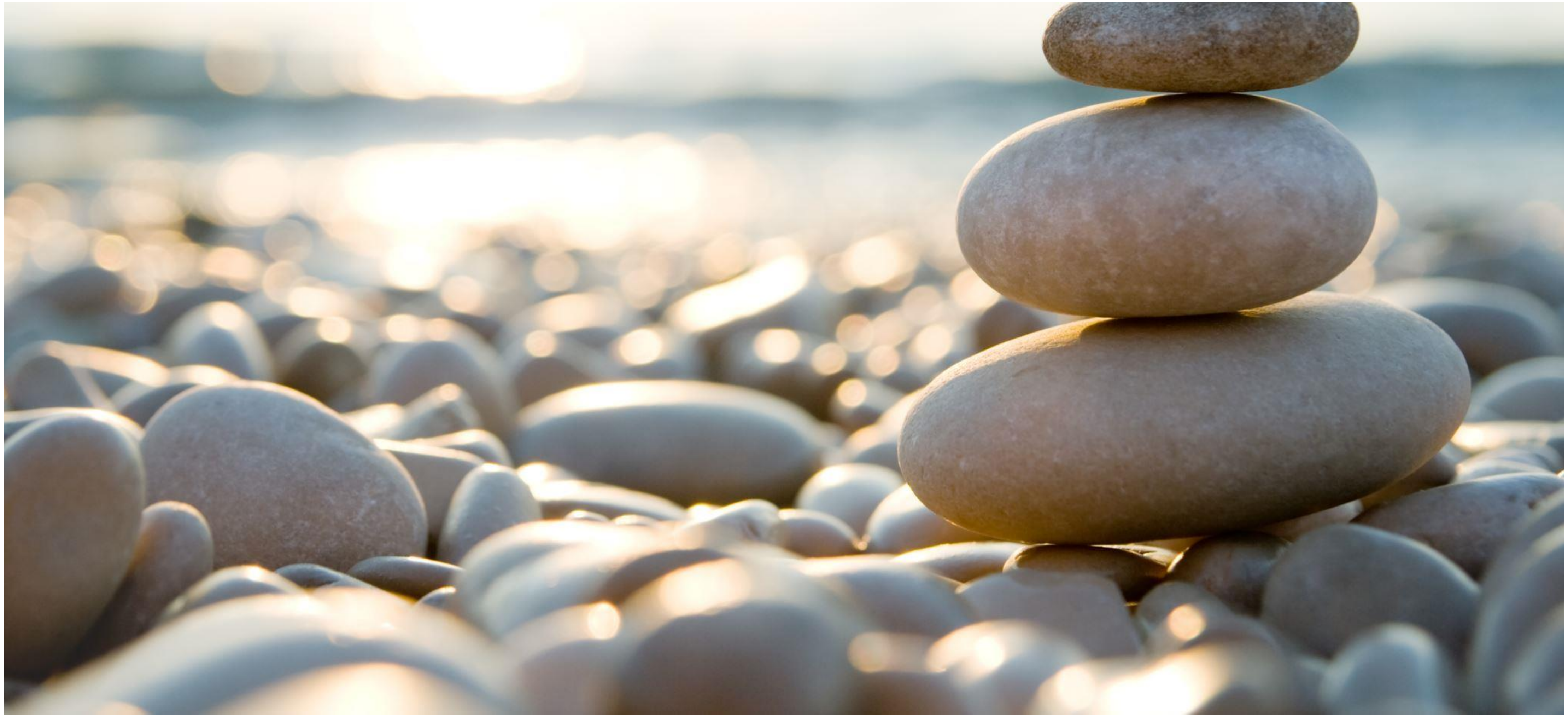
Summary

- Brain activations
  - Patterns of brain activity expressed during training on a serial reaction time motor task reappear during subsequent REM sleep (are replayed)
  - Extent of learning during daytime practice exhibits a positive relationship to the amount of reactivation during REM sleep
- Memory representations
  - Increased activation was identified in motor control structures of the right primary motor cortex left cerebellum*
  - Decreased activation seen in parietal cortices(possibly reflecting a reduced need for conscious spatial monitoring as a result of improved task automation) and limbic system (suggests a decreased emotional task burden)*
  - a night of sleep appears to reorganize the representation not only of procedural motor but also of visual skill memories

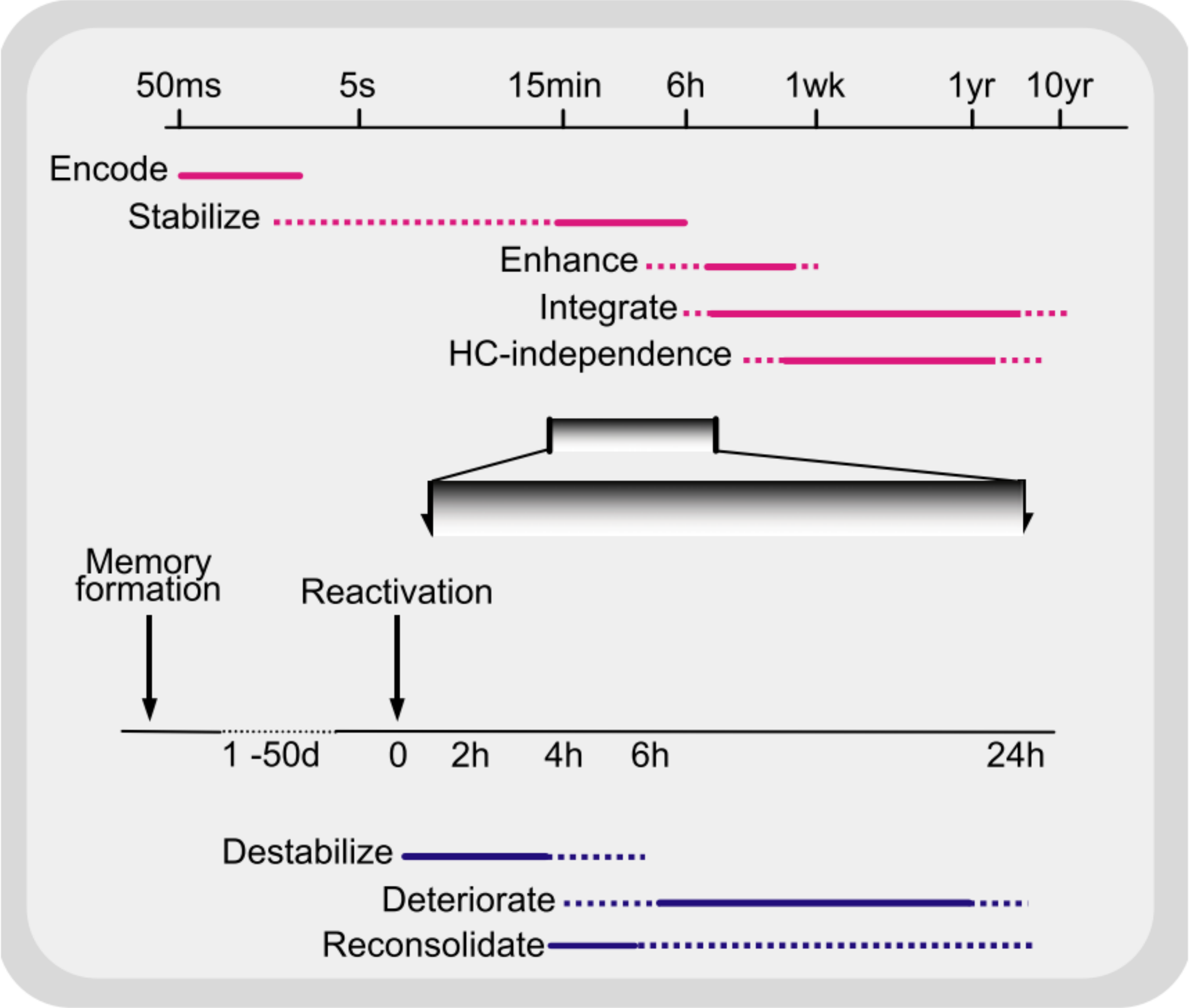
Sleep and memory reconsolidation



Summary

- Degradation is defined behaviorally as diminished performance of a learned task.
- Upon recall of **previously consolidated information**, the memory returns to an **unstable state**, once more requiring consolidation, or "reconsolidation."
- Not completely clear what is happening.
- Time course of destabilization is unclear, but duration is known. Half-life for the destabilized state of about 2 hours.
- Any degradation of the memory appears to be complete 24 hours after reactivation
- Hypothesis: both degradation and reconsolidation processes can, and in some circumstances must, occur during sleep.

Timescales involved here



Stickgold, R., & Walker, M. P. (2007). Sleep-dependent memory consolidation and reconsolidation.
https://doi.org/10.1016/j.sleep.2007.03.011

Final summary

- Sleep good, no sleep bad
- Sleep deprivation before or after learning generally decreases its efficacy
- Different brain regions seem to be affected differently
- When sleep deprived, memories with negative emotions associated with them might be more likely to be kept over memories with neutral or positive associated emotions
- Training is sometimes followed by with increases in REM sleep and spindle density
- Overnight learning benefits are associated with system-level reorganisation of memory throughout the brain

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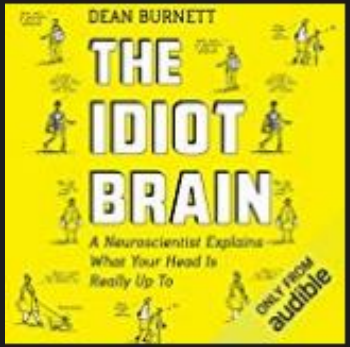
Questions

- Should we be putting our networks to sleep?
- What are we losing by not doing this?
- Could offline learning (run network for some time e.g. 5 hours, accumulate evidence – short term plasticity? – then perform long-term plasticity) yield better, more stable results?

Post-credit sequence

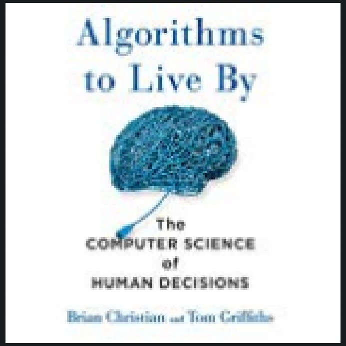


The Idiot Brain: A Neuroscientist Explains What Your Head Is Really up To

By Dean Burnett

Narrated by Matt Addis

10 hours 11 mins

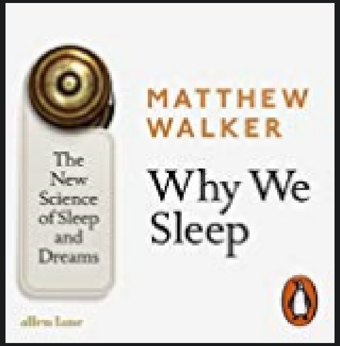


Algorithms to Live By: The Computer Science of Human Decisions

By Brian Christian, Tom Griffiths

Narrated by Brian Christian

11 hours 50 mins



Why We Sleep: The New Science of Sleep and Dreams

By Matthew Walker

Narrated by John Sackville

13 hours 33 mins

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Thank you!

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