

Neural entrainment during sleep to enhance motor learning

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Motor learning

Motor learning is a change in the capability of performing a motor task resulting from a novel experience or from practice (Salomi et al 1984)

Procedural memory : « knowing how » - body related
(>< declarative memory “knowing facts”)

3 phases: acquisition (online), consolidation & retention (offline)

Motor memory consolidation is crucial for motor learning
Consolidation → between practice sessions

Motor learning

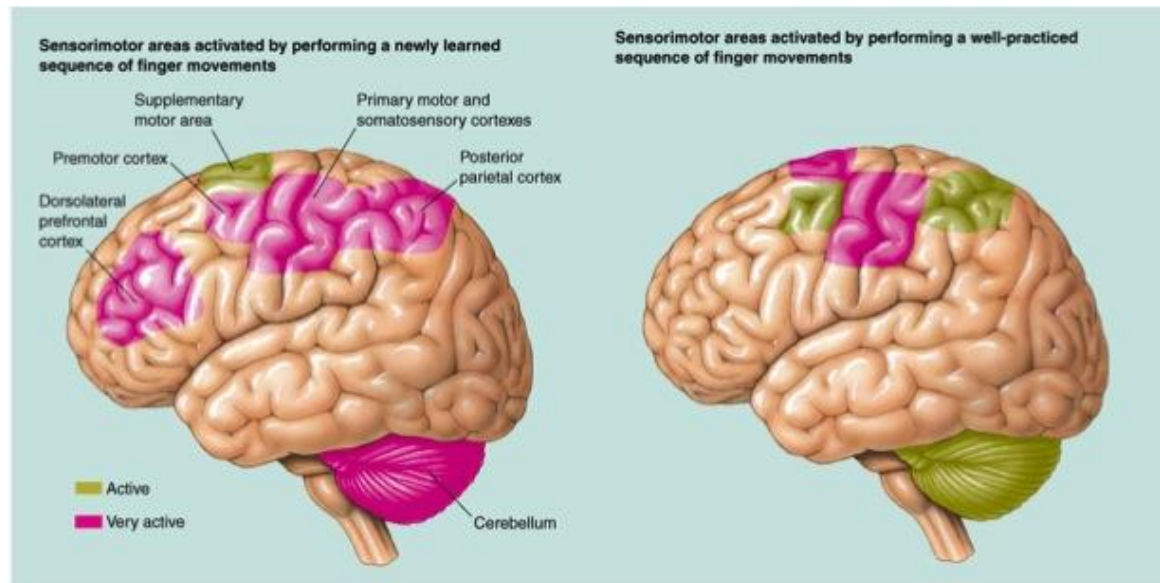
Cortical areas

Motor cortex & prefrontal areas (dorsal & orbitofrontal).

Dorsolateral prefrontal cortex for explicit/conscious motor learning

Sub-cortical areas

Basal ganglia, thalamus & cerebellum



Motor learning

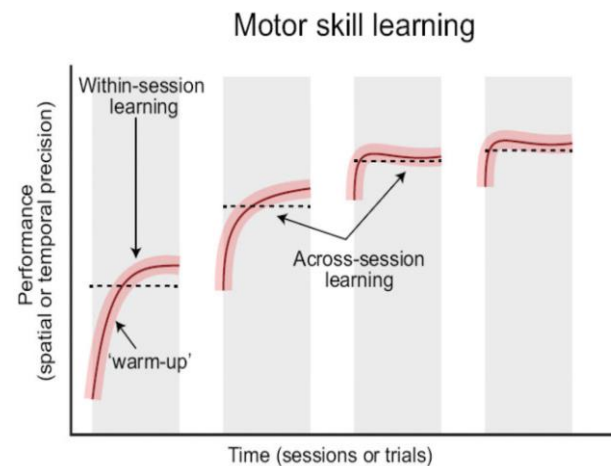
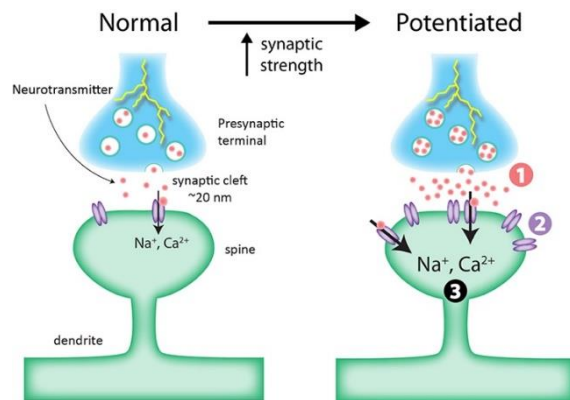
Neurophysiological mechanisms

Motor learning is linked to GABA (reduction), LTP & $\uparrow$ BDNF

Within-session improvements in M1 TMS-evoked responses were blocked by administration of NMDA receptor blocker or GABAA receptor-activating drugs (Butefisch et al., 2000)

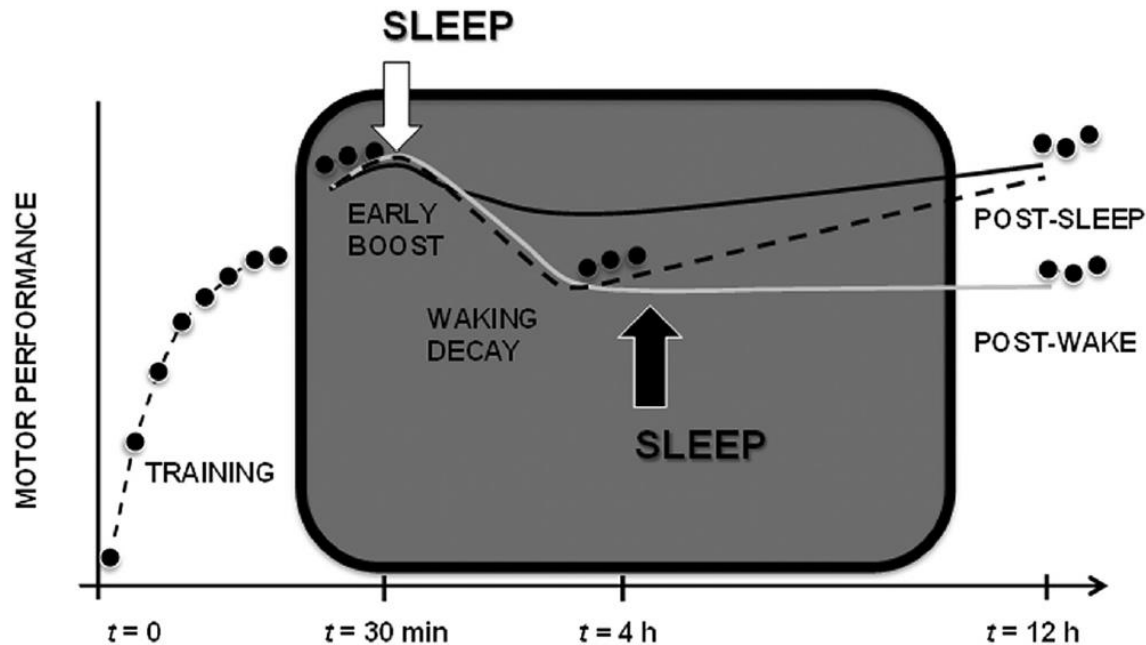
➔ within-session improvements in performance are due to LTP in M1

Increase in synaptic strength



Motor learning

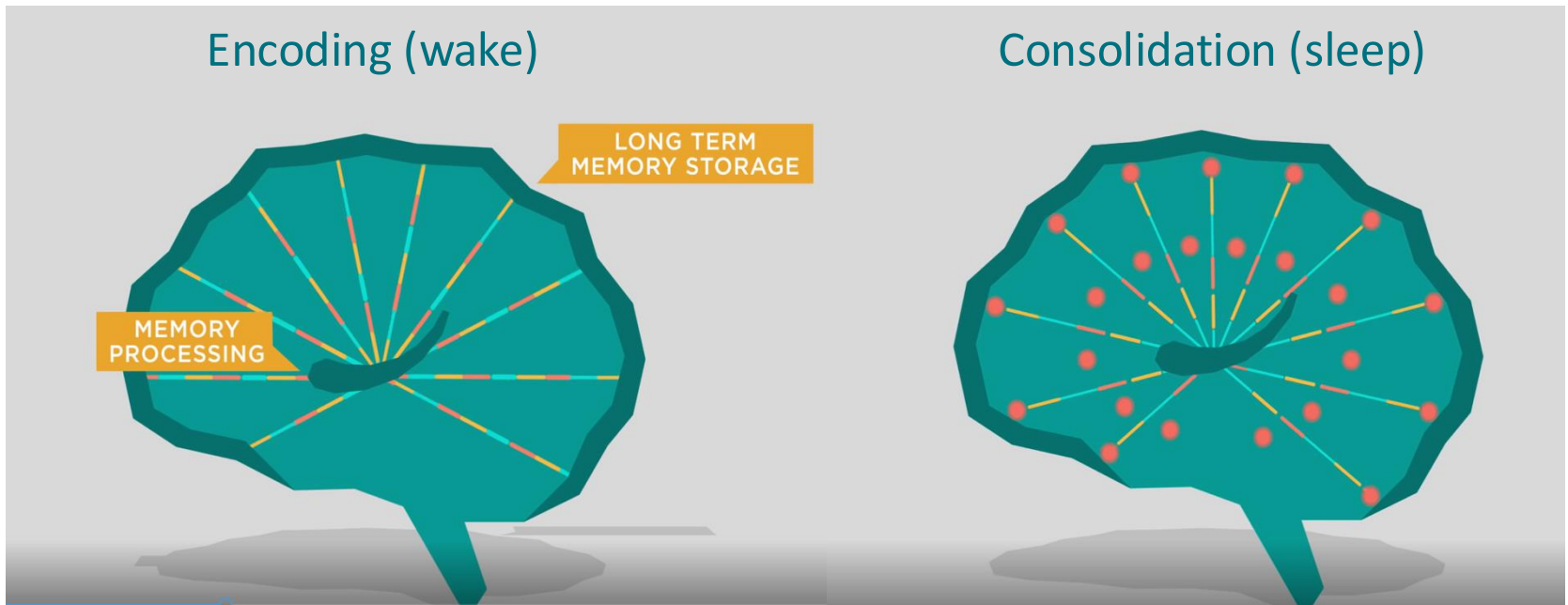
Motor performance & consolidation during sleep



Sleep helps to stabilize & strengthen memories

Motor learning

Sleep is crucial for learning



Promoting sleep-related brain activity could enhance motor learning, leading to faster rehabilitation

Motor learning

Sleep disturbances following brain injury

	TBI	Control	P-Value	Test Value	df	Method
Sleep disorders (No. of patients)	45 (72.6%)	39 (24.7%)	$P < 0.0001$	43.278 χ^2 value		Chi-square
Sleep hours/day *	7.94 $\pm$ 1.07	7.26 $\pm$ 0.58	$P < 0.0001$	4.72 t value	218	t -test
Sleep latency (min) *	13.22 $\pm$ 3.16	13.93 $\pm$ 3.07	P 0.131	1.517 t value	218	t -test

* mean $\pm$ standard deviation.

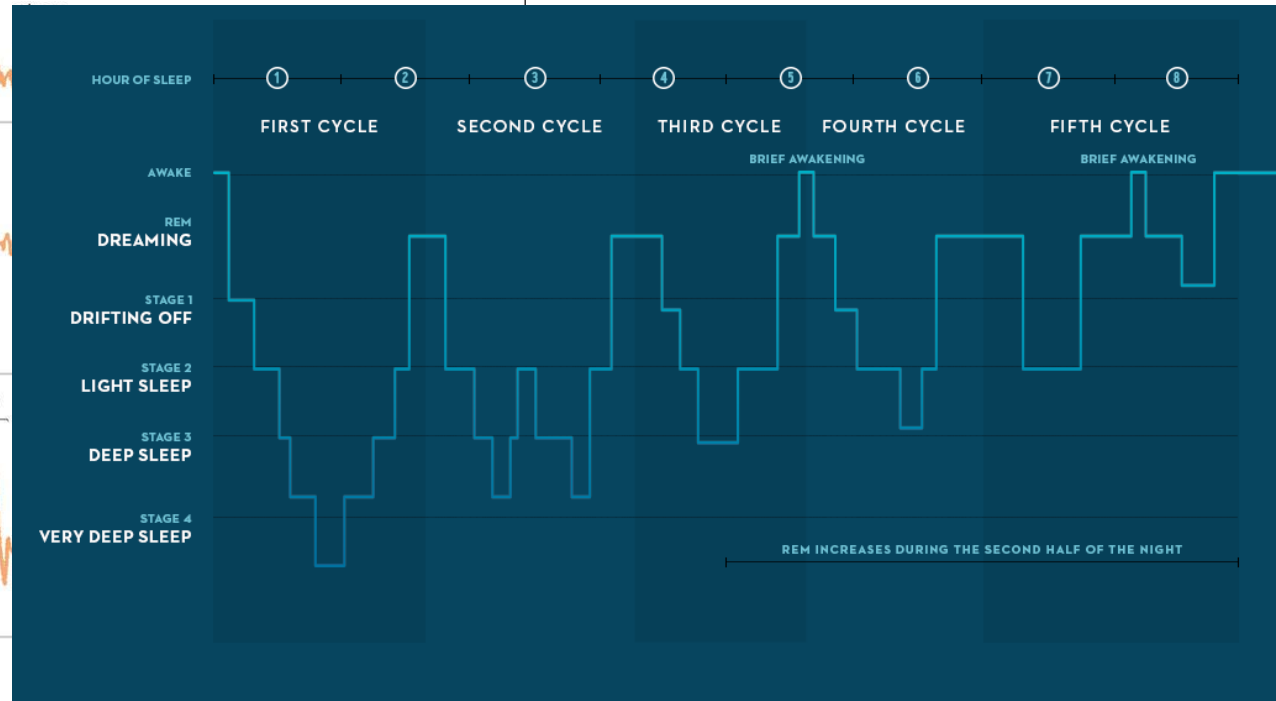
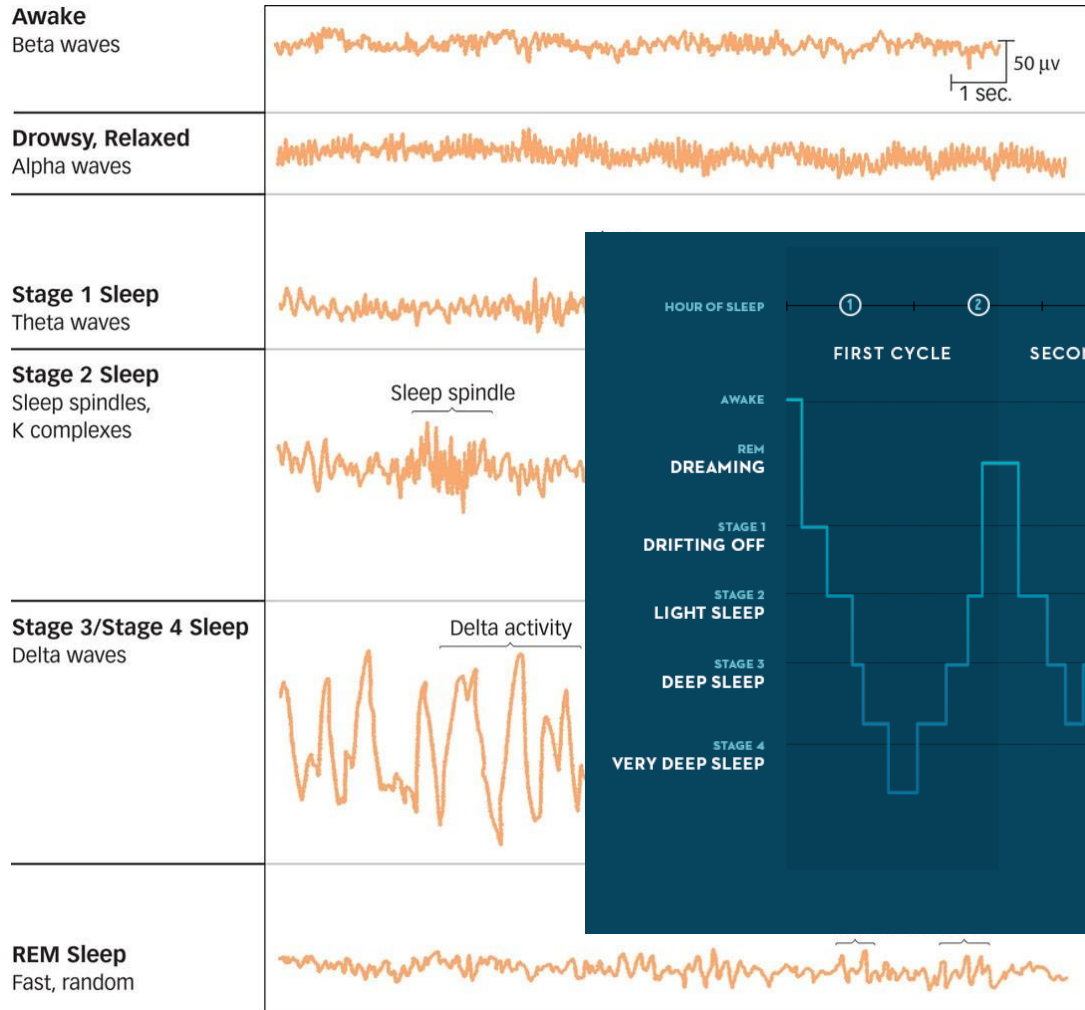
Al-Ameri et al., 2019

➔ 30-70% present sleep disturbances following TBI even mild TBI/concussion

➔ Impact rehabilitation & quality of life

Memory consolidation

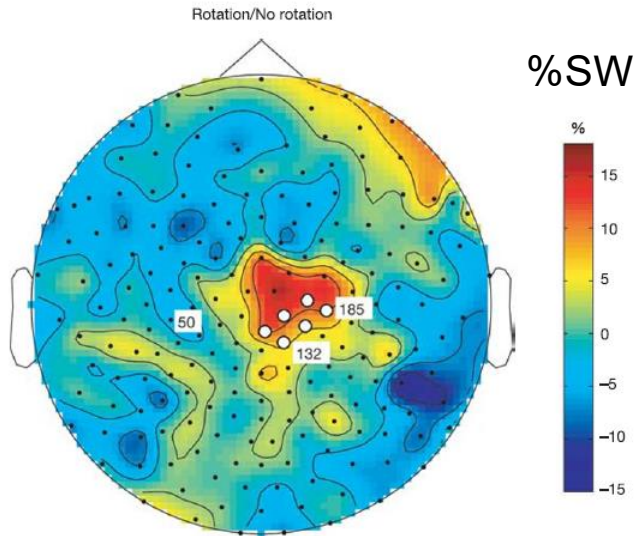
Sleep stages



Memory consolidation

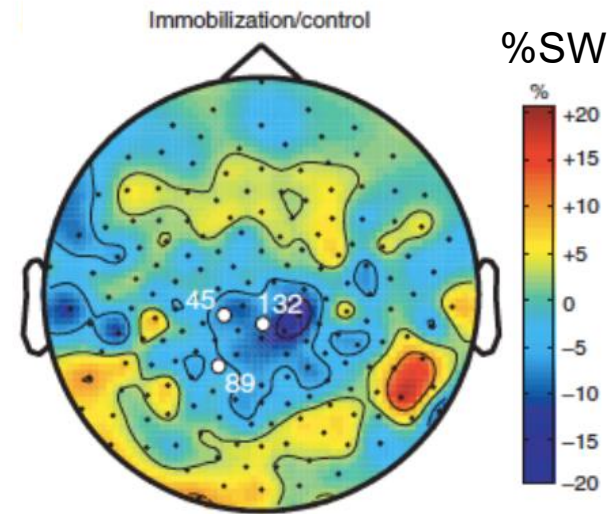
Slow oscillations (0.5-4 Hz) and memory

Learning before sleep increases SW
(visuomotor task)



Hubert et al. 2004

Immobilization of right arm
before sleep reduces SW



Hubert et al. 2006

Performance correlated with local SW activity increase/decrease

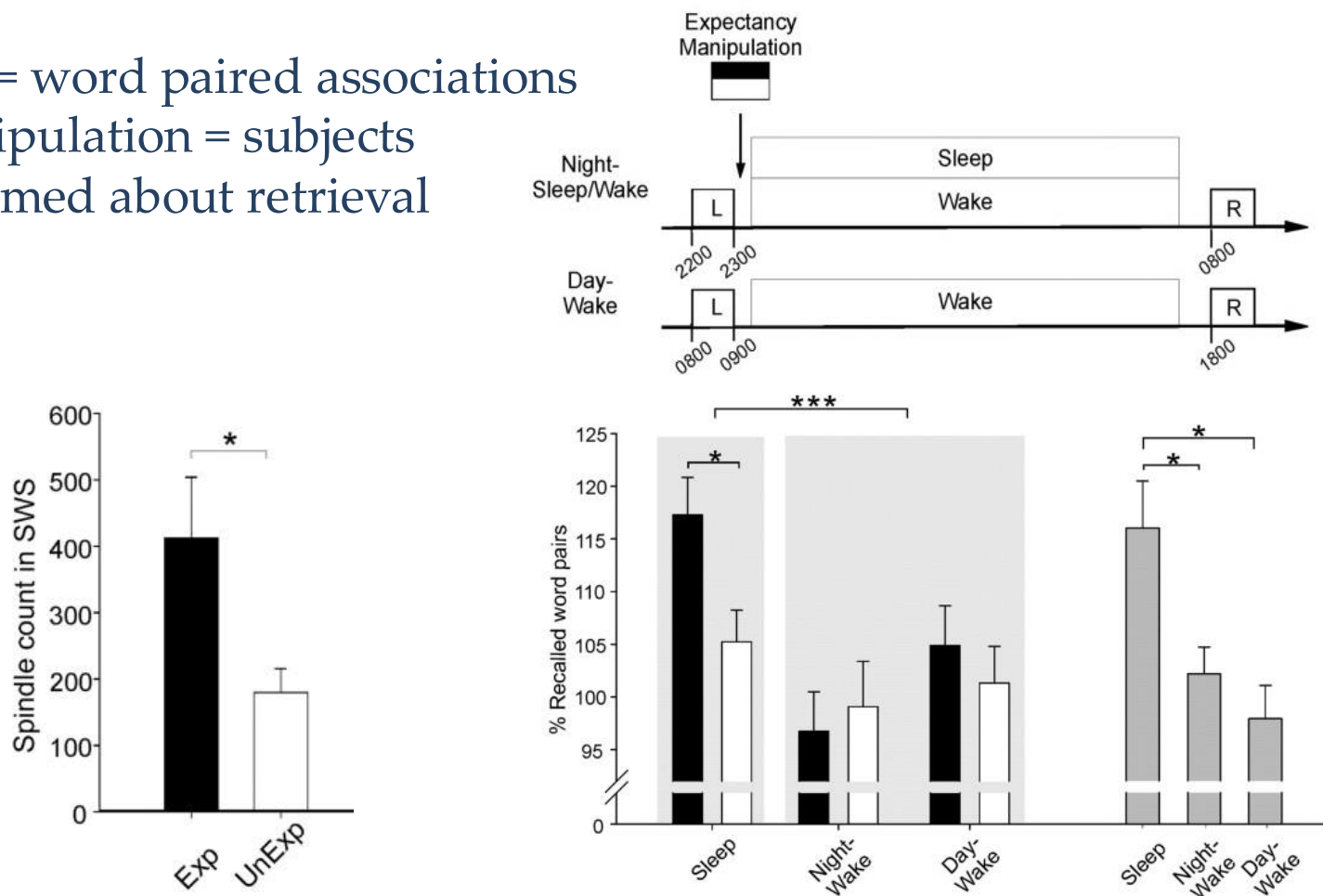
➔ SW activity is related to plastic changes induced by learning

Memory consolidation

How memory are selected to be maintained ?

Test = word paired associations

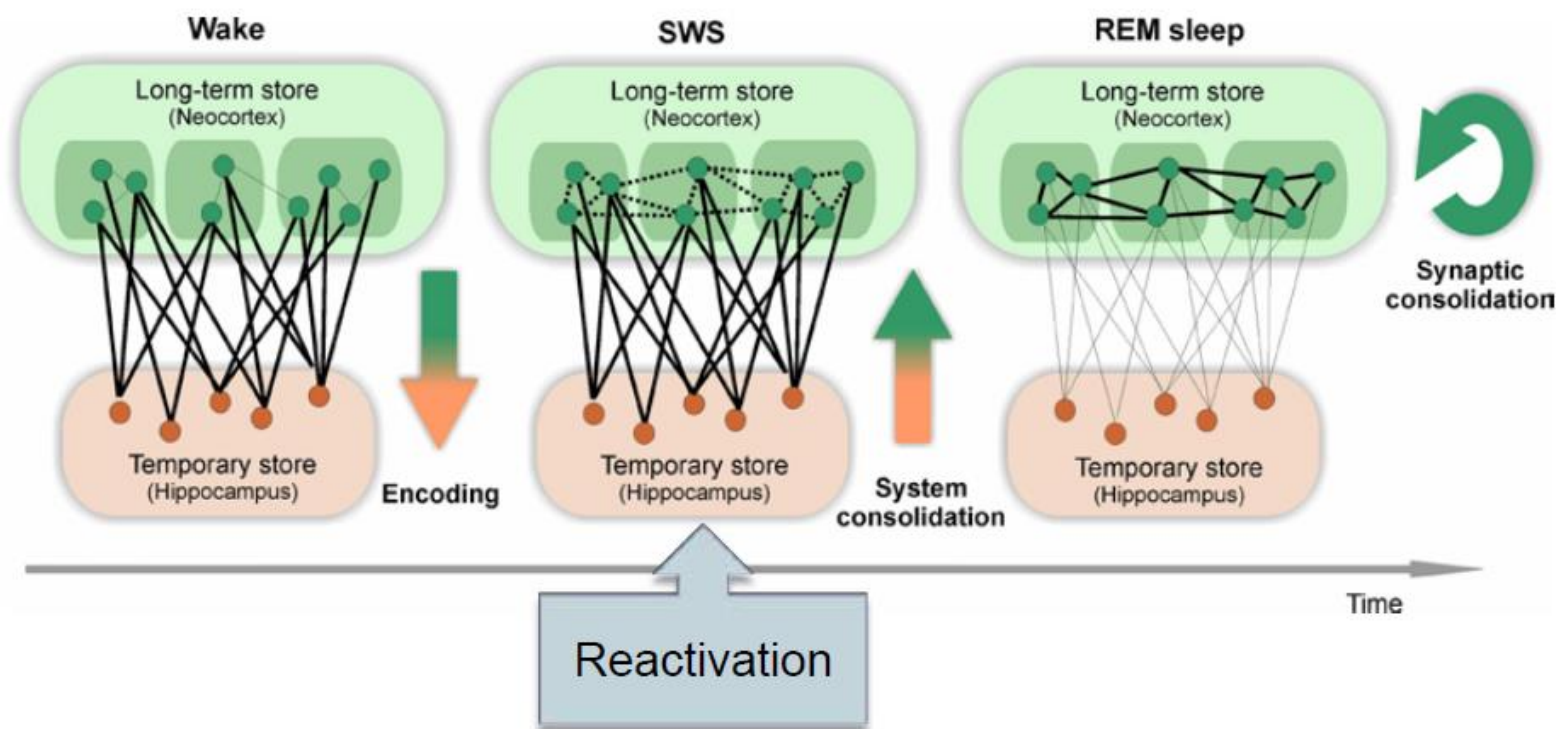
Manipulation = subjects informed about retrieval



Sleep selectively enhances memory expected to be of future relevance

Memory consolidation

Active system memory consolidation



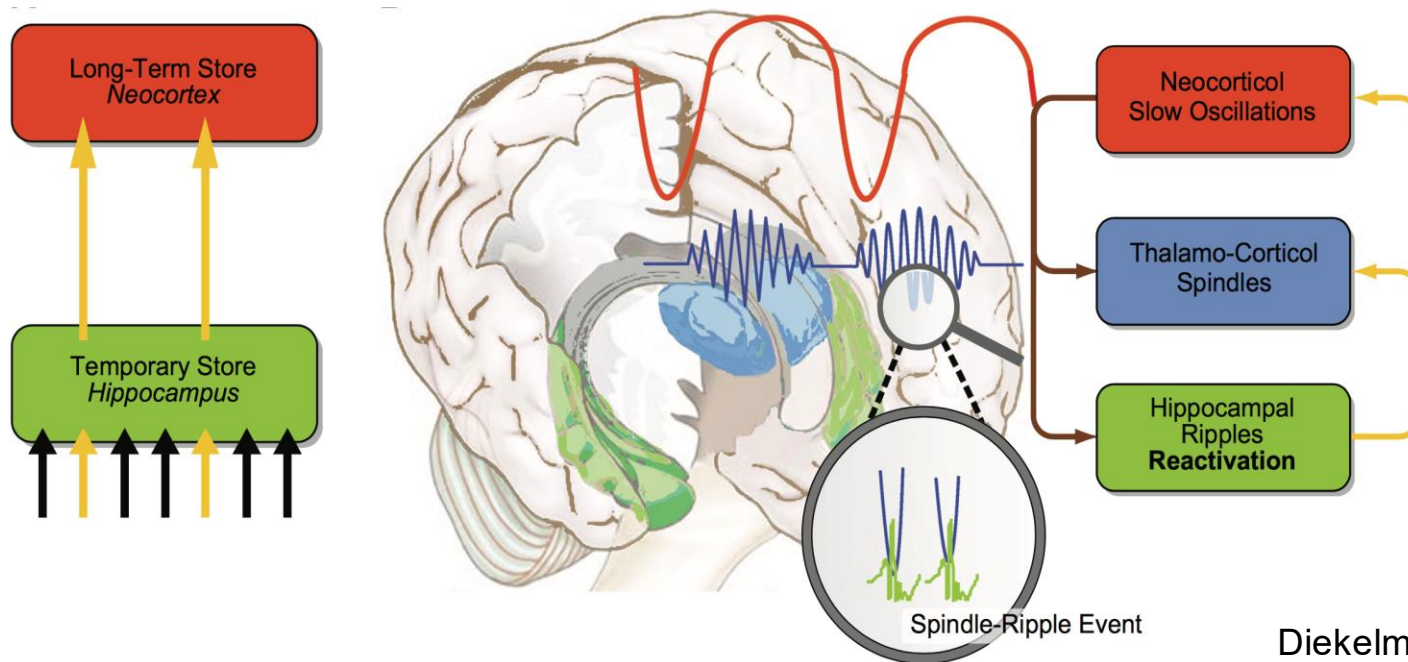
Diekelmann & Born, 2010

Sequential contribution of sleep stages to memory

Memory consolidation

Active system memory consolidation

Dialogue between the neocortex and the hippocampus



Diekelmann & Rash 2010

Ripple events (150-250Hz) : transfer information from hippocampus to neocortex

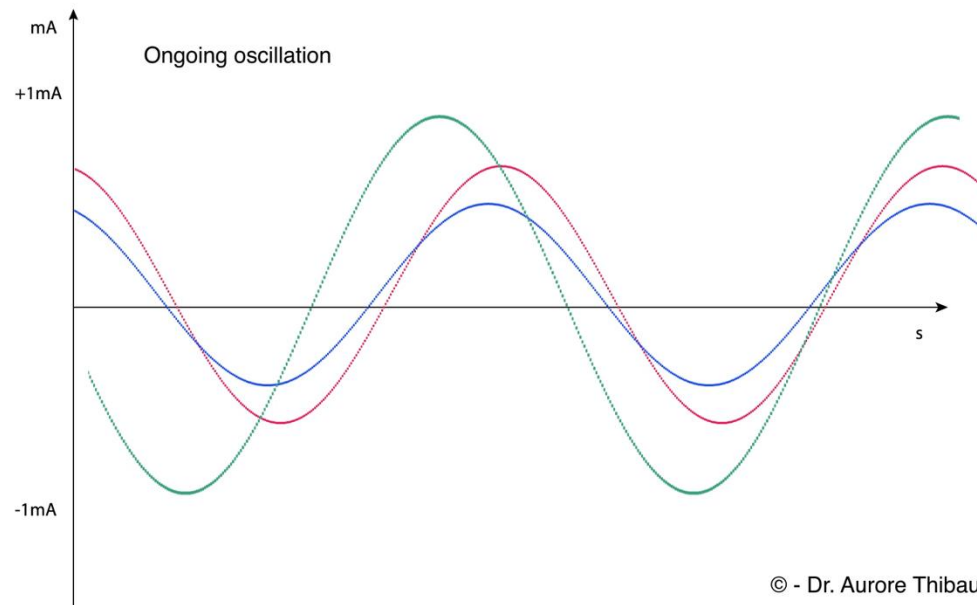
Thalamo-cortical spindles (11-16Hz): enable synchronous feedback from the hippocampus to the neocortex during the slow oscillations up-state

SW (0.5-1.5Hz): needed for the formation of more persistent traces in the neocortex

Neural entrainment

How can we modulate brain activity to enhance specific brain oscillatory activity?

Neural entrainment relies on the capacity of brain oscillations to synchronize themselves to an external stimulation



Neural entrainment

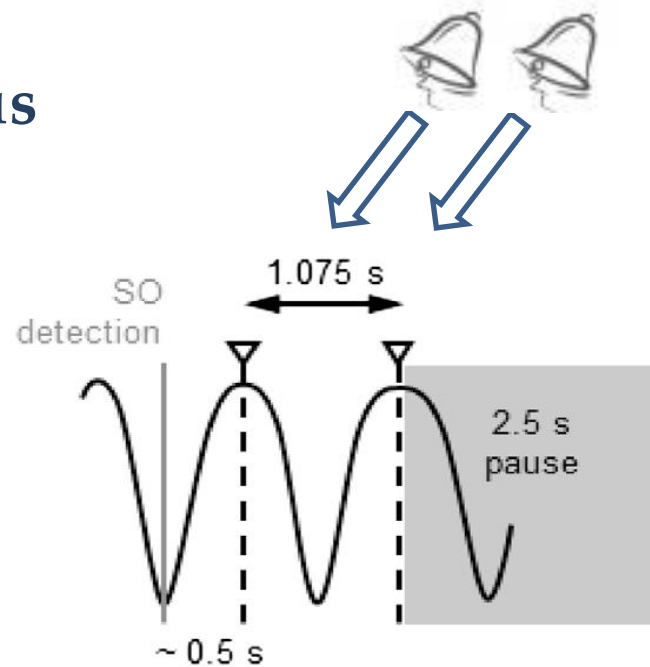
Oscillatory acoustic stimulus

Auditory rhythmic stimulation
matching SW activity

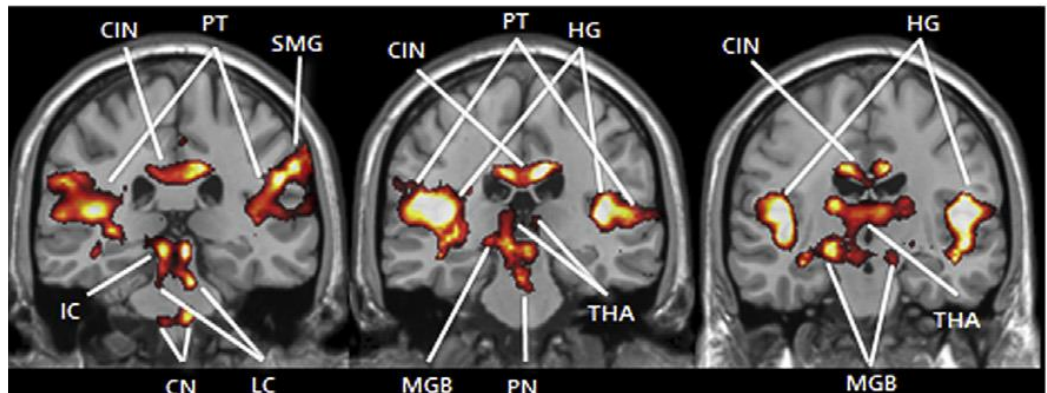
↑ slow waves

↑ declarative memory

↑ activity in auditory
cortices & thalamus (fMRI)



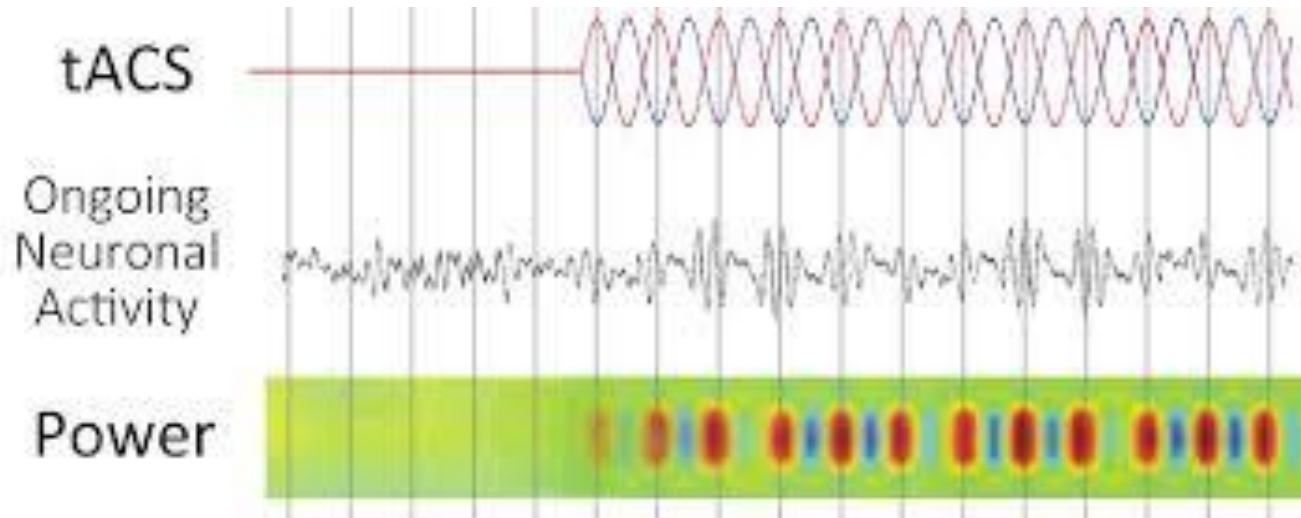
Ngo et al., 2013



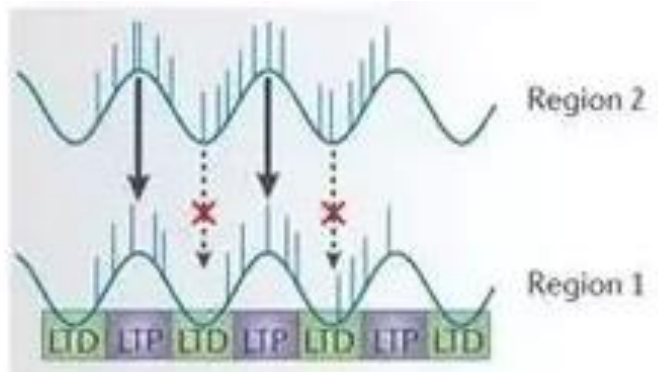
Sigalovsky & Melcher, 2006

Neural entrainment

Oscillatory electrical stimulus



Taken from M. Fuscà



↗ synaptic plasticity (LTP)

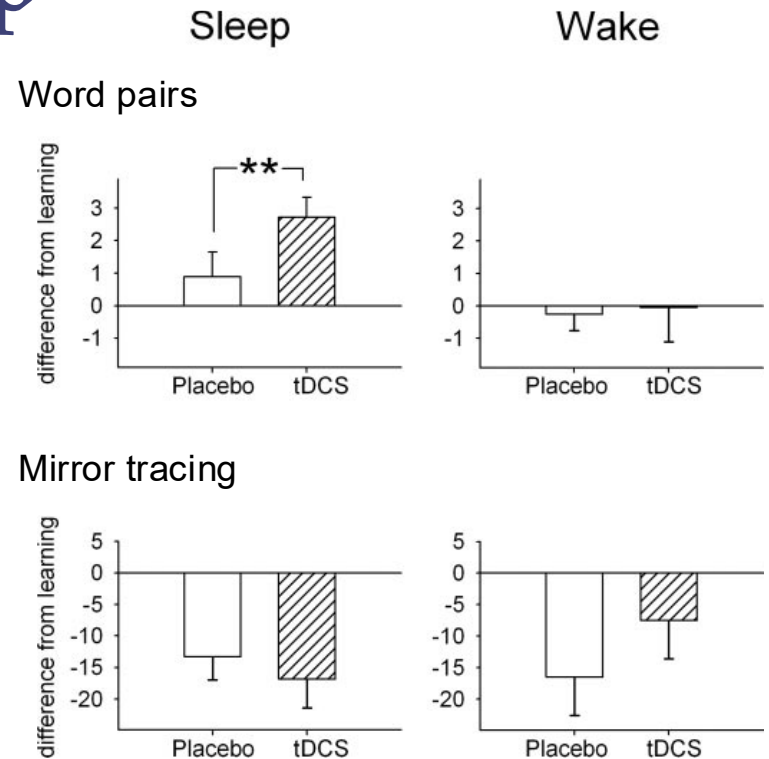
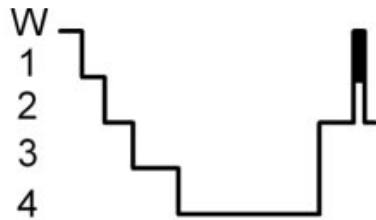
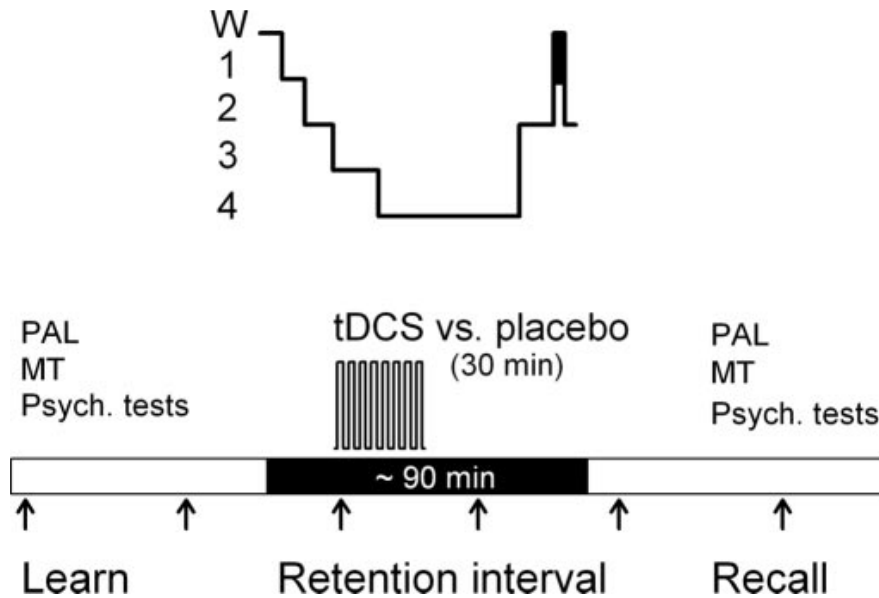
Hermann et al., 2013

TRANSCRANIAL ELECTRICAL STIMULATION (TES)



Transcranial electrical stimulation

tDCS during SW sleep

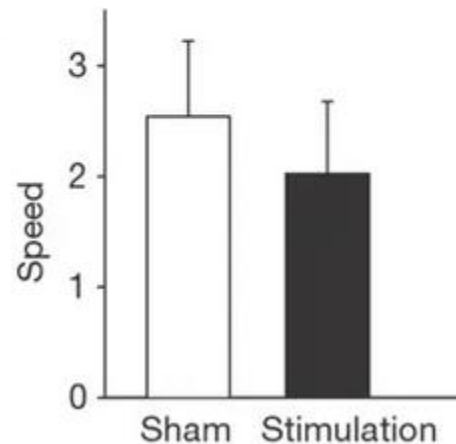
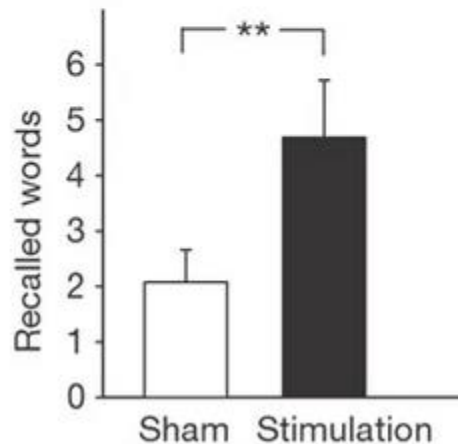
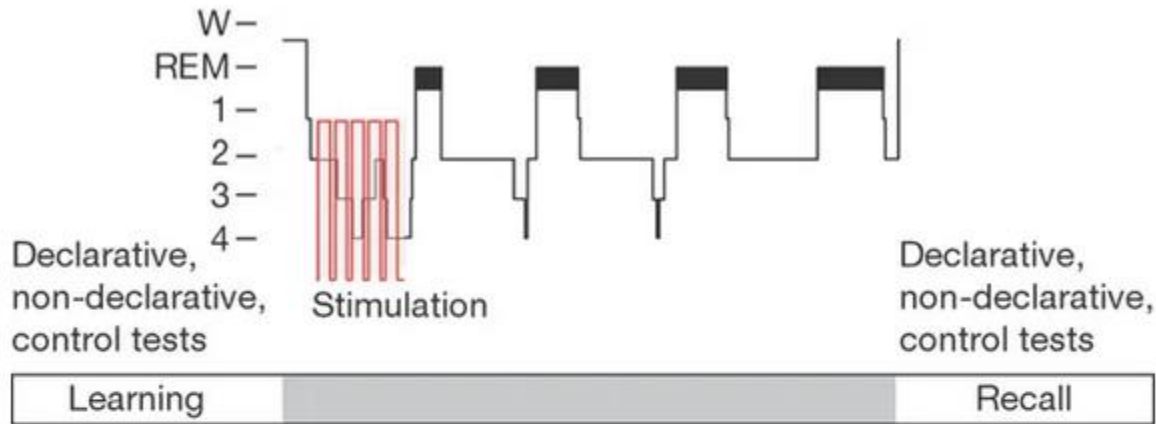


Marshall et al 2004

Improved declarative but not procedural (motor) memory consolidation

Transcranial electrical stimulation

Slow oscillation (so) tDCS during NREM sleep



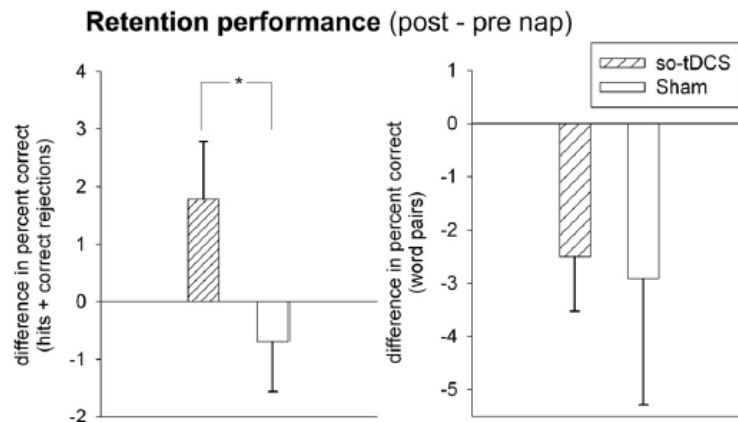
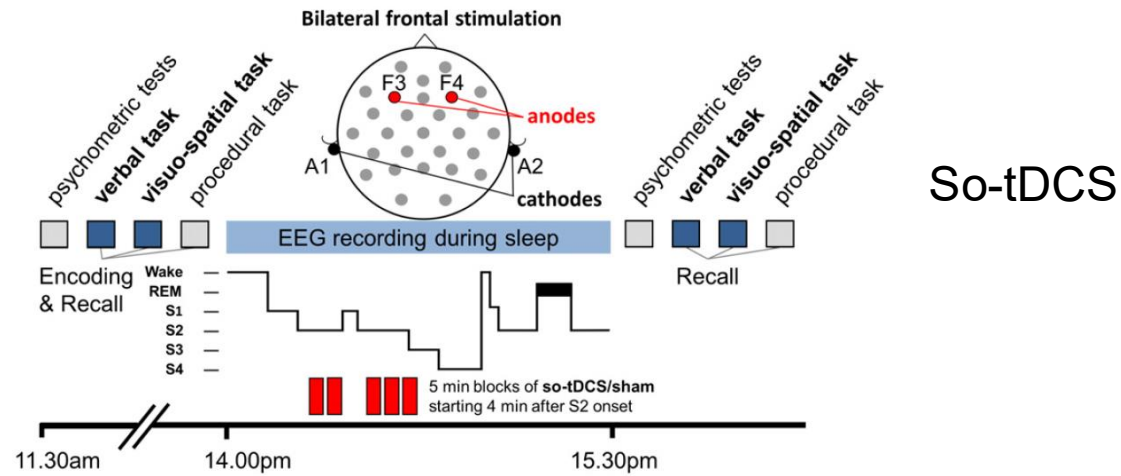
So-tDCS increased SWA

Enhanced declarative memory

No effect on procedural memory

Transcranial electrical stimulation

Brain stimulation during an afternoon nap boosts SWA and memory consolidation in older adults



Increased frontal SW & fast spindle

Improved picture memory retention after 90 min of nap sleep

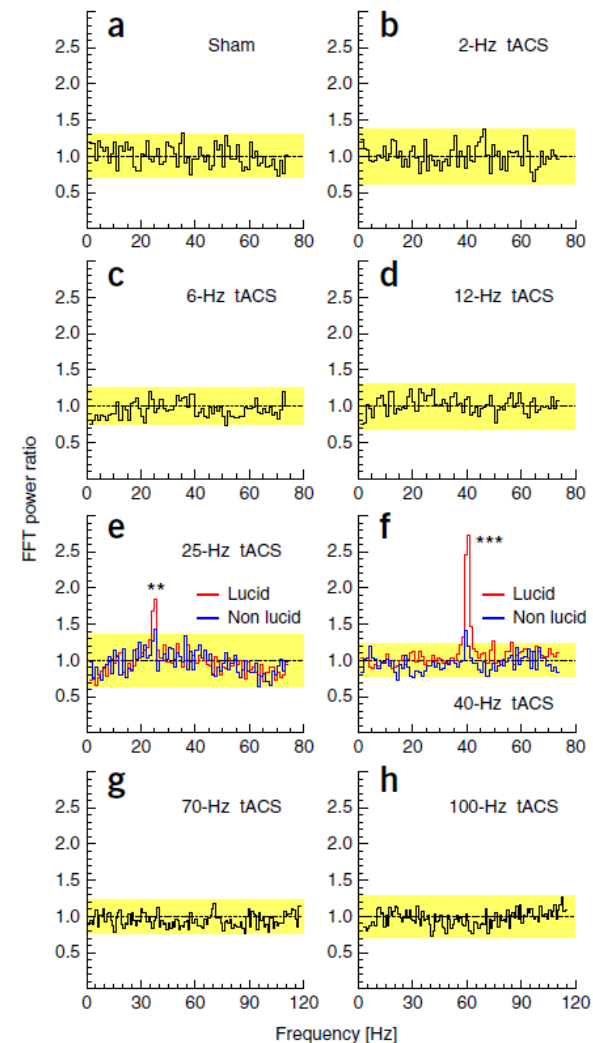
Transcranial electrical stimulation

Induction of lucid dreams through frontal tCS of gamma activity during REM sleep

40-Hz tACS during REM sleep influences ongoing brain activity & induces self-reflective awareness in dreams
→ lucid dreaming

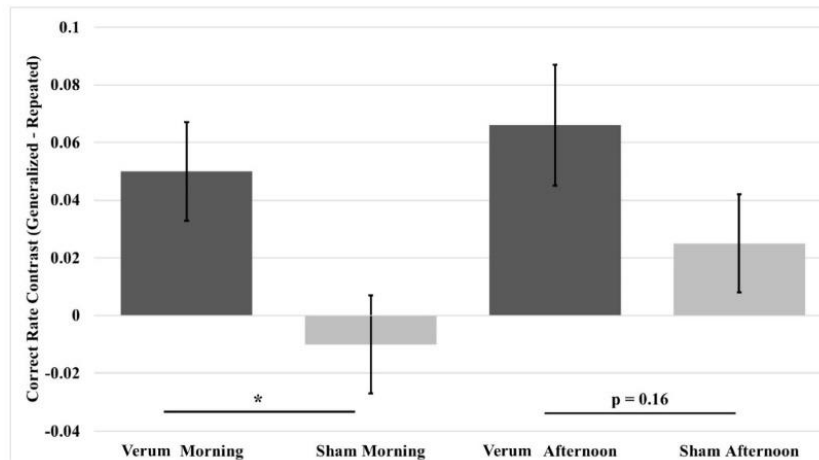
Other frequencies were not effective

→ tACS can be used to evaluate causal relationship between specific brain oscillatory activity & a behaviour

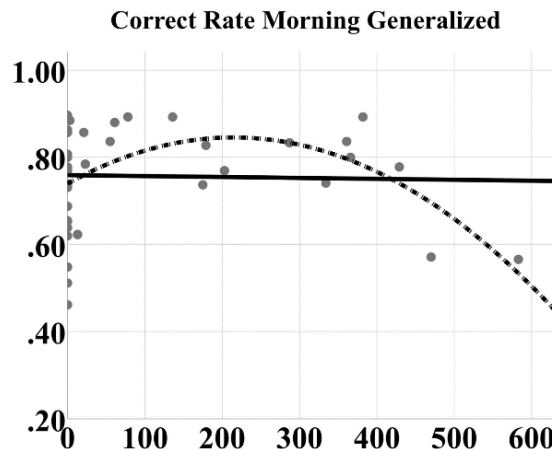


Transcranial electrical stimulation

Dose-dependent effects of closed-loop tACS delivered during slow-wave oscillations on memory consolidation



Rate of correct responses (image detection tasks) higher after tACS in the morning (not afternoon)

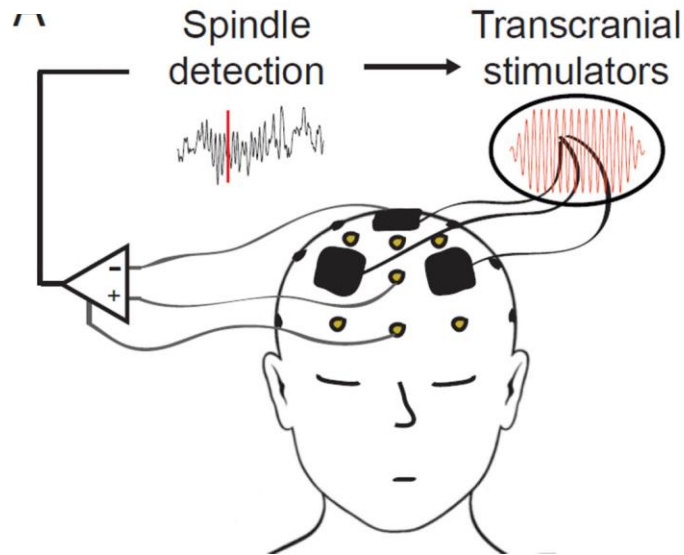


Inverted U-shaped dose effect of sleep tACS
➔ tACS-induced facilitatory & subsequent refractory dynamics

Transcranial electrical stimulation

Closed-loop spindle tACS during SW sleep

In phase with subject endogenous oscillations & triggered at specific time points



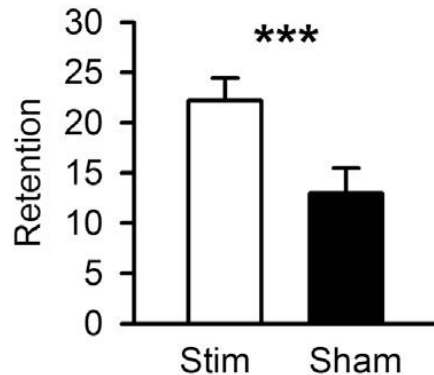
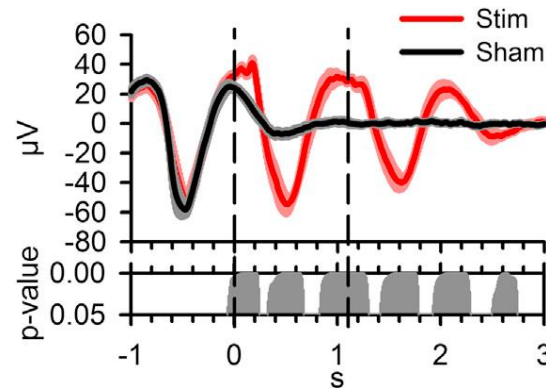
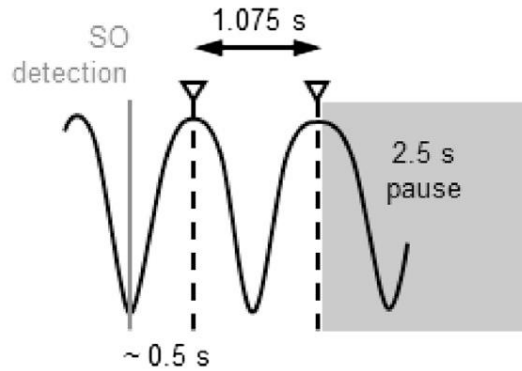
- ↗ sigma (12-16Hz - spindles) activity
- ↗ motor learning (SRTT)

ACOUSTIC STIMULATIONS



Acoustic stimulation

In-phase stimulation of SW oscillations – closed-loop



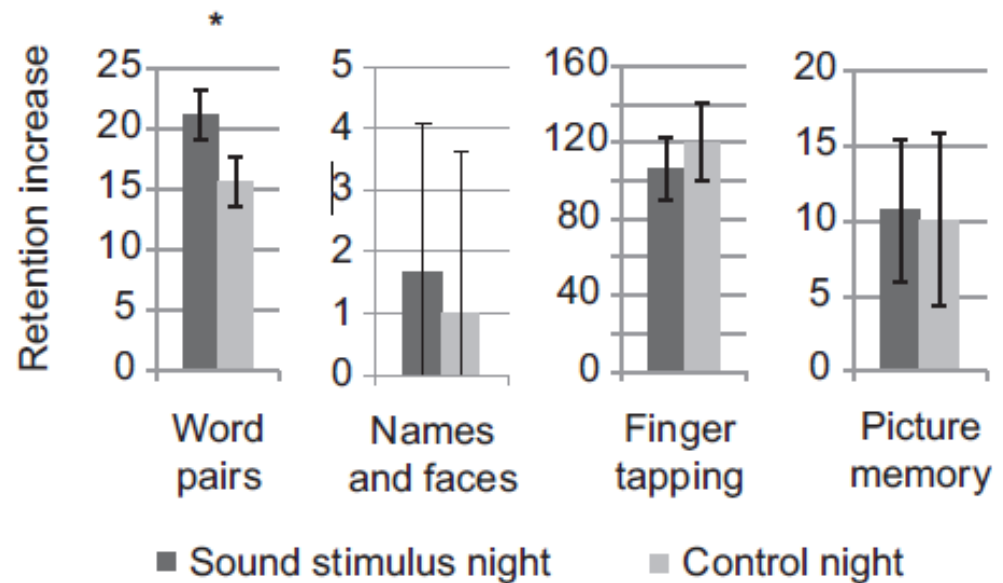
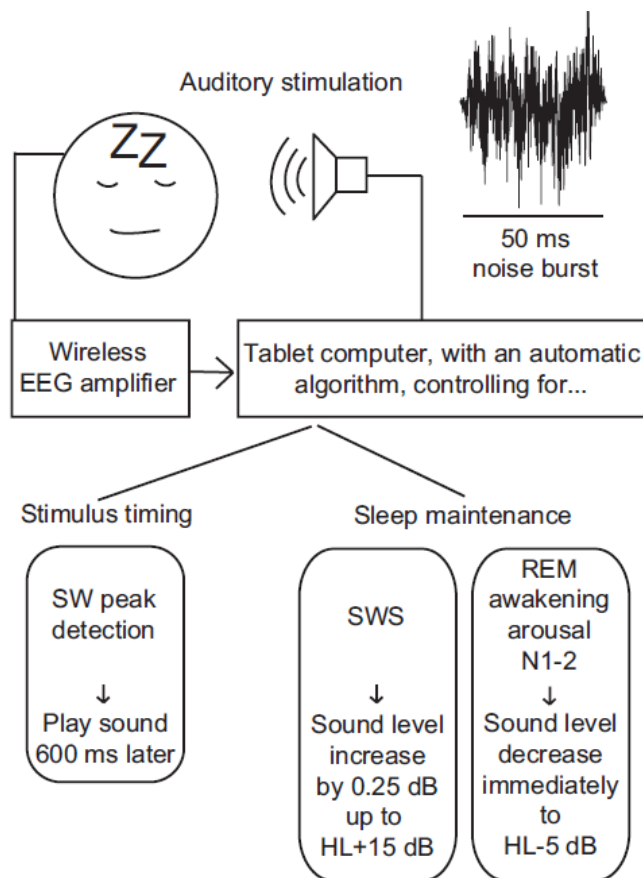
Stimulation out of phase with the ongoing slow oscillation rhythm was ineffective

Ngo et al., 2013

➔ resonating response of brain oscillations induced by the in-phase stimulation leading to enhanced memory consolidation

Acoustic stimulation

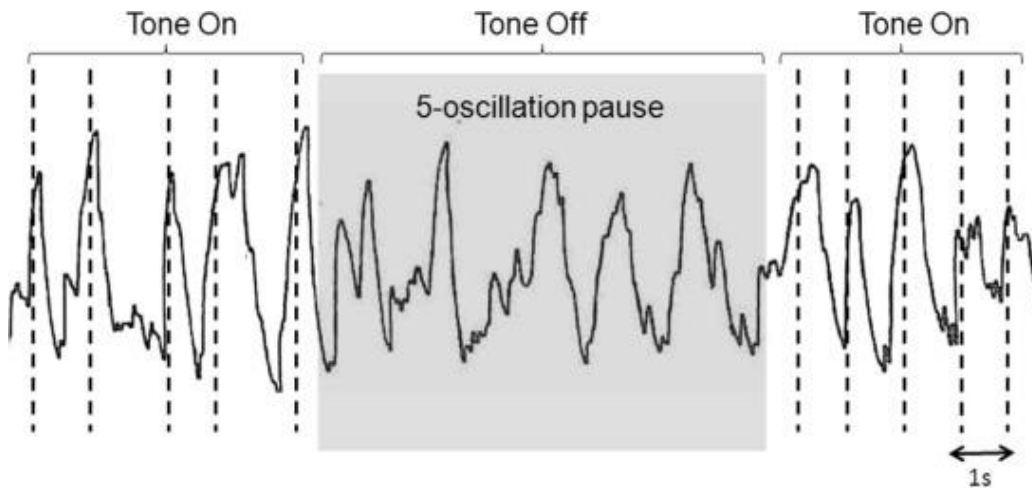
Enhanced memory consolidation via automatic sound stimulation during SW sleep



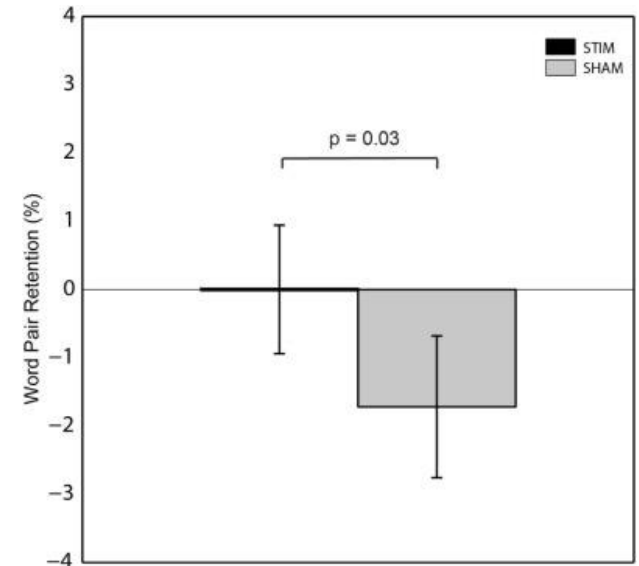
Acoustic stimulation

Effects of phase-locked acoustic stimulation during a nap on EEG spectra and declarative memory consolidation

Phase-locked – SW up-state



Retention post-nap

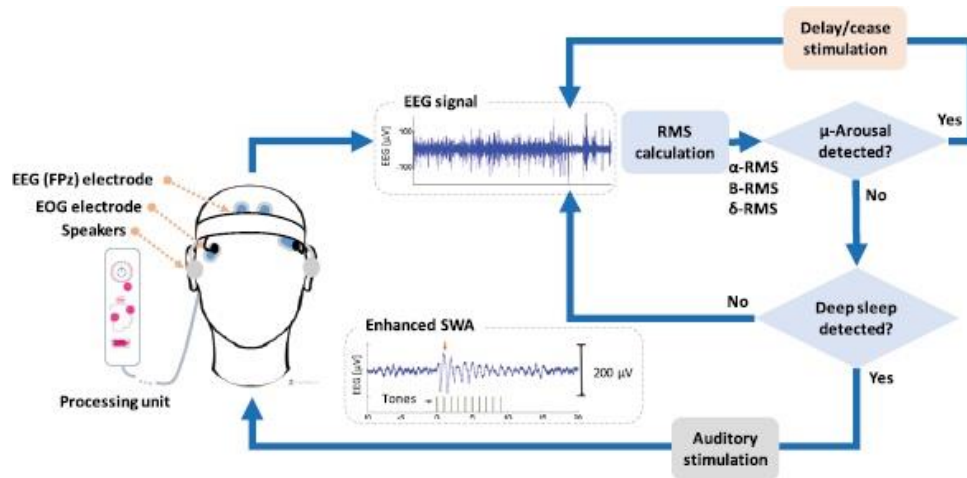


Ong et al., 2016

SW acoustic stimulation during nap prevent memory to decay

Acoustic stimulation

Closed-loop home-based system to enhance SWA



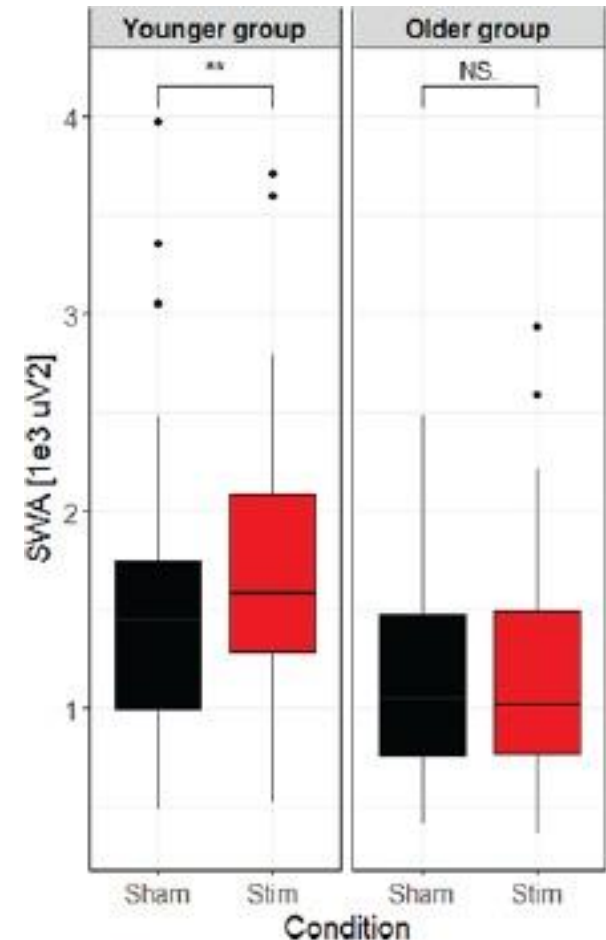
Enhance SW in young adult only

Older group – no effect

➔ less SWS, less stimulation

➔ sleep disturbance?

tCS better to boost/normalize SW activity?

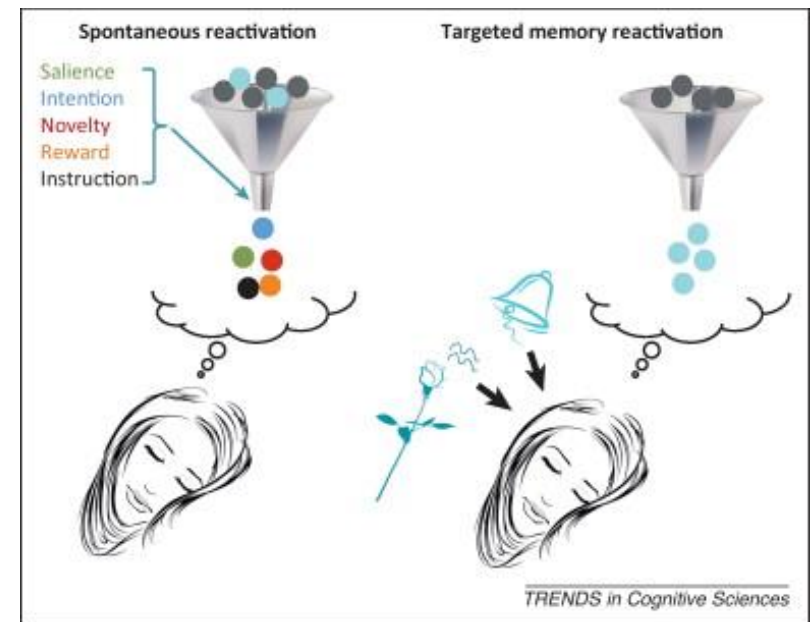
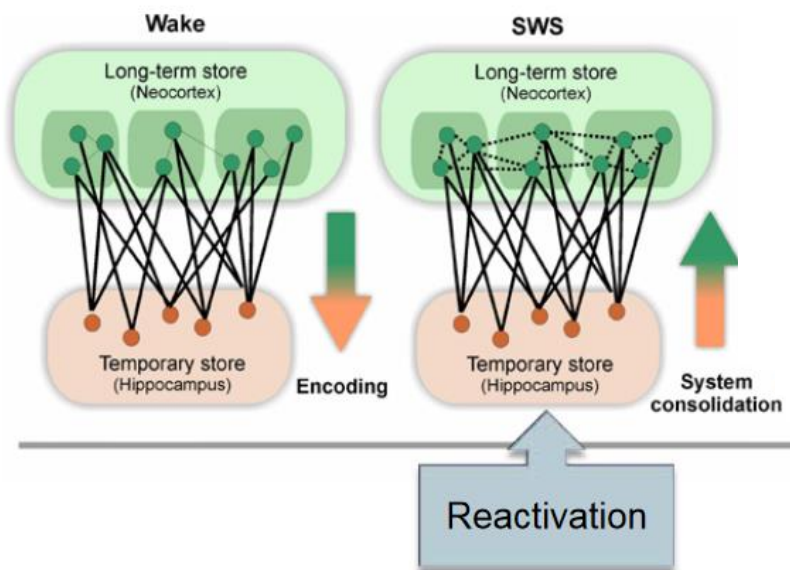


TARGETED MEMORY REACTIVATION

Targeted memory reactivation

Reactivation of previously learned memories
via auditory or olfactory cues

Specific reactivation of previously learned
memory during SWS

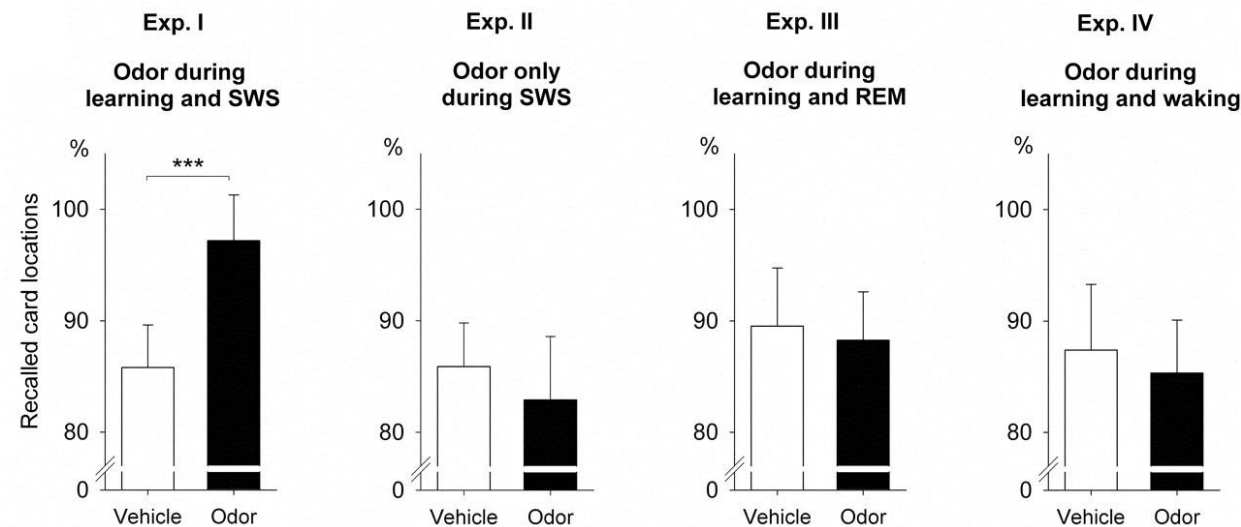


Oudiette & Paller, 2013

Select memories that need to be consolidated

Targeted memory reactivation

Memory stabilization with targeted reactivation during SW sleep

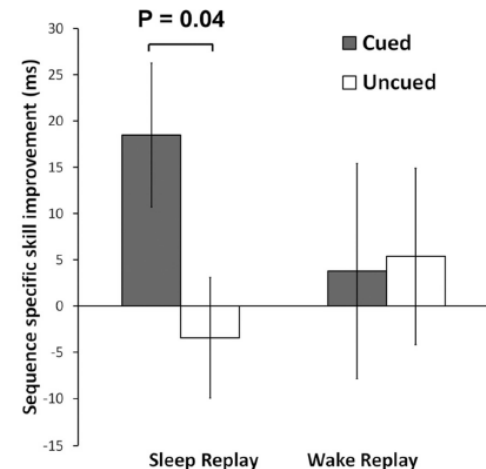
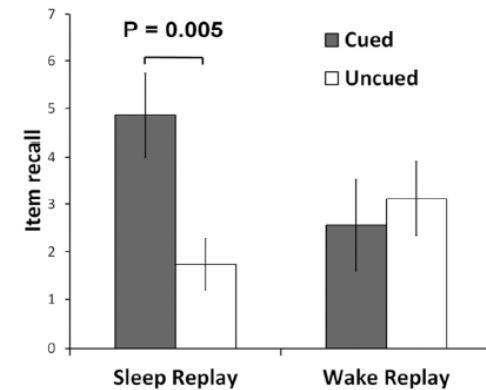
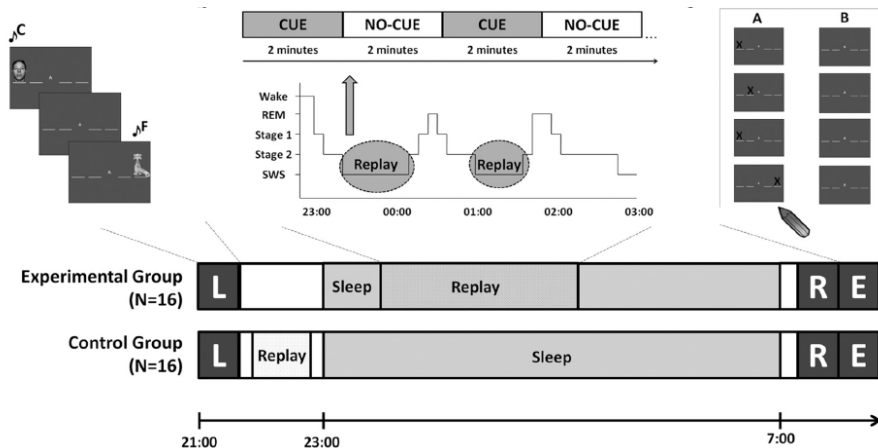


Re-exposure to the odor during SWS improved the retention of associative memories (not procedural)

Odor re-exposure was ineffective during rapid eye movement sleep or wakefulness → specific to SWS

Targeted memory reactivation

Cued memory reactivation during SW sleep promotes explicit knowledge of a motor sequence



Greater explicit knowledge & better procedural skill for the cued sequences

Fast spindles (13.5–15 Hz) predicted overnight enhancement in procedural skill

CONCLUSIONS

Conclusions

- Quality sleep is important for memory consolidation
- Literature is still limited for motor learning and motor memory consolidation during sleep – critical in rehab
- Electrical & acoustic stimulations can modulate neural activity during sleep in phase-locked and closed-loop manner & enhance learning

Target spindles rather than SW?

- Cuing memories during the acquisition phase (TMR) could also enhance memory consolidation & promising results for motor learning – combined with tACS?

THANK YOU



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