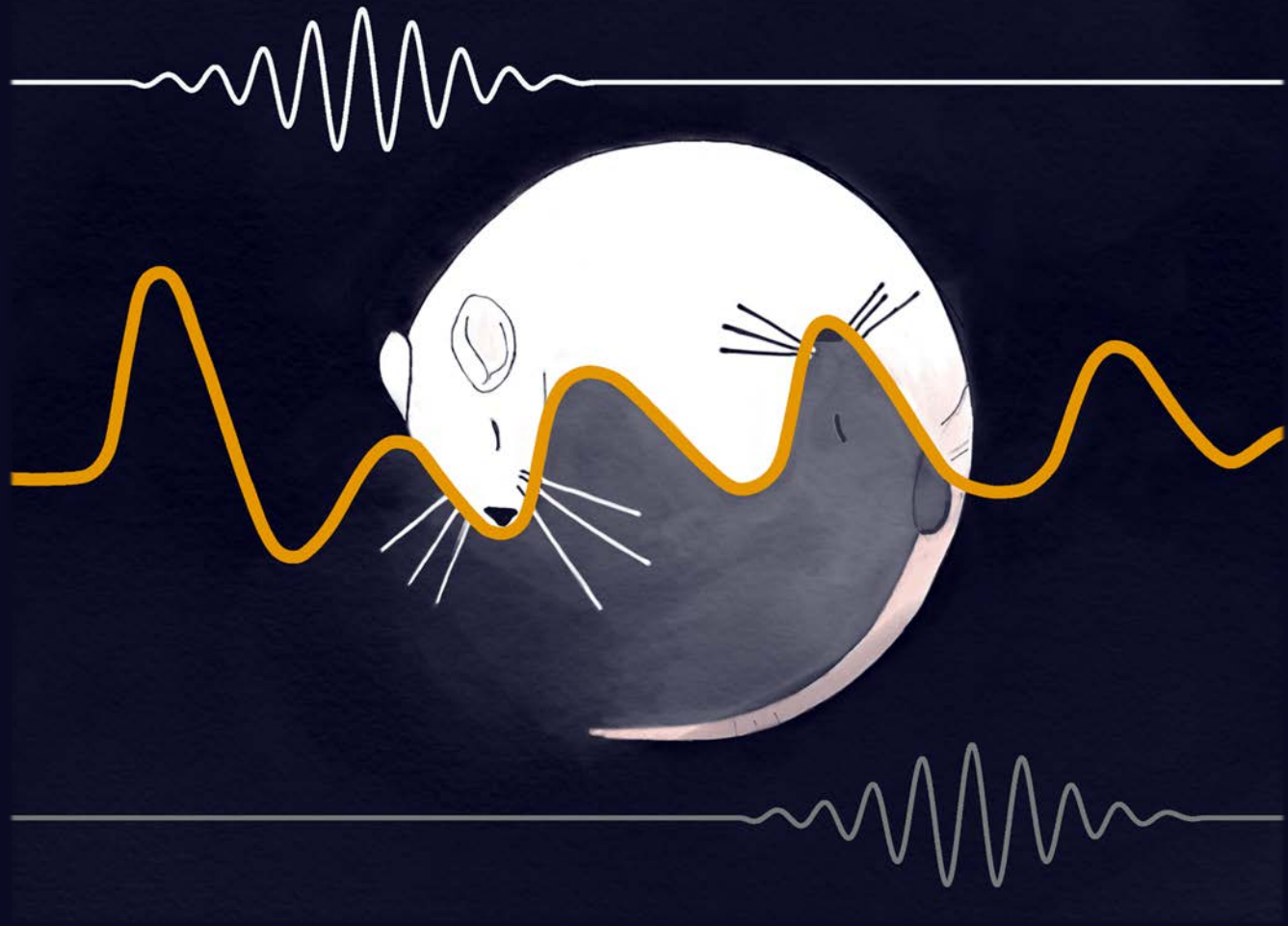
Role of Sleep Oscillations in Memory Consolidation of Brain-Machine Interface

김재경 / Jaekyung Kim, PhD

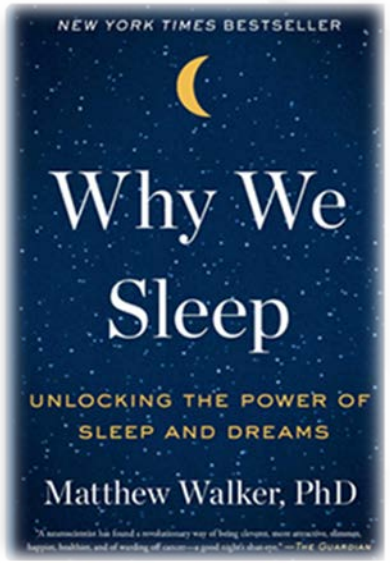
박사후 연구원 / Postdoctoral Fellow

UCSF, Neural Engineering & Plasticity LAB
(PI: Karunesh Ganguly, MD PhD)

한국뇌공학회 심포지엄
02 / 25 / 2021



Why do we have a Sleep?



Matt Walker
Sleep is your superpower

Matthew Walker, PhD
Professor of Neuroscience and Psychology at the UC, Berkeley

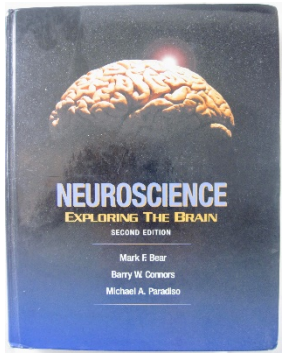
On average, a third of our lives pass by in sleep.

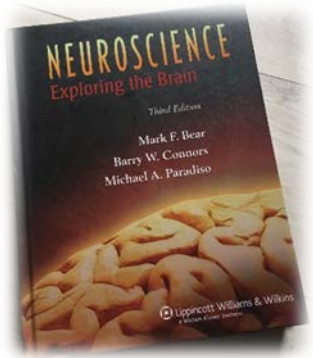
Answer 1: Sleep restores brain energy.
Answer 2: Sleep might enable the brain to clear out toxic products produced when we're awake. (Krueger et al., 2016)
…

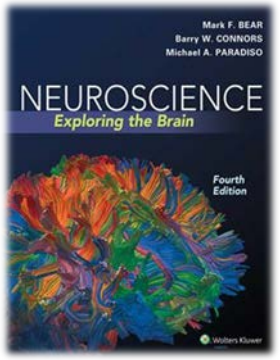
Perhaps the primary function of sleep is that
“it plays a major role in the brain's connectivity and plasticity”.
(Sejnowski and Destexhe, 2000)

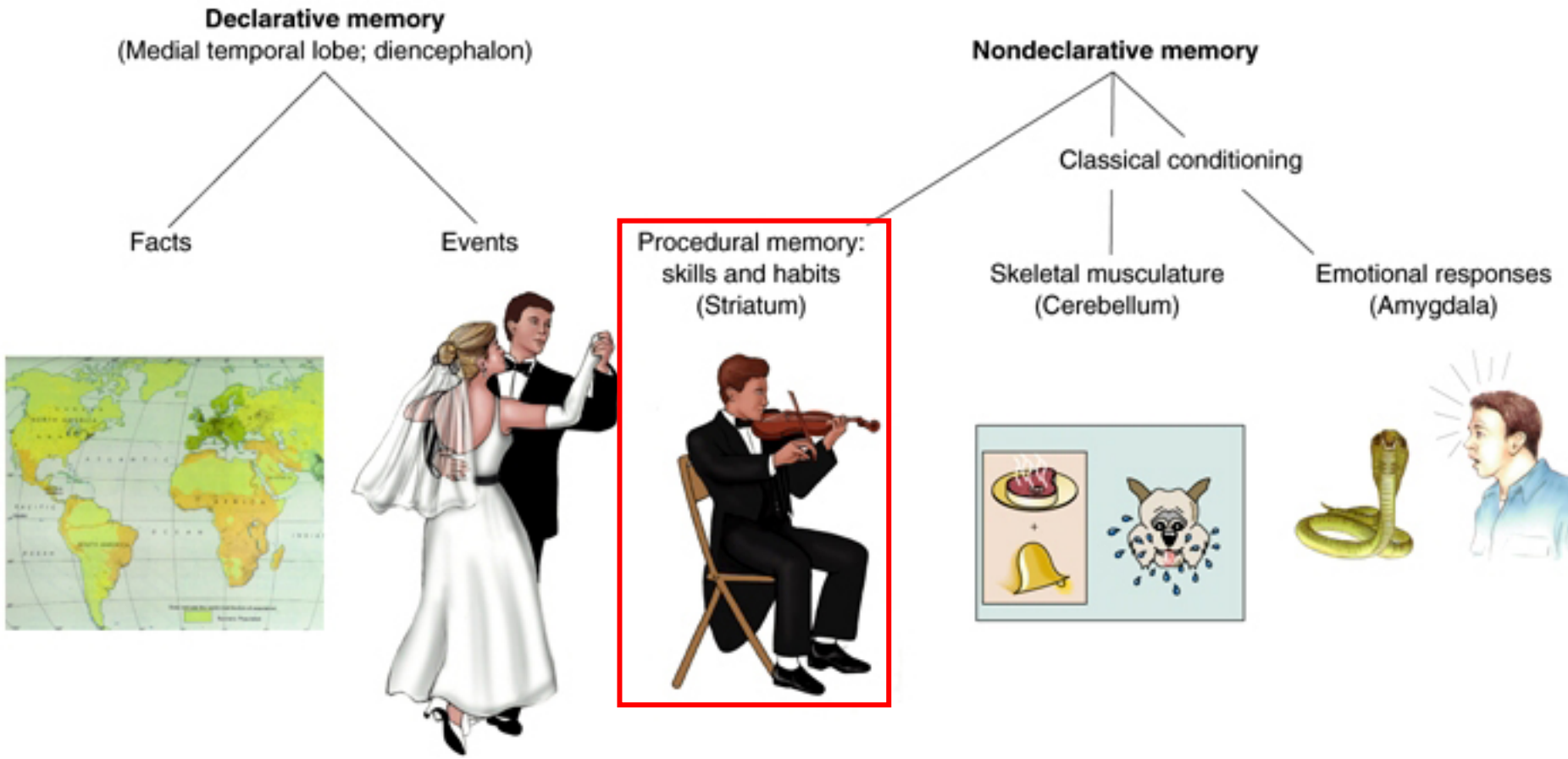
MEMORY

Memory



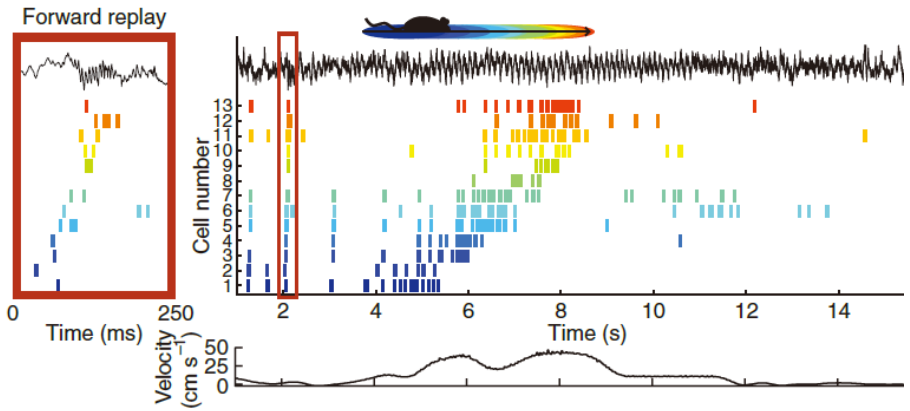






Memory Consolidation During Sleep

- Most studied for declarative memory formation
  - Replay of neural activity during sleep and awake periods
  - Pavlides & Winson, 1989; Wilson & McNaughton, 1994; Roumis and Frank, 2015;



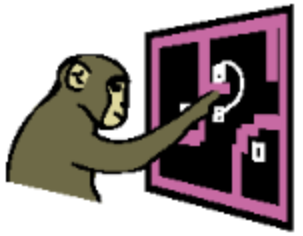
(Joo and Frank, 2018)

- **Sleep can also enhance motor performance**
  - Walker et al. 2002; Huber et al., 2004; Eschenko et al., 2006;
  - Brief naps can enhance long-term retention of a skill (Korman et al., 2007)
  - Rodents: Motor memory consolidation linked to motor cortex activation during sleep (Gulati et al. 2014, 2017; Ramanathan et al., 2015)

Reaching task

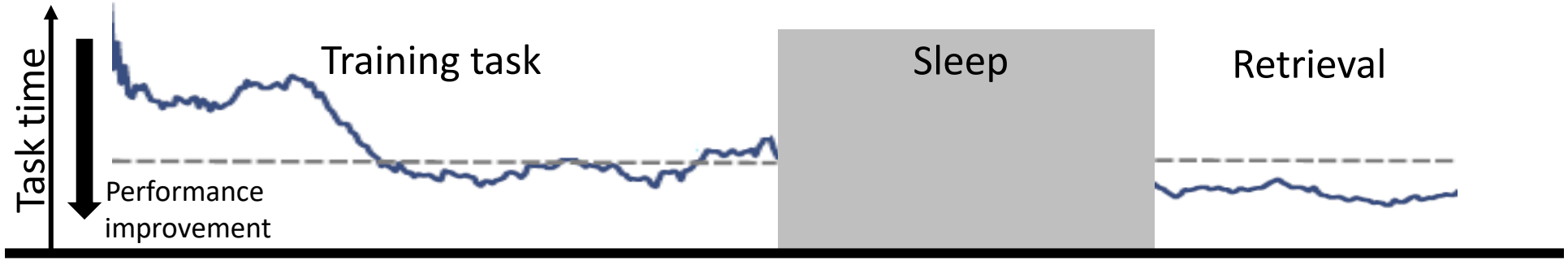
(Stefan et al., 2019)

Reach maze task

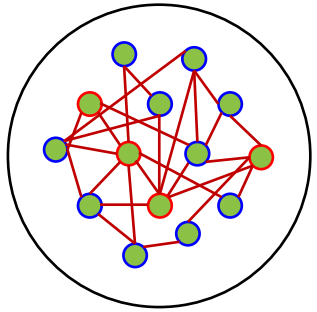


(Sussillo et al., 2015)

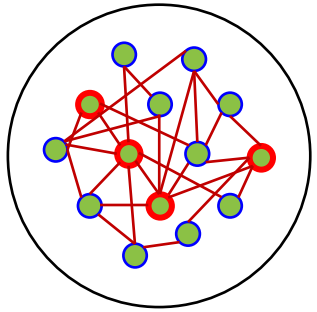
Sleep-Dependent Skill Consolidation



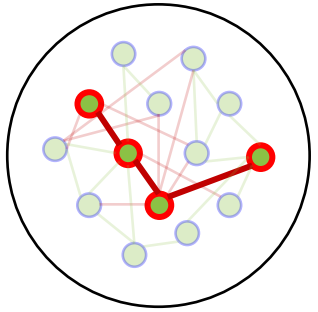
Early Practice
- Many neurons active
- High Variability
- Exploration



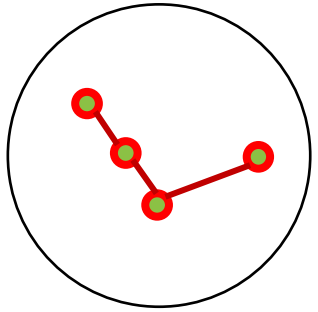
Late Practice
- Task related neurons
- Exploitation



Sleep
- Task related neurons reactivation
- Task unrelated neurons downscaling



Skill Consolidated
- Sparse neuronal activation

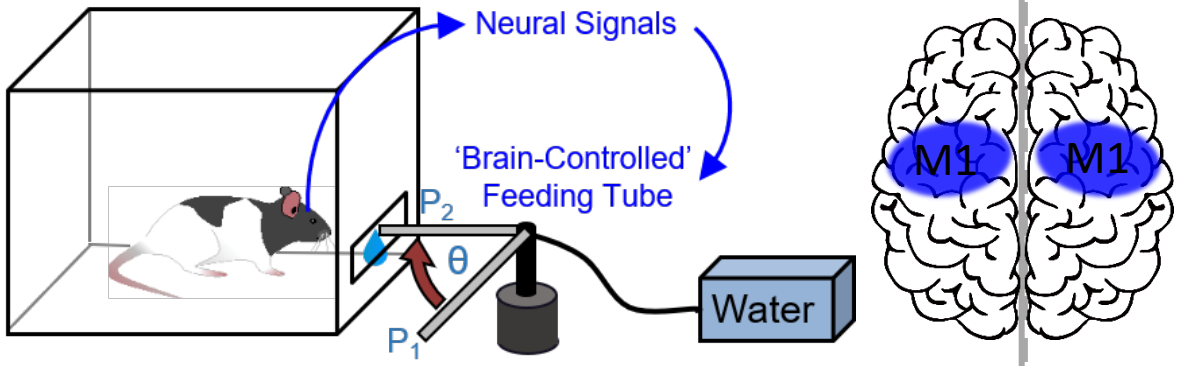


Kim et al., *Cell*, 2019
Gulati et al., *Nature Neuroscience,* 2014, 2017
Ramanathan et al., *PLOS Biology,* 2015

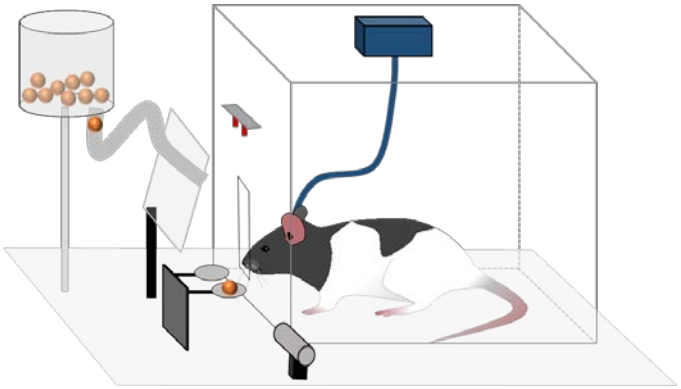
Dual Approaches

Motor task type

Brain-Machine Interface (BMI) Task

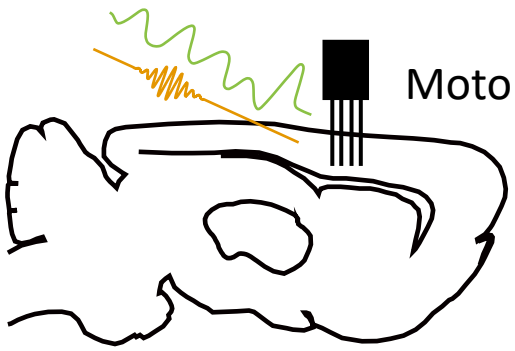


Reaching Task

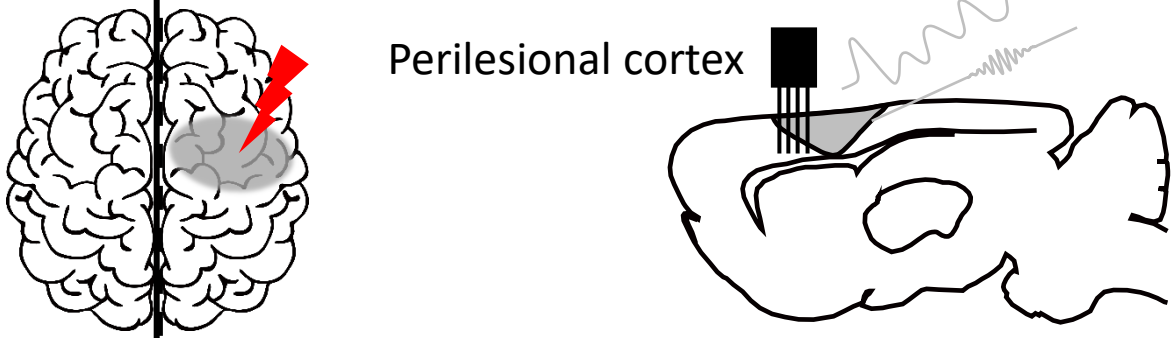


Brain process type

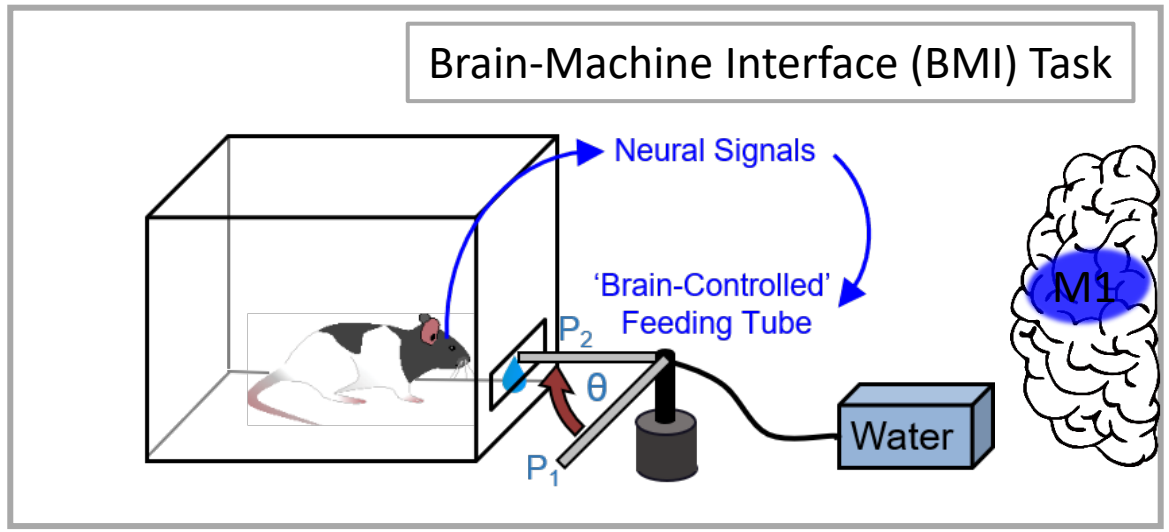
Natural learning

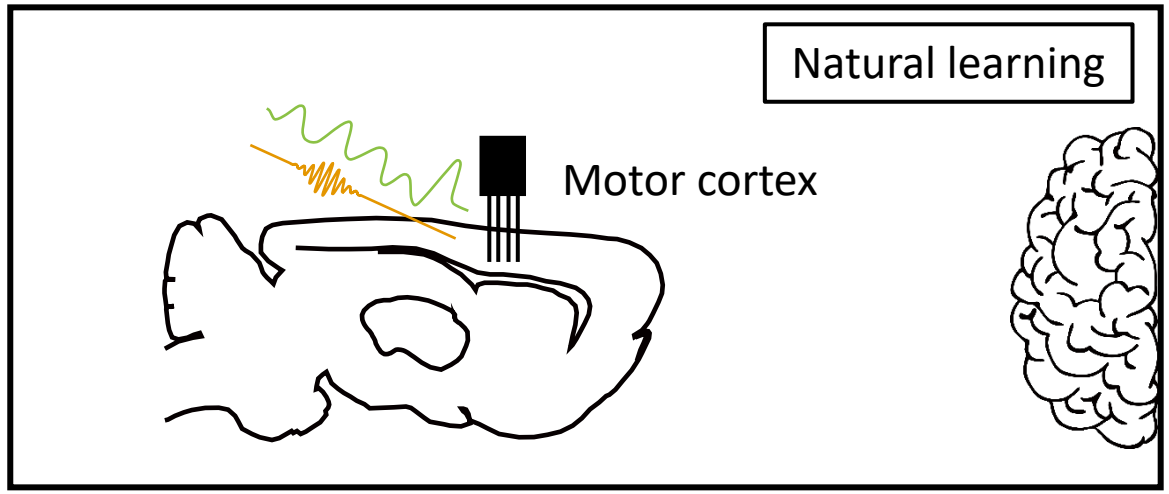


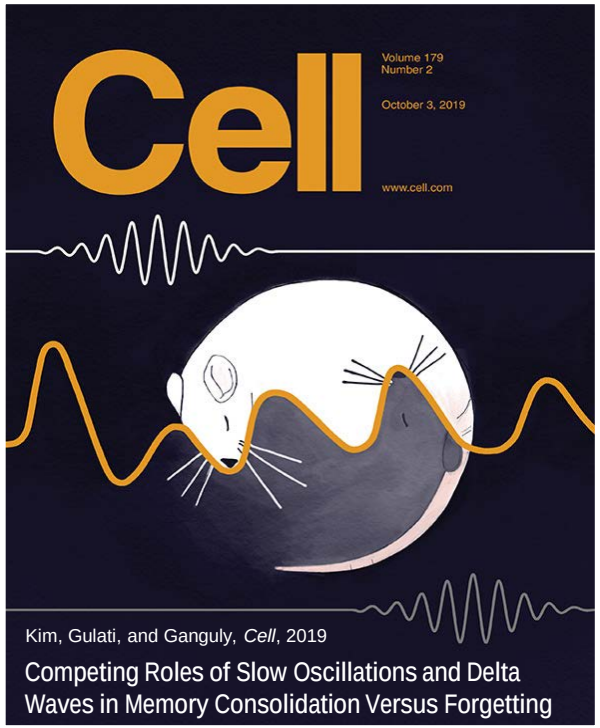
Post-stroke recovery

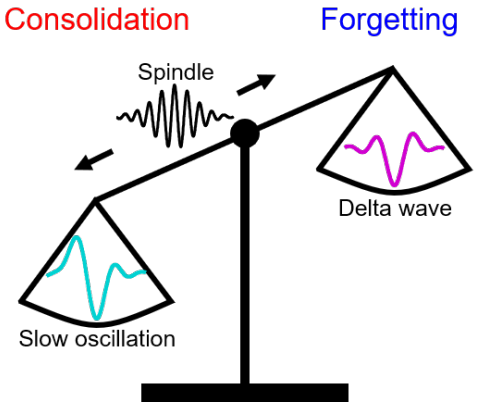


Part 1: Memory Consolidation vs. Forgetting



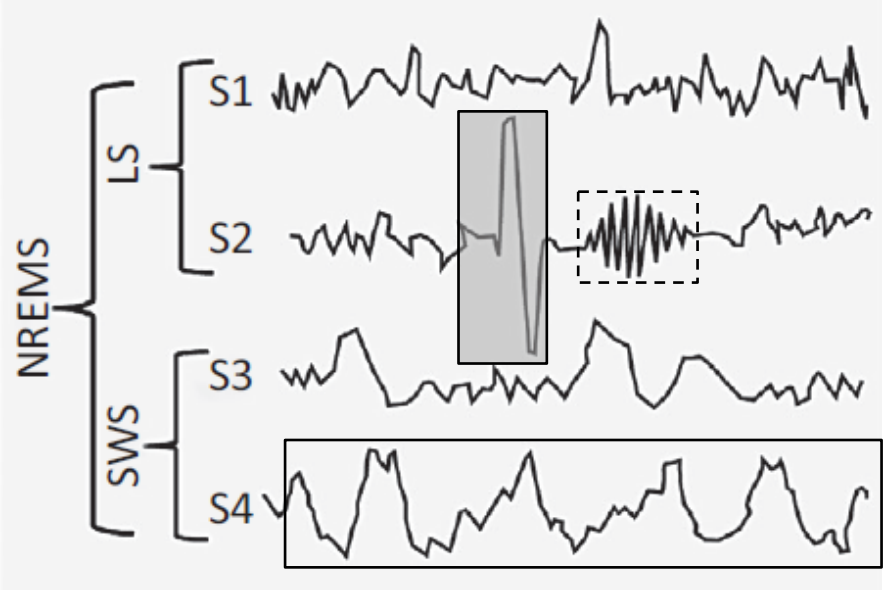






Sleep Oscillations

Human, (Genzel et al., 2014)

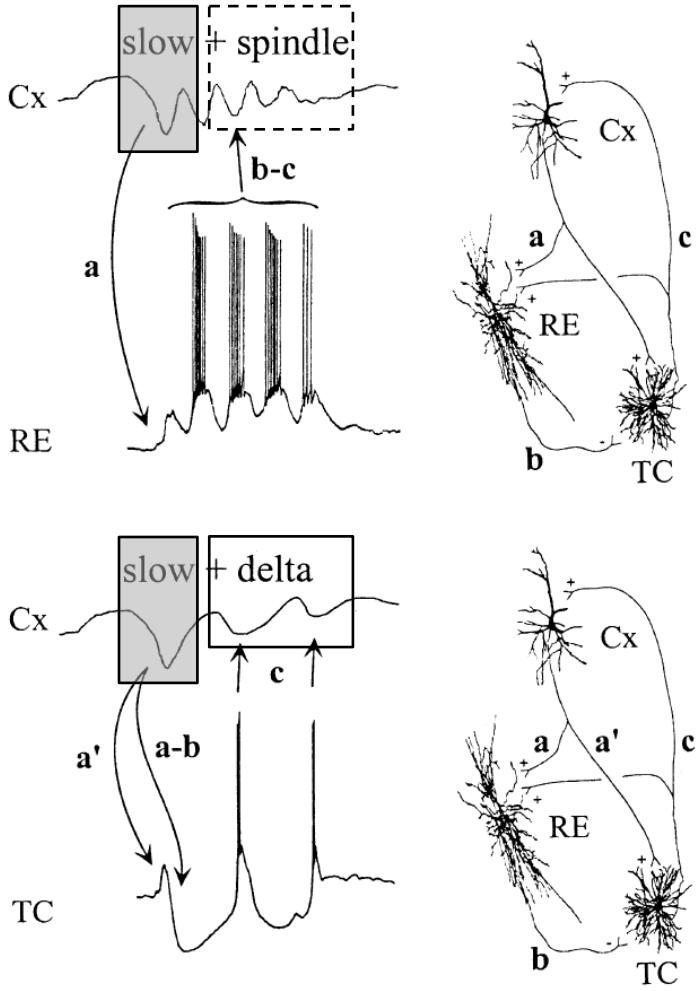


Slow-oscillations

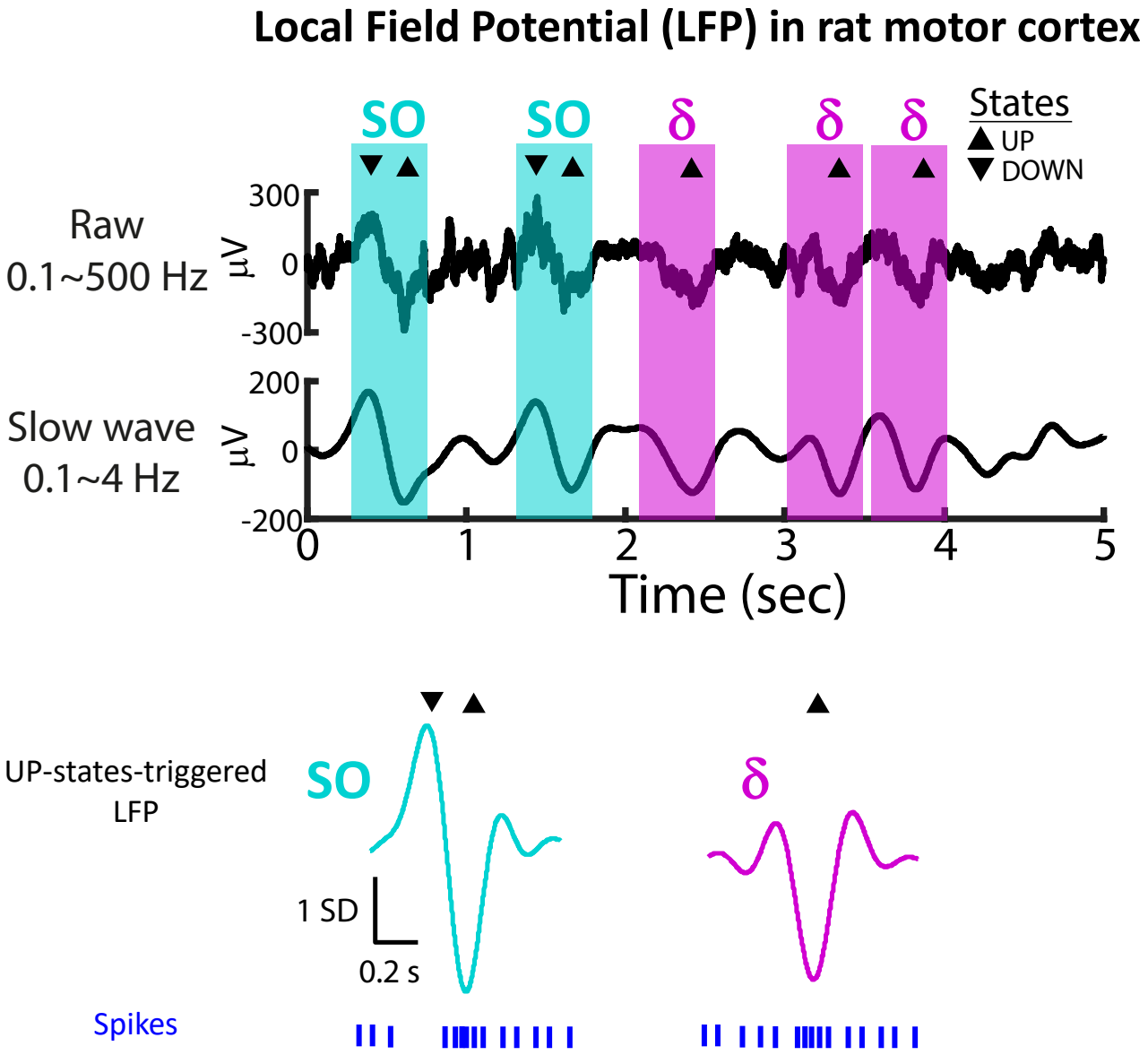
Delta-waves

Spindles

Cats, (Steriade and Timofeev, 2003)



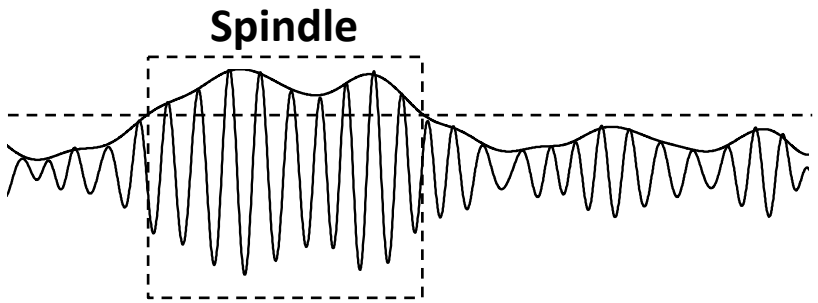
Distinction of Slow-Oscillations and Delta-Waves in Rats



(Kim et al., *Cell*, 2019)

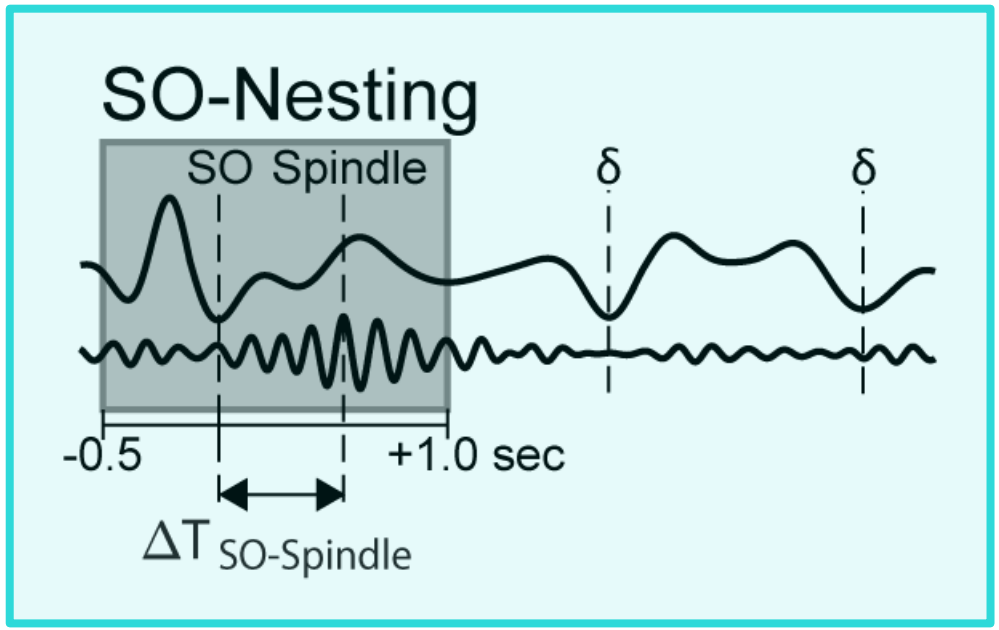
Temporal Coupling of Spindles to SO relative to δ

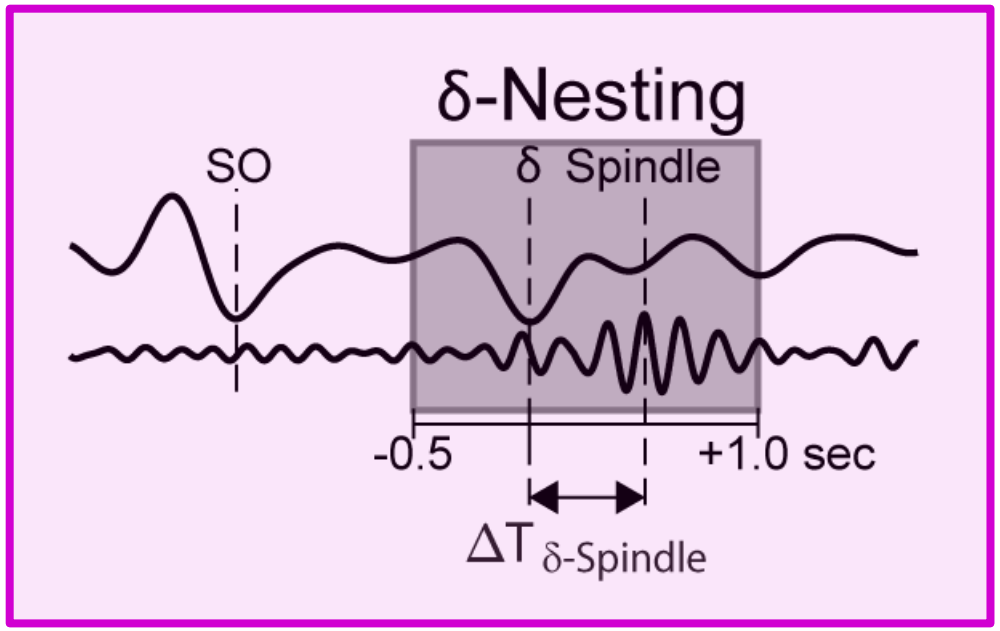
Spindles
10~15 HZ



Memory consolidation is closely related to spindles.

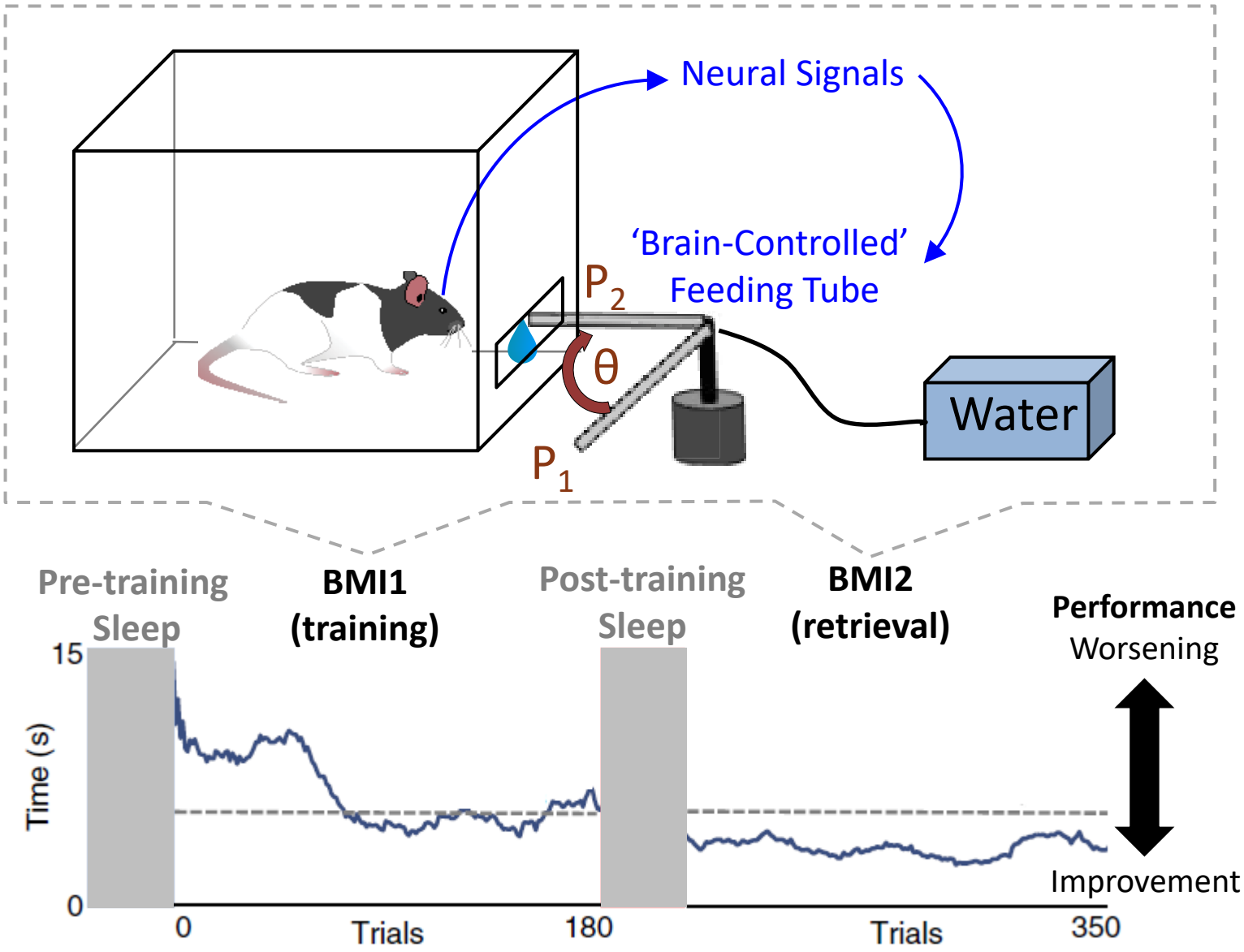
(Bergmann and Born, 2018; Cairney et al., 2018; Diekelmann and Born, 2010; Genzel et al., 2014; Helfrich et al., 2018; Latchoumane et al., 2017; Maingret et al., 2016; Miyamoto et al., 2017; Navarro-Lobato and Genzel, 2019; Ngo et al., 2013; Peyrache et al., 2009; Sejnowski and Destexhe, 2000; Staresina et al., 2015)

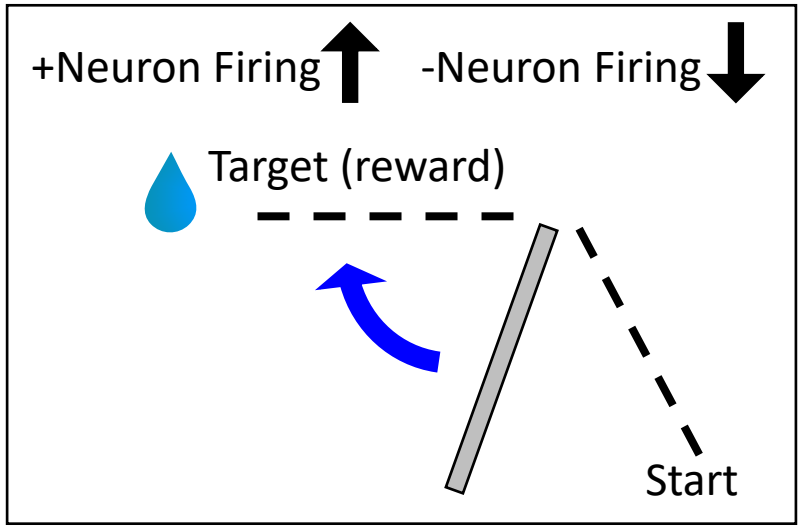


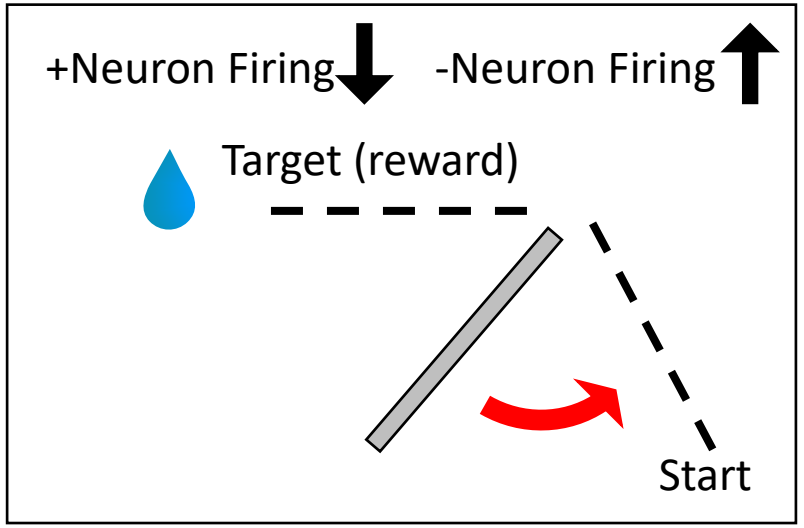


(Kim et al., *Cell*, 2019)

Consolidation of BMI Tasks



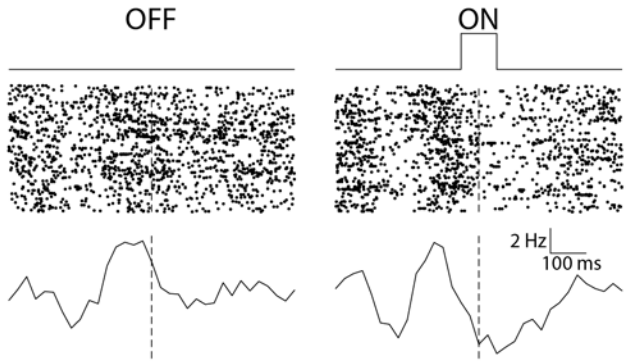




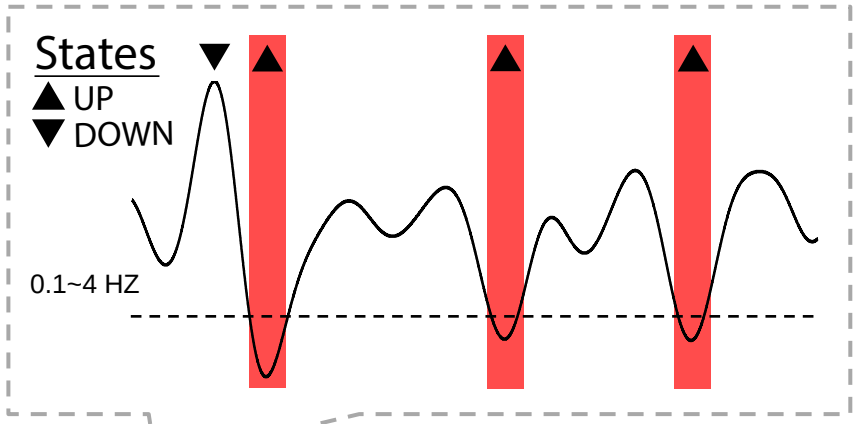
(Gulati et al., *Nature Neuroscience,* 2014, 2017; Kim et al., *Cell*, 2019)

Closed-Loop Optogenetic Inhibitions during Sleep

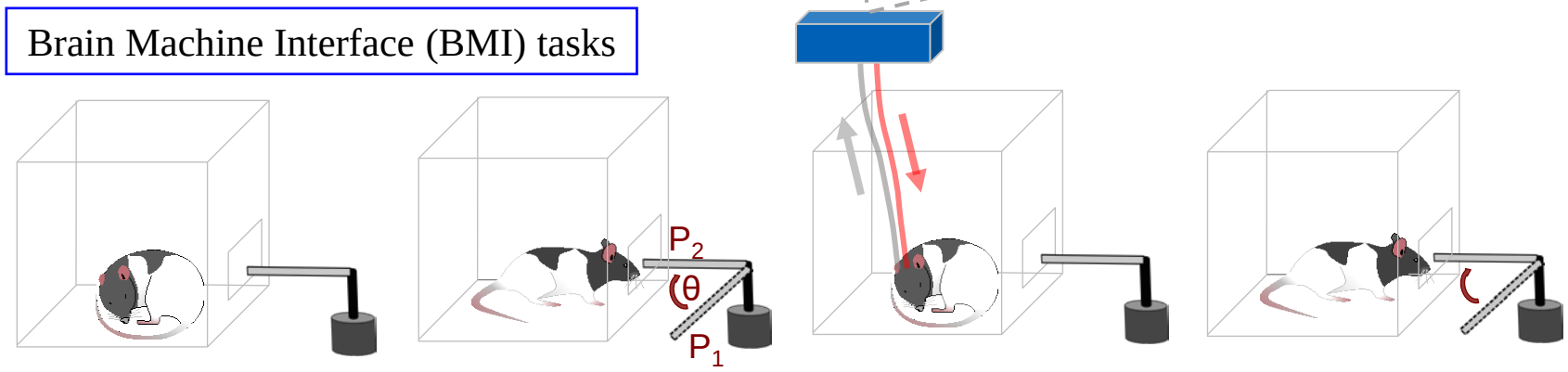
Up-states triggered spike activity



Closed-loop optogenetic inhibitions



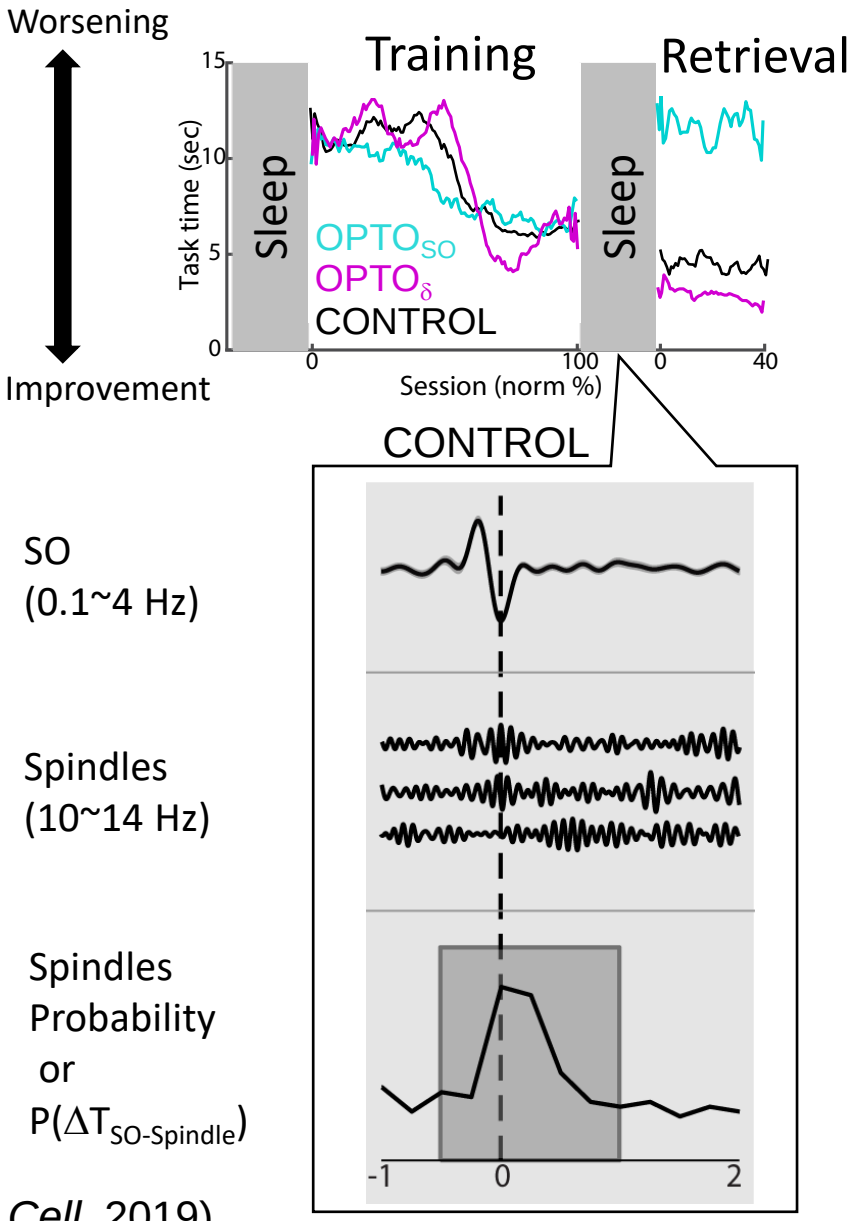
Brain Machine Interface (BMI) tasks

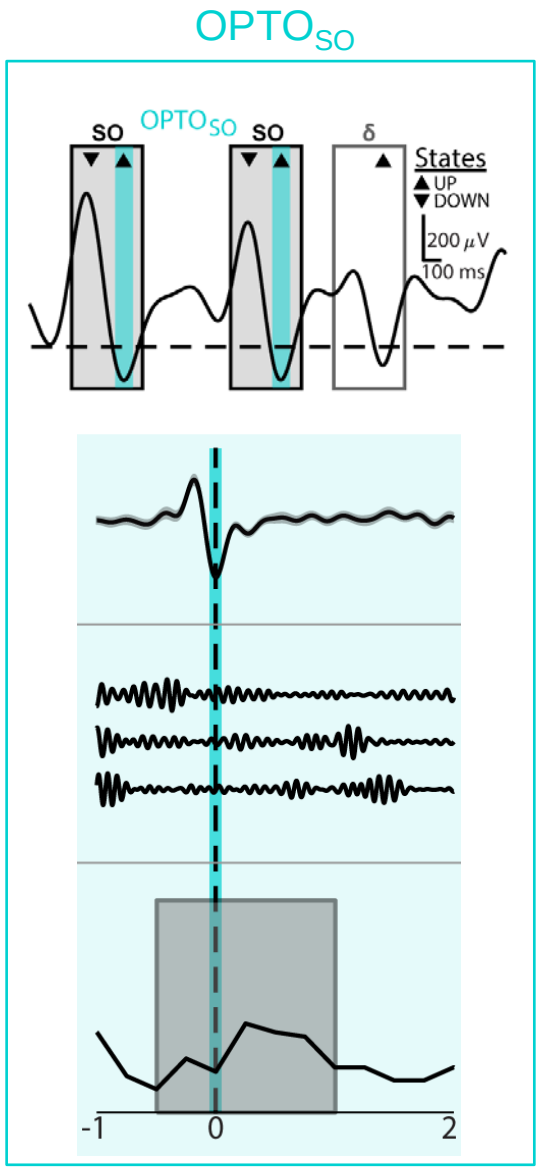


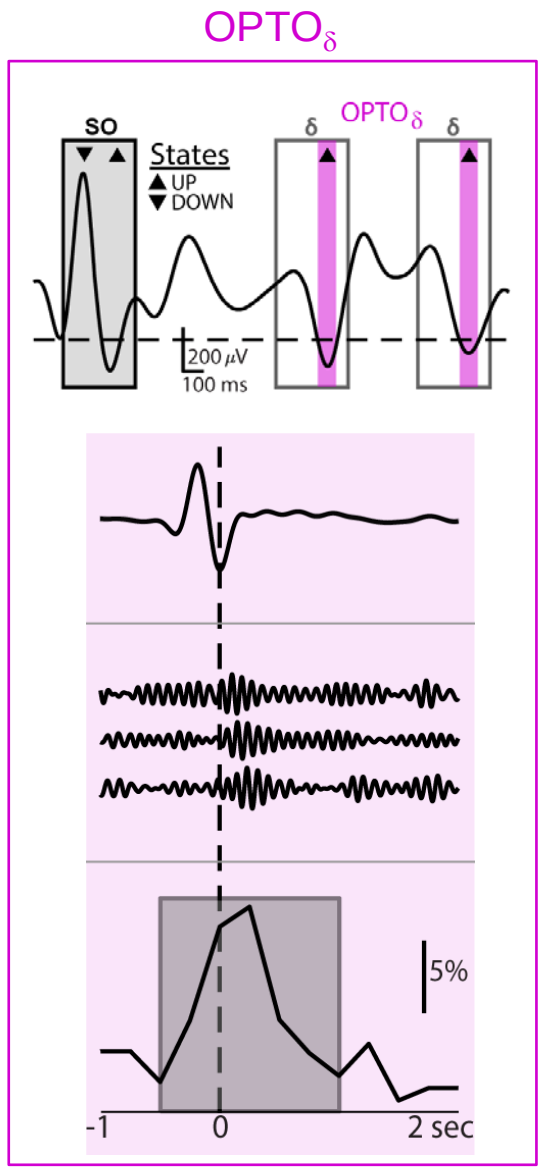
Pre-training Sleep **BMI1 (training)** **Post-training Sleep** **BMI2 (retrieval)**

(Kim et al., *Cell*, 2019)

Inhibitions during Up-States of δ Enhance Consolidation

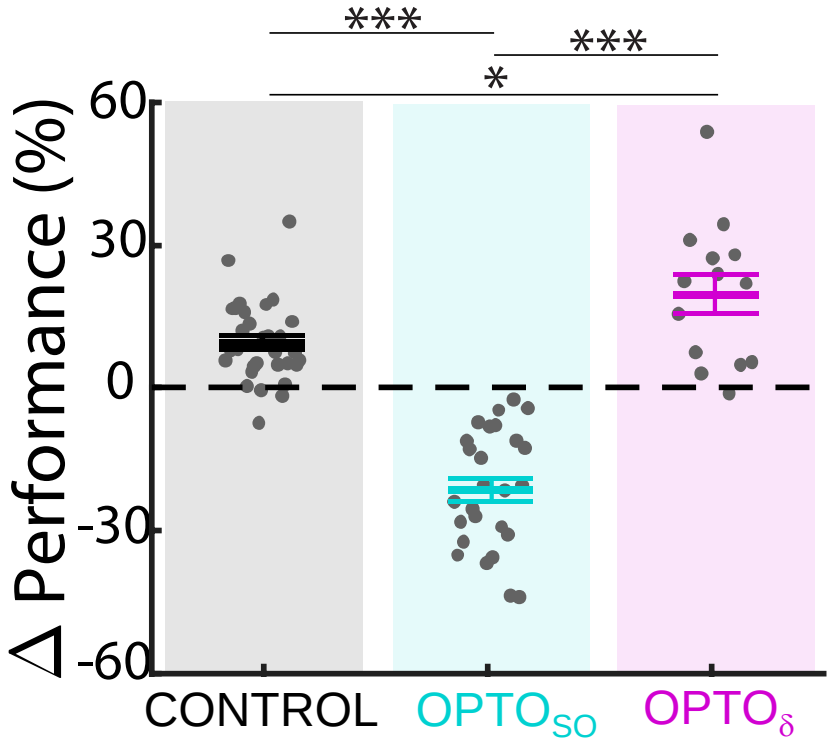


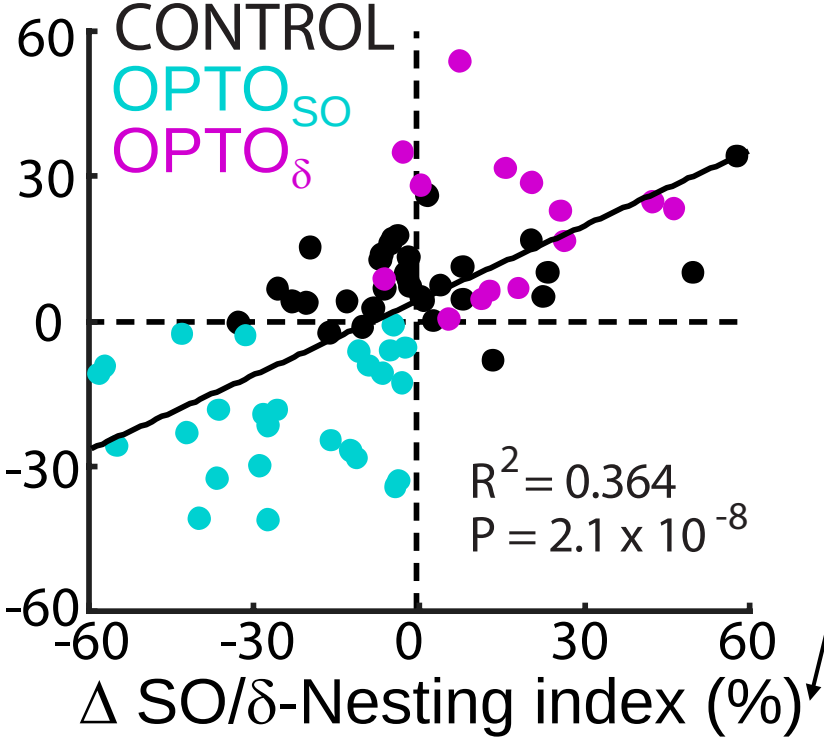


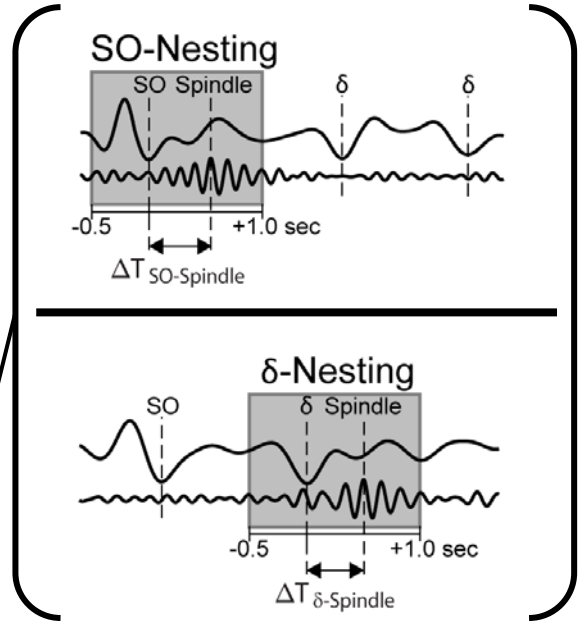


(Kim et al., *Cell*, 2019)

Nesting of SO with Spindles Correlates with Performance





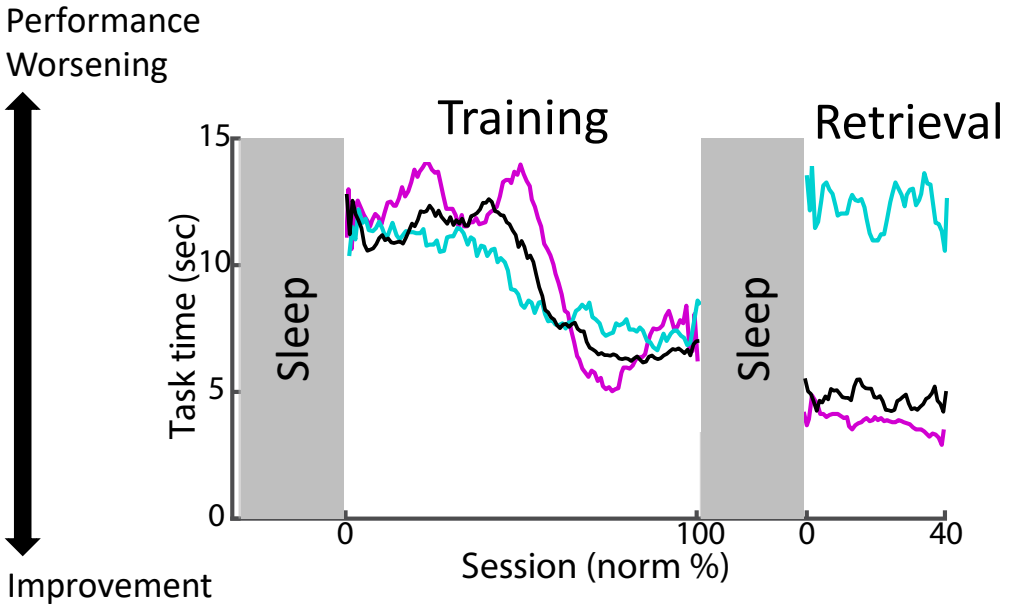


Nesting of spindles to SO relative δ has an essential role in motor memory consolidation.

Inhibitions during SO → Weaken Consolidation
Inhibitions during δ waves → Weaken Forgetting / Boost Consolidation

(Kim et al., *Cell*, 2019)

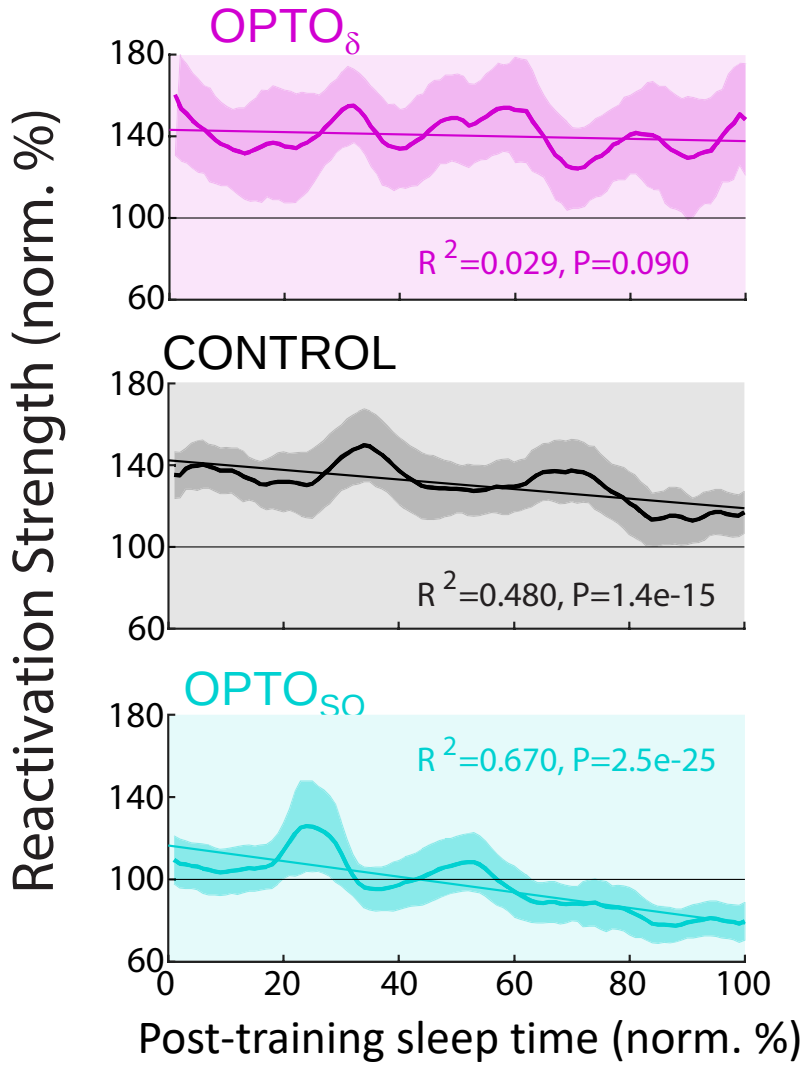
Bidirectional Shift of Memory Reactivation



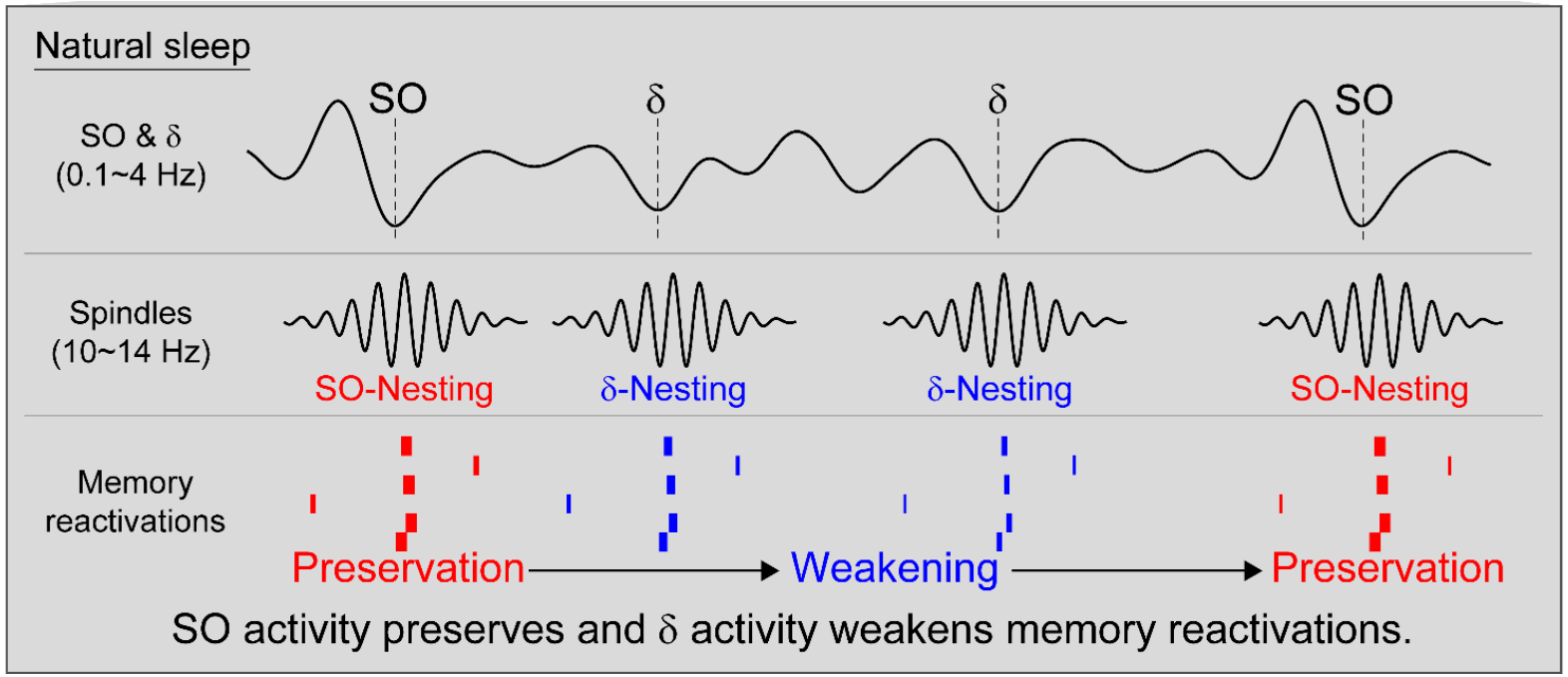
SO → Consolidation
δ Waves → Forgetting

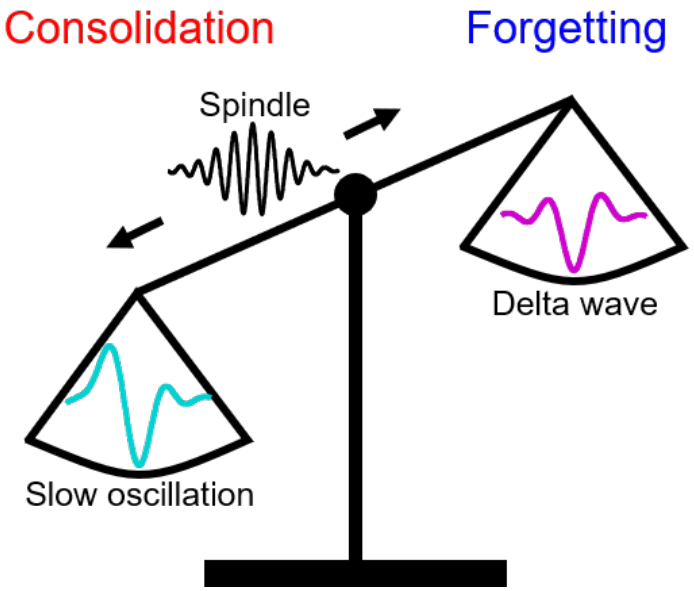
(Kim et al., *Cell*, 2019)

Reactivation analysis (Gulati et al., *Nat. Neurosci.*, 2014, 2017; Peyrache et al., *Nat. Neurosci.*, 2009)



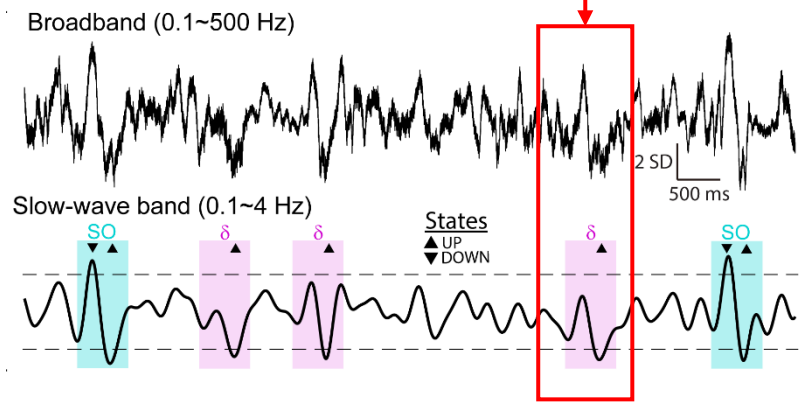
Summary of Part 1

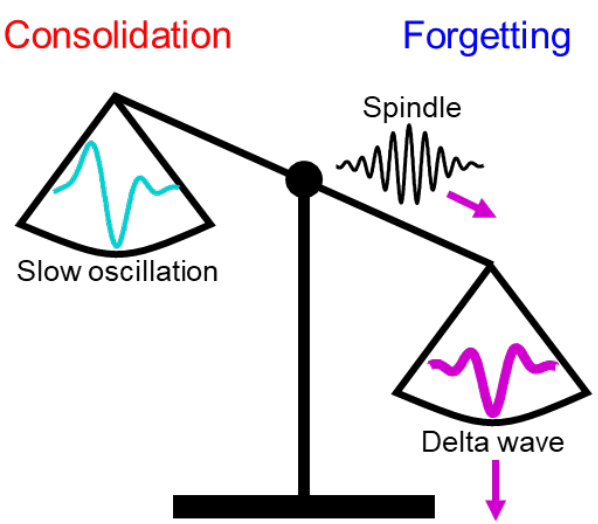




Part 2: Sleep and Motor Recovery after Stroke

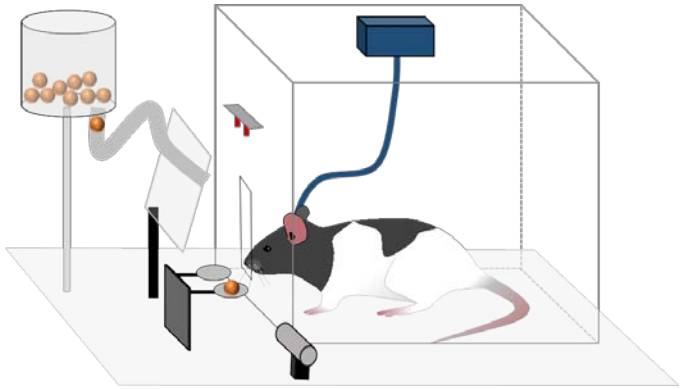
Pathological increase of delta waves





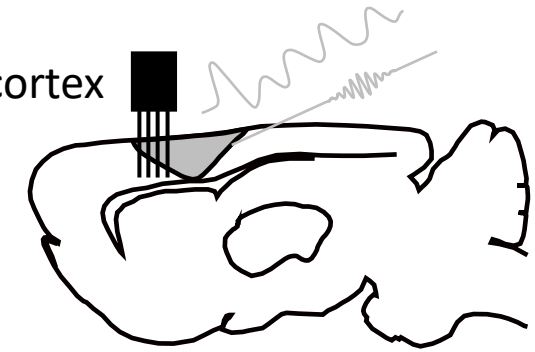
(Kim et al., BioRxiv, 2021)

Reaching Task



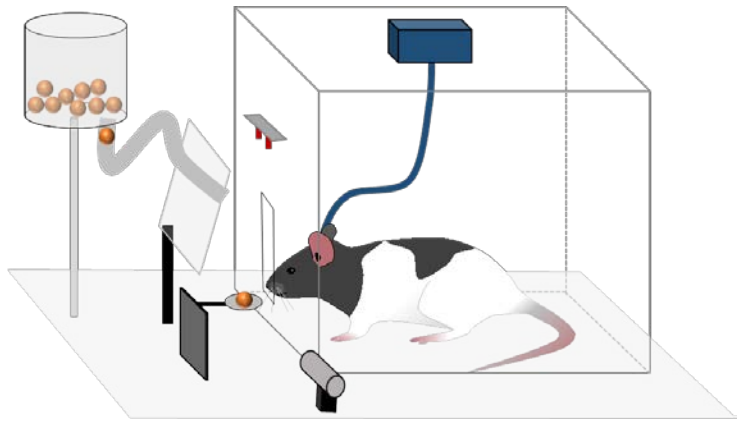
Post-stroke recovery

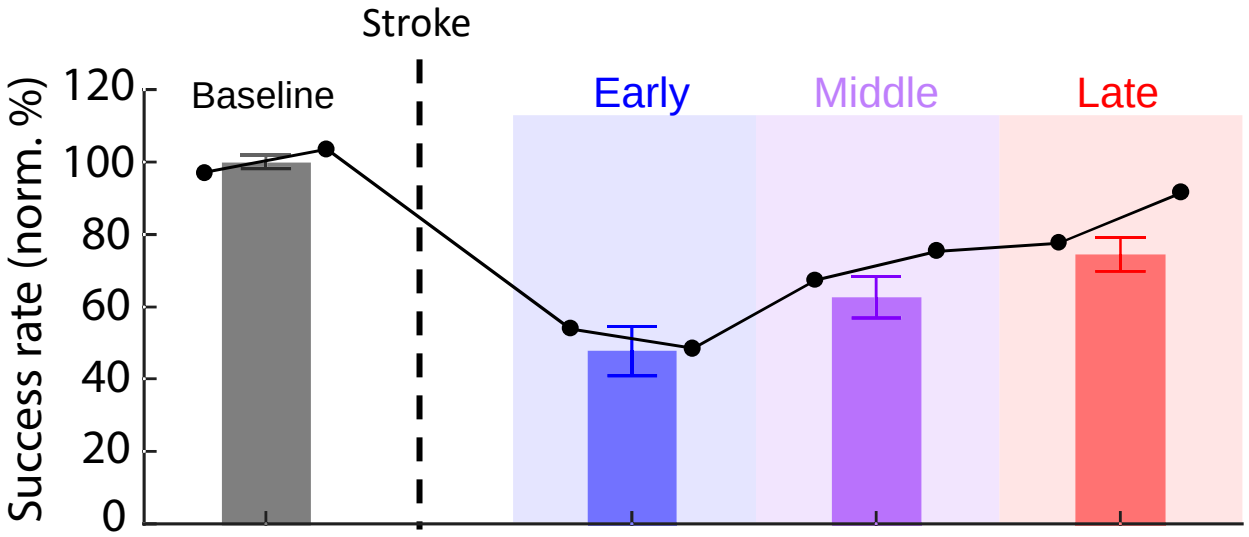
Perilesional cortex

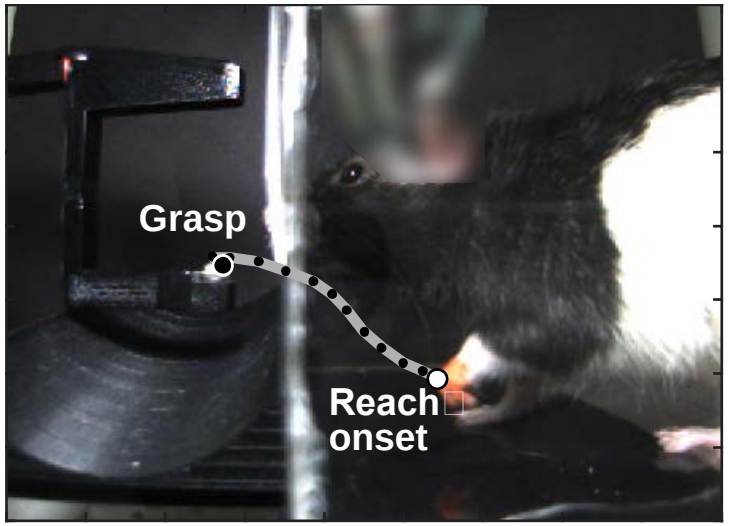


Reaching Recovery after Stroke

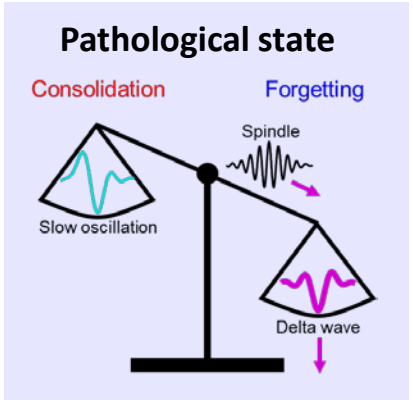
Reaching Task / Reach-to-Grasp

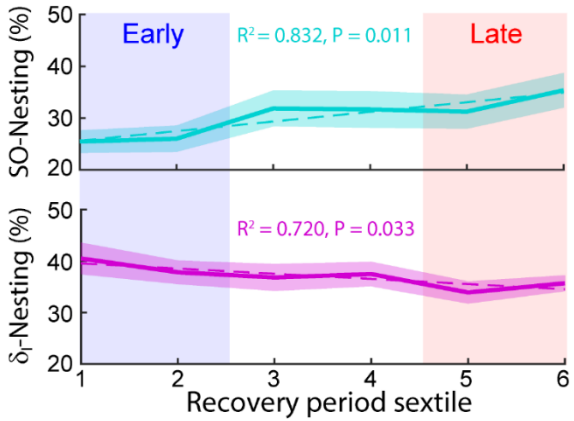


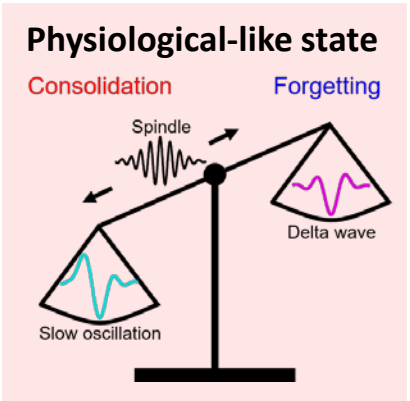




Redistribution of spindles toward SO with recovery after stroke

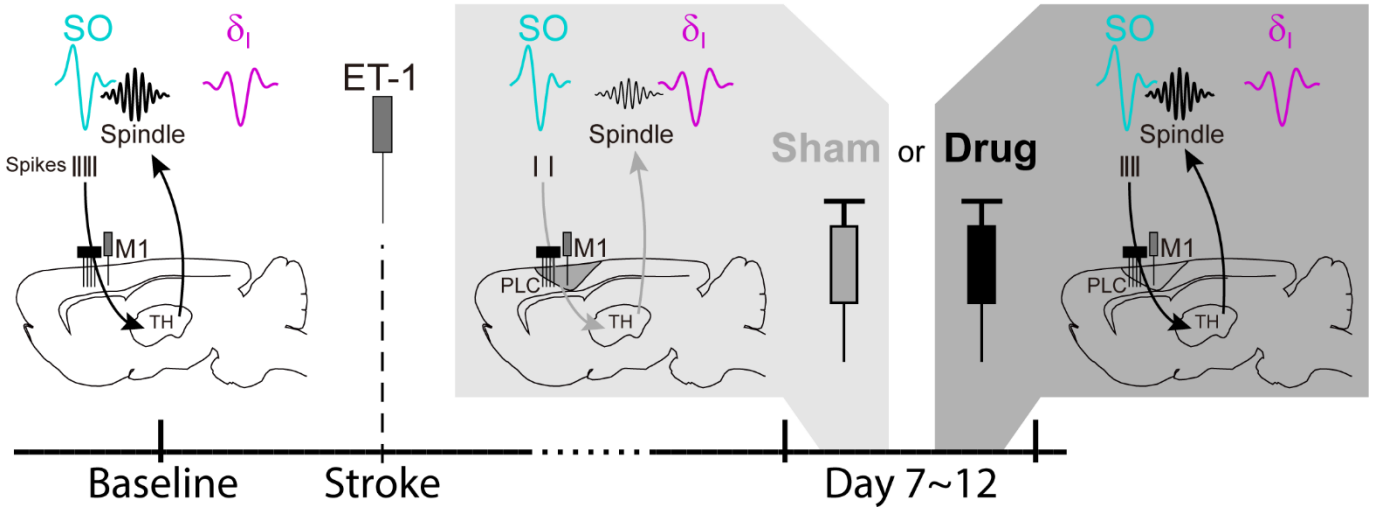






(Kim et al., BioRxiv, 2021)

Counterbalancing Tonic Inhibitions Can Alter Sleep Architecture



Drug (L655,708): $GABA_A$ α5-subtype inverse agonist weakens GABAergic tonic inhibition
(Clarkson et al., *Nature*, 2010)

Other potential therapeutic approach (Closed-Loop)

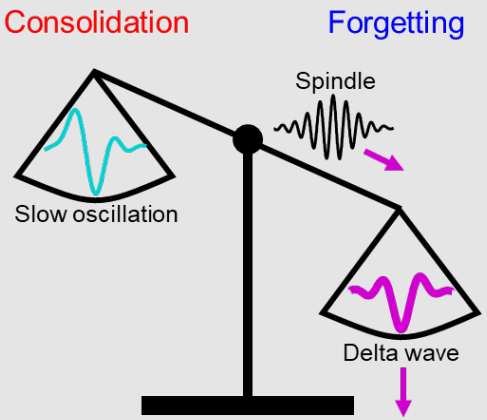
Auditory stim (Ngo et al., *Neuron*, 2013)

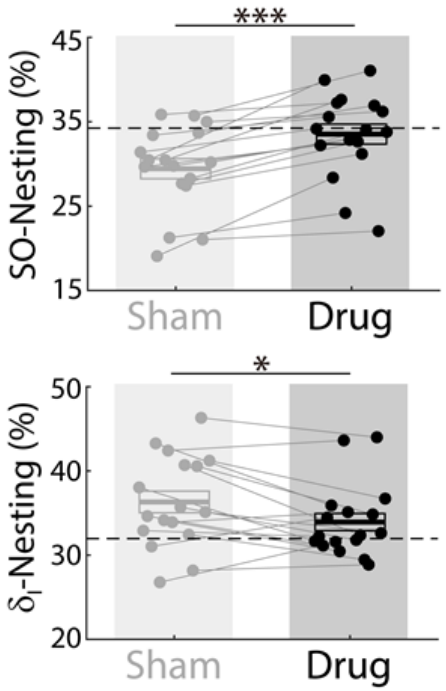
Electrical stim (Vyazovskiy et al., *J. Neurophysiol.*, 2009)

Optogenetic stim (Kim et al., *Cell*, 2019; Latchoumane et al., Neuron, 2017)

Sham

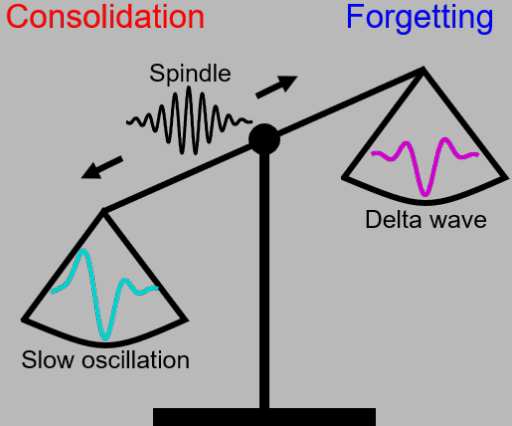
Pathological state





Drug

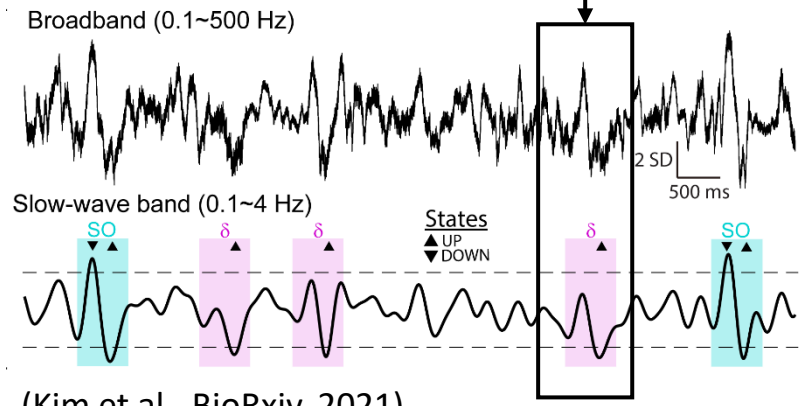
Physiological-like state



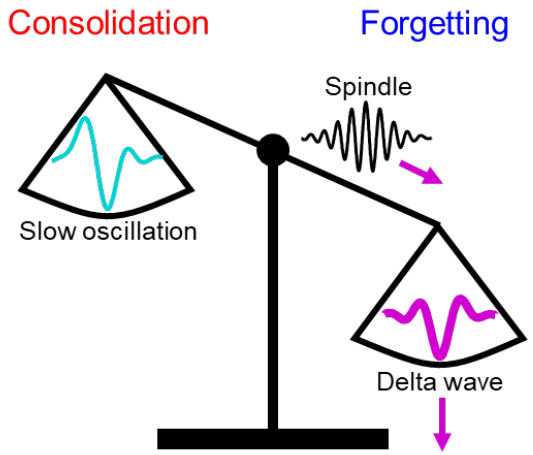
(Kim et al., BioRxiv, 2021)

Sleep and Motor Memory Consolidation

Pathological increase of delta waves

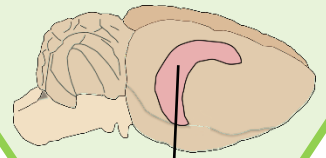


(Kim et al., BioRxiv, 2021)



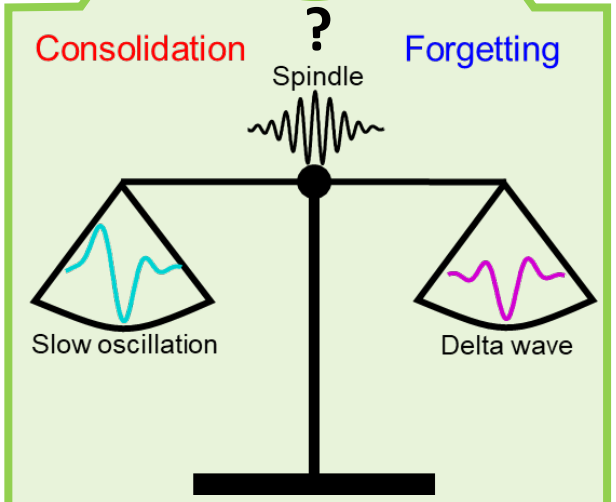
Motor memory

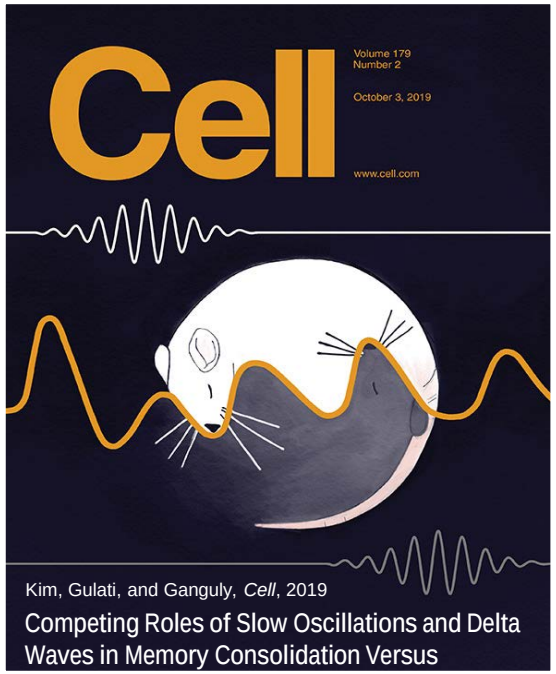
Hippocampus dependent?

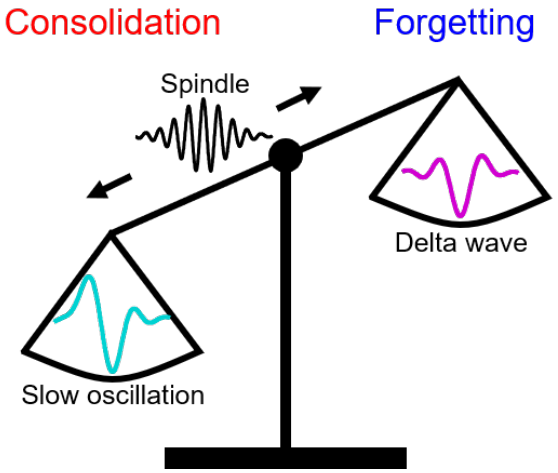


Ripple

?



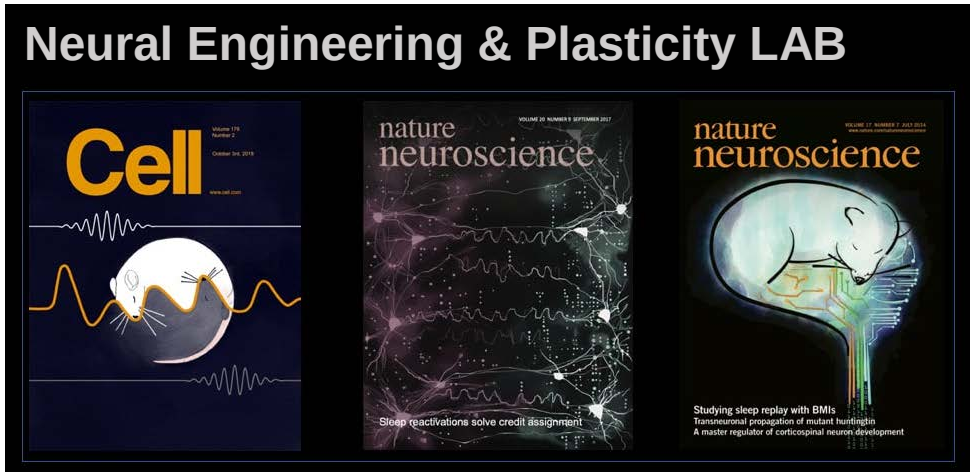




Acknowledgements

Neural Engineering & Plasticity LAB, UCSF
Joined in November 2017

Karunesh Ganguly, MD PhD
Department of Neurology, UCSF
Neurology and Rehabilitation Service,
SF VA Medical Center



Grants

VA Merit: 1I01RX001640 to K.G.
NIH: 5K02NS093014 to K.G.
NRF, Korea: 2018R1A6A3A03013031 to J.K.
2019 교육부 우수성과 50선 선정 (교육부장관상, 2020)