Sleep to remember: mechanisms linking sleep oscillations to memory consolidation

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A role for mathematics in understanding the brain: Addressing complexity and bridging across fields

... the underlying causes of most of neurological and psychiatric conditions remain largely unknown, due to the vast complexity of the human brain. If we are ever to develop effective ways of helping people suffering from these devastating conditions, researchers will first need a more complete arsenal of tools and information for understanding how the brain functions both in health and disease. 

(BRAIN initiative)
Sleep and Memory

Acquisition → Consolidation → Retrieval

= resilience to interference

influenced by sleep

Procedural learning of perceptual and motor skills

Declarative memory

Complex learning

Formation and stabilization of new synaptic components
Memory consolidation during sleep: the active consolidation hypothesis

Sleep allows for re-organization of memory traces across the brain through cortical-subcortical dialogue

Saletin et al. 2010
The main actors of memory consolidation during sleep

**Sleep Rhythms**

- Slow Oscillations
- Spindles
- Ripples

**Reactivation**

- Diekelmann and Born 2010
- Ji and Wilson 2007

**Synaptic Plasticity**

- Bi et al. 1998
Coordination of sleep rhythms across time scales

Neocortical Slow Oscillations
- 0.5-1.5 Hz
- 1-10 s

Thalamo-Cortical Spindles
- 9-16 Hz
- 0.5-3 s

Hippocampal Ripples
- 120-150 Hz
- 50-100 ms

Coordination hierarchy of rhythms found both in humans and animals

Rach and Born 2013
Sleep rhythms influence memory performance

Sleep is an active brain state that can be recruited to optimize neurorehabilitation
What about sleep in TBI? It depends...

Mantua et al. 2018 [https://doi.org/10.1016/j.smrv.2018.01.004]

Pandi-Perumal et al., Springer, 2014

<table>
<thead>
<tr>
<th>Group</th>
<th>NREM1</th>
<th>NREM2</th>
<th>SWS</th>
<th>REM</th>
<th>Sleep Latency</th>
<th>Wake After Sleep Onset</th>
<th>Total Sleep Time</th>
<th>Sleep Efficiency</th>
<th>REM Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Sample</td>
<td>=</td>
<td>=</td>
<td>↑</td>
<td>=</td>
<td>=</td>
<td>↑*</td>
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<tr>
<td>Mild TBI</td>
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<tr>
<td>Mod-Severe TBI</td>
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<td>↑*</td>
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<td>↓*</td>
</tr>
</tbody>
</table>

Summary of meta-analysis results, including the full sample and sub-groups by TBI severity. Arrows indicate the TBI group had significantly more or less (or increased/decreased) than controls for that particular sleep outcome. Summary results with an asterisk* report on results after sensitivity analyses.
What about sleep-and-memory in TBI?

Word-pair association task

Recognizing images with different emotional values

<table>
<thead>
<tr>
<th>Sleep parameter</th>
<th>Non-TBI (n = 14)</th>
<th>TBI (n = 16)</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>TST (min)</td>
<td>339.8 ± 61.5</td>
<td>365.8 ± 51.2</td>
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<tr>
<td>Sleep efficiency (%)</td>
<td>90.2 ± 2.2</td>
<td>88.2 ± 6.2</td>
<td>.25</td>
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<tr>
<td>WASO (min)</td>
<td>26.9 ± 13.1</td>
<td>27.7 ± 15.2</td>
<td>.87</td>
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<tr>
<td>Sleep latency (min)</td>
<td>10.4 ± 6.2</td>
<td>18.9 ± 17.0</td>
<td>.08</td>
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<tr>
<td>REM latency (min)</td>
<td>107.6 ± 33.8</td>
<td>141.6 ± 43.2</td>
<td>.02*</td>
</tr>
<tr>
<td>N1 (%)</td>
<td>2.4 ± 1.7</td>
<td>2.3 ± 1.9</td>
<td>.89</td>
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<tr>
<td>N2 (%)</td>
<td>54.2 ± 6.9</td>
<td>56.8 ± 7.6</td>
<td>.33</td>
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<tr>
<td>SWS (%)</td>
<td>28.1 ± 7.4</td>
<td>30.1 ± 6.2</td>
<td>.43</td>
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<tr>
<td>REM (%)</td>
<td>15.4 ± 3.7</td>
<td>10.8 ± 5.03</td>
<td>.01*</td>
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</tbody>
</table>

Rebecca Spencer’s group: Mantua et al. 2015, 2017
Location of sleep SWA after motor training can show where the injured brain is re-mapping motor learning
We can identify sleep oscillations affected by TBI and non-invasively modulate them to promote recovery.