The role of sleep in consolidating semantic knowledge

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Introduction

Sleep is thought to be crucial for initial placement of new arbitrary, episodic information into cortical knowledge structures1,2. During slow wave sleep (SWS), the hippocampus replays memories of recent experiences, promoting consolidation of the memories in cortex3.

- How does sleep impact the learning of new structured information?
- What computational mechanisms might underly changes in this structured knowledge during sleep vs. wake periods? In particular, how might the hippocampus and cortex interact to support the consolidation of semantic information?

Stimuli and design

Each “satellite” had properties shared with class (class name, shared visual features) and idiosyncratic properties (code name, unique visual feature):

<table>
<thead>
<tr>
<th>Class</th>
<th>Code Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>malar</td>
<td>benin</td>
</tr>
<tr>
<td>colar</td>
<td>nodon</td>
</tr>
<tr>
<td>praxa</td>
<td></td>
</tr>
</tbody>
</table>

Simulation results

- Offline learning with strong hippocampal influence results in improved performance for all object features as well as improved generalization.
- Offline learning with weak hippocampal influence helps shared features and generalization, but hurts memory for idiosyncratic properties.
- All changes significant (p<0.01)

Summary and discussion

- Sleep uniquely enhances memory for idiosyncratic properties of category exemplars. Sleep and wake periods both improve shared properties and generalization ability.
- These effects can be simulated using a neural network model that learns autonomously during offline periods based on just-formed attractors.
- Different kinds of offline learning may be characterized by varying degrees of hippocampal influence (more during SWS and less during wake).
- Ongoing and future directions: Running a nap version of paradigm in collaboration with Sara Mednick to directly assess contributions of sleep stages with PSG, and running fMRI version to test model’s predictions about representational changes over different kinds of offline learning periods.

References and funding


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A computational account

- The brain receives minimal input and no feedback from the environment during sleep, making useful learning a computational challenge.
- Model has layers representing satellite features, a cortical hidden layer, and a hippocampal layer, where each unit connects to all features of one satellite.
- Training: all features except one clamped during minus phase and remaining feature added during plus phase.

- Sleep begins by setting unit activations randomly; network falls into nearby attractor.
- Synaptic depression causes transition to next attractor. Also prevents repeatedly visiting the same attractor1.
- Inhibitory oscillations distort pattern to reveal weak parts of memories and competing memories.
- Plus phase corresponds to period of high stability in activation pattern; slight drop in stability triggers minus phase, which continues until further drop below threshold.
- Same learning as above: modify distorted versions of pattern to look more like clean pattern.
- Quiet wake: Weak influence of hippocampus. Less stringent stability criteria.

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Sleep condition | Training (Spm) | Test 12 hours (including sleep) | Test
Wake condition | Training (Spm) | Test 12 hours (wake) | Test

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