Hippocampo-cortical oscillatory interactions during unperturbed SWS.

a. Temporal cross-correlation between SPW-Rs and delta waves at different timescales. The two peaks around SPW-R times indicate that SPW-Rs are both preceded and followed by delta waves. b. Temporal cross-correlation between delta waves and spindles. Note the increased spindle probability immediately following delta waves.
Supplementary Figure 2

Incidence of hippocampo-cortical rhythms is unchanged between coupled and delayed stimulation epochs.

a. A large fraction of the applied stimulations efficiently triggered delta waves (left) or delta-spindle sequences (right) in both delayed (purple bars) and coupled (green bars) conditions. Stimulation efficacy was identical across conditions (delta waves efficacy, coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 0.18, P = 0.859; delta-spindle efficacy, coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 0.06, P = 0.953). b. SPW-R, delta wave and spindle occurrence rates during Pre-sleep (black bars) and during stimulation epochs (purple and green bars). As expected, delta waves and spindles were more frequent during stimulation than Pre-sleep epochs, but their occurrence rates were identical between stimulation conditions. SPW-R incidence, Friedman test, χ² = 2.57, n = 7, d.f. = 2, P = 0.277. Spindle incidence, Friedman test, χ² = 10.57, n = 7, d.f. = 2, P = 0.005; Wilcoxon matched pairs test, n = 7, Pre-sleep vs. coupled: Z = 2.36, *P = 0.018; Pre-sleep vs. delayed: Z = 2.36, *P = 0.018; coupled vs. delayed: Z = 0.17, P = 0.866.
Delta incidence, Friedman test, $\chi^2 = 10.57$, $n = 7$, d.f. = 2, $P = 0.005$; Wilcoxon matched pairs test, $n = 7$, Pre-sleep vs. coupled: $Z = 2.36$, $^*P = 0.018$; Pre-sleep vs. delayed: $Z = 2.36$, $^*P = 0.018$; coupled vs. delayed: $Z = 0.34$, $P = 0.735$. c. Delta power was similar between naturally occurring and induced events (black, Pre-sleep; green, coupled stimulation; purple; delayed stimulation) Friedman test, $\chi^2 = 0.89$, $n = 9$, d.f. = 2, $P = 0.641$. d. Same as in c for spindle peaks. Friedman test, $\chi^2 = 0.67$, $n = 9$, d.f. = 2, $P = 0.716$. e. Proportion of endogenous (black) and induced (gray) delta waves associated with a down state revealing a strong correlation between these events (Wilcoxon matched pairs test, $n = 11$ sessions with $n_{PFC\text{ neurons}}>7$, $Z = 0.27$, $P = 0.790$). f. Mean HPC population activity during delta-down events identified in e, relative to the firing rate outside of these events during SWS (Wilcoxon matched pairs test, $n = 11$ sessions with $n_{PFC\text{ neurons}}$ & $n_{HPC\text{ neurons}}>7$, $Z = 0.27$, $P = 0.790$). Error bars represent s.e.m.
Supplementary Figure 3

Stimulation did not trigger direct, hyper-synchronous activation of mPFC neurons.

A. Average local field potential recorded in the mPFC (top trace, low-pass filtered) around stimulations (n = 1,000) in one example session. B. Top, Multiunit activity of mPFC pyramidal cells. Bottom, average population firing rate across stimulations. C. Same as in B.
for mPFC interneurons. While stimulation-induced delta waves are accompanied by neuronal silence characteristic of endogenous down states, neither pyramidal cells nor interneurons dramatically increase their firing rates at the time of stimulation.
Stimulation conditions and global sleep architecture.

**a.** The duration of uninterrupted SWS epochs was similar during delayed (purple) and coupled (green) stimulation sessions (coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 0.56, P = 0.575).

**b.** Same as in **a**, for REM epochs (coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 0.98, P = 0.327).

**c.** Average REM/SWS ratios were similar across stimulation conditions (coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 0.70, P = 0.484). Error bars represent s.e.m.

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Supplementary Figure 5

Stimulation-induced delta waves did not alter subsequent SPW-R occurrence rates.

a. Proportion of delta waves preceded by SPW-Rs during Pre-sleep (black) and coupled (green bars) and delayed (purple bars) stimulation periods (only stimulation-evoked delta waves were counted in post-exploration sleep sessions). Friedman test, $\chi^2 = 11.14$, $n = 7$, d.f. = 2, $P = 0.004$; Wilcoxon matched pairs test, $n = 7$, Pre-sleep vs. coupled: $Z = 2.36$, *$P = 0.018$; Pre-sleep vs. delayed: $Z = 1.18$, $P = 0.237$; coupled vs. delayed: $Z = 2.36$, *$P = 0.018$. b. The proportion of delta waves followed by SPW-Rs was similar across conditions (only stimulation-evoked delta waves were counted in post-exploration sleep sessions). Friedman test, $\chi^2 = 0.29$, $n = 7$, d.f. = 2, $P = 0.867$. Error bars represent s.e.m.
Supplementary Figure 6

Coupling hippocampal and cortical oscillations enhances recall above chance level and induces preferential exploration of the displaced object.

Memory performance remained significantly above chance level in the coupled condition for the whole duration (5 minutes) of the recall phase, whereas in the delayed condition, performance did not differ from chance (2 min coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 2.66, **P = 0.008; 2 min coupled vs chance, Wilcoxon signed-rank test, n = 9, Z = 2.66, **P = 0.008; 2 min delayed vs chance, Wilcoxon signed-rank test, n = 9, Z = 1.48, P = 0.139. 3 min coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 2.66, **P = 0.008; 3 min coupled vs chance, Wilcoxon signed-rank test, n = 9, Z = 2.66, **P = 0.008; 3 min delayed vs chance, Wilcoxon signed-rank test, n = 9, Z = 0.65, P = 0.515. 5 min coupled vs delayed, Wilcoxon matched pairs test, n = 9, Z = 2.31, *P = 0.021; 5 min coupled vs chance, Wilcoxon signed-rank test, n = 9, Z = 2.66, **P = 0.008; 5 min delayed vs chance, Wilcoxon signed-rank test, n = 9, Z = 0.889, P = 0.374). Error bars represent s.e.m.
Supplementary Figure 7

Random, non SPW-R–triggered stimulation does not lead to memory consolidation on the spatial object recognition task.

**a.** Random stimulation protocol (top) and temporal cross-correlation between SPW-Rs and stimulation onset (bottom). **b.** Stimulation efficacy for the random stimulation protocol. **c.** Incidence of hippocampo-cortical events (left: SPW-R-delta, right: SPW-R-delta-spindle) during Pre-sleep (black) and random stimulation periods (blue). SPW-R-delta incidence, Wilcoxon matched pairs test, n = 6, Z = 1.57, P = 0.116; SPW-R-delta-spindle incidence, Wilcoxon matched pairs test, n = 6, Z = 1.36, P = 0.173. **d.** Performance did not differ from chance during recall following the random stimulation protocol (2 min random vs chance, Wilcoxon signed-rank test, n = 6, Z = 0.73, P = 0.463; 3 min random vs chance, Wilcoxon signed-rank test, n = 6, Z = 0.52, P = 0.600; 5 min random vs chance, Wilcoxon signed-rank test, n = 6, Z = 1.57, P = 0.116) Error bars represent s.e.m.
Supplementary Figure 8

Medial prefrontal cortical cells were not responsive to the objects during the encoding phase.

Cumulative distributions of mPFC responsivity indices to each object during the encoding phase of the task preceding each stimulation condition. mPFC cells were not responsive to any object in any condition (displaced object: coupled vs delayed, Wilcoxon rank-sum test, $n = 77$, $n = 93$, $Z = 1.14$, $P = 0.255$; coupled vs zero, Wilcoxon matched pairs test, $n = 77$, $Z = 1.32$, $P = 0.188$; delayed vs zero, Wilcoxon matched pairs test, $n = 93$, $Z = 0.14$, $P = 0.890$; stable object: coupled vs delayed, Wilcoxon rank-sum test, $n = 77$, $n = 93$, $Z = 0.79$, $P = 0.432$; coupled vs zero, Wilcoxon matched pairs test, $n = 77$, $Z = 1.65$, $P = 0.099$; delayed vs zero, Wilcoxon matched pairs test, $n = 93$, $Z = 0.65$, $P = 0.516$).
<table>
<thead>
<tr>
<th>Condition</th>
<th>n</th>
<th>Displaced object (s)</th>
<th>Stable object (s)</th>
<th>Discrimination index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naive (3 min encoding)</td>
<td>8</td>
<td>9.57 ± 0.99</td>
<td>11.73 ± 1.35</td>
<td>0.45 ± 0.04</td>
</tr>
<tr>
<td>Trained (20 min encoding)</td>
<td>6</td>
<td>13.74 ± 2.04</td>
<td>5.22 ± 0.81</td>
<td>0.72 ± 0.03</td>
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<tr>
<td>Coupled stimulation (3 min encoding)</td>
<td>9</td>
<td>14.77 ± 1.55</td>
<td>6.67 ± 1.19</td>
<td>0.69 ± 0.03</td>
</tr>
<tr>
<td>Delayed stimulation (3 min encoding)</td>
<td>9</td>
<td>9.94 ± 1.48</td>
<td>11.75 ± 1.98</td>
<td>0.46 ± 0.04</td>
</tr>
<tr>
<td>Random stimulation (3 min encoding)</td>
<td>6</td>
<td>10.17 ± 2.00</td>
<td>10.00 ± 1.25</td>
<td>0.48 ± 0.03</td>
</tr>
</tbody>
</table>

**Supplementary Table 1 | Object exploration times.** Time spent exploring the objects during the recall phase for each condition, and corresponding discrimination index. Errors are s.e.m.