Supplemental Information

S1. Subsequent memory inter-item pattern similarity in left hippocampus

For left anterior and posterior hippocampus, a 3(Encoding List: Sleep List, Morning List, Single Study List) x 2(Memory: Remembered, Forgotten) x 2(Axis: Anterior, Posterior) repeated measures ANOVA revealed only a marginal main effect of Axis ($F(1,18) = 3.34$, $p = 0.085$). No other main effects or interaction effects were significant (Encoding List: $F(2,36) = 0.57$; Memory: $F(1,18) = 0.001$; Encoding List x Memory $F(2,36) = 0.37$; Encoding List x Axis $F(2,36) = 1.73$; Memory x Axis $F(1,18) = 1.72$; Encoding List x Memory x Axis $F(2,36) = 2.29$). Thus, the representation for the subsequent memory inter-item similarity did not seem to be modulated by Encoding List or subsequent memory. Furthermore, when specifically examining the subsequent memory inter-item pattern similarity for each Encoding List with a 2(Memory: Remembered, Forgotten) x 2(Axis: Anterior, Posterior) repeated measures ANOVA, there were no significant main effects or interaction effect for any of the Encoding Lists.

S2. Subsequent memory inter-item pattern similarity for scene-word pairs

For scene pairs, we calculated a repeated measures ANOVA with Encoding List (SL, ML, SS), Memory (Remembered, Forgotten), Hemisphere (Right, Left), and Axis region (Anterior, Posterior) as factors. The subsequent memory inter-item pattern similarity for the scene-word pairs did not seem to be modulated by later memory outcome, as there was not a significant main effect of memory ($F(1,17)= 0.33$, $p=0.57$) or any interaction effects with memory as a factor. As with the object-word pairs, overall pattern similarity was higher in posterior hippocampus, compared to anterior hippocampus, suggesting greater overlap amongst these representations (Main effect of Axis: $F(1,17)= 7.5$, $p=0.014$), and particularly in right hippocampus (Axis x Hemisphere interaction $F(1,17)= 3.71$, $p=0.07$). There was also a main effect of List ($F(2,34)=3.31$, $p=0.05$).

We next analyzed each Encoding List, and hemisphere separately by calculating 2(Memory) x 2(Axis region) repeated measures ANOVAs. However, there were no effects with Memory for any of the Lists in either hemisphere, though in right hippocampus, there was consistently a main effect of Axis region, with lower pattern similarity in anterior hippocampus than posterior hippocampus (Main effects of Axis region: SL: $F(1,17)= 6.01$, $p=0.03$, ML: $F(1,17)=4.93$, $p=0.04$; $F(1,17)=12.67$, $p=0.002$). However, in left hemisphere, there was only a significant main effect of Axis region for the Single Study List ($F(1,17)= 3.88$, $p=0.065$).

S3. Univariate activation

Hippocampal univariate activation

Our data suggests that the representational organization of memories in the hippocampus differ depending on the opportunity for sleep-dependent consolidation and the region along the long-axis of the hippocampus. We therefore wanted to examine how delay modulates more general measures of univariate activation. We examined average BOLD univariate activation sorted by later memory success, specifically examining those pairs that were later remembered (source correct) versus those that were forgotten (miss) (see Methods for more details). There was no strong evidence that univariate activation elicited during the restudy scan was related to later memory success. An ANOVA with Encoding List (Sleep List, Morning List, Single Study List), Memory (Remembered, Forgotten), Hemisphere (Right, Left), Category (Object-word, Scene-word) and Axis (Anterior, Posterior) as factors did not result in a significant main effect of memory ($F(1,18)= 0.49$, $p= 0.49$) or a List x Memory interaction ($F(2,36)= 0.28$, $p= 0.76$). However, a marginal Memory x Axis interaction ($F(1,18)=3.59$, $p= 0.07$) resulted from a non-significant numerical difference in Remembered and Forgotten pairs in anterior, but not posterior hippocampus. Further, the scene-word pairs overall evoked greater hippocampal univariate activation (Category main effect $F(1,18)= 18.01$, $p= 0.0005$), particularly in right hemisphere (Category x Hemisphere interaction: $F(1,18)= 10.41$, $p= 0.005$), and in posterior hippocampus (Category x Axis interaction: ($F(1,18)= 3.83$, $p= 0.07$), and potentially depending on the Encoding List (List x Category ($F(2,36)= 2.85$, $p=0.07$). Additionally, univariate activation was also greater in posterior hippocampus than anterior hippocampus (Axis main effect: $F(1,18)= 10.03$, $p= 0.005$).

Relationship between hippocampal univariate activation with sleep

We examined the 'sleep-specific' measure, subtracting the Morning List from the Sleep List, to control for individual differences in overall BOLD activation (see Methods). We first calculated the sleep-specific measure of univariate activation for object-word pairs that were subsequently remembered. Sleep-specific univariate activation in right posterior hippocampus positively correlated with the duration of Slow Wave Sleep (r=0.51, β=110.4, p= 0.036), such that longer durations of overnight Slow Wave Sleep correlated with greater activation in right posterior hippocampus (Figure S1). This was not seen for pairs that were later forgotten (r= 0.03), though, the difference between these correlations was not statistically significant (Williams's test: t= 1.65, p= 0.12).

The correlation between sleep-specific univariate activation in right posterior hippocampus and Stage 2 sleep was not significant for subsequently remembered (r= -0.41, β=-76.04, p= 0.13) or forgotten object-word pairs (r=0.14, β= 84.3, p= 0.15). Finally, no significant correlations were observed for sleep-specific univariate activation and right anterior hippocampus for Slow Wave Sleep (rem: r= 0.38, forg: r= 0.1) or Stage 2 sleep (rem: r= -0.16, forg: r= 0.03).

These results suggest that, similar to the all trial inter-item pattern similarity, the univariate activity in the hippocampus when restudying the pairs initially learned prior to overnight sleep is related to the duration of Slow Wave Sleep during the intervening sleep period.