Supplemental analysis of stationary data:

Rats generally did not spend a great deal of time interacting with the objects. In order to maximize the available data, we chose to combine data from stationary and moving periods of interaction with the objects. However, it was possible that this could have introduced a confound. Thus, we executed the main analyses with periods of movement having been excluded. In general this analysis yielded weaker evidence for a shift from delta to theta. However, all of the critical main findings were replicated. That is, at the intraregional level there were more differences in clusters detected at different frequencies than those detected during different conditions. The outsize remapping of clusters in the delta band in the VTA across conditions was still a notable exception. At the interregional level, both the number and the total strength of connections detected during object periods was markedly lower than that detected during non-object periods.

In the original analysis, we found 31.5 clusters per condition on average. In the new analysis, we found 30.25.

In the original analysis, clusters in the VTA in the delta frequency band exhibited particularly strong remapping both across conditions and relative to other frequencies. This was still true when examined across conditions within frequency (main effect of frequency ($F(4,76) = 12.7$; $p<.001$; linear contrast of delta vs. other frequencies ($F(1,76)=46.0$; $p<.001$)). In our original analysis, the effect size of the frequency main effect on this analysis was $\eta 2=.48$. In the reanalysis the effect size was reduced to $\eta 2=.40$. Further replicating the original analysis, when we examined remapping with respect to condition (w/i frequency) in the stationary only data, we found that there were still main effects of both frequency and condition in the VTA ($Fs(3\text{-}4,76) >5$; $ps<.01$). However, these effects also had lowered effect sizes compared to our original analysis (condition: original $\eta 2=.27$, new original $\eta 2=.18$; frequency: original $\eta 2=.36$, new $\eta 2=.23$).

Turning to the PFC, our original analysis found that there were main effects of both frequency and condition when the similarity of cluster structure was examined across frequency but within condition. These effect sizes had been smaller than those found in the VTA. In analysis limited to stationary periods, the main effect of condition disappeared, but the main effect of frequency was still significant ($F(4,76)=3.95$; $p=.005$), and its effect size was similar to our original analysis (original $\eta 2=.18$, new $\eta 2=.17$). Linear contrast revealed that this effect was driven by high gamma as it was in the original analysis. In addition, the object v. non-object contrast was marginally significant ($p=.09$), suggesting that although the condition main effect was not significant in the new analysis, the same general pattern existed in the data. Examining the PFC with respect to changes between conditions but within frequency the new analysis revealed the same main effect of frequency which was observed in the original analysis ($F(4,76)=4.87$; $p=.001$), and the effect size of this effect was similar to the original analysis (original $\eta 2=.18$, new $\eta 2=.20$). Also replicating the original analysis, there was no main effect of condition or interaction.

Finally, turning to the STR, we first examined cluster remapping across conditions and within frequency. Where main effects of condition and frequency had been marginal in the original analysis ($ps<.1$), in the new analysis, both of these main effects were significant ($Fs(3\text{-}4)>2.9$; $ps<.05$). Effect sizes were small to moderate (condition: $\eta 2=.11$; frequency: $\eta 2=.17$). When analysis was repeated across frequency and within condition, the new analysis replicated the old analysis' main effect of frequency ($F(4,71)=3.6$; $p=.01$), and the effect size of this effect was similar to the original analysis (original $\eta 2=.16$, new $\eta 2=.17$). The new analysis also revealed a new main effect of condition ($F(3,71)=2.9$; $p=.04$), but the effect size of this effect was small ($\eta 2=.11$).

Taken together, these analyses which follow the analyses of intraregional cluster changes presented in Figure 6 exhibit near perfect replication of the original analysis in the PFC and VTA with some deviation in the STR.

Next, we sought to examine how limiting the analysis to stationary periods would impact our analysis of interregional connectivity. In our original analysis, of all possible connections, 72% were significant in the first open field period. This value dropped to 2% in the novel object period, raised to 52% in the second open field period, and dropped back to 18% in the repeat object period. Limiting analysis to stationary periods yielded similar values: 90%, 25%, 71%, 23%. In general, there were more stably detected connections when data were limited to the stationary periods, but the pattern of decreased connectivity during the object periods was replicated. The overall increase may reflect differences between stationary and movement states which obscured some of the connectivity.

Finally, we repeated the analysis of interregional connectivity using all connections from all rats rather than aggregating. This analysis replicated the main results found in the original analysis. Specifically, when comparing the first open field period to the novel object period, there was a main effect of condition ($F(1,277)=31.5$; $p<.001$) and a condition by frequency interaction ($F(4,277)=2.5$; $p=.04$), both of which replicated the original analysis with similar effect sizes (original: $\eta^2=.60$ and .16, respectively; new $\eta^2=.55$ and .04). When comparing the second open field period to the first, there was no main effect of condition, indicating similar overall network connectivity strength in these conditions, but there was an interaction between condition and frequency ($F(4,280)=7.7$; $p<.001$). These findings replicated the original analysis. The interaction had a similar effect size to that observed in the original analysis (original: $\eta^2=.11$; new $\eta^2=.10$). Further replicating the original results, when comparing the first open field period to the second object exploration period there was a main effect of condition ($F(1,267)=100.6$; $p<.001$) and an interaction between condition and frequency ($F(2,267)=7.1$; $p<.001$). These effects had similar effect sizes in the original and new analysis (original: $\eta^2=.30$ and .18, respectively; new $\eta^2=.27$ and .12).

As was true in the original analysis, there were significant interactions between condition and frequency when comparing the first open field period to each of the other three conditions. This suggests that the distribution of connection strength changed across conditions differently in different frequencies. Post-hoc t-tests found that there was a decrease in delta power connection strength in all conditions relative to the first open field period ($ts> 3$; $ps<.005$). The connection strength of a node is equal to the summed significant correlations of all its connections. The mean delta node connection strengths were .98, .70, .71, .49 for the first open field, novel object, second open field, and repeat object conditions respectively. Contrary to the marginal result found in the original analysis, there was no evidence for an increase in theta connectivity.

Taken together these results indicate that there was a reduction in delta band connectivity in all conditions relative to the first open field condition, but evidence for increased theta, which was already tenuous is weakened further in this analysis.

SUPPLEMENTAL TABLES:

PFC	Df	SumSq	MeanSq	F	P	eta^2 partial
condition	3.00	0.04	0.01	0.56	0.64	
frequency	4.00	0.35	0.09	4.13	0.00	0.18
high gamma	*1.00*	*0.28*	*0.28*	*13.36*	*0.00*	
interaction	12.00	0.04	0.00	0.17	1.00	
Residuals	76.00	1.62	0.02			

STR	Df	SumSq	MeanSq	F	P	eta^2 partial
condition	3.00	0.03	0.01	0.36	0.79	
frequency	4.00	0.41	0.10	3.67	0.01	0.16
theta	*1.00*	*0.12*	*0.12*	*4.23*	*0.04*	
low gamma	*1.00*	*0.24*	*0.24*	*8.35*	*0.01*	
interaction	12.00	0.06	0.00	0.17	1.00	
Residuals	76.00	2.14	0.03			

VTA	Df	SumSq	MeanSq	F	P	eta^2 partial
condition	3.00	0.10	0.03	1.56	0.21	
frequency	4.00	1.47	0.37	17.55	0.00	0.48
delta	*1.00*	*1.42*	*1.42*	*67.55*	*0.00*	
interaction	12.00	0.14	0.01	0.54	0.88	
Residuals	76.00	1.59	0.02			

Supplemental Table 1. Cluster stability across conditions within frequency

PFC	Df	SumSq	MeanSq	F	P	eta^2 partial
condition	3.00	0.12	0.04	3.79	0.01	0.13
Object periods	*1.00*	*0.08*	*0.08*	*7.18*	*0.01*	
frequency	4.00	0.18	0.04	4.19	0.00	0.18
high gamma	*1.00*	*0.15*	*0.15*	*13.94*	*0.00*	
interaction	12.00	0.07	0.01	0.56	0.87	
Residuals	76.00	0.80	0.01			

STR	Df	SumSq	MeanSq	F	P	eta^2 partial
condition	3.00	0.09	0.03	2.13	0.10	
frequency	4.00	0.13	0.03	2.20	0.08	
interaction	12.00	0.05	0.00	0.28	0.99	
Residuals	76.00	1.12	0.01			

VTA	Df	SumSq	MeanSq	F	P	eta^2 partial
condition	3.00	0.27	0.09	9.48	0.00	0.27
Object periods	*1.00*	*0.23*	*0.23*	*24.57*	*0.00*	
frequency	4.00	0.40	0.10	10.62	0.00	0.36
delta	*1.00*	*0.13*	*0.13*	*13.98*	*0.00*	
beta/gamma	*1.00*	*0.05*	*0.05*	*5.07*	*0.03*	
high gamma	*1.00*	*0.22*	*0.22*	*23.40*	*0.00*	
interaction	12.00	0.16	0.01	1.42	0.18	
Residuals	76.00	0.72	0.01			

Supplemental Table 2. Cluster stability across frequency within condition

Open Field vs. Novel Obj	Df	SumSq	MeanSq	F	P	eta^2 partial
cond	1.00	4.52	4.52	114.26	0.00	0.29
freq	4.00	16.72	4.18	105.76	0.00	0.60
reg	2.00	0.30	0.15	3.82	0.02	0.03
cond:freq	4.00	2.05	0.51	12.96	0.00	0.16
cond:reg	2.00	0.16	0.08	1.99	0.14	
freq:reg	7.00	0.85	0.12	3.08	0.00	0.07
cond:freq:reg	7.00	0.24	0.03	0.86	0.54	
Residuals	288.00	13.04	0.05			

Supplemental Table 3. Strength changes Open Field vs. Baseline Object

Open Field vs. Open Field 2	Df	SumSq	MeanSq	F	P	eta^2 partial
cond	1.00	0.00	0.00	0.06	0.81	
freq	4.00	25.56	6.39	141.14	0.00	0.66
reg	2.00	0.28	0.14	3.09	0.05	0.02
cond:freq	4.00	1.59	0.40	8.79	0.00	0.11
cond:reg	2.00	0.01	0.00	0.08	0.92	
freq:reg	7.00	1.78	0.25	5.62	0.00	0.12
cond:freq:reg	7.00	0.52	0.07	1.63	0.13	
Residuals	288.00	13.04	0.05			

Supplemental Table 4. Strength changes Open Field vs. Open Field 2

Open Field vs. Repeat Obj	Df	SumSq	MeanSq	F	P	eta^2 partial
cond	1.00	4.22	4.22	121.23	0.00	0.30
freq	4.00	16.98	4.25	122.03	0.00	0.63
reg	2.00	0.11	0.05	1.54	0.22	
cond:freq	4.00	2.10	0.53	15.10	0.00	0.18
cond:reg	2.00	0.08	0.04	1.13	0.32	
freq:reg	7.00	1.05	0.15	4.31	0.00	0.10
cond:freq:reg	7.00	0.10	0.01	0.41	0.90	
Residuals	283.00	9.84	0.04			

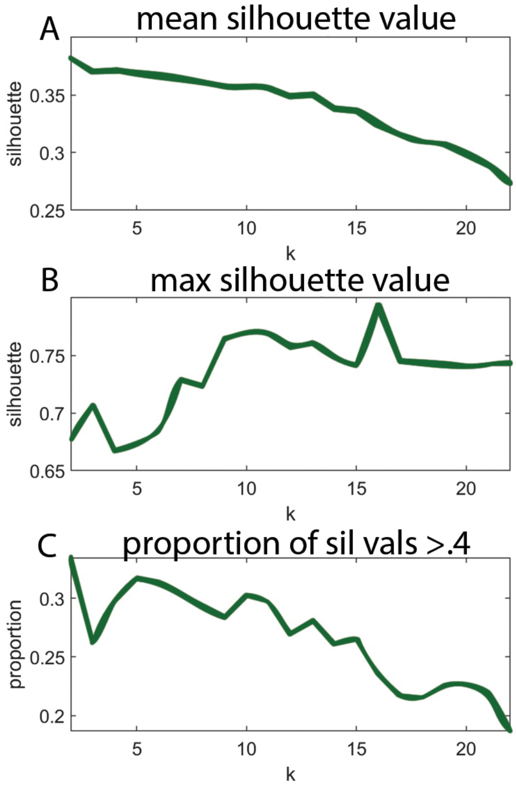
Supplemental Table 5. Strength changes Open Field vs. Repeat Object

Extended data Fig. 3-1 Choosing k for DBscan. a the mean silhouette value (y-axis) of clustering schemes calculated for all rats, regions, conditions, and frequencies using different values of k (x-axis). b The maximum silhouette value (y-axis) of clustering schemes calculated for different values of k (x-axis). c The proportion of silhouette values greater than .4 (y-axis) for different values of k (x-axis).

Extended Data Fig 7-1 Network connections related to memory. For significant connections (main text Fig. 7a-d), we assessed the correlation between session connection strength and session memory. Memory was calculated as the proportion of time spent exploring the object during the Novel Object period minus the similar proportion for the Repeat Object period. There were two outlier sessions with memory <-.2 (main text Figure 1e), which were excluded from this analysis. a-d Network maps depicting connections that exhibited a significant correlation with memory strength. e-l Scatter plots depict the individual data points that went into all significant correlations. Before calculating correlations, each animal's mean connection strength across sessions and mean memory strength across sessions were calculated. These animal mean values were submitted to correlation analysis. This analysis was also done using data from individual sessions in the correlation analysis. In general, a similar set of significant correlations were discovered. Different colors/shapes of points indicate the individual sessions for different animals. The large black circles indicate animal means. The regression line of best fit is shown (all $ps<.05$).

Extended data Fig 7-2 Network connections between clusters versus between regions. a-d Network maps are the same as panels a-d of Figure 7 (main text). e-h Network maps are calculated using all the same procedures as those in a-d, except each region was treated as a single cluster. Without considering the functional organization of signals within region (using clustering), many of the connections detected in panels a-d were missed in panels e-

h. This is particularly evident during the Repeat Object period (panel h) where all of the complex high frequency interactions between regions have been missed.



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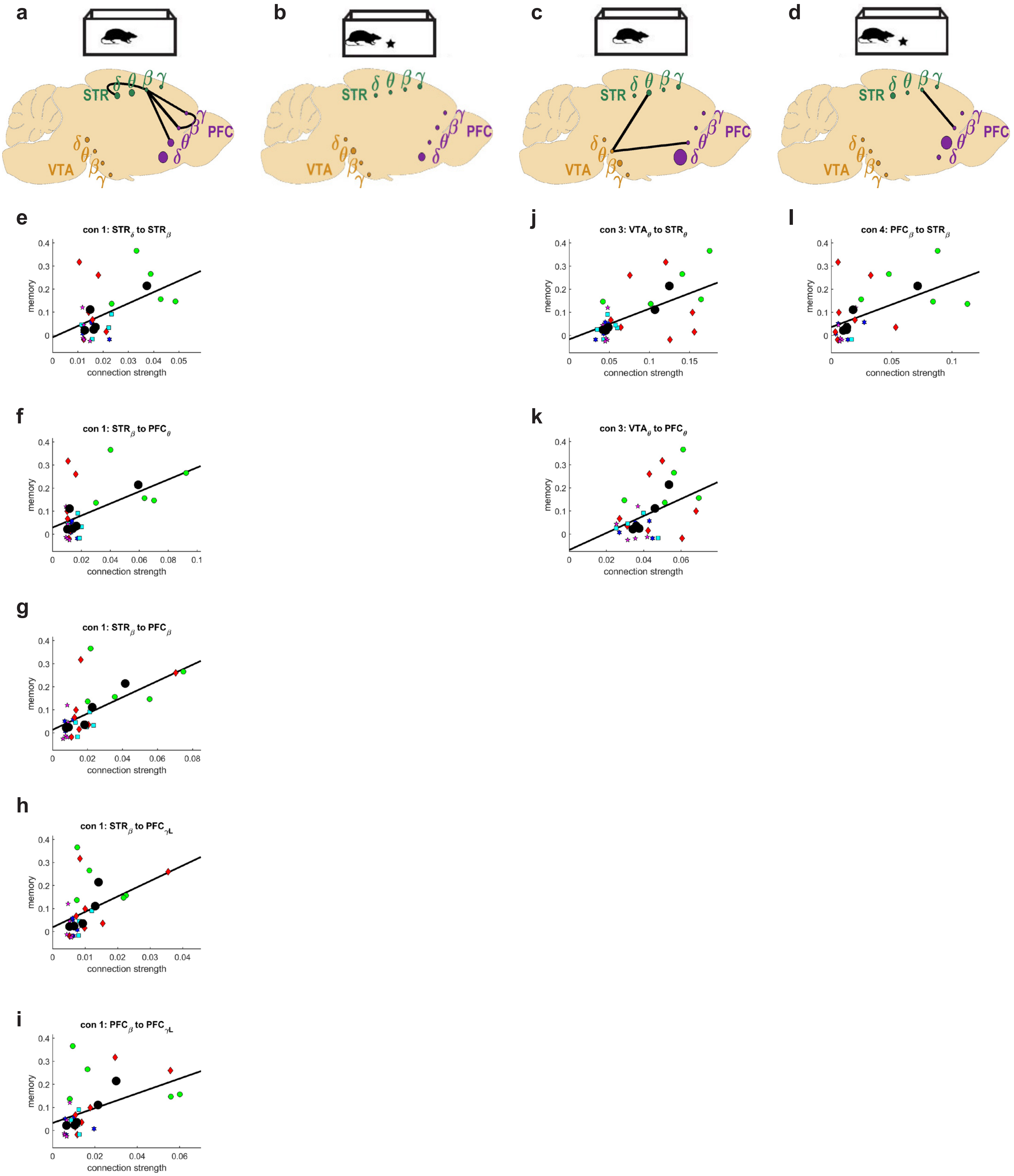
Group-level memory-predicting connections



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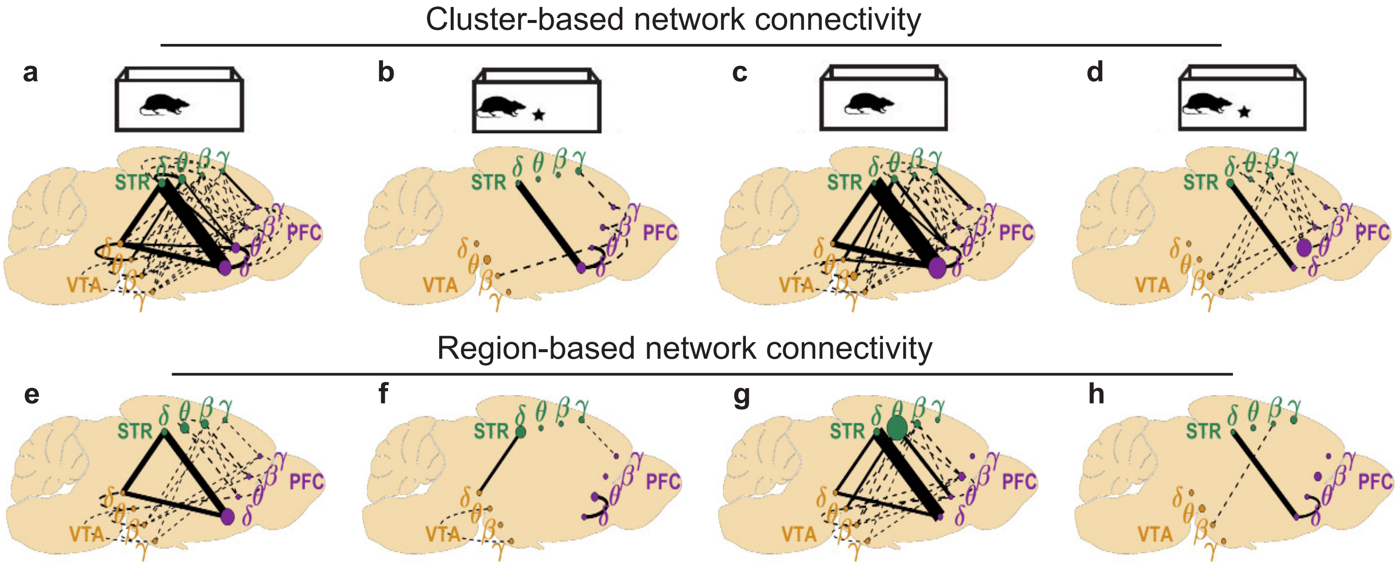

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