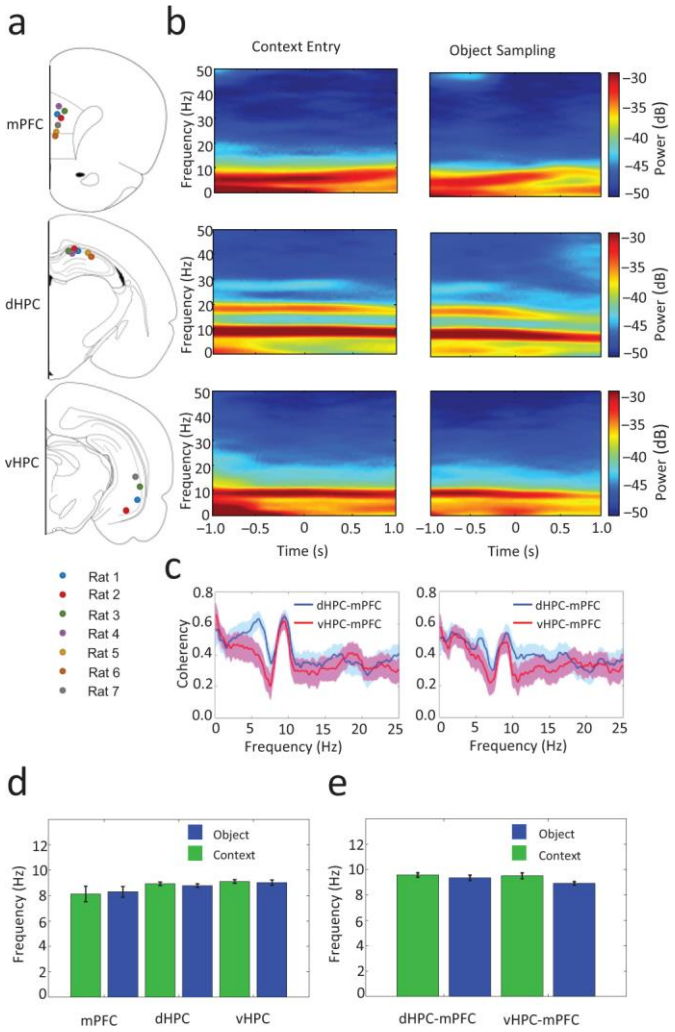
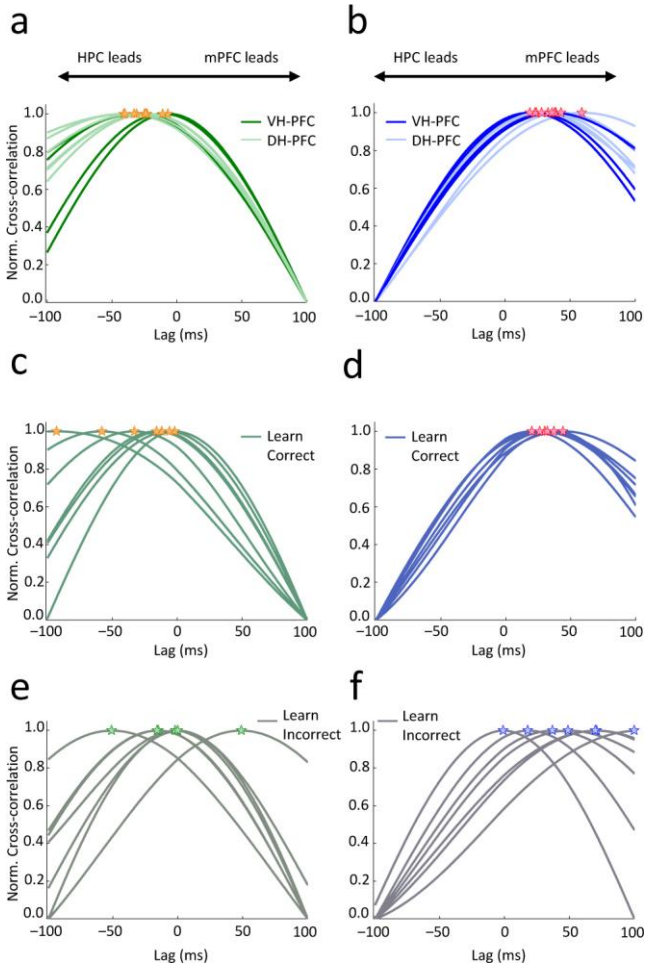


Supplementary Figure 1.

Electrode locations and characteristics of local field potentials.

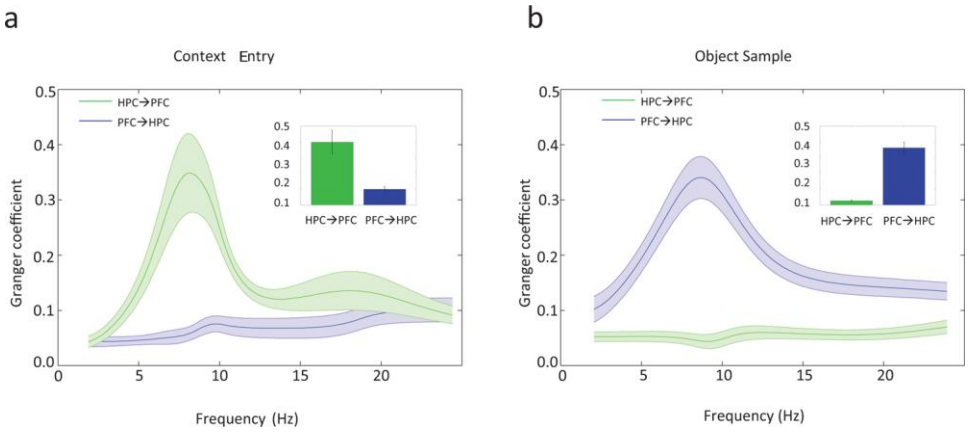
(a) Locations of electrode tips in prefrontal cortex (mPFC), dorsal hippocampus (dHPC), and ventral hippocampus (vHPC) at mm AP to bregma: mPFC 3.20; dHPC 3.14 ; vHPC -5.60. mPFC electrodes were localized in layers II/III (n=7); dHPC in the pyramidal layer (n=6); vHPC in the pyramidal layer (n=2) or stratum radiatum (n=2). **(b)** Frequency spectra show prominent power spectral density in the theta band during both the context exploration (Peak Frequency = 8.13 $\pm$ 0.61 Hz, mPFC; 8.93 +/- 0.15 Hz, dHPC; 9.11 $\pm$ 0.15 Hz, vHPC) and object sampling periods (Peak Frequency = mPFC: 8.3 $\pm$ 0.43 Hz; dHPC: 8.79 $\pm$ 0.14 Hz; vHPC: 9.03 $\pm$ 0.13 Hz). **(c)** Mean coherence between dHPC and vHPC and mPFC was maximal at theta frequency both for the context exploration (Peak Frequency = dHPC-mPFC: 9.57 Hz $\pm$ 0.17 Hz; vHPC-mPFC: 9.51 $\pm$ 0.23 Hz) and object sampling periods (Peak Frequency = dHPC-mPFC: 9.34 $\pm$ 0.21; vHPC-mPFC: 8.91 $\pm$ 0.14 Hz). Shading indicates S.E.M. (**d)** Peak power frequency during first 1-s of context exploration and object sampling did not significantly differ among areas (One-way ANOVA $F_{1, 30} = 0$, $p = 0.97$ $\pm$ S.E.M. **e.** Peak Coherence Frequency during first 1 s of context exploration and versus object sampling did not significantly differ (One-way ANOVA, $F_{1, 18} = 3.49$, $p = 0.08$). Coherence values for these frequencies were greater than those predicted by 95% jackknife-estimated confidence intervals (0.1069) for both context exploration (Coherency = dHPC-mPFC: 0.47 $\pm$ 0.04; vHPC-mPFC: 0.38 $\pm$ 0.02) and object sampling (Coherency = dHPC-mPFC: 0.42 $\pm$ 0.05; vHPC-mPFC: 0.32 $\pm$ 0.02).



Supplementary Figure 2

Normalized correlations between instantaneous theta amplitude across a range of shifts between LFPs recorded in hippocampus (HPC) and prefrontal cortex (mPFC) for individual subjects.

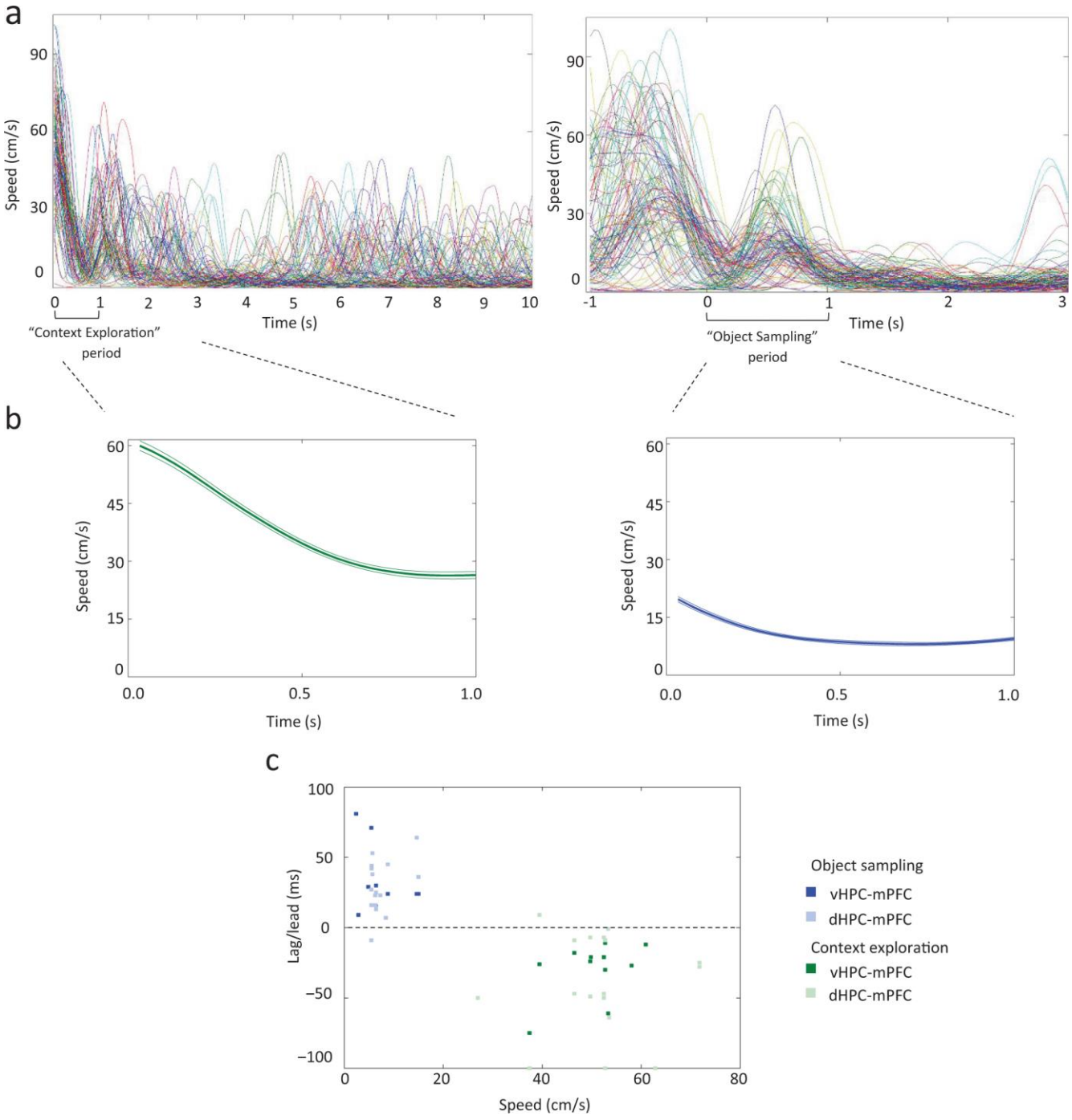
Correlation patterns for post-learning sessions **(a,b)** and for correct trials **(c,d)** and errors **(e,f)** during learning sessions.



Supplementary Figure 3

Granger causal (GC) relationships (1–25 Hz) across sessions for context exploration and object sampling.

GC was greater from HPC to mPFC during (**a**) context exploration (Two-way ANOVA, F = 1033.46, df = 1, p = 9.83e-215), while mPFC better predicted HPC activity during instances of (**b**) object sampling (Two-way ANOVA, F = 2571.27, df = 1, p < 0.0001). Furthermore, maximal GC was within the theta range for both context exploration (9.16 $\pm$ 0.83 Hz) and object sampling periods (9.27 $\pm$ 0.92 Hz), and the causal flow reversed within the HPC-PFC circuit at this frequency as a function of behavioral phase, such that HPC directed mPFC activity during context exploration (GC = 0.3983 $\pm$ 0.07, Wilcoxon rank-sum, z_{42} = 4.60, p = 4.15e-6) and mPFC engaged HPC during object sampling (GC = 0.3518 $\pm$ 0.04, Wilcoxon rank-sum, z_{42} = 4.96, p = 7.14e-8). Bayesian Information Criterion (BIC) indicated the best fitting model order was at 40 ($\pm$ 2.60) ms and 26 ($\pm$ 2.50) ms lags for context versus object sampling periods respectively. The HPC lead over mPFC observed during contextual exploration is consistent with previously demonstrated Granger causal predictions of HPC-mPFC functional connectivity[13]. Shaded plots represent S.E.M. across sessions. Inset bar graph: Comparison between GC directionality for frequency of peak GC (mean +/- standard error).



Supplementary Figure 4

Movement speed patterns during context exploration and object sampling.

(a) Speed patterns over the entire 10 sec context exploration period and period surrounding object sampling for each trial in an example session. On individual trials rats rapidly enter the context then alternate irregularly between rapid movements and periods of immobility. During object sampling, rats typically sniff standing still then adjust the head to a new position for additional sampling, such that the changes in speed observed during the object sampling period reflect head turning while standing relatively still examining the object.. **(b)** Movement speed pattern for 1 sec context exploration and object sampling periods averaged (± SE) for all sessions. Note that "speed" in these periods reflects qualitatively different behaviors when the animal is walking through space or turning its head while still. **(c)** Scatter plot of PFC-HPC lag/leads and speed over 1 sec context exploration (context) and object sampling (object) periods from all

sessions. Lag/lead did not significantly correlate with speed during the context exploration period (vHPC-mPFC: r = 0.06, p = 0.85; dHPC-mPFC: r = 0.009, p = 0.97; combined HPC-mPFC: Pearson r = -0.008, p = 0.96) or the object exploration period (vHPC-mPFC: r = -0.33, p = 0.28; dHPC-mPFC: r = 0.413, p = 0.08; combined HPC-mPFC: r = 0.023, p = 0.90). Note the r-value closest to significance (p = 0.08) hints at a positive correlation suggesting greater mPFC lead over dHPC with increasing speed, which is opposite the direction observed during higher speeds associated with context exploration.

Supplementary Tables

Supplementary Table 1. Regional profile of individual neurons that are selective for specific task features and theta modulated during context exploration or object sampling

	Context Exploration	Object Sampling		
	Context	Context	Object	Valence
Region	n/N (%)	n/N (%)	n/N (%)	n/N (%)
dHPC	78/98 (80)	43/58 (74)	42/57 (74)	35/56 (63)
vHPC	32/38 (84)	14/19 (74)	7/13 (54)	7/11 (64)
mPFC	46/89 (52)	26/68 (38)	31/71 (44)	35/98 (36)

For each brain region, n = number of cells selective for a specific feature that are theta-modulated, N = total number of cells that are selective for that feature, and % = percentage of feature selective cells that are theta modulated.

Supplementary Table 2 | PFC-HPC lag/lead of maximal correlation during accurate performance by individual subjects

Subject	Context exploration (ms)	Object sampling (ms)
1 - VH	-36	24
1 - DH	-41	59
2 - VH	-8	38
2 - DH	-23	39
3 - VH	-11	19
3 - DH	-28	23
4 - DH	-40	43
5 - DH	-24	33
6 - DH	-33	28
7 - VH	-33	36

Negative values indicate HPC leads; vs. positive values indicate PFC leads.

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Supplementary Table 3 | PFC-HPC lag/lead of maximal correlation during correct trials and errors during learning in individual subjects

	Correct trials		Errors	
Subject	Context exploration (ms)	Object sampling (ms)	Context exploration (ms)	Object sampling (ms)
1	-60	29	-2	37
2	-2	30	-51	18
3	-12	32	0	71
4	-93	32	49	100
5	-33	20	0	70
6	-16	26	-15	49
7	-6	37	-16	-1

Negative values indicate HPC leads; vs. positive values indicate PFC leads.

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