Supplemental Text

All Learned Locations

Navigation to all learned locations was calculated as the number of crossings or time spent divided by the total number of currently known platforms (e.g., on trial 4, the total number of crossings divided by 3). Comparing crossings through the most recently learned location and all learned locations revealed a significant main effect of experiment half (β = 0.02, t = 3.29, p = 0.002), distance traveled (β = -0.01, t = -4.11, $p < 0.001$), and location type (β = -0.02, t = -2.55, p = 0.012). There were significantly fewer crossings through all locations than through the most recently learned location (Z = -2.73 , p = 0.006, r = 0.50, 95% CI = [0.0026, 0.021]). Time spent in all learned locations was not significantly different from time spent in the most recently learned location (β = -1.86, t = -0.30, p = 0.762). Overall, defining episodic navigation based on the most recently learned location was more conservative than the normalized all learned locations, for comparison with the mean location (see Fig. S1).

Other Individual Locations

We compared the most recently learned location with two other ways of defining episodic navigation based on individual locations: the first learned location and a previous location randomly sampled (with recency weighting) from memory. For location crossings, we found a main effect of location type (β = 0.03, t = 4.86, $p < 0.001$). Participants crossed through the most recently learned location more than the first learned location (Z = -3.49, $p < 0.001$, r = 0.64, 95% CI = [-0.042, -0.009]) and the randomly sampled location (Z = -4.73, $p < 0.001$, r = 0.86, 95% CI = [0.014, 0.036]). We also found a main effect of location type for time in location (β = 15.30, t = 3.27, p = 0.001). More time was spent in the most recently learned location than the first learned location (Z = -3.07, p = 0.002, r = 0.56, 95% CI = [-22.32, -5.09]) and the randomly sampled location (Z = -4.58, $p < 0.001$, r = 0.84, 95% CI = [9.72, 25.05]) (see Fig. S2).

To further evaluate navigation to these locations, as well as navigation to the cumulative mean location, we compared crossings and time spent in each location to what would be expected by chance. We established chance behavior by rotating the points of the distribution of platforms around the mean, then rotated the distribution itself around the origin of the arena, at a random degree of rotation. We repeated this procedure 1000 times for each participant, resulting in a participant-specific null distribution of crossings and times in location. We then calculated the proportion of null crossings and times in location equal to or exceeding the empirical values, which corresponds to a non-parametric, randomization-based significance value (p_{rand}; see Table S1).

During the first half of the experiment, only crossings through the most recently learned location were above chance ($p_{rand} = 0.016$). By the second half of the experiment, crossings through the mean ($p_{rand} = 0.020$), most recently learned ($p_{rand} = 0.016$), and randomly sampled ($p_{rand} = 0.028$) locations all exceeded chance. Time spent was not significantly above chance for any location during the first half of the experiment, and only time in the mean location was above chance in the second half ($p_{rand} = 0.020$). These findings further support the use of the most recently learned location as a conservative episodic comparison for the mean location.

Different Platform Radius Calculations

We felt that the FWHM of the cumulative distribution of previously learned locations was a principled way to define a flexible representation of the mean (see Fig. S3), especially given that the mean itself was never a platform location. Although estimated for the mean, we employed this same radius for each search trial around the most recently learned location as well, to equate surface area across conditions. As a result, radius size did not confer any baseline advantage for pattern- vs. episode-based navigation. Nevertheless, our findings did not depend on this approach for defining the platform radius, as shown by the results for two other definitions below.

First, we reanalyzed our human participant data after applying a fixed radius across all search trials — the grand average of the trial-specific FWHM above — and replicated the critical interaction between experiment half and location condition. This was true for crossings (β = 0.03, t = 2.36, p = 0.021; comparison to main effects model $\chi^2(1)$ = 5.62, p = 0.018), with an increase in mean crossings from first to second half (Z = -2.47, p = 0.014, r = 0.45, 95% CI = [-0.058, -0.0065]) and more mean than most recently learned location crossings in the second (Z = -3.66, p $<$ 0.001, r = 0.67, 95% CI = [-0.057, -0.01]) but not first half (Z = -1.12, p = 0.262, r = 0.20, 95% CI = [-0.025, 0.0068]). This was also true for time in location (β = 19.45, t = 2.09, p = 0.040; comparison to main effects model $\chi^2(1)$ = 4.43, p = 0.035), with an increase of time in mean from first to second half (Z = -3.43, p $<$ 0.001, r = 0.63, 95% CI = [-47.52, -11.50]) and more time in mean than most recently learned location in second (Z = -3.28, p = 0.001, r = 0.60, 95% CI = [-22.73, -4.93]) but not first half (Z = -0.65, p = 0.516, r = 0.12, 95% CI = [-5.35, 12.22]).

Second, we reversed the order of the FWHM changes across trials in Figure S3. The key interaction remained significant for location crossings (β = 0.03, t = 2.38, p = 0.019; comparison to main effects model $\chi^2(1)$ = 5.75, p = 0.016), with an increase in mean crossings from first to second half (Z = -2.14, p = 0.033, r = 0.39, 95% CI = [-0.052, -0.0034]) and more mean than most recently learned location crossings in the second (Z = -3.53, p $<$ 0.001, r = 0.64, 95% CI = [-0.052, -0.0091]) but not first half (Z = -0.77, p = 0.440, r = 0.14, 95% CI = [-0.022, 0.013]). The interaction was no longer reliable for time in location under this approach (β = 9.07, t = 1.00, p = 0.323). Because the radius defined in this way was smaller on average in the second half, we interpret the weaker time in location effect as the participants crossing the edge of the radius (and thus counting as a crossing), without spending much time within it. The original and fixed radius definitions were larger for these trials, suggesting that participants may have had a somewhat fuzzy representation of the mean.

Return Trials

We repeated our main regression analysis on the return trials to explore how learned patterns may have influenced behavior even under explicit instructions to navigate to the most recently learned location (see Fig. S4).

For location crossings, we found main effects of condition (β = -0.12, t = -7.98, p < 0.001), experiment half (β = 0.04, t = 2.73, p = 0.008), and distance (β = -0.04, t = -4.02, p < 0.001), as well as interactions between condition and experiment half (β = 0.09, t = 4.25, p < 0.001), and experiment half and distance (β = -0.03, t = -2.67, p < 0.009). Comparison to a main effects model revealed a superior fit ($\chi^2(3)$ = 25.87, p < 0.001). Unlike the search trials, there were fewer crossings through the mean location than the most recently learned location in the second half (Z = -3.59, p < 0.001, r = 0.65, 95% CI = [0.02, 0.05]), as well as in the first half (Z = -5.15, p < 0.001, r = 0.94, 95% CI = [0.08, 0.15]).

For time in location, we found main effects of condition (β = -52.72, t = -4.03, p < 0.001) and experiment half (β = 26.61, t = 2.02, p = 0.046), and interactions between condition and experiment half (β = 68.06, t = 3.67, p < 0.001), and experiment half and distance (β = -31.41, t = -3.00, p = 0.003). Comparison to a main effects model again revealed a superior fit ($\chi^2(3)$ = 22.12, p < 0.001). Similar to the search trials, more time was spent in the mean location than the most recently learned location in the second half (Z = -2.09, p = 0.036, r = 0.38, 95% CI = [-32.49, -0.83]), though there was reliably less time spent in the mean than most recently learned location in the first half (Z = -3.72, p < 0.001, r = 0.68, 95% CI = [23.22, 69.37]).

Continuous Trial Variable

Binning trials by experiment half was a statistical convenience for assessing learning. Regardless, the key interaction of condition by time held when time was defined as a continuous function of trial number rather than with two levels of experiment half, for both crossings (β = 0.02, t = 2.68, p = 0.008; comparison to main effects model: $\chi^2(3) = 27.70$, p<0.001) and time in location (β = 15.38, t = 3.23, p = 0.001, comparison to main effects model: $\chi^2(3) = 13.48$, p = 0.004).

Navigation Strategies

We developed algorithms to quantify two types of exploratory behaviors, zigzagging and spiraling. A zigzag was defined as a bout of movement with no change in heading direction, followed by a 90 to 180° change in heading, followed by a second bout of movement with no change in heading direction, and then a -90 to -180° change (two back and forths). A spiral was defined as a continuous, monotonic change in heading direction totalling 720° (two full rotations). In addition to quantifying these behaviors (see Fig. S5), we also controlled for them in our regression models.

For location crossings, there were no main effects or interactions involving zigzagging or spiraling behavior (ps > 0.216). However, the interaction between condition and experiment half remained significant (β = 0.03, t = 2.06, p = 0.043), and this model fit better than a simple main effects model ($\chi^2(3) = 14.48$, p = 0.002).

For time in location, there was a main effect of zigzagging (β = -12.62, t = -2.30, p = 0.023) and a marginal effect of spiraling (β = -8.81, t = -1.97, p = 0.051), but no interactions with either (ps > 0.962). Again, the interaction between condition and experiment half remained significant (β = 21.74, t = 2.18, p = 0.033), with the model again fitting better than a main effects model ($\chi^2(3) = 19.66$, $p < 0.001$).

Episode Avoidance Model

We assumed in the episode model that agents will use episodic memory to navigate towards previous locations. However, given that locations never repeated exactly, participants might have adopted a strategy of intentionally avoiding these locations. To address this possibility, we created an “episode avoidance model” with similar functional architecture to our original episode model, but where memory for learned locations weighted by recency biased behavior towards the coordinates of those locations translated across the origin (i.e., in the opposite direction).

We then fit this model's data to participant behavior and compared it to the fits for the original episode model (see Fig. S8). In predicting crossings, there were main effects of model ($F(1,999) = 205.41$, $p < 0.001$) and experiment half ($F(1,999) = 1655.21$, $p < 0.001$), as well as an interaction between model and experiment half ($F(1,999) = 123.20$, $p < 0.001$). The episode model fit better than the episode avoidance model overall ($t(999) = -12.15$, $p < 0.001$, $d = 0.38$, 95% CI = [-0.0067, -0.0049]), and this difference was greater in the first half ($t(999) = -18.10$, $p < 0.001$, $d = 0.38$, 95% CI = [-0.011, -0.0091]) than the second half ($t(999) = -2.42$, $p = 0.016$, $d = 0.11$, 95% CI = [-0.0024, -0.00026]).

The difference in fit was also evident in predicting time in location, with significant main effects of model ($F(1,999) = 1771.49$, $p < 0.001$) and experiment half ($F(1,999) = 1229.26$, $p < 0.001$), and a significant model by experiment half interaction ($F(1,999) = 144.67$, $p < 0.001$). The episode model again fit better overall ($t(999)= -36.90$, $p < 0.001$, $d = 0.38$, 95% CI = [-10.15, -9.13]), but this time the difference was greater in the second half ($t(999) = -34.57$, $p < 0.001$, $d = 1.50$, 95% CI = [-13.04, -11.64]) than the first half ($t(999) = -25.10$, $p < 0.001$, $d = 1.10$, 95% CI = [-7.48, -6.40]).

Supplemental Figures

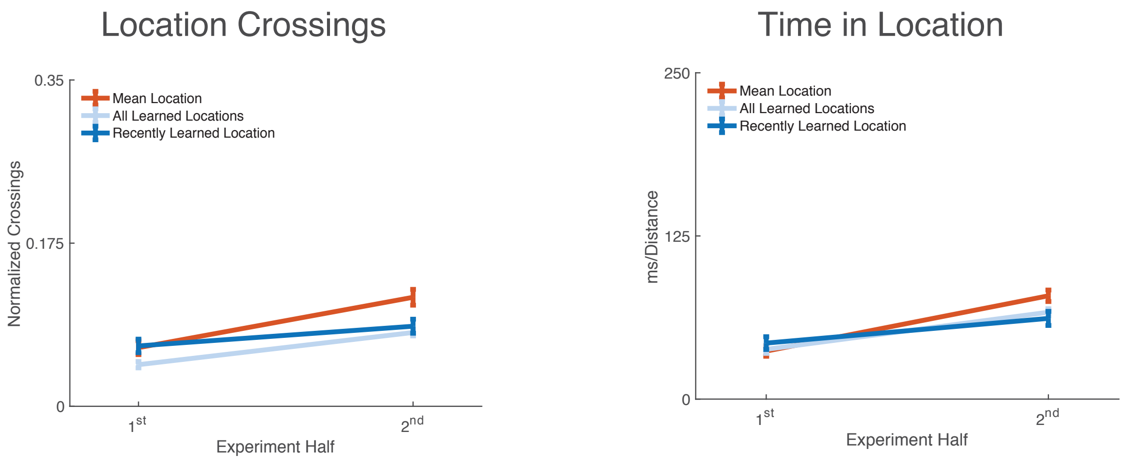

Fig. S 1. Human behavioral crossings and time spent in the mean, most recently learned, and all learned locations. Error bars are ±1 within-subject SE. Individual data points are not shown given the number of conditions plotted.

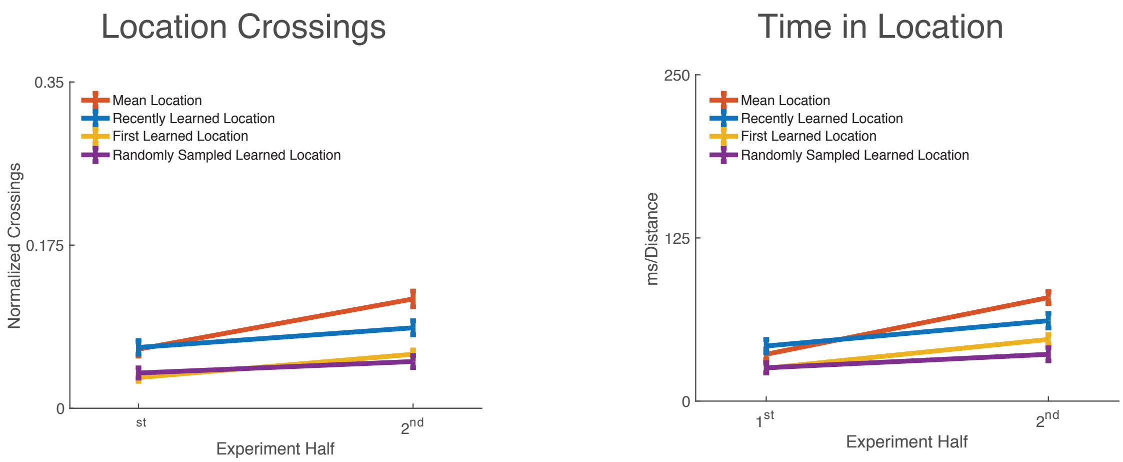

Fig. S 2. Human behavioral crossings and time spent in the mean, most recently learned, first learned, and randomly sampled learned location. Error bars are ±1 within-subject SE.

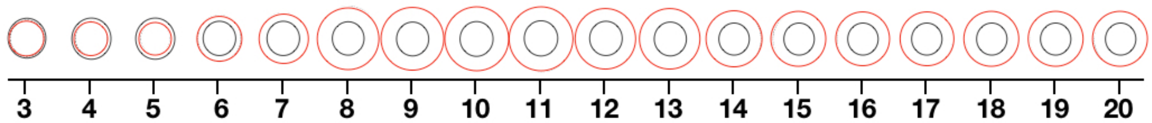

Fig. S 3. Change across trials in the radius used to calculate location crossings and time in location, based on the full width, half maximum (FWHM) of the cumulative location distribution (red circles). Starts in trial 3 because 2+ locations are needed for the calculation. This is compared against a reference of the fixed platform size used in the virtual navigation task itself (black circles).

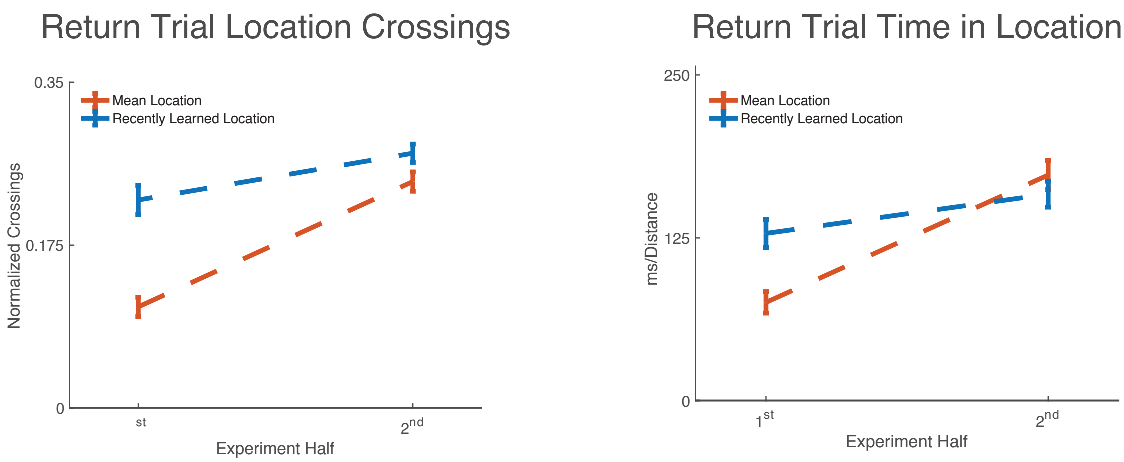

Fig. S 4. Human behavioral crossings and time spent in the mean and most recently learned locations on return trials. Error bars are ±1 within-subject SE.

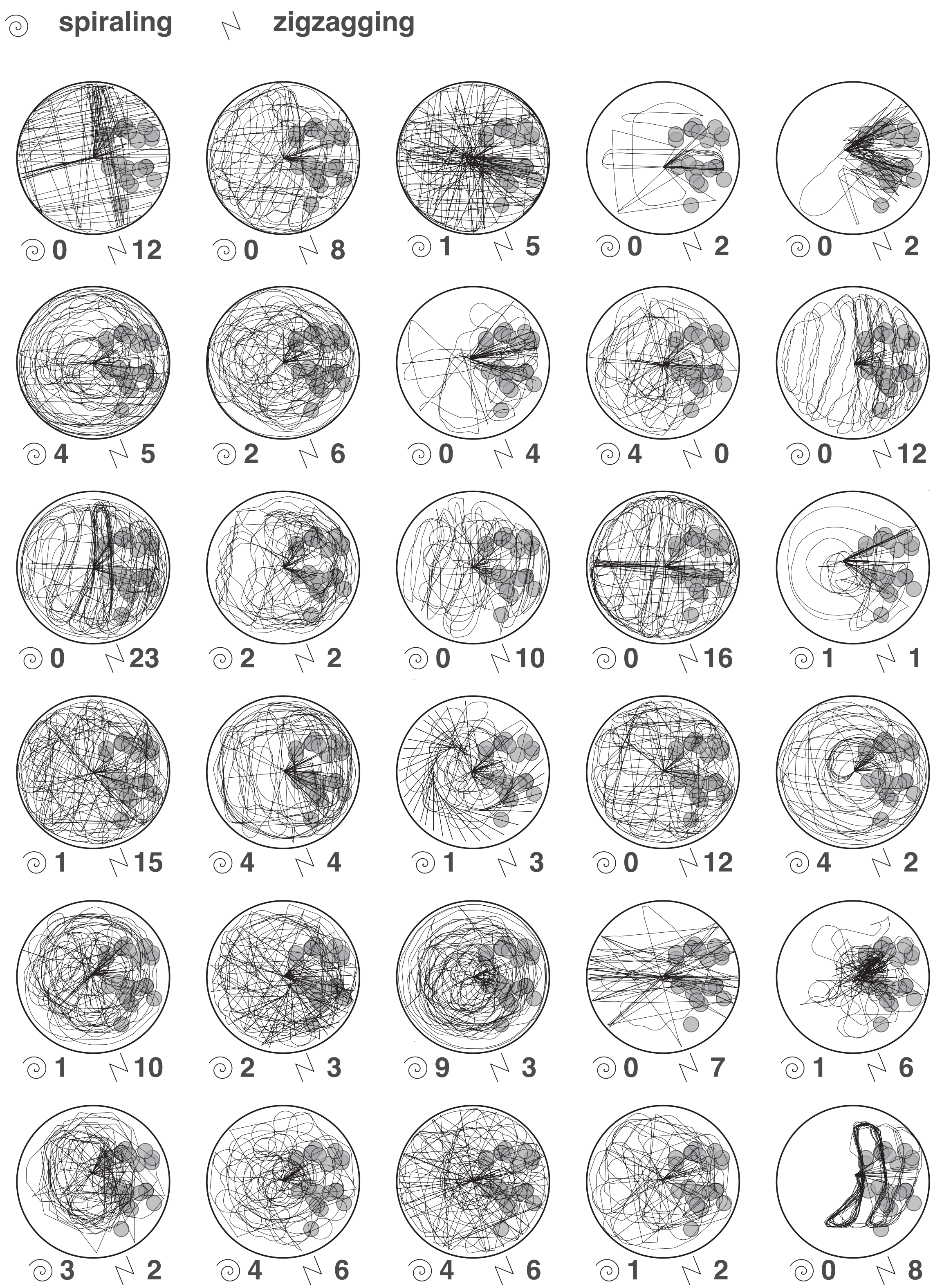

Fig. S 5. Trajectories for all 30 trials for each participant, with a quantification of how much 'spiraling' and 'zigzagging' the participant displayed during the experiment.

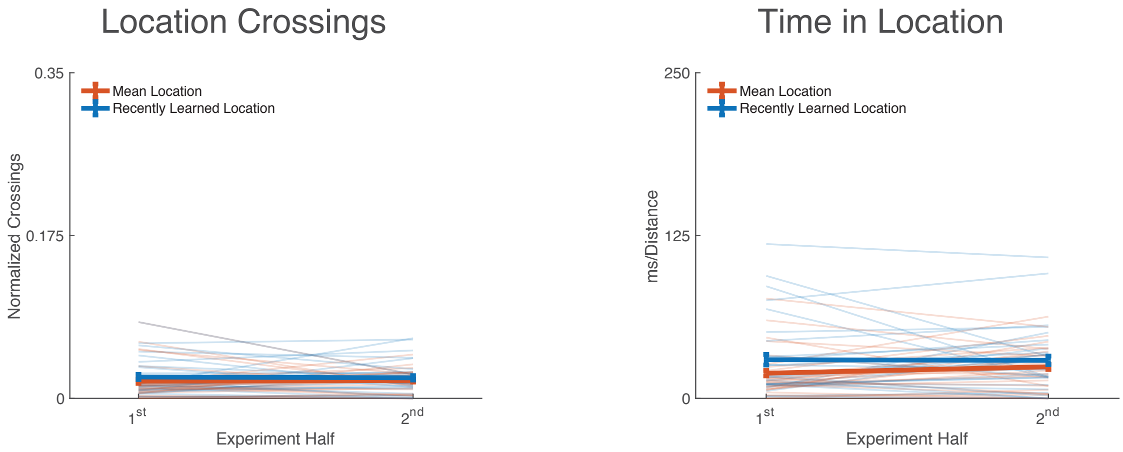

Fig. S 6. Human navigation through the 90° rotated control distribution. Light lines are individual participants, bold lines represent the mean, and error bars are ±1 within-subject SE.

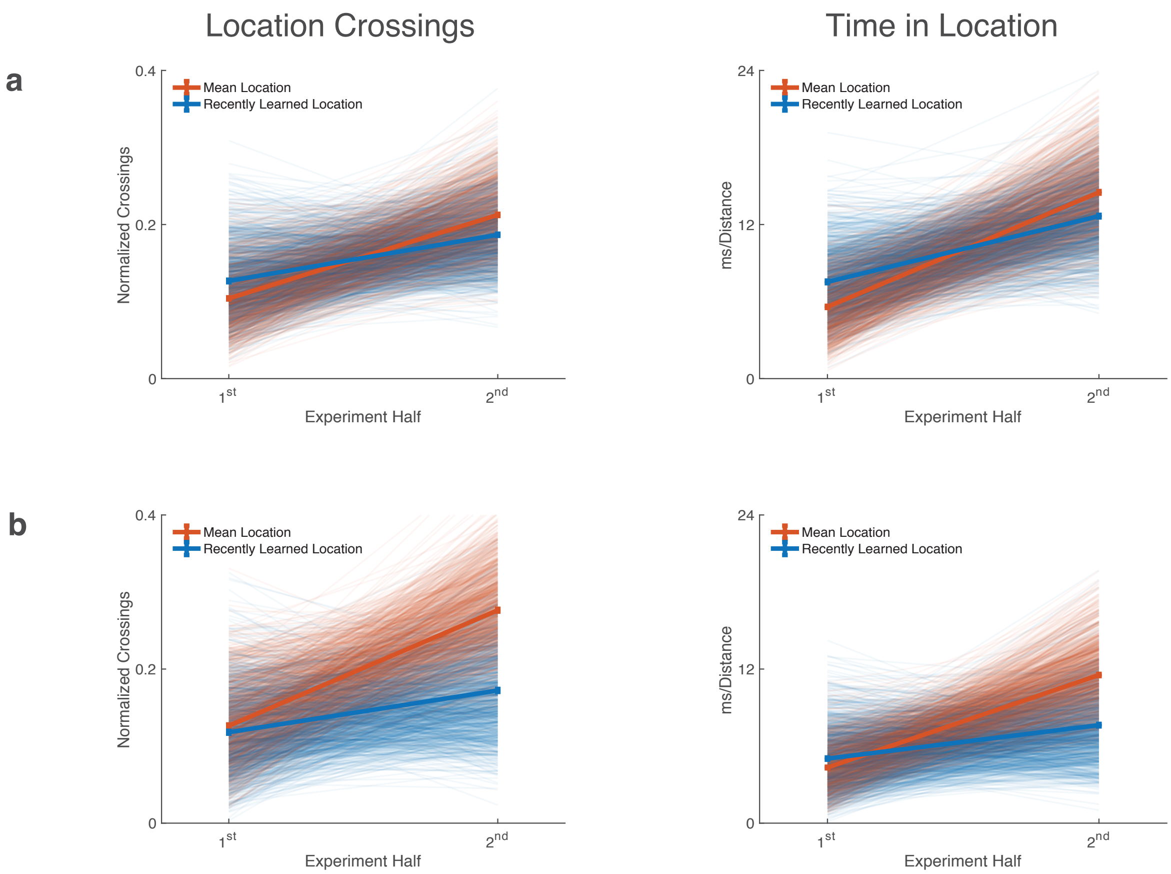

Fig. S 7. Simulated navigation through the true location distribution for the (a) episode model and (b) pattern model. Light lines are individual simulations, bold lines represent the mean, and error bars are ±1 within-agent SE.

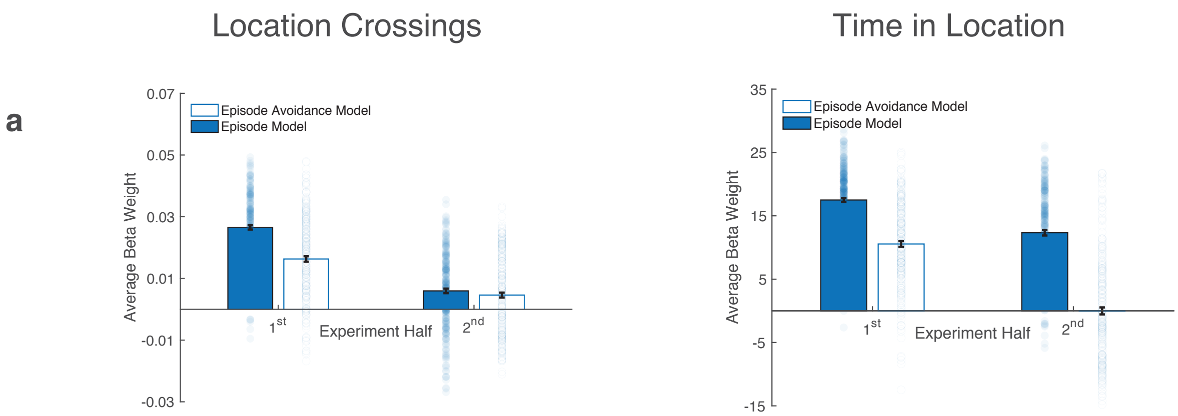

Fig. S 8. Average beta weights from 1000 bootstrapped regressions, using simulated agent performance under the episode model (solid blue) and the episode avoidance model (outlined blue) to predict human behavior in each experiment half. A subset of the individual beta weights (250) is visualized for each model. Error bars are 95% confidence intervals.

Supplemental Tables

Table S1. Randomization-based p values for crossings (x) and time points (t, per 40 ms) through the cumulative mean location (M), most recently learned location (L), first learned location (F), and a recency-weighted randomly sampled location (R), by experiment half.

	xM	**xL**	**xF**	**xR**	**tM**	**tL**	**tF**	**tR**
First Half	0.120	0.016	0.192	0.156	0.232	0.316	0.344	0.316
Second Half	0.020	0.016	0.120	0.028	0.020	0.236	0.268	0.228

Table S2. Raw numbers of crossings (x) and time points in location (t, per 40 ms) through the cumulative mean location (M) and most recently learned location (L), as well as the distance (Dist, arbitrary units) traveled for each participant (Sub), per experiment half.

	First Half					**Second Half**				
Sub	**xM**	**xL**	**tM**	**tL**	**Dist**	**xM**	**xL**	**tM**	**tL**	**Dist**
1	13	16	452	599	837.52	10	11	365	387	192.54
2	10	11	330	260	338.81	11	9	404	227	542.10
3	8	6	225	144	435.37	29	25	850	1146	1170.07
4	6	5	250	148	191.28	13	5	347	206	63.74
5	9	10	210	447	165.90	45	41	2418	2822	360.72
6	6	7	207	243	694.74	13	12	579	560	407.65
7	11	11	333	347	418.09	14	17	661	760	640.82
8	15	18	546	727	307.13	16	17	677	820	192.43
9	6	5	216	230	492.60	9	8	501	332	147.60
10	7	6	215	208	200.37	18	20	735	823	495.01
11	8	8	256	284	674.68	15	15	611	593	567.07
12	5	7	470	611	534	12	10	623	924	281.22
13	10	10	313	332	453.46	9	8	256	296	201.19
14	9	9	289	329	725.27	13	15	473	460	439.86
15	6	11	142	371	154.80	21	19	823	805	131.94
16	8	8	240	281	564.78	11	12	387	439	734.81
17	9	5	269	195	834.61	13	10	520	404	188.94
18	6	8	254	340	619.07	6	9	278	323	243
19	13	10	485	488	747.09	7	7	197	202	291.06
20	8	7	224	219	461.55	12	10	469	419	260.70
21	8	8	317	216	701.49	13	6	427	326	377.70
22	8	6	312	226	685.39	20	17	840	779	670.64
23	17	16	529	612	938.52	10	12	421	401	267.66
24	8	7	305	210	314.77	19	13	679	475	322.87
25	10	8	509	323	363.74	46	36	3663	4875	359.70
26	9	8	507	420	330.36	17	17	1372	951	446.76
27	8	11	245	347	592.32	14	12	648	454	134.58
28	12	11	505	425	680.99	17	9	584	347	484.48
29	8	7	296	158	297.36	12	12	616	565	297
30	5	8	169	306	313.58	15	15	639	578	408.21