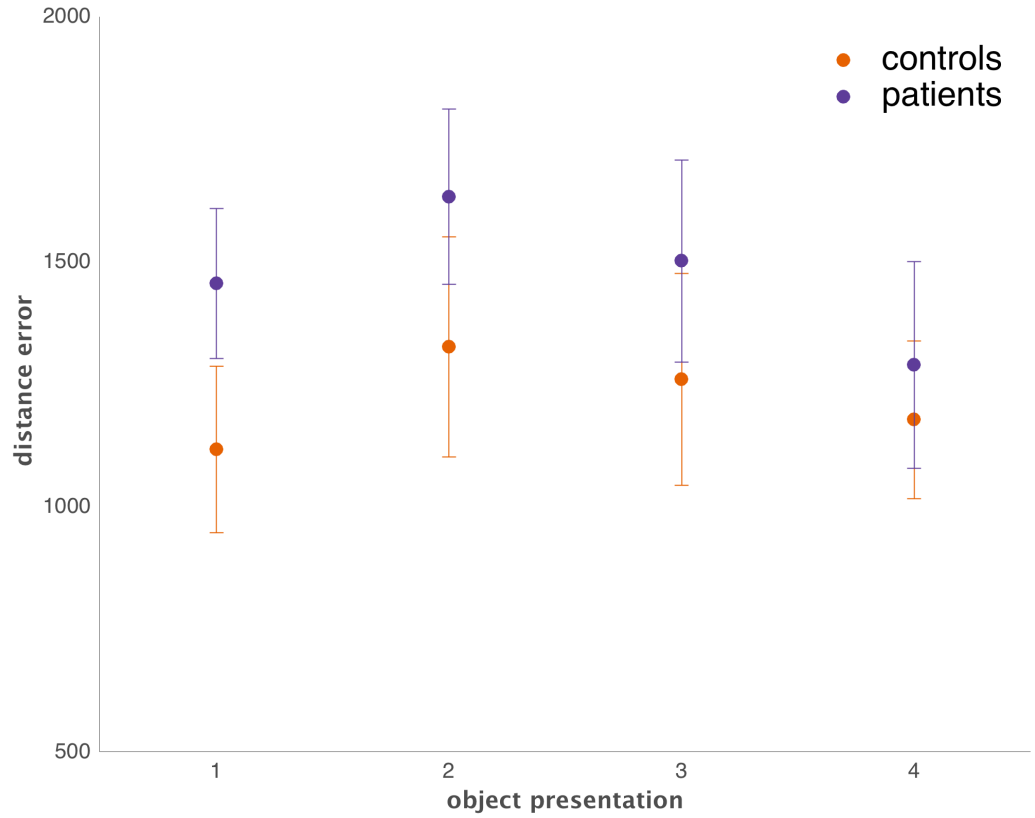

Figure S1. Related to Figure 4: Distance error (arbitrary units) for all objects during the first 4 presentations that constitute block 1. *Error bars indicate standard error. Mean distance error across the whole first block was not quite significantly greater for patients during this first block ($F_{1,38}$= 4.0279, p=0.0519). Note that the low distance error already from object presentation 1 reflects the fact that some learning had already taken place, since the location of each object was shown once to participants before they made their first response.*

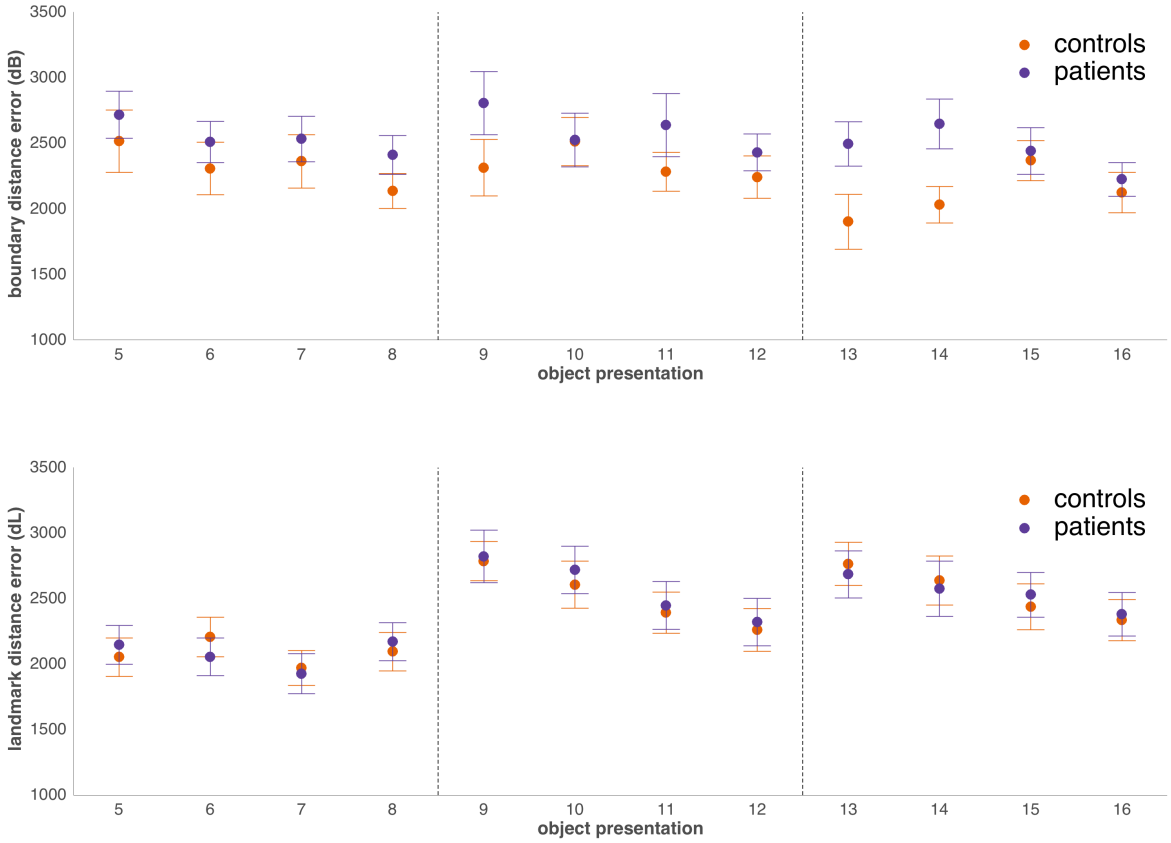

Figure S2. Related to Figure 4: Boundary (dB) and response (dL) distance error (arbitrary units) for all objects on trials across all object presentations in blocks 2-3, broken down with respect to error relative to either cue type's position in the previous block. *Dotted lines separate blocks. Error bars indicate standard error. Following object presentation 4, 8 and 12 (i.e. after block 1,2 and 3) the landmark moved in relation to boundaries of the arena. This movement allows us to establish to what extent object locations were learnt in relation to boundary cues or landmark cues on the most recent block. The distinguishability should be the greatest on the trials immediately following the movement of the landmark. Performance differences are not necessarily expected on the remaining trials, as performance based on the object's most recent location, with respect to either cue, would there be equivalent. Even so, when calculating the boundary and landmark distance error for each object on all trials in block 2-4, based on location in the most recent block, we still see group by distance error type interaction on mean distance error ($F_{1, 37.7} = 4.1524$, $p = 0.0486$) (see Table S14). Note that our main result it Figure 5 were calculated as the mean of distance error from object presentations 5, 9 and 13. These trials were selected, as in Doeller et al. (2008), since they cleanly dissociate performance based on which cue-type the location was remembered in relation to.*

Term	z	pValue	Estimate	SE
'(Intercept)'	7.254	0.000	1.530	0.211
'Reward'	4.413	0.000	0.365	0.083
'Rare'	0.564	0.573	-0.043	0.077
'zAge'	0.756	0.45	0.113	0.150
'zIQ'	1.073	0.283	0.161	0.150
'Patients'	0.375	0.708	0.112	0.300
'Reward:Rare'	3.334	1.E-03	-0.280	0.084
'Reward:zAge'	1.727	0.084	0.101	0.058
'Rare:zAge'	0.986	0.324	0.053	0.054
'Reward:zIQ'	0.917	0.359	0.055	0.060
'Rare:zIQ'	0.100	0.920	-0.006	0.056
'Reward:Patients'	1.242	0.214	0.147	0.119
'Rare:Patients'	0.318	0.751	-0.035	0.110
'Reward:Rare:zAge'	1.206	0.228	0.071	0.059
'Reward:Rare:zIQ'	1.225	0.221	-0.074	0.061
'Reward:Rare:Patients'	1.364	0.173	0.164	0.120

Table S1. Related to Figure 3: *Results from binomial mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Dependent variable is whether the participant stayed with the first same first level action as on the last trial. Reward variable is coded -1 for no reward and 1 for reward on most recent trial. Rare variable is coded -1 for common transition and 1 for rare transition on most recent trial. Patient variable is coded 0 for controls and 1 for patients. IQ and Age are z-scored.*

Parameter	Mean	2.5%	97.5%
β^{MB}_{cont}	0.33	0.10	0.55
β^{MF0}_{cont}	-0.06	-0.14	0.01
β^{MF1}_{cont}	0.30	0.15	0.46
β^{stick}_{cont}	1.16	0.78	1.54
β^{2stage}_{cont}	1.17	0.85	1.50
α_{cont}	0.26	0.18	0.38
$\beta^{MB}_{pat\_diff}$	-0.2	-0.52	0.13
$\beta^{MF0}_{pat\_diff}$	0.05	-0.05	0.15
$\beta^{MF1}_{pat\_diff}$	0.20	-0.02	0.42
$\beta^{stick}_{pat\_diff}$	0.25	-0.29	0.79
$\beta^{2stage}_{pat\_diff}$	-0.04	-0.49	0.41
α_{pat_diff}	0.07	-0.06	0.22

Table S2. Related Figure 3: *Estimates of free parameters (mean, 2.5% confidence interval and 97.5% confidence interval) from the full RL model (see STAR Methods), which includes age and IQ as covariates. Free parameters: β^{MB} - inverse temperature based on model-based Q values, β^{MF0} - inverse temperature based on TD0 model-free Q values, β^{MF1} - inverse temperature based on TD1 model-free Q values, β^{stick} - value-independent bias to stay or switch, α- learning rate. Cont indicates free-parameter estimates of the control group. Pat_diff indicates how patient group free parameter estimates differ from control group.*

Term	F	DF1	DF2	pValue	Estimate	SE
'(Intercept)'	221.834	1	59.633	0.000	2.22E+03	149.265
'zIQ'	13.035	1	45.635	1.0E-03	-332.574	92.116
'zAge'	4.054	1	45.560	0.05	186.298	92.528
'Patients'	12.086	1	59.516	1.0E-03	735.806	211.656
'L_Error '	0.176	1	110.824	0.676	-80.283	191.560
'B_Object'	0.004	1	173.462	0.950	-11.656	186.852
'zIQ: L_Error '	6.799	1	101.097	0.011	258.163	99.008
'zAge: L_Error '	7.878	1	101.025	0.006	-279.562	99.601
'Patients: L_Error '	7.997	1	110.729	0.006	-767.436	271.385
'Patients:B_Object'	3.924	1	173.562	0.049	-523.462	264.247
'L_Error:B_Object'	10.527	1	782.382	1.0E-03	829.469	255.653
'Patients:L_Error:B_Object'	2.643	1	782.108	0.104	587.775	361.565

Table S3. Related to Figure 5: *Results from linear mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Trials included are critical trials following landmark movements. Dependent variable is Distance Error. Dependent variable is Distance Error. Patient variable is coded 0 for Controls and 1 for Patients. L_Error variable is coded 0 for boundary distance error and 1 for landmark distance error. B_Object variable is coded 0 for landmark objects and 1 for boundary objects. Age and IQ are z-scored.*

Term	F	DF1	DF2	pValue	Estimate	SE
'(Intercept)'	275.3	1	39.476	0.000	2.22E+03	133.729
'zIQ'	15.285	1	39.421	0.000	-369.149	94.421
'zAge'	3.455	1	39.467	0.071	176.537	94.969
'Patients'	6.301	1	39.408	0.016	476.411	189.787
'L_Error'	5.327	1	97.877	0.023	330.305	143.115
'zIQ:L_Error'	7.822	1	97.748	0.006	282.572	101.034
'zAge:L_Error'	7.225	1	97.858	0.008	-273.188	101.633
'Patients:L_Error '	5.508	1	97.577	0.021	-476.522	203.034

Table S4. Related to Figure 5*: Results from linear mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Trials included are all critical trials following the movement of the landmark. Dependent variable is Distance Error. Patient variable is coded 0 for controls and 1 for patients. L_Error variable is coded 0 for boundary distance error and 1 for landmark distance error. IQ and Age are z-scored.*

Term	F	DF1	DF2	pValue	Estimate	SE
'(Intercept)'	939	1	432	0.000	0.458	0.015
'zIQ'	0.533	1	432	0.465	-0.012	0.017
'zAge'	1.786	1	432	0.182	0.021	0.016
'Patients'	8.213	1	432	0.004	0.060	0.021

Table S5. Related to Figure 5: *Results from linear mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Trials included are all critical trials following the movement of the landmark. Dependent variable is ratio dB/(dB+dL). Patient variable is coded 0 for controls and 1 for patients. IQ and Age are z-scored.*

Term	z	pValue	Estimate	SE
'(Intercept)'	6.838	0.000	1.549	0.227
'Reward'	4.536	0.000	0.407	0.090
'Rare'	0.158	0.874	0.013	0.081
'zIQ'	0.867	0.386	0.160	0.185
'Patients'	0.338	0.736	0.109	0.323
'Boundary'	0.045	0.969	-0.010	0.253
'Reward:Rare'	2.164	0.031	-0.187	0.087
'Reward:zIQ'	1.348	0.178	0.101	0.075
'Rare:zIQ'	0.729	0.466	0.050	0.068
'Reward:Patients'	0.378	0.706	0.049	0.129
'Rare:Patients'	0.612	0.540	-0.071	0.117
'Reward:Boundary'	0.443	0.658	0.047	0.106
'Rare:Boundary'	1.640	0.101	0.159	0.097
'Patients:Boundary'	0.266	0.790	-0.089	0.335
'Reward:Rare:zIQ'	0.411	0.681	0.030	0.072
'Reward:Rare:Patients'	0.490	0.624	0.061	0.125
'Reward:Rare:Boundary'	2.578	0.010	0.267	0.103
'Reward:Patients:Boundary'	0.699	0.484	0.096	0.137
'Rare:Patients:Boundary'	2.022	0.043	-0.253	0.125
'Reward:Rare:Patients:Boundary'	2.137	0.033	-0.285	0.133

Table S6. Related to Figure 6: *Results from binomial mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Dependent variable is whether the participant stayed with the first same first level action as on the last trial. Reward variable is coded -1 for no reward and 1 for reward on most recent trial. Rare variable is coded -1 for common transition and 1 for rare transition on most recent trial. Patient variable is coded 0 for controls and 1 for patients. Boundary is z-scored participant-wise mean boundary distance error. IQ is z-scored.*

Term	z	pValue	Estimate	SE
'(Intercept)'	1.628	0.103	1.915	1.176
'Ratio'	0.327	0.744	-0.828	2.536
'Reward'	0.071	0.947	-0.032	0.48
'Rare'	0.423	0.672	-0.186	0.44
'zIQ'	0.823	0.411	0.143	0.174
'Left'	0.773	0.439	-2.69	3.479
'Right'	0.141	0.887	-0.45	3.173
'Ratio:Reward'	0.853	0.394	0.882	1.035
'Ratio:Rare'	0.332	0.74	0.314	0.948
'Reward:Rare'	2.268	0.023	-1.054	0.465
'Reward:zIQ'	1.374	0.17	0.096	0.07
'Rare:zIQ'	0.032	0.976	0.002	0.064
'Tatio:Left'	0.769	0.442	5.309	6.905
'Reward:Left'	1.78	0.075	-2.678	1.505
'Rare:Left'	0.85	0.395	-1.176	1.384
'Ratio:Right'	0.221	0.826	1.393	6.316
'Reward:Right'	0.645	0.519	0.816	1.266
'Rare:Right'	0.743	0.458	0.858	1.155
'Ratio:Reward:Rare'	1.695	0.09	1.698	1.001
'Reward:Rare:zIQ'	0.228	0.82	-0.015	0.067
'Ratio:Reward:Left'	1.784	0.075	5.349	2.999
'Ratio:Rare:Left'	0.72	0.471	1.989	2.761
'Reward:Rare:Left'	1.124	0.261	-1.637	1.456
'Ratio:Reward:Right'	0.547	0.585	-1.373	2.512
'Ratio:Rare:Right'	0.706	0.48	-1.618	2.291
'Reward:Rare:Right'	1.558	0.119	1.907	1.224
'Ratio:Reward:Rare:Left'	1.126	0.26	3.272	2.904
'Ratio:Reward:Rare:Right'	1.473	0.141	-3.575	2.427

Table S7. Related to Figure 7 Bottom: *Results from binomial mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Dependent variable is whether the participant stayed with the first same first level action as on the last trial. Reward variable is coded -1 for no reward and 1 for reward on most recent trial. Rare variable is coded -1 for common transition and 1 for rare transition on most recent trial. Left variable is coded 1 for left lateralized patients and 0 otherwise. Right variable is coded 1 for right lateralized patients and 0 otherwise. Ratio variable is mean participant-wise estimate of ratio dB/(dB+dL). IQ is z-scored.*

Parameter	Mean	2.5%	97.5%
$\beta^{MB\text{-}dB}_{cont}$	-0.27	-0.52	-0.02
$\beta^{MF0\text{-}dB}_{cont}$	0.00	-0.08	0.07
$\beta^{MF1\text{-}dB}_{cont}$	0.12	-0.07	0.31
$\beta^{stick\text{-}dB}_{cont}$	-0.14	-0.59	0.31
$\beta^{2stage\text{-}dB}_{cont}$	-0.38	-0.73	-0.02
$\alpha\text{-}dB_{cont}$	0.47	0.35	0.59
$\beta^{MB\text{-}dB}_{pat\_diff}$	0.29	-0.05	0.64
$\beta^{MF0\text{-}dB}_{pat\_diff}$	-0.03	-0.15	0.09
$\beta^{MF1\text{-}dB}_{pat\_diff}$	-0.04	-0.30	0.22
$\beta^{stick\text{-}dB}_{pat\_diff}$	0.06	-0.53	0.65
$\beta^{2stage\text{-}dB}_{pat\_diff}$	0.51	0.03	0.98
$\alpha\text{-}dB_{pat\_diff}$	0.54	0.39	0.70

Table S8. Related to Figure 6: *Estimates (mean, 2.5% confidence interval and 97.5% confidence interval) of how boundary distance error (dB) predicts free parameters (see Table S2) in the full RL model (see STAR Methods), which includes IQ as a covariate. Cont indicates how dB predicts free parameter estimates of the control group. Pat_diff indicates difference in how dB predicts free parameter estimates in patient group compared to control group.*

Term	z	pValue	Estimate	SE
'(Intercept)'	7.351	0.000	1.525	0.207
'Reward'	4.429	0.000	0.362	0.082
'Rare'	0.671	0.502	-0.050	0.074
'zAge'	0.844	0.398	0.126	0.149
'zIQ'	1.055	0.291	0.156	0.148
'Left'	0.134	0.892	-0.050	0.365
'Right'	0.734	0.463	0.264	0.359
'Reward:Rare'	3.389	0.001	-0.281	0.083
'Reward:zAge'	1.802	0.072	0.105	0.058
'Rare:zAge'	1.168	0.243	0.061	0.052
'Reward:zIQ'	0.924	0.355	0.055	0.059
'Rare:zIQ'	0.152	0.879	-0.008	0.054
'Reward:Left'	0.542	0.588	0.078	0.144
'Rare:Left'	1.241	0.215	-0.161	0.130
'Reward:Right'	1.453	0.146	0.210	0.144
'Rare:Right'	0.647	0.518	0.085	0.131
'Reward:Rare:zAge'	1.264	0.206	0.075	0.059
'Reward:Rare:zIQ'	1.218	0.223	-0.074	0.060
'Reward:Rare:Left'	0.702	0.483	0.103	0.146
'Reward:Rare:Right'	1.472	0.141	0.216	0.146

Table S9. Related to Figure 7 Top: *Results from binomial mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Dependent variable is whether the participant stayed with the first same first level action as on the last trial. Reward variable is coded -1 for no reward and 1 for reward on most recent trial. Rare variable is coded -1 for common transition and 1 for rare transition on most recent trial. Left variable is coded 1 for left lateralized patients and 0 otherwise. Right variable is coded 1 for right lateralized patients and 0 otherwise. IQ and Age are z-scored.*

Term	F	DF1	DF2	pValue	Estimate	SE
'(Intercept)'	275.705	1	39.396	0.000	2.22E+03	133.658
'zIQ'	15.214	1	39.361	0.000	-368.380	94.444
'zAge'	3.232	1	39.567	0.080	173.229	96.358
'Left'	4.551	1	40.701	0.039	504.971	236.713
'Right'	3.817	1	38.445	0.058	448.983	229.822
'L_Error'	5.326	1	95.787	0.023	331.076	143.462
'zIQ:L_Error'	7.872	1	95.739	0.006	284.415	101.368
'zAge:L_Error'	7.345	1	96.441	0.008	-280.519	103.508
'Left:L_Error'	2.644	1	100.694	0.107	-415.528	255.541
'Right:L_Error'	4.635	1	92.218	0.034	-528.769	245.598

Table S10. Related to Figure 7 Middle: *Results from linear mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Trials included are all critical trials following the movement of the landmark. Dependent variable is Distance Error. Left variable is coded 1 for left lateralized patients and 0 otherwise. Right variable is coded 1 for right lateralized patients and 0 otherwise. L_Error variable is coded 0 for boundary distance error and 1 for landmark distance error. IQ and Age are z-scored.*

Term	z	pValue	Estimate	SE
'(Intercept)'	6.874	0.000	1.540	0.224
'Reward'	4.457	0.000	0.385	0.086
'Rare'	0.032	0.979	-0.002	0.078
'zIQ'	0.796	0.426	0.152	0.191
'Left'	0.045	0.966	-0.017	0.402
'Right'	0.600	0.548	0.230	0.382
'Boundary'	0.095	0.925	-0.024	0.253
'Reward:Rare'	2.479	0.013	-0.208	0.084
'Reward:zIQ'	0.780	0.436	0.060	0.077
'Rare:zIQ'	0.349	0.727	0.024	0.070
'Reward:Left'	0.418	0.676	-0.065	0.155
'Rare:Left'	1.422	0.155	-0.198	0.139
'Reward:Right'	1.087	0.277	0.165	0.151
'Rare:Right'	0.339	0.734	0.047	0.137
'Reward:Boundary'	0.063	0.950	0.006	0.104
'Rare:Boundary'	1.378	0.168	0.131	0.095
'Left:Boundary'	0.130	0.897	-0.056	0.431
'Right:Boundary'	0.077	0.938	-0.032	0.410
'Reward:Rare:zIQ'	0.214	0.830	-0.016	0.075
'Reward:Rare:Left'	0.197	0.844	-0.030	0.151
'Reward:Rare:Right'	1.047	0.295	0.154	0.147
'Reward:Rare:Boundary'	2.182	0.029	0.222	0.102
'Reward:Left:Boundary'	1.527	0.127	0.274	0.180
'Rare:Left:Boundary'	0.778	0.436	-0.128	0.164
'Reward:Right:Boundary'	0.095	0.926	0.015	0.161
'Rare:Right:Boundary'	1.905	0.057	-0.278	0.146
'Reward:Rare:Left:Boundary'	0.444	0.658	-0.078	0.176
'Reward:Rare:Right:Boundary'	2.563	0.010	-0.403	0.157

Table S11. Related to Figure 7 Bottom: *Results from binomial mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Dependent variable is whether the participant stayed with the first same first level action as on the last trial. Reward variable is coded -1 for no reward and 1 for reward on most recent trial. Rare variable is coded -1 for common transition and 1 for rare transition on most recent trial. Left variable is coded 1 for left lateralized patients and 0 otherwise. Right variable is coded 1 for right lateralized patients and 0 otherwise. Boundary is z-scored participant-wise mean boundary distance error. IQ is z-scored.*

Term	z	pValue	Estimate	SE
'(Intercept)'	1.519	0.129	2.489	1.638
'Reward'	0.268	0.789	0.180	0.669
'Rare'	0.817	0.414	-0.589	0.722
'zAge'	1.538	0.124	0.503	0.327
'zIQ'	0.411	0.681	-0.092	0.225
'Left'	0.341	0.734	-0.847	2.488
'HippLesion'	0.281	0.779	-0.007	0.027
'TotalLesion'	0.736	0.462	-0.552	0.751
'Reward:Rare'	2.921	0.004	-2.191	0.750
'Reward:zAge'	3.178	0.002	0.399	0.125
'Rare:zAge'	0.000	0.996	-0.001	0.137
'Reward:zIQ'	0.114	0.910	-0.010	0.089
'Rare:zIQ'	1.481	0.139	0.145	0.098
'Reward:Left'	1.333	0.182	1.295	0.971
'Rare:Left'	0.241	0.809	-0.255	1.056
'Reward:HippLesion'	0.813	0.416	0.009	0.011
'Rare:HippLesion'	0.879	0.379	0.010	0.012
'Left:HippLesion'	0.263	0.793	0.010	0.039
'Reward:TotalLesion'	1.932	0.053	-0.584	0.302
'Rare:TotalLesion'	0.859	0.390	-0.281	0.327
'Left:TotalLesion'	0.950	0.342	0.930	0.979
'Reward:Rare:zAge'	1.584	0.113	0.226	0.143
'Reward:Rare:zIQ'	1.231	0.218	0.123	0.100
'Reward:Rare:Left'	2.152	0.031	2.367	1.100
'Reward:Rare:HippLesion'	2.831	0.005	0.034	0.012
'Reward:Left:HippLesion'	1.595	0.111	-0.024	0.015
'Rare:Left:HippLesion'	0.126	0.898	-0.002	0.016
'Reward:Rare:TotalLesion'	2.372	0.018	-0.803	0.338
'Reward:Left:TotalLesion'	2.247	0.025	0.868	0.387
'Rare:Left:TotalLesion'	0.063	0.949	0.027	0.421
'Reward:Rare:Left:HippLesion'	2.508	0.012	-0.042	0.017
'Reward:Rare:Left:TotalLesion'	1.612	0.107	0.702	0.436

Table S12. Related to Figure 8: *Results from binomial mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Dependent variable is whether the participant stayed with the first same first level action as on the last trial. Reward variable is coded -1 for no reward and 1 for reward on most recent trial. Rare variable is coded -1 for common transition and 1 for rare transition on most recent trial. Left variable is coded 0 for right lateralized patients and 1 for left lateralized patients. Hippocampal Lesion size coded as percentage of hippocampus resected. Total lesion size, IQ and Age are z-scored.*

Term	F	DF1	DF2	pValue	Estimate	SE
'(Intercept)'	178.432	1	216	0.000	2.72E+03	203.290
'zIQ'	2.792	1	216	0.096	-187.932	112.466
'zAge'	0.726	1	216	0.395	132.151	155.072
'Left'	0.859	1	216	0.355	-241.008	260.111
'HippLesion'	1.734	1	216	0.189	17.540	13.320
'TotalLesion'	0.800	1	216	0.372	-323.655	361.816
'Left:HippLesion'	1.146	1	216	0.286	-20.570	19.220
'Left:TotalLesion'	0.073	1	216	0.787	-127.861	471.690

Table S13. Related to Figure 5: *Results from linear mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Trials included are all critical trials following the movement of the landmark. Dependent variable is Boundary Distance Error (dB). Left variable is coded 0 for right lateralized patients and 1 for left lateralized patients. Hippocampal Lesion size coded as percentage of hippocampus resected. Total lesion size, IQ and Age are z-scored.*

Term	F	DF1	DF2	pValue	Estimate	SE
'(Intercept)'	450.804	1	37.837	0.000	2.24E+03	105.348
'zIQ'	1.679	1	37.580	0.203	-162.853	125.666
'zAge'	0.008	1	37.991	0.928	10.466	115.567
'L_Error '	1.586	1	37.834	0.216	114.119	90.630
'Patients'	3.499	1	37.814	0.069	279.963	149.660
'zIQ:L_Error '	3.096	1	37.214	0.087	189.699	107.815
'zAge:L_Error '	0.633	1	38.183	0.431	-79.205	99.575
'L_Error:Patients'	4.152	1	37.771	0.049	-262.291	128.717

Table S14. Related to Figure 4: *Results from linear mixed regression model, with participant as random factor, implemented using Matlab function fitglme. Trials included are all trials in blocks 2-4. Dependent variable is Distance Error. Patient variable is coded 0 for Controls and 1 for Patients. L_Error variable is coded 0 for boundary distance error and 1 for landmark distance error. Age and IQ are z-scored.*