

Supplementary Information

Differential coding of goals and actions in ventral and dorsal corticostriatal circuits during goal-directed behavior

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SUPPLEMENTARY FIGURES

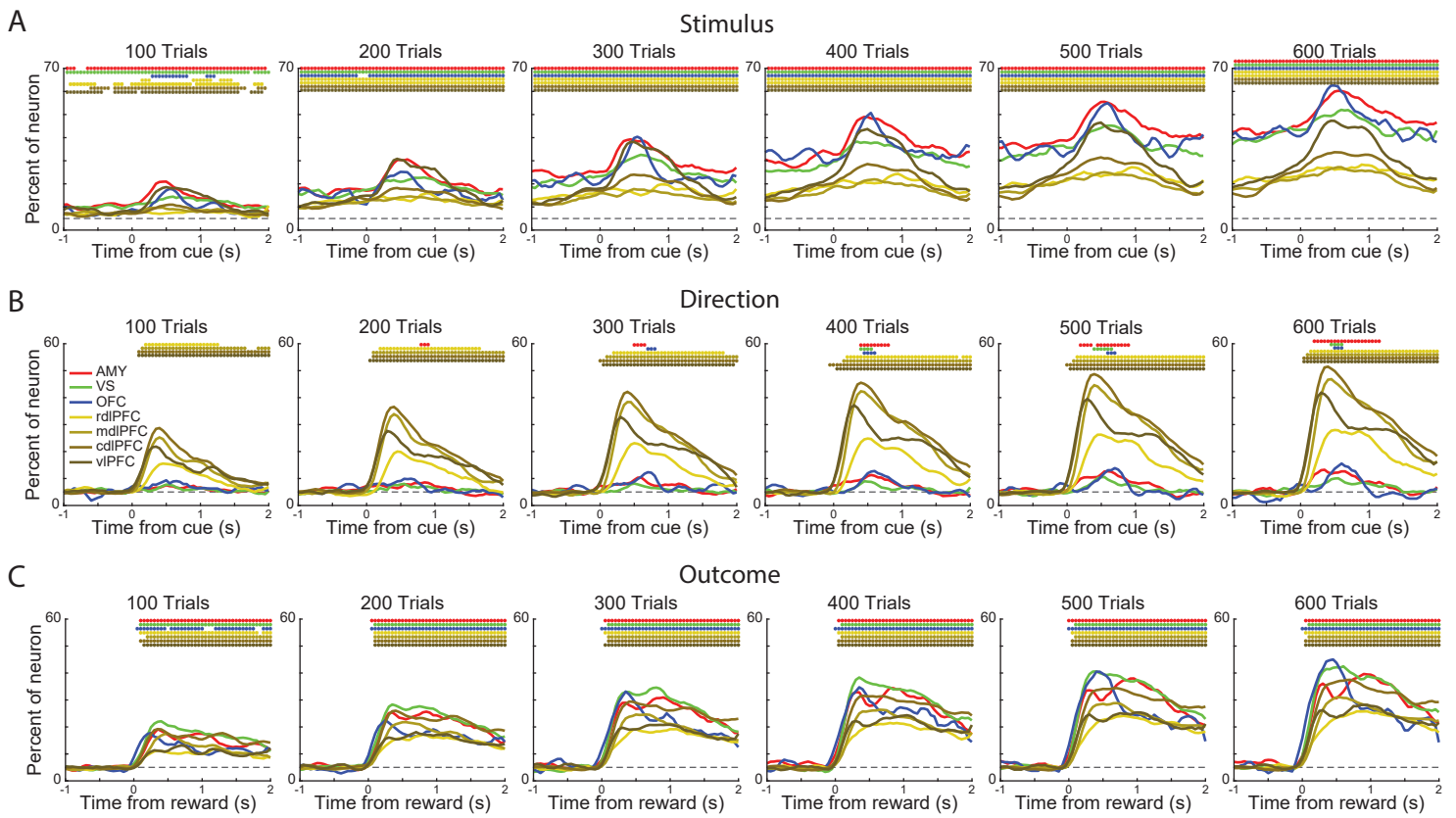


Figure S1. Population encoding of stimulus identity, direction and outcome, split by the different number of trials used.

Related to Figure 4.

(A-C) Percentage of responsive neurons in each area encoding the Stimulus identity (A), Direction (B) of the chosen option, and the Outcome on the current trial (C). Successive panels represent the different numbers (from 100 to 600) of trials since the start of the session used in this analysis. Conventions are the same as Figure 4.

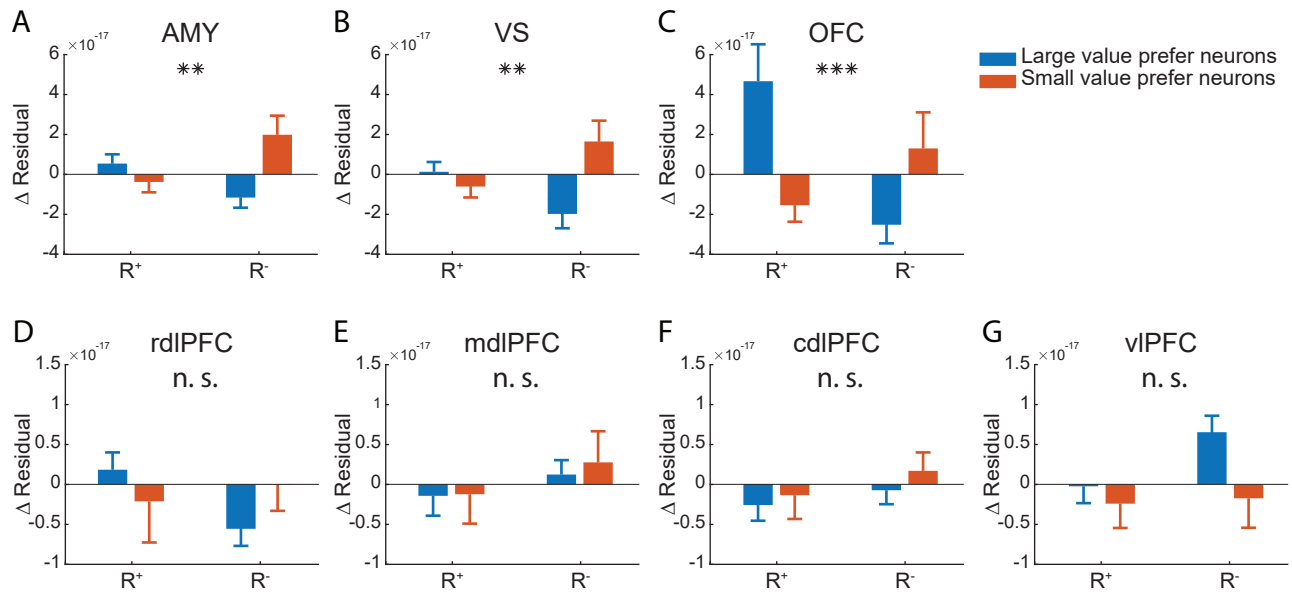


Figure S2. Hold period value signal is modulated by previous outcomes. *Related to Figure 5.*

(A-G) The influence of previous trial outcomes on value signal maintained by different groups of neurons during the hold period. Δ residual: difference of residual in the IEV-excluded ANOVA model between using the hold period activity on the current and previous trials. Large-/small- value-prefer neurons had higher/lower residuals in trials with a higher reward probability (*a priori* reward). R^+/R^- indicates rewarded/non-rewarded on the previous trial. Error bars represent SEM. 2-way ANOVA; ** $p < 0.01$, *** $p < 0.001$, n. s. - not significant.

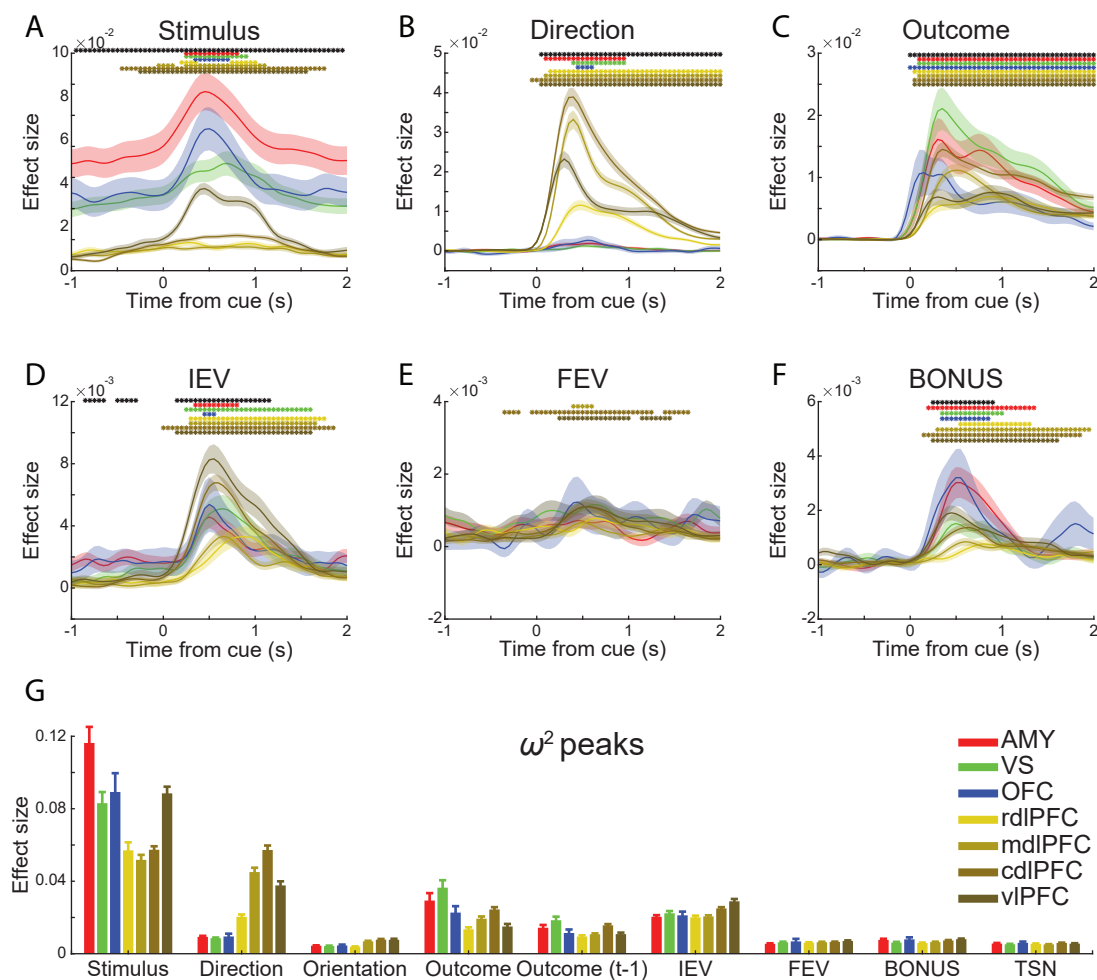


Figure S3. Population encoding of chosen stimulus, direction, outcome, and POMDP derived value signals, all neurons are included. *Related to Figures 4 and 5.*

(A-F) Mean effect size (ω^2) for all neurons encoding the chosen Stimulus (A), Direction (B), Outcome (C), IEV (D), FEV (E) and BONUS (F) of the chosen options.

(G) Mean peak value of effect size of all the recorded neurons in the amygdala, VS, OFC, and LPFC regions. Number of neurons used in the effect size analyses is indicated in Table S1. Conventions are the same as Figure 5.

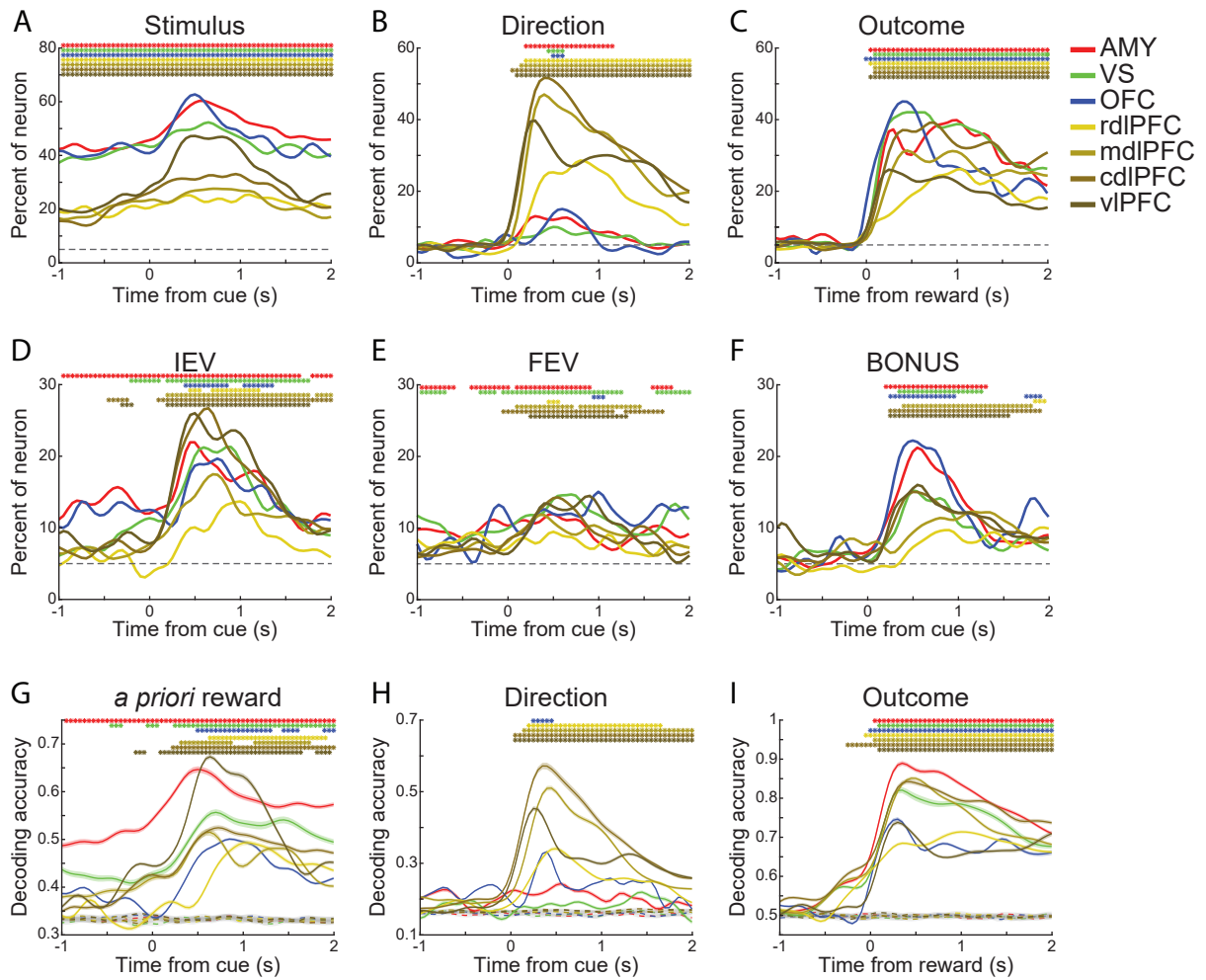


Figure S4. Population coding of chosen stimulus, direction, outcome, and POMDP derived value signals, using only one session of PFC data from each monkey. Related to Figures 4-6.

(A-F) Percentage of responsive neurons in each area encoding the Stimulus (A), Direction (B) of the chosen option, and the Outcome on the current trial (C), IEV (D), FEV (E) and BONUS (F) of the chosen options. Conventions are the same as Figure 4.

(G-I) The time course of mean decoding accuracy of *a priori* assigned reward value of choices (D), the saccade Direction (E), and the Outcome on the current trial (F) using a pseudo-population of 100 neurons. Results were averaged from 100 repetitions, $n = 100$. Conventions are the same as Figure 6.

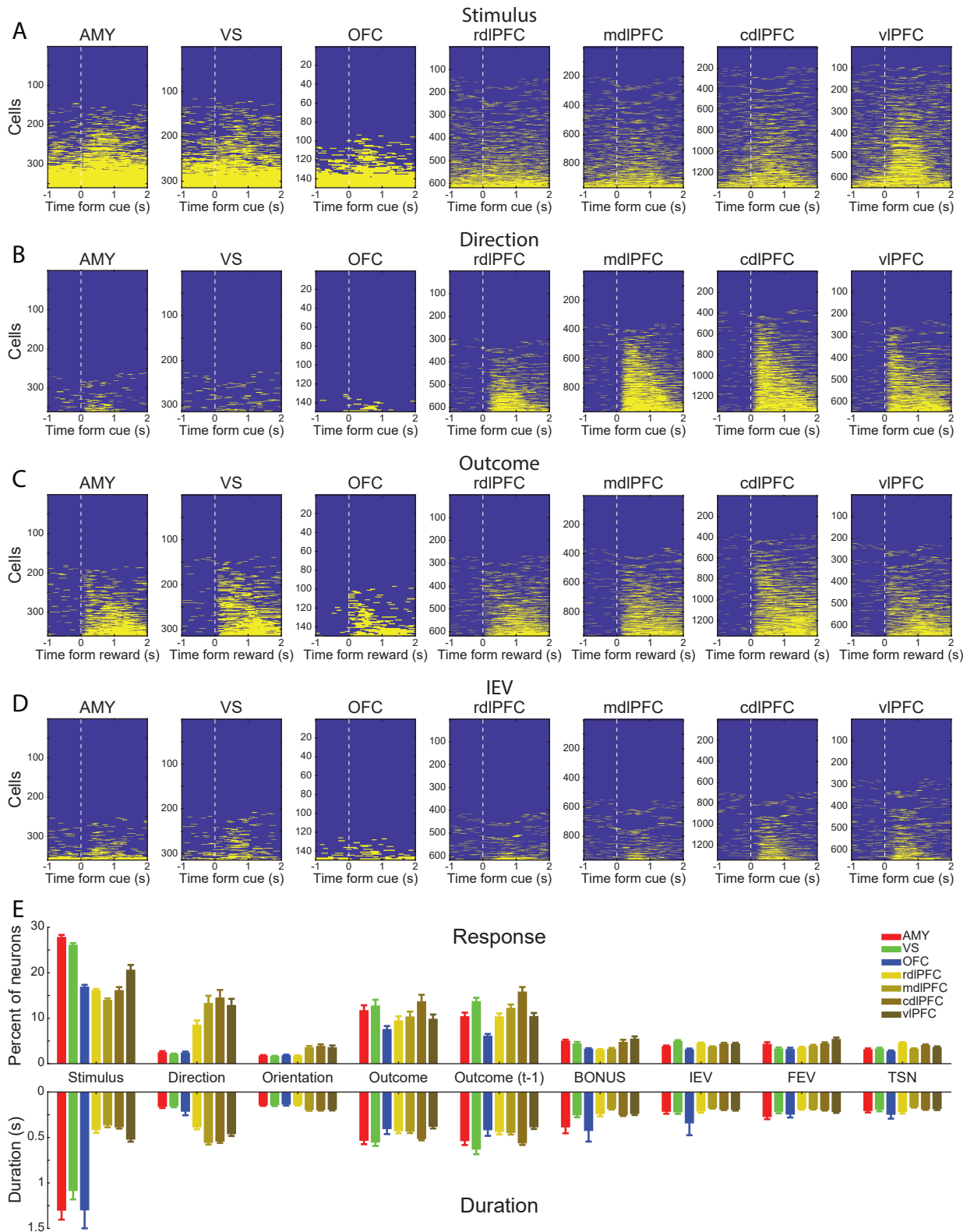


Figure S5. Duration and strength of the representation of task factors. *Related to Figures 4 and 5.*

(A-D) Factors represented by every single neuron, plotted along the time course of a trial. Chosen Stimulus (A), Direction (B), Outcome (C), and IEV (D) are displayed separately. Each row represents a single neuron. The yellow horizontal bars represent the responsive time zones.

(E) Mean response strength (top) and duration (bottom) of the nine factors in the amygdala, VS, OFC, and LPFC regions. Error bars represent SEM.

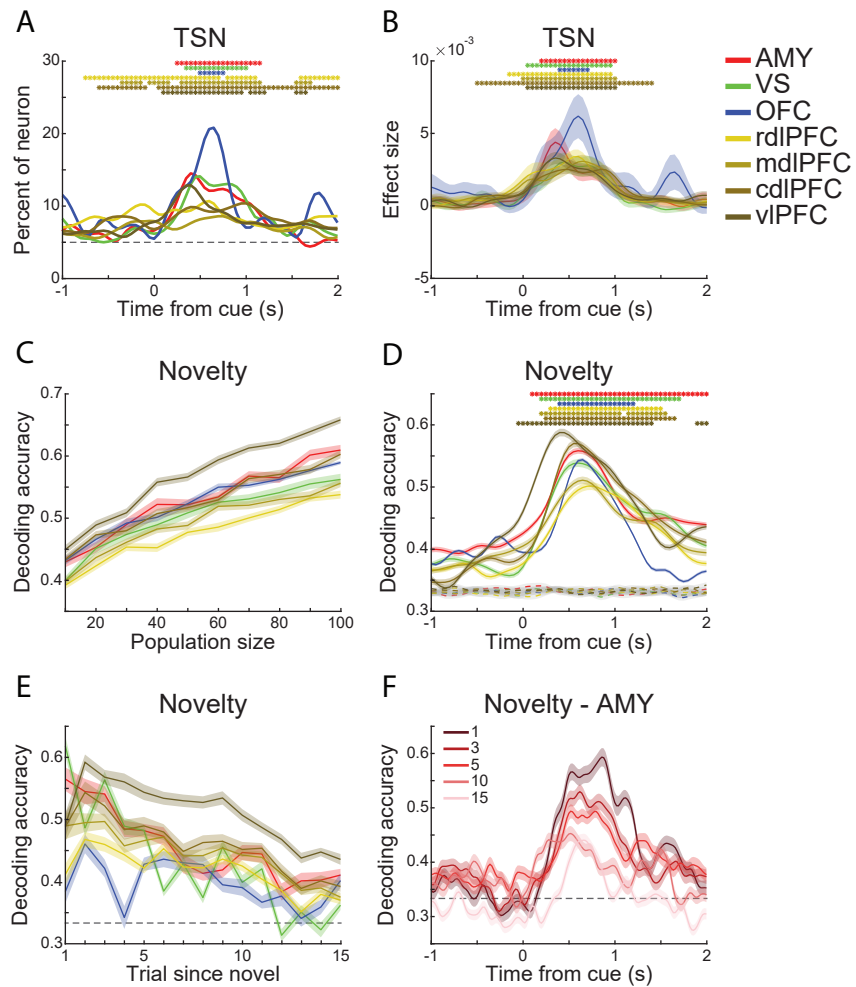


Figure S6. Population coding and decoding of novelty choices. Related to Figures 5-7.

(A-B) Percentage of responsive neurons (A) and their mean effect size (B) in each region for the encoding of whether the monkey had chosen the novel, best or worst alternative option. Conventions are the same as Figure 5.

(C) Decoder accuracy in predicting which option was chosen as a function of pseudo-population size for each region.

(D) Time course of mean decoding accuracy.

(E) Mean decoder performance (250 to 750 ms after stimulus onset) predicts which option was chosen as a function of the number of trials since a novel option was introduced.

(F) For the amygdala, the time course of mean decoding accuracy of chosen the novel, best or worst alternative options using the 1st, 3rd, 5th, 10th, 15th trials since introducing a novel option.

(D-F) A pseudo-population of 100 neurons was used in each condition. Conventions are the same as Figure 6.

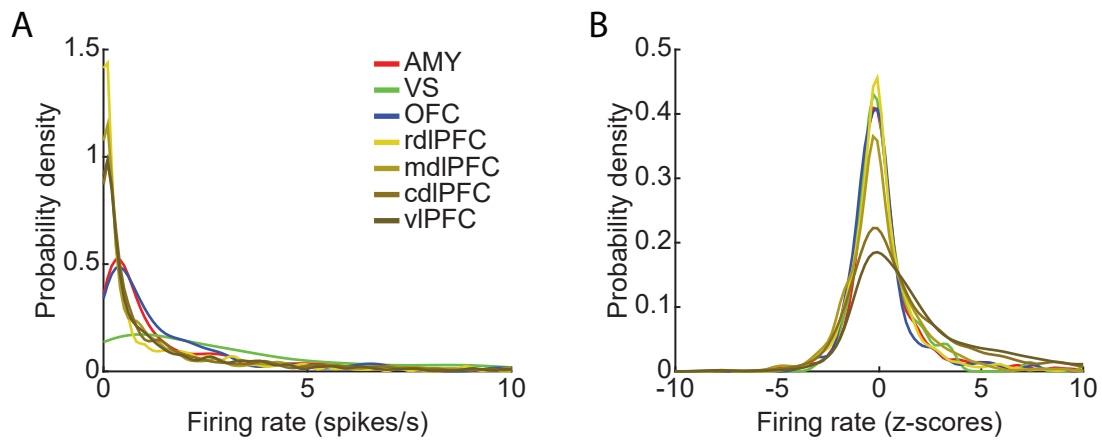


Figure S7. Distribution of raw and z-scored firing rate of single-cell responses to choice options. *Related to STAR Methods.*

Neuronal activities were collected from 0 to 1000 ms after stimulus onset. (A) Raw firing rate, (B) z-scored activity. The distributions are created by sorting the single-cell activities into 40 bins, then fitted with the kernel smoothing function.

SUPPLEMENTARY TABLES

Table S1. Number of neurons recorded by area and monkey. Related to Figure 1.

Monkey	Area						
	Amygdala	Ventral Striatum	OFC	rdLPFC	mdLPFC	cdLPFC	cvLPFC
F	59	60	47	-	-	-	-
H	208	177	14	-	-	-	-
N	93	77	88	-	-	-	-
V	-	-	-	208	412	564	473
W	-	-	-	427	568	811	192
Total	360	314	149	635	980	1375	665

Table S2. Chi-square test for the percentage of neurons encoding stimulus, direction, outcome, and values. Related to Figures 4 and 5.

Area 1	Area 2	df	samples	Stimulus		Direction		Outcome		IEV		FEV		BONUS	
				X ²	p	X ²	p	X ²	p	X ²	p	X ²	p	X ²	p
AMY	VS	1	674	0.27	0.603	1.87	0.171	2.67	0.102	2.80	0.095	0.20	0.657	2.48	0.116
AMY	OFC	1	509	0.07	0.788	0.00	0.979	0.66	0.418	0.01	0.909	0.09	0.764	0.17	0.684
AMY	rdIPFC	1	995	36.48	< 0.001	16.80	< 0.001	11.44	0.001	8.61	0.003	0.62	0.431	17.43	< 0.001
AMY	mdIPFC	1	1340	55.23	< 0.001	76.02	< 0.001	1.74	0.187	11.02	0.001	1.17	0.279	12.64	< 0.001
AMY	cdIPFC	1	1735	61.84	< 0.001	102.15	< 0.001	0.44	0.507	10.56	0.001	0.29	0.593	4.88	0.027
AMY	vlPFC	1	1025	33.38	< 0.001	42.80	< 0.001	7.00	0.008	4.98	0.026	0.24	0.628	1.04	0.308
VS	OFC	1	463	0.01	0.940	0.85	0.357	0.08	0.778	1.10	0.294	0.00	1.000	2.29	0.130
VS	rdIPFC	1	949	27.60	< 0.001	27.80	< 0.001	28.05	0.000	0.53	0.468	1.73	0.189	4.20	0.040
VS	mdIPFC	1	1294	42.61	< 0.001	91.43	< 0.001	11.38	0.001	0.78	0.377	2.71	0.100	1.65	0.199
VS	cdIPFC	1	1689	47.41	< 0.001	118.39	< 0.001	2.14	0.144	0.50	0.478	1.25	0.264	0.00	0.996
VS	vlPFC	1	979	24.92	< 0.001	56.58	< 0.001	20.98	< 0.001	0.01	0.938	1.03	0.309	0.79	0.373
OFC	rdIPFC	1	784	11.48	0.001	5.44	0.020	8.93	0.003	2.85	0.092	0.66	0.416	10.35	0.001
OFC	mdIPFC	1	1129	16.50	< 0.001	23.43	< 0.001	2.76	0.097	3.32	0.069	0.97	0.326	7.02	0.008
OFC	cdIPFC	1	1524	17.37	< 0.001	30.78	< 0.001	0.27	0.604	2.91	0.088	0.42	0.519	3.07	0.080
OFC	vlPFC	1	814	10.25	0.001	13.61	< 0.001	6.27	0.012	1.49	0.222	0.39	0.534	1.13	0.287
rdIPFC	mdIPFC	1	1615	1.23	0.268	46.64	< 0.001	8.74	0.003	0.02	0.881	0.10	0.753	1.34	0.247
rdIPFC	cdIPFC	1	2010	1.57	0.210	80.19	< 0.001	33.87	< 0.001	0.01	0.904	0.20	0.655	8.80	0.003
rdIPFC	vlPFC	1	1300	0.13	0.716	12.81	< 0.001	0.91	0.339	0.74	0.389	0.15	0.694	14.83	< 0.001
mdIPFC	cdIPFC	1	2355	0.01	0.936	4.43	0.035	10.54	0.001	0.10	0.748	0.81	0.369	4.46	0.035
mdIPFC	vlPFC	1	1645	2.32	0.128	9.62	0.002	3.84	0.050	1.24	0.265	0.58	0.448	10.13	0.001
cdIPFC	vlPFC	1	2040	2.89	0.089	26.40	< 0.001	23.60	< 0.001	0.82	0.366	0.00	0.994	2.18	0.140

Table S3. Number of responsive neurons recorded in each area by factor. *Related to Figures 4 and 5.*

Factor	amygdala	VS	OFC	rdlPFC	mdlPFC	cdlPFC	vlPFC
Stimulus	173	162	52	292	454	769	439
Direction	56	33	12	233	525	867	350
Orientation	31	29	11	76	241	397	194
Outcome	144	146	48	251	452	783	312
Outcome (t-1)	104	105	24	201	349	602	242
TSN	57	56	16	115	149	273	148
IEV	63	71	17	82	195	393	229
FEV	57	69	13	108	177	346	154
BONUS	78	57	26	121	198	362	200
Intersection*	210	206	62	507	816	1220	586

* The number of neurons responding to at least one factor.

Table S4. The frequency of chosen options across two consecutive trials, grouped by *a priori* reward probability. Related to Figure 7.

Switch rate (%)		Current chosen Stimulus		
		Best	Medium	Worst
Previous chosen Stimulus	Best	18.67	11.36	10.79
	Medium	11.44	10.47	8.73
	Worst	10.66	8.88	9.01