Supplementary Information

Inverse reinforcement learning reveals action-oriented value signals in naturalistic decision making

Supplementary Results

Association between prior experience and task performance

We conducted exploratory analysis of the post-experimental survey to examine associations between prior driving or gaming experience and highway task performance. Data from a total 44 participants were included in the analysis.

Survey responses were systematically coded. Binary items were coded as 1 (*yes*) and 0 (*no*), while frequency and duration items were coded on ordinal numeric scales reflecting increasing levels (e.g., driving frequency: 1 = *less than once a month*, 5 = *nearly every day*; gaming frequency: 1 = *less than once per month*, 3 = *every day*). Open-ended responses were manually assigned to the appropriate category. Group differences based on binary experience were assessed using Welch's t-tests. We found no significant difference in task scores between participants with (n = 21, M = 872.93, SD = 222.98) and without (n = 23, M = 845.71, SD = 199.68) driving experience, $t(40.35)$ = 0.425, p = 0.673. Similarly, scores did not significantly differ between participants with (n = 34, M = 873.37, SD = 217.28) and without (n = 10, M = 808.83, SD = 155.38) gaming experience, $t(42)$ = 1.01, p = 0.33. Further comparisons by specific gaming genres revealed no significant differences in task performance between participants with and without experience in a given genre (with experience: Action: n = 34, Racing: n = 32, Sports: n = 32, Role-playing: n = 36, Others: n = 19; all ps > 0.34; **Supplementary Table 1**).

Finally, we assessed correlations using Spearman's rank correlation given the ordinal nature of these variables. Task score was not significantly associated with driving frequency ($\rho = 0.156$, $p = 0.311$), or duration of driving experience ($\rho = 0.113$, $p = 0.461$). Likewise, the breadth of gaming experience, defined as the total number of game genres a participant reported playing, was not significantly associated with task scores ($\rho = 0.101$, $p = 0.516$). Furthermore, we examined the correlations between task score and the frequency or duration of play at the individual genre level; no significant correlations were found (all *p*s > 0.2; **Supplementary Table 2**).

Supplementary Table 1. Comparison of highway task scores on experience with specific game genres. One person could be included in multiple game genres. The total number of participants was 44. The table shows the mean highway task scores categorized by participants' experience on each game genre. For each genre, an independent-samples Welch's t-test was used to compare the scores between the two groups.

Game genre	**mean score (SD)**			
	with experience	**without experience**	***t***	***p***
Action	832.59 (213.06)	866.38 (204.08)	-0.43	.68
Racing	842.16 (215.53)	864.91 (202.863)	-0.31	.76
Sports	875.04 (207.34)	852.58 (206.04)	0.31	.76
Role-playing	883.23 (234.16)	853.25 (199.61)	0.32	.76
Others	884.78 (217.23)	824.40 (186.34)	0.98	.34

Supplementary Table 2. Correlations between task score and gaming experience metrics within each genre. This table presents the results of Spearman's rank correlation analyses between task score and frequency of play and duration per session.

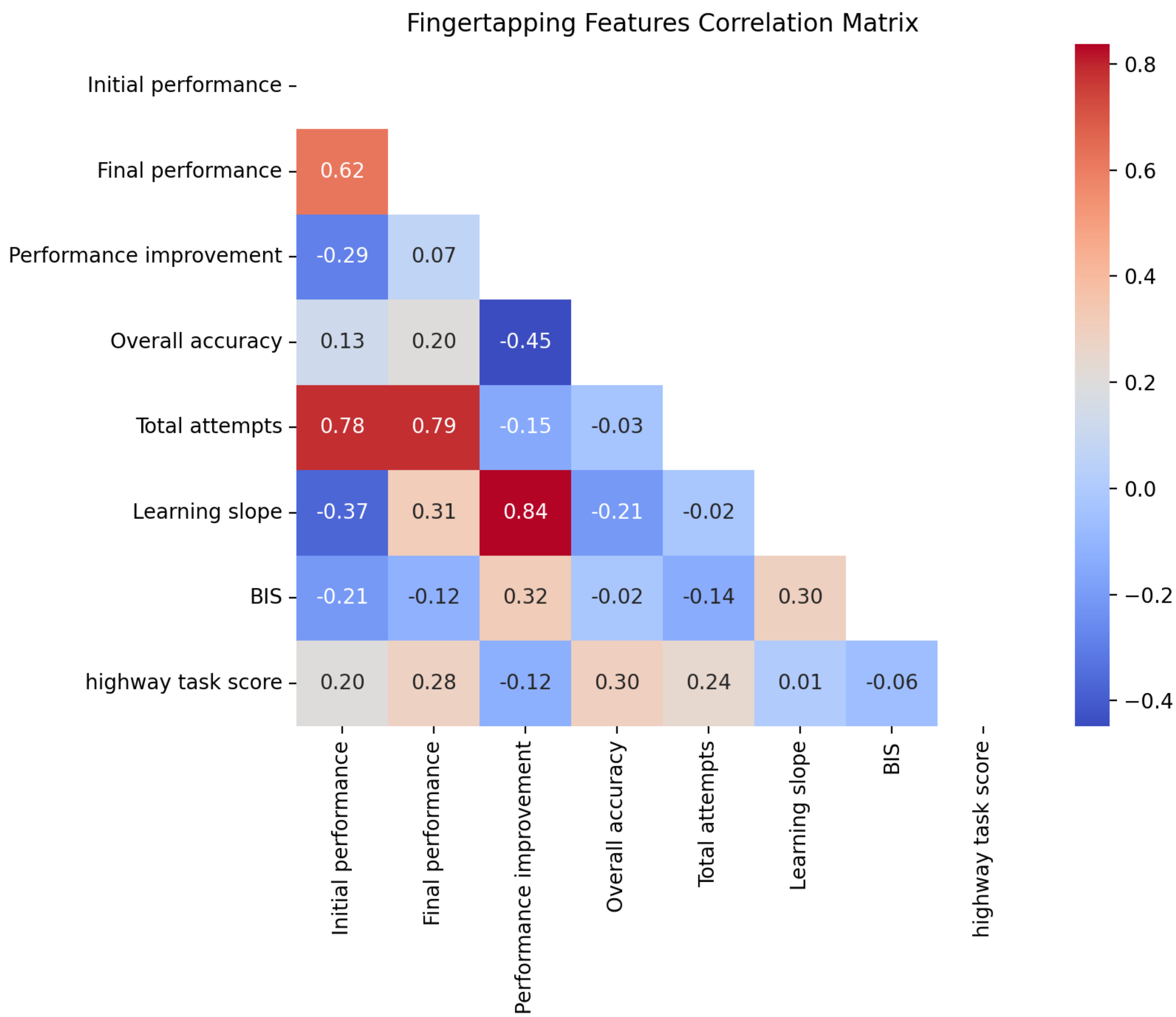
Game genre	**frequency**		**duration per session**	
	ρ	***p***	***ρ***	***p***
Action	0.01	.92	0.05	.74
Racing	0.04	.80	0.06	.71
Sports	0.07	.64	0.05	.75
Role-playing	0.02	.87	0.04	.77
Others	0.15	.32	0.19	.21

Association between motor ability and task performance

To investigate the association between motor ability and highway task performance, an exploratory analysis was conducted. Data from a total 44 participants were included in the analysis. Motor ability was quantified using five features derived from the fingertapping task: (1) *Initial performance*: the number of correct chunks in the first trial, (2) *Final performance*: the number of correct chunks in the last trial, (3) *Performance improvement*: the relative improvement in performance, calculated as the absolute gain (mean number of correct chunks in last three trials - that of first three trials) normalized by the mean of the first three trials, (4) *Overall accuracy*: the proportion of correct chunks relative to across trials (number of correct chunks / total number of attempted chunks), (5) Total attempts: number of total typed numbers, regardless of accuracy, (6) *Slope*: the slope from linear regression fitted to the number of chunks across 12 trials.

Given the intercorrelation among these features (**Supplementary Fig. 1**), a feature selection process was first performed using Lasso regression with 5-fold cross-validation to mitigate potential multicollinearity. All features were standardized prior to the Lasso analysis. Three predictors identified non-zero coefficients: *Final performance*, *Performance improvement*, and *Overall accuracy*. To examine whether the selected features could predict highway task performance, a multiple linear regression analysis using ordinary least squares (OLS) was conducted using the three predictors. None of the individual predictors significantly predicted task performance (all *p*s > .1). The results indicate the absence of a clear linear association between motor ability and highway task performance (**Supplementary Table 3**).

In addition, we examined whether BIS score predicted highway task performance. A simple linear regression revealed that BIS was not a significant predictor (Model 1; β = -13.173, p = .68). To control for the potential influence of motor ability, a multiple regression was conducted including the three fingertapping features as covariates. In this model, BIS remained a non-significant predictor (Model 2; β = 0.684, p = .98), indicating that BIS did not predict highway task performance even after accounting for individual differences in motor ability (**Supplementary Table 4**).



Supplementary Figure 1. Correlation matrix of fingertapping variables with BIS and mean highway task score. Correlations were computed with Pearson correlation.

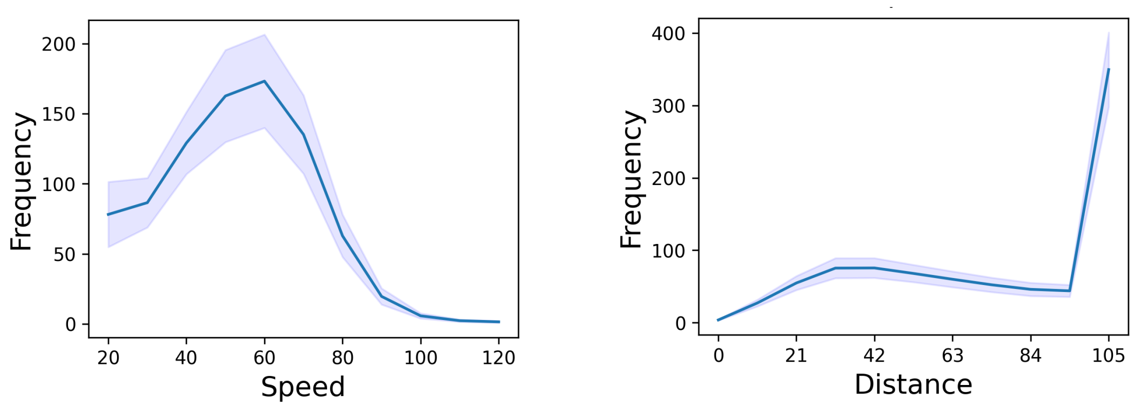
Supplementary Table 3. Results of the multiple linear regression model predicting the mean highway task score. Predictors selected from lasso regression were standardized and included into the OLS regression model. $F(3,40) = 2.415$, $p = .081$, adj-R^2 = 0.090.

	β	**95% CI**	t	p
Overall accuracy	42.263	[-24.907, 109.432]	1.272	.21
Performance improvement	-24.982	[-90.880, 40.916]	-0.766	.45
Final performance	50.956	[-11.528, 113.441]	1.648	.11

Supplementary Table 4. Results of the regression models predicting the mean highway task score with BIS and fingertapping task features. Model 1: simple linear regression; Model 2: multiple linear regression including fingertapping task features. Model 1: $F(1,42) = 0.172$, $p = .68$, adj-$R^2 = -0.020$); Model 2: $F(4,39) = 1.767$, $p = .16$, adj-$R^2 = 0.067$.

	β	**95% CI**	***t***	***p***
Model 1				
BIS	-13.173	[-77.233, 50.887]	-0.415	.68
Model 2				
BIS	0.684	[-64.664, 66.031]	0.021	.98
Overall accuracy	42.164	[-26.565, 110.893]	1.241	.22
Performance improvement	-25.220	[-95.791, 45.350]	-0.723	.47
Final performance	51.068	[-13.151, 115.287]	1.608	.12

Supplementary Figures and Tables



Supplementary Figure 2. Frequency distribution of (a) participant's speed and (b) distance from the car ahead in the highway task across all subjects. Speed > 100 accounts for less than 0.4% of the data.

Supplementary Table 5. Full list of GLM clusters peaks for overtaking and crash contrasts (N=45). For each event type, subject-level beta maps were submitted to a group-level one-sample t-test against zero. Coordinates (X,Y,Z) are reported in MNI152 space. Voxels were thresholded at $p < 0.01$ Bonferroni-corrected across the whole brain, with a minimum cluster extent of 100 voxels. Sub-peaks that could not be assigned to a labeled region in AAL2, as well as duplicate sub-peaks falling within the same anatomical region as another sub-peak in the cluster, were omitted, retaining the sub-peak with the largest absolute t-value. Cluster peaks that were not labeled in AAL2 were replaced by the sub-peak with the largest absolute t-value within the same cluster (marked with an asterisk).

		cluster peak				
	ROI	**X**	**Y**	**Z**	***t***	**Cluster Size (mm^3)**
Overtaking						
	Cerebellum IX (R)	10.0	-56.0	-44.0	15.834948	39224
	Superior parietal gyrus (R)	18.0	-60.0	58.0	13.784118	
	Paracentral lobule (L)	-12.0	-14.0	76.0	13.779321	36768
	Superior frontal gyrus (R)	26.0	2.0	60.0	12.795658	
	Precentral gyrus (L)	-18.0	-12.0	74.0	12.769328	
	Middle frontal gyrus (R)	30.0	0.0	52.0	12.223913	
	Middle occipital gyrus (L)	-28.0	-82.0	22.0	14.733875	24712
	Superior parietal gyrus (L)	-30.0	-58.0	58.0	13.459487	

Caudate (L)	-8.0	10.0	4.0	11.614848	13560
Putamen (L)	-22.0	6.0	-10.0	11.185341	
Inferior frontal triangular (R) *	36.0	22.0	10.0	9.809741	8416
Putamen (R)	24.0	12.0	6.0	9.724011	
Caudate (R)	18.0	18.0	4.0	9.383140	
Precuneus (L)	-6.0	-56.0	42.0	-8.337656	2680
Precuneus (R)	2.0	-50.0	36.0	-8.137155	
Middle occipital gyrus (R)	40.0	-66.0	4.0	9.673705	1400
Cerebellum VIII (L)	-22.0	-52.0	-48.0	9.742180	1248
Angular gyrus (L)	46.0	-62.0	26.0	-8.051478	872
Parahippocampal gyrus (L)	-28.0	-32.0	-18.0	-9.515575	840
Hippocampus (L)	-30.0	-22.0	-18.0	-8.182460	
Insula (R)	42.0	-14.0	14.0	-9.695752	816
Crash					
Fusiform (R)	36.0	-66.0	-14.0	16.976770	102544
Hippocampus (R)	24.0	-30.0	-4.0	15.006371	
Cuneus (L)	-6.0	-86.0	28.0	14.609423	
Calcarine fissure (L)	-6.0	-74.0	16.0	13.787267	
Postcentral gyrus (R)	42.0	-24.0	48.0	10.633245	11720
Putamen (L) *	-18.0	6.0	-10.0	-13.253072	9800
Caudate (L)	-10.0	6.0	-12.0	-10.337922	
Putamen (R)	22.0	8.0	-10.0	-15.414958	8696
Anterior cingulate cortex (L)	-6.0	40.0	18.0	9.621293	4808
Middle cingulate cortex (L)	-2.0	18.0	36.0	7.373085	
Superior frontal gyrus (medial; L)	-2.0	48.0	32.0	6.964084	
Superior frontal gyrus (medial; R)	8.0	30.0	58.0	11.200533	3832
Supplementary motor area (R)	8.0	22.0	60.0	9.127370	
Supplementary motor area (L)	0.0	18.0	60.0	8.718455	
Middle cingulate cortex (L)	-6.0	-38.0	48.0	10.062043	3152
Middle cingulate cortex (R)	4.0	-32.0	42.0	8.177912	
Middle cingulate cortex (R)	6.0	-20.0	30.0	10.460085	3088
Rolandic Operculum (R)	40.0	-12.0	20.0	9.745925	2520
Insula (R)	36.0	-16.0	12.0	9.305426	
Postcentral (L)	-26.0	-40.0	74.0	9.840838	2360
Supramarginal gyrus (L)	-60.0	-52.0	32.0	12.369618	2032

Paracentral lobule (L)	-14.0	-20.0	72.0	-8.871484	1704
Precentral gyrus (L)	-30.0	-12.0	54.0	-8.126646	
Angular gyrus (R)	36.0	-62.0	48.0	9.398784	1592
Insula (L)	-36.0	-18.0	10.0	9.051588	1000
Rolandic Operculum (L)	-44.0	-22.0	18.0	8.073177	
Inferior parietal gyrus (L)	-36.0	-66.0	48.0	7.455056	808

Supplementary Table 6. Full list of beta coefficients for the elastic net model predicting full trajectory. Coefficients in the top 10% by absolute value are marked with an asterisk. For Cerebellum Crus I–II, Cerebellum III–X and Vermis I–X, subregions were combined, and the minimum and maximum beta values across subregions are reported.

ROI	Beta Coefficient (left/right)
Precentral gyrus	-0.000633/0.000062
Superior frontal gyrus	0.000233/0.000179
Middle frontal gyrus *	-0.001081/0.000270
Inferior frontal opercular	left: 0.000482
Inferior frontal triangular	0.000333/0.000208
IFG pars orbitalis	-0.000051/0.000016
Rolandic Operculum	0.000036/-0.000321
Supplementary motor area	0.000011/0.000355
Olfactory cortex	-0.000037/0.000064
Superior frontal gyrus (medial)	0.000372/-0.000095
Superior frontal gyrus (medial orbital)	-0.000139/0.000289
Gyrus rectus	-0.000090/0.000059
Medial orbital gyrus	0.000369/-0.000105
Anterior orbital gyrus	-0.000032/0.000014
Posterior orbital gyrus	-0.000058/0.000037
Lateral orbital gyrus	0.000183/0.000198
Insula	0.000326/0.000597
Anterior cingulate cortex	-0.000228/0.000044
Middle cingulate cortex	-0.000384/-0.000068
Posterior cingulate cortex	-0.000364/-0.000345
Hippocampus	-0.000274/-0.000770
Parahippocampal gyrus	0.000093/-0.000121
Amygdala	-0.000092/-0.000153
Calcarine fissure *	0.000370/-0.001044

Cuneus *	-0.000748/0.000046
Lingual gyrus	0.000272/0.000215
Superior occipital gyrus	0.000599/0.000602
Middle occipital gyrus *	-0.000597/0.001309
Inferior occipital gyrus	-0.000645/-0.000415
Fusiform gyrus *	-0.000012/0.001602
Postcentral gyrus *	-0.000960/0.001146
Superior parietal gyrus	0.000605/-0.000426
Inferior parietal gyrus	0.000282/-0.000125
Supramarginal gyrus	0.000342/0.000281
Angular gyrus	0.000022/0.000036
Precuneus	0.000681/0.000249
Paracentral lobule	-0.000611/0.000144
Caudate	0.000635/0.000364
Putamen *	-0.000316/-0.000838
Pallidum	-0.000077/0.000026
Thalamus	right: -0.000296
Heschl's gyrus	-0.000257/-0.000062
Superior temporal gyrus	-0.000037/-0.000270
Temporal pole (superior temporal gyrus)	0.000054/-0.000093
Middle temporal gyrus	-0.000399/0.000486
Temporal Pole (middle temporal gyrus)	left: -0.000052
Inferior temporal gyrus *	-0.000143/-0.002128
Cerebellum Crus I–II	left: [-0.000665, 0.000705] right: [0.000038, 0.000161]
Cerebellum III–X *	left: [-0.000186, 0.000963] right: [-0.000672, 0.000781]
Vermis I–X	[-0.000137, 0.000309]

Supplementary Table 7. Correlations between Neurosynth-based reward BOLD signals and BOLD signals in selected ROIs. The same elastic net pipeline used in the main analysis was repeated with the IRL reward replaced by the mean BOLD signal across voxels within the Neurosynth meta-analytic "reward" mask. Correlations from regions that had non-zero beta coefficients and significant correlation (Bonferroni-corrected $p < 0.01$) are shown. The number of significant ROIs was markedly reduced compared to the main analysis, although the functional associations were consistent. Negative correlations were observed in the orbitofrontal cortex only in crash, and positive correlations were observed in the putamen, instead of the caudate in overtaking.

ROI	Overtaking (left/right r)	crash (left/right r)
Olfactory cortex	right: 0.81	—
Amygdala	left: 0.82	—
Inferior occipital gyrus	right: -0.93	left: 0.85
Putamen	0.85/0.85	—
Pallidum	left: 0.85	—
Frontal medial orbital cortex	—	right: -0.80
Gyrus rectus	—	left: -0.90
Medial orbitofrontal cortex	—	right: -0.91
Anterior orbitofrontal cortex	—	right: -0.87
Lateral orbitofrontal cortex	—	left: -0.80
Supramarginal gyrus	—	right: 0.77
Paracentral lobule	—	right: 0.79