Reinforcement learning with associative or discriminative generalization across states and actions: fMRI at 3 T and 7 T

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Supporting Information:
Supplementary Figures and Tables
| Model         | df | Absolute Dev. | AICc | Residual Dev. | AICc |
|---------------|----|---------------|------|---------------|------|
| Chance        | 0  | 501.26        | 501.26 | -11.46        | -3.35 |
| Intercept     | 1  | 497.80        | 499.81 | -8.00         | -1.90 |
| Hysteresis    | 4  | 489.80        | 497.91 | 0             | 0     |
| A0 | S0  | 5  | 427.99        | 438.16 | 61.81         | 59.76 |
| A- | S0  | 5  | 434.12        | 444.30 | 55.67         | 53.62 |
| AX | S0  | 6  | 422.57        | 434.81 | 67.23         | 63.10 |
| A0 | S+  | 5  | 485.94        | 496.11 | 3.86          | 1.80  |
| A0 | S-  | 5  | 432.66        | 442.83 | 57.14         | 55.08 |
| A0 | SY  | 6  | 422.67        | 434.91 | 67.12         | 63.01 |
| A- | S+  | 5  | 487.87        | 498.04 | 1.93          | -0.13 |
| A- | S-  | 5  | 444.43        | 454.60 | 45.37         | 43.31 |
| AW | SW  | 6  | 421.49        | 433.73 | 68.31         | 64.18 |
| AX | SY  | 7  | **419.25**    | **433.57** | **70.55**    | **64.34** |
| AX | SY | Z  | 8  | 417.92        | 434.33 | 71.88         | 63.58 |
| SPE           | 5  | 453.01        | 463.18 | 36.79         | 34.73 |
| SPE+RL       | 7  | 421.59        | 435.91 | 68.21         | 62.00 |
| HMM0          | 5  | 468.23        | 478.41 | 21.56         | 19.51 |
| HMM           | 6  | 439.55        | 451.79 | 50.25         | 46.12 |
| HMM0+RL      | 7  | 426.46        | 440.78 | 63.34         | 57.13 |
| HMM+RL       | 8  | 420.13        | 436.54 | 69.67         | 61.37 |
**Table S1. Model comparison: 3-T Face/House version (Good-learner group).** Listed first for 3 nonlearning models and 17 learning models fitted to empirical data are absolute scores for deviance and the corrected Akaike information criterion (AICc) (where a lower score is better). These absolute scores were translated to residual goodness of fit relative to the hysteresis model (where a higher score is better). Winning results determined by the AICc are highlighted with boldface and italics. “df” stands for degrees of freedom. This table is related to Figure 3. The conventions for displaying this table also apply for Tables S2-S15.
| Model          | df | Absolute Dev. | AICc | Residual Dev. | AICc |
|---------------|----|---------------|------|---------------|------|
| Chance        | 0  | 489.05        | 489.05 | -39.39        | -31.27 |
| Intercept     | 1  | 469.39        | 471.41 | -19.73        | -13.62 |
| Hysteresis    | 4  | 449.67        | 457.78 | 0             | 0     |
| A0 | S0   | 5  | 425.49        | 435.67 | 24.17        | 22.12 |
| A- | S0   | 5  | 438.05        | 448.22 | 11.62        | 9.56  |
| AX | S0   | 6  | 424.63        | 436.88 | 25.03        | 20.90 |
| A0 | S+   | 5  | 446.84        | 457.01 | 2.83         | 0.77  |
| A0 | S-   | 5  | 446.79        | 456.97 | 2.87         | 0.82  |
| A0 | SY   | 6  | 423.03        | 435.28 | 26.64        | 22.51 |
| A- | S+   | 5  | 446.13        | 456.30 | 3.54         | 1.48  |
| A- | S-   | 5  | 448.97        | 459.15 | 0.69         | -1.36 |
| AW | SW   | 6  | 422.23        | 434.48 | 27.44        | 23.31 |
| AX | SY   | 7  | 420.73        | 435.06 | 28.94        | 22.73 |
| AX | SY | Z   | 8  | 420.12        | 436.54 | 29.55        | 21.24 |
| SPE           | 5  | 449.56        | 459.74 | 0.10          | -1.96 |
| SPE+RL       | 7  | 425.46        | 439.79 | 24.20         | 17.99 |
| HMM0         | 5  | 445.87        | 456.05 | 3.79          | 1.73  |
| HMM          | 6  | 445.37        | 457.61 | 4.30          | 0.17  |
| HMM0+RL      | 7  | 425.40        | 439.73 | 24.26         | 18.05 |
| HMM+RL       | 8  | 424.46        | 440.88 | 25.21         | 16.90 |
Table S2. Model comparison: 3-T Face/House version (Poor-learner group). This table is related to Figure 3.
| 3-T Face/House Nonlearner ($n = 7$) | Absolute | Residual |
|------------------------------------|----------|----------|
| Model df                          | Dev. AICc | Dev. AICc |
| Chance 0                          | 481.64 481.64 | -28.92 -20.80 |
| Intercept 1                       | 468.01 470.03 | -15.29 -9.19 |
| Hysteresis 4                      | 452.72 460.84 | 0 0 |
| A0 | S0 5                   | 452.50 462.68 | 0.22 -1.84 |
| A- | S0 5                   | 452.51 462.69 | 0.21 -1.85 |
| AX | S0 6                   | 452.42 464.67 | 0.31 -3.83 |
| A0 | S+ 5                   | 452.52 462.70 | 0.20 -1.86 |
| A0 | S- 5                   | 452.53 462.71 | 0.19 -1.87 |
| A0 | SY 6                   | 452.12 464.37 | 0.60 -3.53 |
| A- | S+ 5                   | 452.43 462.61 | 0.29 -1.77 |
| A- | S- 5                   | 452.48 462.66 | 0.24 -1.82 |
| AW | SW 6                   | 452.06 464.31 | 0.66 -3.47 |
| AX | SY 7                   | 451.26 465.60 | 1.46 -4.76 |
| AX | SY | Z 8                   | 450.51 466.94 | 2.21 -6.10 |
| SPE 5                             | 452.51 462.69 | 0.21 -1.85 |
| SPE+RL 7                          | 452.37 466.71 | 0.35 -5.87 |
| HMM0 5                            | 452.44 462.62 | 0.28 -1.77 |
| HMM 6                             | 452.31 464.56 | 0.42 -3.72 |
| HMM0+RL 7                         | 452.50 466.84 | 0.22 -6.00 |
| HMM+RL 8                          | 452.21 468.64 | 0.51 -7.80 |
Table S3. Model comparison: 3-T Face/House version (Nonlearner group). Nonlearners were defined as such in cases where the hysteresis model provided the best fit post-correction.
### 7-T Color/Motion

#### Empirical data

| Model       | df | Absolute Dev. | AICc  | Residual Dev. | AICc  |
|-------------|----|---------------|-------|---------------|-------|
| Chance      | 0  | 478.79        | 478.79| -17.13        | -9.01 |
| Intercept   | 1  | 470.80        | 472.82| -9.14         | -3.04 |
| Hysteresis  | 4  | 461.66        | 469.78| 0             | 0     |
| A0 | S0 | 5  | 423.83        | 434.01| 37.83         | 35.77 |
| A- | S0 | 5  | 404.11        | 414.29| 57.55         | 55.49 |
| AX | S0 | 6  | 399.51        | 411.76| 62.15         | 58.02 |
| A0 | S+ | 5  | 457.19        | 467.37| 4.47          | 2.41  |
| A0 | S- | 5  | 419.36        | 429.54| 42.30         | 40.24 |
| A0 | SY | 6  | 409.20        | 421.45| 52.47         | 48.33 |
| A- | S+ | 5  | 459.62        | 469.80| 2.04          | -0.02 |
| A- | S- | 5  | 421.81        | 431.99| 39.85         | 37.79 |
| AW | SW | 6  | 404.13        | 416.39| 57.53         | 53.40 |
| AX | SY | 7  | **396.84**    | **411.17**| **64.82**  | **58.61** |
| AX | SY | 7  | **396.84**    | **411.17**| **64.82**  | **58.61** |
| SPE        | 5  | 433.90        | 444.08| 27.76         | 25.70 |
| SPE+RL     | 7  | 407.90        | 422.23| 53.76         | 47.55 |
| HMM0       | 5  | 453.50        | 463.68| 8.16          | 6.10  |
| HMM        | 6  | 422.17        | 434.42| 39.39         | 35.36 |
| HMM0+RL    | 7  | 422.06        | 436.40| 39.60         | 33.38 |
| HMM+RL     | 8  | 407.47        | 423.91| 54.19         | 45.87 |
Table S4. Model comparison: 7-T Color/Motion version (Good-learner group). This table is related to Figure 4.
| Empirical data | Poor learner (n = 5) |
|---------------|----------------------|
| Model | df | Absolute Dev. | AICc | Residual Dev. | AICc |
| | | | |
| Chance | 0 | 447.50 | 447.50 | -50.57 | -42.43 |
| Intercept | 1 | 428.76 | 430.78 | -31.83 | -25.71 |
| Hysteresis | 4 | 396.93 | 405.06 | 0 | 0 |
| A0 | S0 | 5 | 393.22 | 403.42 | 3.71 | 1.64 |
| A- | S0 | 5 | 394.36 | 404.56 | 2.57 | 0.51 |
| AX | S0 | 6 | 391.58 | 403.86 | 5.35 | 1.20 |
| A0 | S+ | 5 | 391.06 | 401.26 | 5.87 | 3.80 |
| A0 | S- | 5 | 394.82 | 405.02 | 2.11 | 0.04 |
| A0 | SY | 6 | 387.78 | 400.06 | 9.15 | 5.00 |
| A- | S+ | 5 | 392.46 | 402.66 | 4.47 | 2.41 |
| A- | S- | 5 | 394.99 | 405.19 | 1.94 | -0.13 |
| AW | SW | 6 | 387.72 | 400.00 | **9.21** | **5.06** |
| AX | SY | 7 | 386.62 | 401.00 | 10.31 | 4.07 |
| AX | SY | Z | 8 | 384.06 | 400.55 | 12.87 | 4.51 |
| SPE | 5 | 394.81 | 405.01 | 2.12 | 0.05 |
| SPE+RL | 7 | 391.80 | 406.18 | 5.13 | -1.12 |
| HMM0 | 5 | 396.71 | 406.91 | 0.22 | -1.84 |
| HMM | 6 | 394.83 | 407.11 | 2.10 | -2.05 |
| HMM0+RL | 7 | 393.22 | 407.60 | 3.71 | -2.54 |
| HMM+RL | 8 | 391.81 | 408.30 | 5.12 | -3.23 |
Table S5. Model comparison: 7-T Color/Motion version (Poor-learner group). This table is related to Figure 4.
Figure S1. Discriminability of the GRL model: 3-T Face/House version. Compare to Figure 3. Each fitted instantiation of the 7-parameter “generalized reinforcement learning” (GRL) model (“AX I SY”) was used to simulate a data set yoked to that of the respective subject. Replications of the results from the original model comparison were achieved with these simulations as a demonstration of the discriminability of this preferred model with its additional degrees of freedom. This figure is related to Tables S6-S8.
| 3-T Face/House AX | SY sim. | Good learner \(n=31\) | Absolute | Residual |
|-------------------|--------|------------------------|----------|----------|
| Model             | df     | Dev.       | AICc     | Dev.       | AICc     |
| Chance            | 0      | 501.26     | 501.26   | -14.25    | -6.14    |
| Intercept         | 1      | 496.29     | 498.30   | -9.29     | -3.18    |
| Hysteresis        | 4      | 487.01     | 495.12   | 0         | 0        |
| A0 | S0      | 5      | 423.30     | 433.47   | 63.71     | 61.65    |
| A- I S0           | 5      | 425.33     | 435.51   | 61.67     | 59.61    |
| AX | S0      | 6      | 414.55     | 426.79   | 72.46     | 68.33    |
| A0 | S+      | 5      | 481.62     | 491.80   | 5.38      | 3.32     |
| A0 | S-      | 5      | 431.04     | 441.21   | 55.96     | 53.90    |
| A0 | SY      | 6      | 414.51     | 426.75   | 72.49     | 68.36    |
| A- I S+           | 5      | 484.09     | 494.26   | 2.92      | 0.86     |
| A- I S-           | 5      | 438.90     | 449.07   | 48.11     | 46.05    |
| AW | SW      | 6      | 410.90     | 423.14   | 76.10     | 71.98    |
| AX | SY      | 7      | 408.68     | 423.01   | **78.32** | **72.11**|
| AX | SY | Z       | 8      | 408.32     | 424.73   | 78.69     | 70.38    |
| SPE               | 5      | 447.36     | 457.53   | 39.64     | 37.58    |
| SPE+RL            | 7      | 414.00     | 428.32   | 73.01     | 66.80    |
| HMM0              | 5      | 467.64     | 477.81   | 19.37     | 17.31    |
| HMM               | 6      | 435.28     | 447.52   | 51.73     | 47.60    |
| HMM0+RL           | 7      | 421.33     | 435.65   | 65.67     | 59.46    |
| HMM+RL            | 8      | 414.09     | 430.51   | 72.91     | 64.61    |
Table S6. Discriminability of the GRL model: 3-T Face/House version (Good-learner group). This table is related to Figure S1.
| Model          | df | Absolute Dev. | AICc  | Residual Dev. | AICc  |
|----------------|----|---------------|-------|---------------|-------|
| Chance         | 0  | 489.05        | 489.05| -42.53        | -34.41|
| Intercept      | 1  | 461.11        | 463.12| -14.58        | -8.48 |
| Hysteresis     | 4  | 446.53        | 454.64| 0             | 0     |
| A0 | S0  | 5  | 418.93        | 429.11| 27.60         | 25.54 |
| A- | S0  | 5  | 427.58        | 437.76| 18.94         | 16.88 |
| AX | S0  | 6  | 418.58        | 430.83| 27.95         | 23.82 |
| A0 | S+  | 5  | 442.22        | 452.39| 4.31          | 2.25  |
| A0 | S-  | 5  | 443.81        | 453.99| 2.72          | 0.66  |
| A0 | SY  | 6  | 415.89        | 428.13| 30.64         | 26.51 |
| A- | S+  | 5  | 441.22        | 451.39| 5.31          | 3.25  |
| A- | S-  | 5  | 443.81        | 453.99| 2.72          | 0.66  |
| AW | SW  | 6  | 415.83        | 428.07| 30.70         | 26.57 |
| AX | SY  | 7  | **413.59**    | **427.92**| **32.94**   | **26.73**|
| AX | SY | Z  | 8  | 413.31        | 429.73| 33.22         | 24.91 |
| SPE            | 5  | 445.26        | 455.44| 1.27          | -0.79 |
| SPE+RL        | 7  | 418.09        | 432.42| 28.44         | 22.22 |
| HMM0       | 5  | 437.09        | 447.26| 9.44          | 7.38  |
| HMM          | 6  | 435.31        | 446.56| 11.21         | 7.08  |
| HMM0+RL     | 7  | 418.76        | 433.09| 27.77         | 21.55 |
| HMM+RL      | 8  | 417.53        | 433.96| 28.99         | 20.69 |
Table S7. Discriminability of the GRL model: 3-T Face/House version (Poor-learner group). This table is related to Figure 1.
| Model         | df | Absolute Dev. | AICc | Residual Dev. | AICc |
|---------------|----|---------------|------|---------------|------|
| Chance        | 0  | 481.64        | 481.64 | -33.47        | -25.36 |
| Intercept     | 1  | 466.24        | 468.25 | -18.07        | -11.97 |
| Hysteresis    | 4  | **448.16**    | **456.28** | **0**         | **0** |
| A0 | S0 | 5             | 447.48 | 457.66        | 0.68  | -1.38  |
| A0 | S+ | 5             | 447.20 | 457.38        | 0.96  | -1.10  |
| A0 | S- | 5             | 447.24 | 457.42        | 0.92  | -1.14  |
| A0 | SY | 6             | 445.30 | 457.55        | 2.86  | -1.27  |
| A- | S+ | 5             | 446.73 | 456.91        | 1.43  | -0.63  |
| A- | S- | 5             | 447.32 | 457.50        | 0.84  | -1.22  |
| AW | SW | 6             | 445.04 | 457.29        | 3.13  | -1.01  |
| AX | SY | 7             | 443.28 | 457.61        | 4.89  | -1.33  |
| AX | SY | 8             | 442.44 | 458.87        | 5.72  | -2.59  |
| SPE           | 5  | 447.45        | 457.63 | 0.71          | -1.34 |
| SPE+RL       | 7  | 446.82        | 461.15 | 1.35          | -4.87 |
| HMM0          | 5  | 447.99        | 458.17 | 0.17          | -1.89 |
| HMM           | 6  | 447.43        | 459.68 | 0.73          | -3.40 |
| HMM0+RL      | 7  | 447.48        | 461.81 | 0.68          | -5.53 |
| HMM+RL       | 8  | 447.04        | 463.47 | 1.12          | -7.19 |
Table S8. Discriminability of the GRL model: 3-T Face/House version (Nonlearner group). Compare to Table S3. The hysteresis model also provided the best fit for Nonlearners in silico.
Figure S2. Discriminability of the GRL model: 7-T Color/Motion version. Compare to Figures 4 and S1. This figure is related to Tables S9 and S10.
| Model          | df | Chance  | 478.79 | 478.79 | -19.00 | -10.88 |
|---------------|----|---------|--------|--------|--------|--------|
| Intercept     | 1  | 472.41  | 474.42 | -12.62 | -6.51  |
| Hysteresis    | 4  | 459.79  | 467.81 | 0      | 0      |
| A0 | S0  | 5  | 411.55  | 421.72 | 48.24  | 46.18  |
| A- | S0  | 5  | 400.91  | 411.09 | 58.88  | 56.82  |
| AX | S0  | 6  | 397.20  | 409.45 | 62.59  | 58.46  |
| A0 | S+  | 5  | 454.41  | 464.59 | 5.38   | 3.32   |
| A0 | S-  | 5  | 419.71  | 429.89 | 40.07  | 38.01  |
| A0 | SY  | 6  | 405.64  | 417.89 | 54.15  | 50.01  |
| A- | S+  | 5  | 456.83  | 467.01 | 2.96   | 0.90   |
| A- | S-  | 5  | 422.61  | 432.79 | 37.17  | 35.11  |
| AW | SW  | 6  | 399.57  | 411.82 | 60.22  | 56.08  |
| AX | SY  | 7  | 392.63  | 406.96 | 67.16  | 60.94  |
| AX | SY | Z  | 8  | 391.86  | 408.30 | 57.92  | 59.61  |
| SPE           | 5  | 431.43  | 441.60 | 28.36  | 26.30  |
| SPE+RL       | 7  | 407.04  | 421.38 | 52.75  | 46.53  |
| HMM0         | 5  | 451.83  | 462.01 | 7.96   | 5.90   |
| HMM          | 6  | 428.73  | 440.98 | 31.06  | 26.93  |
| HMM0+RL      | 7  | 411.10  | 425.44 | 48.68  | 42.47  |
| HMM+RL       | 8  | 406.78  | 423.22 | 53.00  | 44.69  |
Table S9. Discriminability of the GRL model: 7-T Color/Motion version (Good-learner group). This table is related to Figure S2.
| Model          | df | Chance     | Intercept | Hysteresis | A0 I S0  | A- I S0  | AX I S0  | A0 I S+  | A0 I S-  | A0 I SY  | A- I S+  | A- I S-  | AW I SW  | AX I SY  | AX I SY I Z | SPE    | SPE+RL    | HMM0     | HMM       | HMM0+RL  | HMM+RL    |
|----------------|----|------------|-----------|------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-------------|--------|-----------|----------|----------|----------|----------|
|                |    | Dev.       | AICc      | Dev.       | AICc     | Dev.     | AICc     | Dev.     | AICc     | Dev.     | AICc     | Dev.     | AICc     | Dev.       | AICc   | Dev.     | AICc    |
| Chance         | 0  | 447.50     | 447.50    | -56.38     | -48.25   |          |          |          |          |          |          |          |          |          |             |        |          |         |
| Intercept      | 1  | 420.10     | 422.11    | -28.99     | -22.87   |          |          |          |          |          |          |          |          |          |             |        |          |         |
| Hysteresis     | 4  | 391.11     | 399.25    | 0          | 0        |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A0 I S0        | 5  | 386.21     | 396.41    | 4.90       | 2.84     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A- I S0        | 5  | 383.08     | 393.28    | 8.03       | 5.97     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| AX I S0        | 6  | 380.26     | 392.54    | 10.86      | 6.71     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A0 I S+        | 5  | 383.18     | 393.38    | 7.94       | 5.87     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A0 I S-        | 5  | 386.37     | 396.57    | 4.74       | 2.68     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A0 I SY        | 6  | 375.92     | 388.20    | 15.19      | 11.04    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A- I S+        | 5  | 381.32     | 391.52    | 9.80       | 7.73     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| A- I S-        | 5  | 388.05     | 398.25    | 3.06       | 0.99     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| AW I SW        | 6  | 375.88     | 388.17    | 15.23      | 11.08    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| AX I SY        | 7  | 371.68     | 386.06    | 19.43      | 13.19    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| AX I SY I Z    | 8  | 371.12     | 387.60    | 20.00      | 11.64    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| SPE            | 5  | 387.89     | 398.09    | 3.22       | 1.15     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| SPE+RL         | 7  | 383.55     | 397.93    | 7.56       | 1.32     |          |          |          |          |          |          |          |          |          |             |        |          |         |
| HMM0           | 5  | 390.85     | 401.05    | 0.27       | -1.80    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| HMM            | 6  | 387.05     | 399.33    | 4.06       | -0.09    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| HMM0+RL        | 7  | 386.21     | 400.59    | 4.91       | -1.34    |          |          |          |          |          |          |          |          |          |             |        |          |         |
| HMM+RL         | 8  | 381.66     | 398.15    | 9.45       | 1.10     |          |          |          |          |          |          |          |          |          |             |        |          |         |
Table S10. Discriminability of the GRL model: 7-T Color/Motion version (Poor-learner group). This table is related to Figure S2.
Figure S3. Discriminability of the basic RL model: 3-T Face/House version. Compare to Figure S1. The basic RL model was recovered in lieu of the GRL model when substituting data simulated with basic RL. This converse model recovery again demonstrates an absence of overfitting. This figure is related to Tables S11-S13.
| 3-T Face/House Model | 3-T Face/House Model | Good learner \((n = 31)\) Absolute \(\text{Residual}\) |
|---------------------|---------------------|-----------------|-----------------|
|                     |                     | \(\text{Dev.}\) | \(\text{AICc}\) | \(\text{Dev.}\) | \(\text{AICc}\) |
| Chance 0            | 501.26              | 501.26          | -14.78          | -6.67           |
| Intercept 1         | 496.62              | 498.63          | -10.15          | -4.04           |
| Hysteresis 4        | 486.47              | 494.59          | 0               | 0               |
| A0 \(\mid\) S0 5   | 424.94              | 435.11          | 61.53           | 59.47           |
| A- \(\mid\) S0 5   | 438.74              | 448.91          | 47.73           | 45.67           |
| AX \(\mid\) S0 6   | 424.23              | 436.47          | 62.24           | 58.12           |
| A0 \(\mid\) S+ 5   | 482.94              | 493.11          | 3.54            | 1.48            |
| A0 \(\mid\) S- 5   | 442.59              | 452.76          | 43.88           | 41.83           |
| A0 \(\mid\) SY 6   | 423.93              | 436.17          | 62.55           | 58.42           |
| A- \(\mid\) S+ 5   | 485.14              | 495.31          | 1.33            | -0.73           |
| A- \(\mid\) S- 5   | 453.18              | 463.35          | 33.3            | 31.24           |
| AW \(\mid\) SW 6   | 423.83              | 436.07          | 62.64           | 58.52           |
| AX \(\mid\) SY 7   | 423.20              | 437.53          | 63.27           | 57.06           |
| AX \(\mid\) SY \(\mid\) Z 8 | 422.92              | 439.34          | 63.55           | 55.25           |
| SPE 5              | 465.01              | 475.18          | 21.47           | 19.41           |
| SPE+RL 7           | 423.78              | 438.10          | 62.70           | 56.49           |
| HMM0 5             | 465.23              | 475.41          | 21.24           | 19.18           |
| HMM 6              | 445.88              | 458.12          | 40.59           | 36.47           |
| HMM0+RL 7          | 424.45              | 438.77          | 62.02           | 55.81           |
| HMM+RL 8           | 423.09              | 439.50          | 63.39           | 55.09           |
Table S11. Discriminability of the basic RL model: 3-T Face/House version (Good-learner group). This table is related to Figure S3.
| 3-T Face/House | Poor learner (n = 9) |
|----------------|-----------------|
| Model          | df              | Absolute | Residual |
|                |                 | Dev.     | AICc      | Dev.     | AICc      |
| Chance         | 0               | 489.05   | 489.05    | -40.78   | -32.66   |
| Intercept      | 1               | 465.73   | 467.74    | -17.45   | -11.34   |
| Hysteresis     | 4               | 448.28   | 456.39    | 0        | 0        |
| A0 | S0 sim.        | 5               | 429.53   | 439.71    | 18.74    | 16.69    |
| A- | S0             | 5               | 435.55   | 445.73    | 12.73    | 10.67    |
| AX | S0             | 6               | 429.00   | 441.25    | 19.27    | 15.15    |
| A0 | S+             | 5               | 446.60   | 456.77    | 1.68     | -0.38    |
| A0 | S-             | 5               | 437.27   | 447.45    | 11.00    | 8.95     |
| A0 | SY             | 6               | 429.06   | 441.30    | 19.22    | 15.09    |
| A- | S+             | 5               | 447.28   | 457.46    | 0.99     | -1.06    |
| A- | S-             | 5               | 444.05   | 454.23    | 4.22     | 2.17     |
| AW | SW             | 6               | 428.74   | 440.99    | 19.53    | 15.40    |
| AX | SY             | 7               | 428.31   | 442.64    | 19.97    | 13.76    |
| AX | SY | Z             | 8               | 427.37   | 443.80    | 20.91    | 12.60    |
| SPE            | 5               | 447.64   | 457.81    | 0.64     | -1.42    |
| SPE+RL         | 7               | 428.88   | 443.21    | 19.40    | 13.19    |
| HMM0           | 5               | 437.34   | 447.51    | 10.94    | 8.88     |
| HMM            | 6               | 436.64   | 448.89    | 11.63    | 7.50     |
| HMM0+RL        | 7               | 429.09   | 443.42    | 19.19    | 12.98    |
| HMM+RL         | 8               | 428.40   | 444.83    | 19.87    | 11.57    |
Table S12. Discriminability of the basic RL model: 3-T Face/House version (Poor-learner group). This table is related to Figure S3.
| Model | df | Absolute Dev. | Absolute AICc | Residual Dev. | Residual AICc |
|-------|----|---------------|---------------|---------------|---------------|
| Chance | 0  | 481.64 | 481.64 | -30.70 | -22.58 |
| Intercept | 1 | 466.57 | 468.59 | -15.63 | -9.53 |
| Hysteresis | 4 | **450.94** | **459.06** | 0 | 0 |
| A0 | S0 | 5 | 450.33 | 460.51 | 0.61 | -1.45 |
| A- | S0 | 5 | 450.52 | 460.70 | 0.42 | -1.64 |
| AX | S0 | 6 | 450.20 | 462.45 | 0.74 | -3.39 |
| A0 | S+ | 5 | 449.07 | 459.24 | 1.87 | -0.18 |
| A0 | S- | 5 | 450.33 | 460.51 | 0.61 | -1.45 |
| A0 | SY | 6 | 448.29 | 460.53 | 2.66 | -1.48 |
| A- | S+ | 5 | 450.91 | 461.09 | 0.03 | -2.03 |
| A- | S- | 5 | 450.81 | 460.99 | 0.13 | -1.93 |
| AW | SW | 6 | 448.35 | 460.60 | 2.59 | -1.54 |
| AX | SY | 7 | 447.33 | 461.67 | 3.61 | -2.61 |
| AX | SY | Z | 8 | 444.90 | 461.42 | 5.95 | -2.37 |
| SPE | 5 | 450.59 | 460.76 | 0.36 | -1.70 |
| SPE+RL | 7 | 450.14 | 464.47 | 0.80 | -5.42 |
| HMM0 | 5 | 450.88 | 461.06 | 0.06 | -2.00 |
| HMM | 6 | 450.04 | 462.29 | 0.90 | -3.23 |
| HMM0+RL | 7 | 450.33 | 464.66 | 0.61 | -5.60 |
| HMM+RL | 8 | 449.42 | 465.85 | 1.52 | -6.79 |
Table S13. Discriminability of the basic RL model: 3-T Face/House version (Nonlearner group). Compare to Tables S3 and S8. The hysteresis model also provided the best fit for Nonlearners in silico.
Figure S4. Discriminability of the basic RL model: 7-T Color/Motion version. Compare to Figures S2 and S3. This figure is related to Tables S14 and S15.
| 7-T Color/Motion | Good learner \((n = 16)\) |
|-----------------|---------------------------------|
| A0 I S0 sim.    | Absolute                        |
| Model           | df                | Dev.   | AICc | Dev.   | AICc |
| Chance          | 0                 | 478.79 | 478.79 | -18.76 | -10.64 |
| Intercept       | 1                 | 472.35 | 474.36 | -12.31 | -6.20  |
| Hysteresis      | 4                 | 460.03 | 468.15 | 0       | 0      |
| A0 I S0         | 5                 | 420.37 | 430.55 | 39.66   | 37.60  |
| A- I S0         | 5                 | 429.11 | 439.29 | 30.93   | 28.87  |
| AX I S0         | 6                 | 420.09 | 432.34 | 39.94   | 35.81  |
| A0 I S+         | 5                 | 456.58 | 466.76 | 3.45    | 1.39   |
| A0 I S-         | 5                 | 432.00 | 442.18 | 28.04   | 25.98  |
| A0 I SY         | 6                 | 418.66 | 430.91 | 41.38   | 37.24  |
| A- I S+         | 5                 | 458.12 | 468.30 | 1.92    | -0.14  |
| A- I S-         | 5                 | 440.39 | 450.57 | 19.65   | 17.59  |
| AW I SW         | 6                 | 418.79 | 431.04 | 41.24   | 37.11  |
| AX I SY         | 7                 | 418.23 | 432.56 | 41.81   | 35.59  |
| AX I SY I Z     | 8                 | 418.07 | 434.51 | 41.96   | 33.64  |
| SPE             | 5                 | 441.31 | 451.49 | 18.72   | 16.66  |
| SPE+RL          | 7                 | 420.24 | 434.57 | 39.80   | 33.58  |
| HMM0            | 5                 | 444.57 | 454.75 | 15.46   | 13.40  |
| HMM             | 6                 | 433.79 | 446.04 | 26.24   | 22.11  |
| HMM0+RL         | 7                 | 420.14 | 434.48 | 39.89   | 33.67  |
| HMM+RL          | 8                 | 419.95 | 436.38 | 40.09   | 31.77  |
Table S14. Discriminability of the basic RL model: 7-T Color/Motion version (Good-learner group). This table is related to Figure S4.
| 7-T Color/Motion     | Poor learner ($n = 5$) | Absolute | Residual |
|----------------------|-------------------------|----------|----------|
|                      |                         | Dev.     | AICc     | Dev.     | AICc     |
| Chance               | 0                       | 447.50   | 447.50   | -61.44   | -53.31   |
| Intercept            | 1                       | 424.85   | 426.86   | -38.79   | -32.67   |
| Hysteresis           | 4                       | 386.05   | 394.19   | 0        | 0        |
| A0 | S0 sim.          | 5                       | **378.90** | **389.10** | **7.16** | **5.09** |
| A- | S0               | 5                       | 379.38   | 389.58   | 6.67     | 4.61     |
| AX | S0               | 6                       | 378.75   | 391.04   | 7.30     | 3.15     |
| A0 | S+               | 5                       | 385.23   | 395.43   | 0.83     | -1.24    |
| A0 | S-               | 5                       | 379.69   | 389.89   | 6.37     | 4.30     |
| A0 | SY               | 6                       | 379.09   | 391.37   | 6.96     | 2.81     |
| A- | S+               | 5                       | 385.33   | 395.53   | 0.73     | -1.34    |
| A- | S-               | 5                       | 380.61   | 390.82   | 5.44     | 3.37     |
| AW | SW               | 6                       | 378.63   | 390.91   | 7.42     | 3.27     |
| AX | SY               | 7                       | 377.78   | 392.16   | 8.27     | 2.03     |
| AX | SY | Z           | 8                       | 376.69   | 393.17   | 9.37     | 1.01     |
| SPE                  | 5                       | 380.05   | 390.25   | 6.00     | 3.93     |
| SPE+RL               | 7                       | 378.11   | 392.49   | 7.94     | 1.70     |
| HMM0                 | 5                       | 385.72   | 395.92   | 0.33     | -1.74    |
| HMM                  | 6                       | 380.04   | 392.32   | 6.01     | 1.87     |
| HMM0+RL             | 7                       | 378.89   | 393.27   | 7.16     | 0.91     |
| HMM+RL              | 8                       | 377.94   | 394.43   | 8.11     | -0.24    |
Table S15. Discriminability of the basic RL model: 7-T Color/Motion version (Poor-learner group). This table is related to Figure S4.
Figure S5. Predictions of the basic RL model. Compare to Figure 7. Representative dynamics generated by the basic RL model \((g_A = g_S = 0)\) are shown for the same participant. Parameters were assigned as follows for this participant: \(\alpha = 0.724\), \(\lambda = 0.500\), \(\tau = 0.567\), \(\beta_0 = -0.084\), \(\lambda_\beta = 0.715\), and \(\beta_R = 0.252\). Unlike GRL, basic RL updates the value of only the state-action pair experienced on a given trial.
| Group (3-T Face/House) | Variable Region | H | x, y, z | \( t_{df} \) | \( p \) | \( k \) | SVC |
|------------------------|----------------|---|---------|----------|-----|-----|-----|
| **All learners (n = 40)** | | | | \( t_{39} \) | | | |
| **Reward-prediction error** | | | | | | | |
| Nucleus accumbens | L | -12, 14, -8 | 4.88 | \(< 10^{-5}\) | 128 | CP |
| Nucleus accumbens | R | 16, 12, -12 | 3.60 | \(< 10^{-3}\) | 15 | CP |
| Dorsal putamen & Dorsal caudate nucleus | R | 26, 6, 4 | 3.98 | \(10^{-4}\) | 103 | CP |
| Posterior putamen | R | 26, -6, 4 | 3.08 | 0.002 | 15 | - |
| Posterior putamen | L | -28, -13, 4 | 4.22 | \(< 10^{-4}\) | 28 | - |
| Posterior putamen | R | 30, -16, -4 | 3.46 | \(< 10^{-3}\) | 44 | - |
| **Value** | | | | | | | |
| Frontopolar cortex | R | 12, 66, 4 | 4.09 | \(10^{-4}\) | 106 | - |
| Frontopolar cortex | L | -4, 64, 2 | 4.96 | \(< 10^{-5}\) | 108 | - |
| Ventromedial prefrontal cortex | B | 6, 52, -14 | 4.00 | \(10^{-4}\) | 118 | CP |
| Anterior cingulate cortex | R | 10, 46, 2 | 3.63 | \(< 10^{-3}\) | 10 | - |
| Anterior caudate nucleus | L | -12, 24, 2 | 3.93 | \(< 10^{-3}\) | 18 | - |
| Nucleus accumbens & Ventral putamen | R | 16, 16, -10 | 3.15 | 0.002 | 12 | - |
| Nucleus accumbens | R | 8, 14, -4 | 3.95 | \(< 10^{-3}\) | 30 | CP |
| Posterior cingulate cortex | L | -2, -26, 38 | 3.46 | \(< 10^{-3}\) | 13 | p |
| Posterior cingulate cortex | B | 0, -38, 36 | 3.24 | \(10^{-3}\) | 21 | Cp |
| **Reaction time** | | | | | | | |
| Medial frontal cortex & Other regions | B | -6, 10, 54 | 9.13 | \(< 10^{-10}\) | 4575 | CP |
| **Good learners (n = 31)** | | | | \( t_{30} \) | | | |
| **Reward-prediction error** | | | | | | | |
| Nucleus accumbens | L | -12, 14, -8 | 3.70 | \(< 10^{-3}\) | 23 | CP |
| Brain Region                                | Laterality | Coordinates | t-statistic | p-value | Z-score | Group |
|--------------------------------------------|------------|-------------|-------------|---------|---------|-------|
| Dorsal caudate nucleus & Dorsal putamen   | L          | -18, 6, 12  | 4.37        | <10^-4  | 34      | CP    |
| Dorsal putamen & Dorsal caudate nucleus   | R          | 24, 6, 2    | 4.52        | <10^-4  | 138     | CP    |
| Posterior putamen                         | L          | -28, -6, 6  | 4.78        | <10^-4  | 120     | -     |
| Substantia nigra                          | R          | 12, -4, -16 | 3.34        | 10^-3   | 17      | -     |
| **Value**                                 |            |             |             |         |         |       |
| Ventromedial prefrontal cortex            | B          | -6, 62, -2  | 6.48        | <10^-6  | 886     | CP    |
| Anterior cingulate cortex                 | L          | -4, 40, 0   | 3.88        | <10^-3  | 21      | -     |
| Anterior caudate nucleus                  | L          | -12, 24, 2  | 3.59        | <10^-3  | 12      | -     |
| Anterior caudate nucleus                  | R          | 14, 24, -6  | 4.25        | <10^-4  | 41      | cp    |
| Nucleus accumbens                         | R          | 10, 2, -14  | 5.21        | <10^-5  | 80      | CP    |
| Posterior cingulate cortex                | B          | 2, -24, 34  | 3.94        | 10^-3   | 49      | cP    |
| **Reaction time**                         |            |             |             |         |         |       |
| Medial frontal cortex & Other regions     | B          | -6, 10, 54  | 8.84        | <10^-9  | 8854    | CP    |
| **Poor learners (n = 9)**                 |            |             |             |         |         |       |
| **Reward-prediction error**               |            |             |             |         |         |       |
| Nucleus accumbens                         | L          | -8, 10, -6  | 4.64        | <10^-3  | 20      | Cp    |
| **Value**                                 |            |             |             |         |         |       |
| Frontopolar cortex                        | R          | 14, 66, -10 | 5.10        | <10^-3  | 10      | -     |
| Posterior cingulate cortex                | L          | -6, -40, 52 | 4.55        | <10^-3  | 11      | -     |
| **Reaction time**                         |            |             |             |         |         |       |
| Medial frontal cortex                     | R          | 2, 28, 38   | 8.93        | <10^-5  | 70      | -     |
| Dorsal anterior cingulate cortex          | L          | -10, 18, 34 | 9.43        | <10^-5  | 35      | -     |
| Medial frontal cortex                     | R          | 6, 14, 46   | 5.60        | <10^-3  | 13      | U     |
| Medial frontal cortex                     | L          | -6, 6, 52   | 7.72        | <10^-4  | 101     | CP    |
| **Nonlearners (n = 7)**                   |            |             |             |         |         |       |

**Note:** The t-statistic values are calculated for both learners and nonlearners, and the p-values are used to determine statistical significance.
| Reaction time                      | L      |   |   |   |   |
|-----------------------------------|--------|---|---|---|---|
| Medial frontal cortex             |        |   |   |   |   |
|                                   | -12, 8, 52 | 10.86 | $< 10^{-4}$ | 13 | - |
| Medial frontal cortex             | B      |   |   |   |   |
|                                   | 0, 2, 56 | 7.41 | $< 10^{-3}$ | 54 | - |
| Medial frontal cortex             | L      |   |   |   |   |
|                                   | -8, -6, 62 | 6.15 | $< 10^{-3}$ | 23 | - |
Table S16. Neural substrates of the RL framework: 3-T Face/House version. Listed for every significant cluster \((p < 0.005, k \geq 10)\) are anatomical regions; hemispheres (“H”) as left (“L”), right (“R”), or bilateral (“B”); stereotactic coordinates in MNI space in mm \((x, y, z)\); test statistics \((t_{df})\); probability values \((p)\); cluster extents in voxels \((k)\); and results of small-volume correction (SVC) at the cluster level (“C”) or the peak level (“P”) \((p_{FWE} < 0.05)\), where marginally significant (“c” or “p” in lower case) \((0.05 < p_{FWE} < 0.10)\) or uncorrected (“U”) \((p < 0.005)\) results are also listed if the most stringent threshold for SVC was not attained within the region of interest. All relevant groupings of participants are included. The conventions for displaying this table also apply for Tables S17, S19, S20, S23, and S24. This table is related to Figure 8 and Table S18.
Reward-prediction error

7CM: Good learners ($n = 16$)
Figure S6. Neural substrates of the RL framework: 7-T Color/Motion version (Dopaminergic midbrain). At 7 T, reward-prediction error (RPE) signals from the GRL model were further localized to the substantia nigra (SN) ($p < 0.005$). This figure is related to Figure 9 and Tables S17 and S18.
| Group (7-T Color/Motion) | Variable | Region | H | x, y, z | t_{df} | p       | k   | SVC |
|--------------------------|----------|--------|---|---------|--------|---------|-----|-----|
| All learners (n = 21)    |          |        |   |         |        |         |     |     |
| Reward-prediction error  |          |        |   |         |        |         |     |     |
| Nucleus accumbens        | R        | 8.4, 10.8, -6 | 4.91 | < 10^{-4} | 44    | CP      |
| Dorsal putamen           | L        | -25, 4.8, 7.2 | 6.20 | < 10^{-5} | 11    | -       |
| Posterior putamen        | L        | -30, -1.2, 6 | 4.97 | < 10^{-4} | 19    | -       |
| Posterior putamen        | L        | -27.6, -9.6, 7.2 | 5.86 | < 10^{-5} | 10    | -       |
| Posterior putamen        | R        | 27.6, -9.6, -8.4 | 5.01 | < 10^{-4} | 20    | -       |
| Value                    |          |        |   |         |        |         |     |     |
| Ventromedial prefrontal cortex | L  | -4.8, 49.2, -12 | 3.71 | < 10^{-3} | 17    | U       |
| Ventromedial prefrontal cortex | R  | 6, 46.8, -12 | 6.22 | < 10^{-5} | 12    | U       |
| Anterior cingulate cortex | L        | -6, 38.4, -10.8 | 4.37 | 10^{-4}  | 13    | U       |
| Nucleus accumbens        | R        | 8.4, 15.6, -4.8 | 4.09 | < 10^{-3} | 19    | C       |
| Nucleus accumbens        | R        | 10.8, 8.4, -9.6 | 4.33 | < 10^{-3} | 14    | U       |
| Dorsal putamen           | R        | 22.8, 8.4, -4.8 | 4.47 | 10^{-4}  | 19    | -       |
| Ventral putamen          | R        | 15.6, 6, -9.6 | 4.19 | < 10^{-3} | 50    | -       |
| Nucleus accumbens        | L        | -10.8, 4.8, -10.8 | 4.52 | 10^{-4}  | 59    | C       |
| Ventral putamen          | L        | -18, 4.8, -10.8 | 4.36 | 10^{-4}  | 25    | -       |
| Posterior cingulate cortex | B  | 0, -45.6, 30 | 3.94 | < 10^{-3} | 23    | -       |
| Reaction time            |          |        |   |         |        |         |     |     |
| Medial frontal cortex    | R        | 8.4, 31.2, 43.2 | 4.97 | < 10^{-4} | 19    | -       |
| Medial frontal cortex    | B        | -3.6, 26.4, 49.2 | 4.29 | < 10^{-3} | 12    | -       |
| Medial frontal cortex    | L        | -4.8, 25.2, 40.8 | 4.61 | < 10^{-4} | 27    | -       |
| Medial frontal cortex    | R        | 7.2, 24, 38.4 | 7.98 | < 10^{-7} | 1885  | CP      |
| Dorsal anterior cingulate cortex | L  | -12, 21.6, 31.2 | 3.35 | 0.002    | 18    | -       |
| Medial frontal cortex    | L        | -6, 18, 33.6 | 4.43 | 10^{-4}  | 12    | -       |
| Region                                      | Side | Coordinates   | Z-score | p-value | t-statistic | Effect Size |
|---------------------------------------------|------|---------------|---------|---------|-------------|-------------|
| Medial frontal cortex                       | L    | -9.6, 14.4, 57.6 | 4.07    | < 10⁻³  | 42          | CP          |
| Dorsal anterior cingulate cortex            | R    | 3.6, 13.2, 24   | 4.56    | < 10⁻⁴  | 12          | -           |
| Medial frontal cortex                       | L    | -9.6, 10.8, 48  | 8.09    | < 10⁻⁷  | 1620        | CP          |
| Medial frontal cortex                       | R    | 18, 3.6, 70.8   | 6.47    | 10⁻⁶    | 181         | -           |
| Medial frontal cortex                       | L    | -2.4, 2.4, 37.2 | 3.77    | < 10⁻³  | 11          | -           |
| Medial frontal cortex                       | R    | 14.4, -14.4, 48 | 3.79    | < 10⁻³  | 11          | -           |
| Good learners (n = 16)                      |      |               |     |         | t₁₅         |             |
| Reward-prediction error                     |      |               |     |         |             |             |
| Nucleus accumbens & Anterior caudate nucleus| R    | 7.2, 13.2, -4.8 | 5.70    | < 10⁻⁴  | 63          | CP          |
| Dorsal caudate nucleus                      | L    | 12, 10.8, 0    | 4.64    | < 10⁻³  | 16          | p           |
| Nucleus accumbens                          | L    | -8.4, 3.6, -3.6 | 4.67    | < 10⁻³  | 18          | p           |
| Ventral putamen                             | R    | 24, 3.6, -9.6  | 5.11    | < 10⁻⁴  | 17          | -           |
| Posterior putamen                           | L    | -30, -1.2, 6   | 4.41    | < 10⁻³  | 10          | -           |
| Posterior putamen                           | R    | 26.4, -2.4, -6 | 3.66    | 10⁻³    | 11          | -           |
| Posterior putamen                           | R    | 28.8, -7.2, -7.2 | 4.38 | < 10⁻³ | 18          | -           |
| Posterior putamen                           | L    | -28.8, -9.6, 13.2 | 4.62 | < 10⁻³ | 11          | -           |
| Substantia nigra                            | L    | -9.6, -24, -16.8 | 4.80   | 10⁻⁴    | 11          | -           |
| Value                                       |      |               |     |         |             |             |
| Ventromedial prefrontal cortex              | L    | -2.4, 50.4, -1.2 | 4.76   | 10⁻⁴    | 16          | -           |
| Ventromedial prefrontal cortex              | R    | 6, 46.8, -12   | 5.85    | < 10⁻⁴  | 10          | U           |
| Ventromedial prefrontal cortex              | L    | -2.4, 44.4, -10.8 | 4.99  | 10⁻⁴    | 46          | CP          |
| Anterior cingulate cortex                   | B    | 0, 38.4, 7.2   | 3.70    | 10⁻³    | 12          | -           |
| Ventromedial prefrontal cortex              | L    | -4.8, 38.4, -9.6 | 5.11   | < 10⁻⁴  | 16          | U           |
| Ventral putamen                             | L    | -20.4, 9.6, -9.6 | 4.55   | < 10⁻³  | 22          | -           |
| Nucleus accumbens                           | L    | -9.6, 7.2, -9.6 | 5.11    | < 10⁻⁴  | 28          | CP          |
| Nucleus accumbens                           | R    | 6, 3.6, -8.4   | 5.20    | < 10⁻⁴  | 14          | -           |
| Posterior cingulate cortex                  | L    | -15.6, -33.6, 50.4 | 4.42  | < 10⁻³  | 14          | -           |
| Reaction time |         |         |     |     |   |     |
|---------------|---------|---------|-----|-----|---|-----|
| Medial frontal cortex | **R** | 7.2, 31.2, 43.2 | 5.13 | $< 10^{-4}$ | 39 | - |
| Medial frontal cortex | **L** | -4.8, 26.4, 40.8 | 3.66 | $10^{-3}$ | 13 | - |
| Dorsal anterior cingulate cortex | **L** | -14.4, 25.2, 26.4 | 6.00 | $10^{-5}$ | 77 | - |
| Medial frontal cortex | **R** | 15.6, 9.6, 58.8 | 3.50 | 0.002 | 11 | - |
| Medial frontal cortex | **R** | 16.8, 3.6, 70.8 | 5.95 | $10^{-5}$ | 98 | - |
| Medial frontal cortex | **B** | -2.4, 2.4, 46.8 | 9.69 | $< 10^{-7}$ | 3476 | CP |
| Medial frontal cortex | **L** | -2.4, 2.4, 37.2 | 4.13 | $< 10^{-3}$ | 10 | - |
| Medial frontal cortex | **R** | 12, -6, 62.4 | 3.93 | $< 10^{-3}$ | 14 | - |
| Medial frontal cortex | **L** | -8.4, -7.2, 73.2 | 7.20 | $< 10^{-5}$ | 134 | - |
| Medial frontal cortex | **R** | 7.2, -8.4, 74.4 | 3.77 | $< 10^{-3}$ | 14 | - |

**Poor learners (n = 5)**

| **t_4** |
|---------|

| Value |         |         |     |     |   |     |
|-------|---------|---------|-----|-----|---|-----|
| Ventral putamen | **R** | 18, 7.2, -10.8 | 6.50 | $< 10^{-3}$ | 11 | - |
| Dorsal putamen | **R** | 22.8, 7.2, -4.8 | 10.89 | $< 10^{-4}$ | 11 | - |
| Ventral putamen | **L** | -18, 1.2, -13.2 | 13.07 | $< 10^{-4}$ | 21 | - |

| Reaction time |         |         |     |     |   |     |
|---------------|---------|---------|-----|-----|---|-----|
| Medial frontal cortex | **R** | 8.4, 13.2, 39.6 | 22.98 | $10^{-5}$ | 18 | - |
| Medial frontal cortex | **L** | -4.8, 1.2, 54 | 16.92 | $< 10^{-4}$ | 18 | - |
| Medial frontal cortex | **L** | -7.2, -7.2, 67.2 | 10.15 | $< 10^{-3}$ | 27 | - |
Table S17. Neural substrates of the RL framework: 7-T Color/Motion version. This table is related to Figures 9 and S6 and Table S18.
| Variable Region of interest | 3-T Face/House | 7-T Color/Motion |
|-----------------------------|---------------|-----------------|
|                             | All | Good | Poor | All | Good | Poor |
| \( n \)                     | 40  | 31   | 9    | 21  | 16   | 5    |
| Reward-prediction error     |     |      |      |     |      |      |
| Striatum                    | U   | U    | U    | U   | U    | -    |
| Dopaminergic midbrain       | -   | U    | -    | -   | U    | -    |
| Set of 7 regions of interest| S   | S    | U    | U   | S    | -    |
| L Anterior caudate nucleus  | CP  | cP   | c    | -   | -    | -    |
| R Nucleus accumbens (8, 12, -4) | -   | -    | -    | CP  | CP   | -    |
| R Ventral putamen (18, 12, -12) | CP  | -    | -    | -   | -    | -    |
| L Nucleus accumbens (-12, 10, -6) | CP  | CP   | C p  | -   | -    | -    |
| R Dorsal putamen (28, 6, 0)  | CP  | CP   | -    | -   | -    | -    |
| L Dorsal caudate nucleus    | -   | CP   | -    | -   | -    | -    |
| L Substantia nigra (-10, -14, -12) | -   | -    | -    | -   | -    | -    |
| Value                       |     |      |      |     |      |      |
| Ventromedial prefrontal cortex | U   | U    | U    | U   | U    | -    |
| Striatum                    | U   | U    | -    | U   | U    | U    |
| Posterior cingulate cortex  | U   | U    | U    | U   | U    | -    |
| Set of 4 regions of interest| S   | S    | -    | S   | S    | -    |
| B Ventromedial prefrontal cortex (0, 46, -8) | CP  | CP   | -    | U   | CP   | -    |
| R Nucleus accumbens (10, 16, -6) | CP  | CP   | -    | C   | -    | -    |
| L Nucleus accumbens (-10, 10, -6) | -   | -    | -    | C   | CP   | -    |
| B Posterior cingulate cortex (-2, -34, 38) | Cp  | cP   | -    | -   | -    | -    |
| Reaction time               |     |      |      |     |      |      |
| Medial frontal cortex       | U   | U    | U    | U   | U    | U    |
| B Medial frontal cortex (0, 12, 48) | CP  | CP   | CP   | CP  | CP   | -    |
Table S18. Neural substrates of the RL framework: Summary. The first portion of fMRI analyses across data sets and participant groups (i.e., “All”, “Good”, and “Poor” learners) are summarized for the RL framework that serves as the foundation of the GRL model. Regions of interest (ROIs) were informed by prior studies modeling the reward-prediction error, value, and reaction time. Initially, broader exploratory ROIs were defined anatomically and tested for uncorrected results (“U”) ($p < 0.005$). For RPE and value signals, coordinate-based ROIs were first tested collectively via SVC at the set level (“S”) ($p_{FWE} < 0.05$). Post-hoc tests followed for individual ROIs via SVC at the cluster level (“C”) or the peak level (“P”) ($p_{FWE} < 0.05$); marginally significant (“s”, “c”, or “p” in lower case) ($0.05 < p_{FWE} < 0.10$) or uncorrected (“U”) ($p < 0.005$) results are listed as well if the most stringent threshold for SVC was not attained. Left (“L”), right (“R”), and bilateral (“B”) refer to hemispheres for each ROI. The conventions for displaying this table also apply for Tables S21, S22, and S25. This table is related to Figures 8, 9, and S6 and Tables S16 and S17.
| Variable | Region               | H  | x, y, z | t_{df} | p       | k  | SVC |
|----------|----------------------|----|---------|--------|---------|----|-----|
| All learners (n = 40) |                      |    |         |        |         |    |     |
| RPE x State generalization |                      |    |         |        |         |    |     |
| Anterior caudate nucleus | R 14, 26, 6          | H  | 14, 26, 6 | 3.98  | 10^{-4} | 19 | -   |
| Dorsal caudate nucleus | R 12, 14, 18         |    | 12, 14, 18 | 4.52  | < 10^{-4} | 24 | -   |
| Anterior caudate nucleus | L -16, 12, 10         |    | -16, 12, 10 | 5.30  | < 10^{-5} | 40 | -   |
| Posterior putamen | L -18, -2, -10        |    | -18, -2, -10 | 5.06  | < 10^{-5} | 76 | -   |
| Posterior putamen | L -22, -4, 12         |    | -22, -4, 12 | 4.19  | < 10^{-4} | 52 | CP  |
| Posterior caudate nucleus | R 16, -12, 26        |    | 16, -12, 26 | 5.33  | < 10^{-5} | 122 | -   |
| Substantia nigra | R 8, -12, -10         |    | 8, -12, -10 | 3.32  | < 10^{-3} | 20 | -   |
| Substantia nigra | L -12, -16, -6        |    | -12, -16, -6 | 3.36  | < 10^{-3} | 16 | U   |
| Substantia nigra | R 14, -24, -8         |    | 14, -24, -8 | 4.56  | < 10^{-4} | 16 | -   |
| Hippocampus | L -18, -16, -22       |    | -18, -16, -22 | 3.73  | < 10^{-3} | 17 | -   |
| Hippocampus | L -28, -16, -24       |    | -28, -16, -24 | 3.95  | < 10^{-3} | 11 | U   |
| Hippocampus | R 30, -16, -20        |    | 30, -16, -20 | 4.25  | < 10^{-4} | 33 | CP  |
| RPE x Action generalization |                      |    |         |        |         |    |     |
| Hippocampus | R 34, -14, -24        |    | 34, -14, -24 | 4.06  | 10^{-4}  | 10 | -   |
| Good learners (n = 31) |                      |    |         |        |         |    |     |
| RPE x State generalization |                      |    |         |        |         |    |     |
| Dorsal caudate nucleus | R 6, 8, 14            |    | 6, 8, 14 | 3.86  | < 10^{-3} | 28 | -   |
| Dorsal caudate nucleus | R 14, 4, 10           |    | 14, 4, 10 | 3.41  | < 10^{-3} | 18 | -   |
| Dorsal putamen & Dorsal caudate nucleus | L -10, -6, -6        |    | -10, -6, -6 | 4.71  | < 10^{-4} | 85 | -   |
| Posterior caudate nucleus | R 18, -12, 26        |    | 18, -12, 26 | 4.63  | < 10^{-4} | 45 | -   |
| Hippocampus | L -30, -14, -22       |    | -30, -14, -22 | 3.84  | < 10^{-3} | 13 | cp  |
| Hippocampus | L -26, -36, 0         |    | -26, -36, 0 | 5.14  | < 10^{-5} | 27 | -   |
| Anatomical Region          | Hemisphere | Coordinates | z-score | p-value | t | df |
|---------------------------|------------|-------------|---------|---------|---|----|
| Hippocampus               | R          | 20, -40, 8  | 3.68    | < 10^{-3} | 14 | -  |
| RPE x Action generalization |            |             |         |         |    |    |
| Anterior caudate nucleus  | R          | 14, 18, 12  | 4.53    | < 10^{-4} | 10 | -  |
| Posterior putamen         | L          | -32, -2, -10| 4.85    | < 10^{-4} | 24 | -  |
| Hippocampus               | R          | 34, -16, -24| 3.55    | < 10^{-3} | 12 | -  |
| Poor learners (n = 9)     |            |             |         |         |    |    |
| RPE x State generalization |            |             |         |         |    |    |
| Dorsal caudate nucleus    | L          | -12, 10, 4  | 4.88    | < 10^{-3} | 35 | -  |
| Ventral putamen           | L          | -16, 0, -12 | 11.13   | < 10^{-5} | 60 | -  |
| Posterior putamen         | L          | -30, -4, -10| 5.27    | < 10^{-3} | 15 | -  |
| Substantia nigra          | R          | 8, -6, -12  | 4.44    | 0.002   | 13 | -  |
| Posterior caudate nucleus | R          | 14, -14, 22 | 6.02    | < 10^{-3} | 53 | -  |
| Hippocampus               | R          | 28, -18, -20| 5.47    | < 10^{-3} | 13 | cp |
| RPE x Action generalization |            |             |         |         |    |    |
| Dorsal caudate nucleus    | R          | 14, 12, 2  | 6.86    | 10^{-4}  | 28 | c  |
| Dorsal putamen & Insular cortex | L    | -34, 8, 8  | 6.43    | < 10^{-3} | 56 | -  |
| Dorsal caudate nucleus    | R          | 18, -2, 20 | 7.52    | < 10^{-4} | 46 | -  |
| Posterior putamen         | L          | -32, -8, -2 | 6.56    | < 10^{-3} | 15 | -  |
| Posterior putamen         | R          | 28, -10, -4| 8.77    | < 10^{-4} | 35 | -  |
| Hippocampus               | L          | -36, -34, -6| 8.92    | < 10^{-4} | 66 | -  |
| Hippocampus               | L          | -26, -42, -6| 4.65    | 10^{-3}  | 21 | -  |
| Nonlearners (n = 7)       |            |             |         |         |    |    |
| RPE x State generalization |            |             |         |         |    |    |
| Anterior caudate nucleus  | R          | 18, 22, 6  | 7.74    | < 10^{-3} | 15 | -  |
| Dorsal putamen            | R          | 26, 10, 6  | 4.71    | 0.003   | 11 | U  |
| Region               | Side | Coordinates | T   | p    | n   | F   |
|----------------------|------|-------------|-----|-----|-----|-----|
| Dorsal caudate nucleus | L    | -16, 2, 6   | 6.53 | $< 10^{-3}$ | 23  | -   |
| Hippocampus          | L    | -20, -10, -26 | 9.52 | $10^{-4}$    | 12  | -   |
Table S19. Neural substrates of the GRL model: 3-T Face/House version. This table is related to Figure 10 and Table S21.
a  RPE x State generalization  
7CM: All learners ($n = 21$)

b  RPE x Action generalization
Figure S7. Neural substrates of the GRL model: 7-T Color/Motion version (Dopaminergic midbrain). (a) At 7 T, interaction effects between RPE signals and state generalization were localized to both the SN and the ventral tegmental area (VTA) ($p < 0.005$). (b) Interaction effects between RPE signals and action generalization were likewise observed in both the SN and the VTA ($p < 0.005$). This figure is related to Figure 10 and Tables S20 and S21.
| Group (7-T Color/Motion) Variable Region | H | x, y, z | t<sub>df</sub> | p   | k  | SVC |
|----------------------------------------|---|---------|---------------|-----|----|-----|
| All learners (n = 21)                  |   |         | t<sub>19</sub> |     |    |     |
| RPE x State generalization             |   |         |               |     |    |     |
| Anterior caudate nucleus               | L | -10.8, 19.2, -7.2 | 4.19         | < 10<sup>-3</sup> | 13  | c   |
| Nucleus accumbens                      | R | 12, 14.4, -6 | 4.79         | < 10<sup>-4</sup> | 19  | CP  |
| Dorsal caudate nucleus                 | L | -8.4, 13.2, 10.8 | 4.19         | < 10<sup>-3</sup> | 15  | -   |
| Dorsal caudate nucleus                 | R | 6, 12, 3.6 | 4.78         | < 10<sup>-4</sup> | 26  | -   |
| Ventral putamen                        | L | -15.6, 12, -13.2 | 4.31         | < 10<sup>-3</sup> | 16  | -   |
| Dorsal caudate nucleus                 | R | 16.8, 10.8, 14.4 | 4.78         | < 10<sup>-4</sup> | 20  | -   |
| Nucleus accumbens                      | R | 10.8, 4.8, -10.8 | 5.23         | < 10<sup>-4</sup> | 17  | -   |
| Dorsal caudate nucleus                 | L | -8.4, 3.6, 15.6 | 4.41         | < 10<sup>-3</sup> | 29  | -   |
| Posterior putamen                      | L | -30, -13.2, -7.2 | 4.17         | < 10<sup>-3</sup> | 14  | -   |
| Posterior putamen                      | R | 32.4, -21.6, 1.2 | 5.71         | < 10<sup>-5</sup> | 12  | -   |
| Substantia nigra & Ventral tegmental area | L | -7.2, -22.8, -14.4 | 4.53         | 10<sup>-4</sup> | 15  | -   |
| RPE x Action generalization            |   |         |               |     |    |     |
| Anterior caudate nucleus               | L | -4.8, 14.4, -2.4 | 4.23         | < 10<sup>-3</sup> | 13  | -   |
| Dorsal caudate nucleus                 | L | -8.4, 13.2, 15.6 | 5.15         | < 10<sup>-4</sup> | 81  | -   |
| Dorsal caudate nucleus                 | L | -9.6, 6, 6   | 4.83         | < 10<sup>-4</sup> | 17  | -   |
| Nucleus accumbens                      | R | 12, 4.8, -10.8 | 3.69         | < 10<sup>-3</sup> | 10  | -   |
| Ventral tegmental area & Substantia nigra | R | 3.6, -21.6, -15.6 | 4.84         | 10<sup>-4</sup> | 13  | -   |
| Good learners (n = 16)                 |   |         | t<sub>14</sub> |     |    |     |
| RPE x State generalization             |   |         |               |     |    |     |
| Anterior caudate nucleus               | R | 9.6, 19.2, -2.4 | 5.26         | 10<sup>-4</sup> | 18  | -   |
| Nucleus accumbens                      | L | -10.8, 16.8, -9.6 | 4.80         | 10<sup>-4</sup> | 17  | Cp  |
| Region                               | Side | Coordinates       | t     | p-value | z-score | RPE x Action generalization |
|--------------------------------------|------|-------------------|-------|---------|---------|-----------------------------|
| Anterior caudate nucleus             | L    | -4.8, 14.4, 0     | 9.57  | < 10^-7 | 28      |                             |
| Nucleus accumbens                    | R    | 10.8, 14.4, -6    | 5.19  | < 10^-4 | 16      | CP                          |
| Anterior caudate nucleus             | R    | 4.8, 13.2, 2.4    | 6.01  | < 10^-4 | 23      | U                           |
| Dorsal caudate nucleus               | L    | -8.4, 13.2, 15.6  | 5.12  | < 10^-4 | 78      |                             |
| Dorsal caudate nucleus               | R    | 15.6, 12, 13.2    | 3.93  | < 10^-3 | 15      |                             |
| Nucleus accumbens                    | L    | -7.2, 10.8, -4.8  | 4.47  | < 10^-3 | 13      | U                           |
| Dorsal caudate nucleus               | L    | -7.2, 6, 4.8      | 5.03  | < 10^-4 | 14      |                             |
| Nucleus accumbens                    | R    | 10.8, 4.8, -10.8  | 7.27  | < 10^-5 | 24      |                             |
| Dorsal putamen                       | L    | -26.4, 3.6, 14.4  | 4.80  | 10^-4   | 16      |                             |
| Posterior putamen                    | R    | 26.4, -2.4, -6    | 4.51  | < 10^-3 | 12      |                             |
| Posterior putamen                    | R    | 31.2, -6, 4.8     | 5.88  | < 10^-4 | 11      |                             |
| Hippocampus                          | L    | -22.8, -18, -20.4 | 4.72  | < 10^-3 | 13      |                             |
| Hippocampus                          | L    | -28.8, -22.8, -12 | 5.07  | < 10^-4 | 22      | C                           |
| Hippocampus                          | R    | 25.2, -27.6, -10.8| 5.01  | < 10^-4 | 28      |                             |
| RPE x Action generalization          |      |                   |       |         |         |                             |
| Anterior caudate nucleus             | L    | -6, 18, -1.2      | 5.76  | < 10^-4 | 18      |                             |
| Anterior caudate nucleus             | L    | -8.4, 13.2, 10.8  | 4.46  | < 10^-3 | 14      |                             |
| Dorsal caudate nucleus               | L    | -8.4, 13.2, 15.6  | 5.75  | < 10^-4 | 67      |                             |
| Dorsal caudate nucleus               | R    | 4.8, 12, 2.4      | 5.78  | < 10^-4 | 17      |                             |
| Dorsal caudate nucleus               | L    | -8.4, 6, 6        | 4.90  | 10^-4   | 12      |                             |
| Nucleus accumbens                    | R    | 10.8, 4.8, -12    | 5.70  | < 10^-4 | 19      |                             |
| Posterior putamen                    | R    | 32.4, -3.6, 4.8   | 4.48  | < 10^-3 | 13      |                             |

**Poor learners (n = 5)**

| Region                               | Side | Coordinates       | t     | p-value | z-score | RPE x State generalization |
|--------------------------------------|------|-------------------|-------|---------|---------|---------------------------|
| Dorsal caudate nucleus               | R    | 9.6, 7.2, 14.4    | 13.39 | < 10^-3 | 12      |                            |
| Posterior putamen                    | L    | -24, -13.2, -1.2  | 26.55 | < 10^-4 | 19      |                            |
Table S20. Neural substrates of the GRL model: 7-T Color/Motion version. This table is related to Figures 10 and S7 and Table S21.
| Variable Region of interest | 3-T Face/House | 7-T Color/Motion |
|-----------------------------|----------------|------------------|
|                             | Good | Poor | Good | Poor |
| **n**                      | 40 | 31 | 9 | 21 | 16 | 5 |
| RPE x State generalization |      |      |      |      |      |
| Striatum                   | U    | U    | U    | U    | U    | U    |
| Dopaminergic midbrain      | U    | -    | U    | U    | -    | -    |
| Set of 7 regions of interest | S    | -    | -    | s    | S    | -    |
| L Anterior caudate nucleus (-8, 18, -8) | -    | -    | -    | c    | Cp   | -    |
| R Nucleus accumbens (8, 12, -4) | -    | -    | -    | CP   | CP   | -    |
| R Ventral putamen (18, 12, -12) | -    | -    | -    | -    | -    | -    |
| L Nucleus accumbens (-12, 10, -6) | -    | -    | -    | -    | U    | -    |
| R Dorsal putamen (28, 6, 0) | -    | -    | -    | -    | -    | -    |
| L Dorsal caudate nucleus (-18, 2, 16) | CP  | -    | -    | -    | -    | -    |
| L Substantia nigra (-10, -14, -12) | U    | -    | -    | -    | -    | -    |
| RPE x Action generalization |      |      |      |      |      |
| Striatum                   | -    | U    | U    | U    | U    | -    |
| Dopaminergic midbrain      | -    | -    | -    | U    | -    | -    |
| Set of 7 regions of interest | -    | -    | U    | -    | -    | -    |
| L Anterior caudate nucleus (-8, 18, -8) | -    | -    | -    | -    | -    | -    |
| R Nucleus accumbens (8, 12, -4) | -    | -    | c    | -    | -    | -    |
| R Ventral putamen (18, 12, -12) | -    | -    | -    | -    | -    | -    |
| L Nucleus accumbens (-12, 10, -6) | -    | -    | -    | -    | -    | -    |
| R Dorsal putamen (28, 6, 0) | -    | -    | -    | -    | -    | -    |
| L Dorsal caudate nucleus (-18, 2, 16) | -    | -    | -    | -    | -    | -    |
| L Substantia nigra (-10, -14, -12) | -    | -    | -    | -    | -    | -    |
Table S21. Neural substrates of the GRL model: Summary (Basal ganglia). The second portion of the fMRI analyses are first summarized for the basal ganglia as further validation of the GRL model. As these effects lack precedent, the ROIs (as before) originated from a prior study that modeled the RPE without including any effects of generalization. This table is related to Figures 10 and S7 and Tables S19 and S20.
| Variable Region of interest | 3-T Face/House | 7-T Color/Motion |
|-----------------------------|---------------|-----------------|
|                             | All | Good | Poor | All | Good | Poor |
| \( n \)                    | 40  | 31   | 9    | 21  | 16   | 5    |

### RPE x State generalization

| Region of interest                      | 3-T Face/House | 7-T Color/Motion |
|----------------------------------------|---------------|-----------------|
| |                             | All | Good | Poor | All | Good | Poor |
| Hippocampus                            | U   | U    | U    | -   | U    | -    |
| Set of 2 regions of interest           | S   | U    | U    | -   | U    | -    |
| L Hippocampus (-28, -18, -16)          | U   | cp   | -    | -   | C    | -    |
| R Hippocampus (28, -18, -16)           | CP  | -    | cp   | -   | -    | -    |

### RPE x Action generalization

| Region of interest                      | 3-T Face/House | 7-T Color/Motion |
|----------------------------------------|---------------|-----------------|
| |                             | All | Good | Poor | All | Good | Poor |
| Hippocampus                            | U   | U    | U    | -   | -    | -    |
| Set of 2 regions of interest           | -   | -    | -    | -   | -    | -    |
| L Hippocampus (-28, -18, -16)          | -   | -    | -    | -   | -    | -    |
| R Hippocampus (28, -18, -16)           | -   | -    | -    | -   | -    | -    |
Table S22. Neural substrates of the GRL model: Summary (Hippocampus). This qualitative summary of the second portion of the fMRI analyses examines the hippocampus. This table is related to Figure 10 and Tables S19 and S20.
| Group (3-T Face/House) | Variable                        | Region                        | H    | x, y, z | t<sub>df</sub> | p      | k   | SVC |
|------------------------|---------------------------------|-------------------------------|------|---------|----------------|--------|-----|-----|
| All learners (n = 40)  | RPE x Learning rate             |                               |      |         | t<sub>38</sub> |        |     |     |
| Dorsal caudate nucleus | R 10, 4, 18                     | 3.76                          | < 10<sup>-3</sup> | 12   | -              |
| Poor learners (n = 9)  | RPE x Learning rate             |                               |      |         | t<sub>7</sub> |        |     |     |
| Ventral tegmental area & Substantia nigra | R 6, -18, -12 | 7.43                          | < 10<sup>-4</sup> | 17   | -              |
| Nonlearners (n = 7)    | RPE x Learning rate             |                               |      |         | t<sub>5</sub> |        |     |     |
| Dorsal caudate nucleus | R 18, -4, 26                    | 7.54                          | < 10<sup>-3</sup> | 11   | -              |
Table S23. Neural substrates of the learning rate: 3-T Face/House version. This table is related to Table S25.
| Group (7-T Color/Motion) Variable Region | H | x, y, z | $t_{df}$ | p   | k | SVC |
|-----------------------------------------|---|---------|--------|-----|---|-----|
| All learners ($n = 21$)                |   |         | $t_{19}$ |     |   |     |
| RPE x Learning rate                    |   |         |        |     |   |     |
| Dorsal caudate nucleus                 | R | 12, -1.2, 14.4 | 4.56 | $10^{-4}$ | 21 | -   |
| Posterior putamen                      | R | 27.6, -12, 13.2 | 4.68 | $<10^{-4}$ | 11 | -   |
| Good learners ($n = 16$)               |   |         | $t_{14}$ |     |   |     |
| RPE x Learning rate                    |   |         |        |     |   |     |
| Dorsal caudate nucleus                 | R | 15.6, -1.2, 14.4 | 5.70 | $<10^{-4}$ | 22 | -   |
| Posterior putamen                      | R | 27.6, -12, 13.2 | 4.46 | $<10^{-3}$ | 12 | -   |
| Poor learners ($n = 5$)                |   |         | $t_{3}$ |     |   |     |
| RPE x Learning rate                    |   |         |        |     |   |     |
| Ventral tegmental area                 | L | -7.2, -15.6, -10.8 | 12.18 | $<10^{-3}$ | 13 | C   |
Table S24. Neural substrates of the learning rate: 7-T Color/Motion version. This table is related to Table S25.
| Variable Region of interest | 3-T Face/House | 7-T Color/Motion |
|-----------------------------|----------------|-----------------|
|                             | All | Good | Poor | All | Good | Poor |
| \( n \)                     | 40  | 31   | 9    | 21  | 16   | 5    |
| RPE x Learning rate          |     |      |      |     |      |      |
| Striatum                    | U   | -    | -    | U   | U    | -    |
| Dopaminergic midbrain       | -   | -    | U    | -   | -    | U    |
| Set of 7 regions of interest | -   | -    | -    | -   | -    | U    |
| L Anterior caudate nucleus (-8, 18, -8) | -   | -    | -    | -   | -    | -    |
| R Nucleus accumbens (8, 12, -4) | -   | -    | -    | -   | -    | -    |
| R Ventral putamen (18, 12, -12) | -   | -    | -    | -   | -    | -    |
| L Nucleus accumbens (-12, 10, -6) | -   | -    | -    | -   | -    | -    |
| R Dorsal putamen (28, 6, 0)  | -   | -    | -    | -   | -    | -    |
| L Dorsal caudate nucleus (-18, 2, 16) | -   | -    | -    | -   | -    | -    |
| L Substantia nigra (-10, -14, -12) | -   | -    | -    | -   | -    | C    |
| RPE x Learning rate          |     |      |      |     |      |      |
| Hippocampus                 | -   | -    | -    | -   | -    | -    |
| Set of 2 regions of interest | -   | -    | -    | -   | -    | -    |
| L Hippocampus (-28, -18, -16) | -   | -    | -    | -   | -    | -    |
| R Hippocampus (28, -18, -16)  | -   | -    | -    | -   | -    | -    |
Table S25. Neural substrates of the learning rate: Summary. The absence of overlap between specific effects of generalization and effects of learning performance indicates that the former are not confounded with the latter. This table is related to Tables S23 and S24.