Results brief summary:

I ran two computational models in Stan – the Value plus Sequential Exploration model (see [Ligneul, 2019](https://journals.plos.org/ploscompbiol/article?id=10.1371/journal.pcbi.1006989)) and the Prospect Valence Learning-Delta model (see [Steingroever et al., 2013](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3847555/)). **Model comparison metrics show the VSE model is the better fit of the GUM4 data by quite a large margin**. Participants who had 62 trials due to the task-crashing bug were still included, as we can still approximate latent parameter values given a 62-trial choice pattern.

VSE model and parameter descriptions are on p2-3. Linear mixed model results and contrasts are p4 and onward.

* Re: the effects of caffeine, results are in line with the original paper. **There are no significant effects of drug on any of the VSE parameter values, nor are there any significant interactions**. The results presented below are of models with the *session* x *drug* interaction term dropped.
* Regression models show:
  + By and large, subjects in the sample are **exploitative** (distribution of Exploration Bonus values entirely in negative range).
  + Subjects are **significantly lower on Value Sensitivity and Decay Rate at 75h TSD**, relative to Baseline
  + Subjects are **significantly lower on Exploration Bonus (became more exploitative) at both 51h and 75h of TSD**, relative to Baseline
  + Subjects **significantly increased in Exploration Update at 51h TSD**, relative to Baseline
  + Subjects **significantly** **increased in Consistency at 51h TSD**, relative to Baseline
* Post-hoc contrasts show:
  + **Significant decrease in Value Sensitivity from 51h to 75h TSD**
  + **Significant decrease in Decay Rate from 51h to 75h TSD**
  + **Significant decrease in Exploration Bonus from Baseline to 51h TSD**
  + **Significant increase in Exploration Update from Baseline to 51h TSD**
  + Effect of Baseline-51h TSD on Consistency no longer significant after Bonferroni correction

# Value plus Sequential Exploration model

The VSE model has 5 free parameters, and two over-arching cognitive components (exploitation and exploration). Its basis is to capture information-seeking behaviour (in addition to value exploitation), which previous cognitive process models of the IGT don’t do adequately. Description of model components as follows.

### 1. Exploitation Weights

Exploitation weights determine the degree to which each deck is likely to be repeatedly selected because of its value. Exploitation weights for each deck are initialised as 0 at the start of the task (trial *t* = 0).

The value of the chosen deckon trial *t* is given by the following equation:

* Where is the **value sensitivity** parameter, bounded between 0 and 1. Higher values indicate higher sensitivity to the net gain/loss each trial.

On each trial, the exploitation weight of deck *d* (*exploitd*) is updated for trial *t +* 1 as follows:

* Where is the **decay rate** parameter, bounded between 0 and 1. indicates perfect retention of deck expected values, and lower values indicate faster “forgetting” of expected values – akin to a working memory component.

### 2. Exploration Weights

Exploration weights determine the degree to which each deck is likely chosen due to “goal-directed exploration”, i.e., information seeking behaviour, *independent of deck values* (see [Wilson et al., 2014](https://pubmed.ncbi.nlm.nih.gov/25347535/)). Exploration weights are initialised as the subject’s exploration bonus parameter value at the start of the task.

On each trial, the exploration weight of deck *d* (*explored*) is updated for trial *t +* 1 as follows:

* Where is the **exploration bonus** parameter, unbounded. Positive values indicate tendency to ***explore***, while negative values indicate a more exploitative choice pattern.
* And is the **learning rate/exploration update\*** parameter, bounded 0-1, controlling the degree to which subjects return to their baseline tendency to explore other deck options (higher = faster return).

\*I’m running with calling this “exploration update” for the paper, which I think is a more accurate representation. “Learning rate” seems like a misnomer because subjects aren’t actually learning anything re: goal-directed exploration – probably just an artefact inherited from reinforcement learning models with a similar delta rule in the equation. As Daniel puts it, if is the baseline level of the itch to explore, then controls how long till the itch needs to be scratched again.

### 3. Softmax Choice Rule

Incorporating both exploitation and exploration modules, the probability of selected deck *d* on each trial is given as follows:

* Where ***C*** is the **consistency** parameter, transformed from an inverse temperature free parameter by the equation \*. Higher values of *C* indicate choices are more deterministic and show a higher degree of alignment with exploitation and exploration modules, whereas lower values of *C* indicate more random choice patterns.

\* For the sake of computational efficiency, I approximated *C* directly, as opposed to approximating and then transforming.

## Summary descriptives of Model Parameters

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Value sensitivity | Decay rate | Exploration bonus | Exploration update | Consistency ***C*** |
| Median | .178 | .343 | -3.148 | 0.776 | 4.452 |
| Min. | .116 | .262 | -3.242 | .660 | 3.932 |
| Max. | .264 | .439 | -2.740 | .800 | 4.875 |
| SD | .038 | .038 | .098 | .026 | .246 |

## Regression model results (Value Sensitivity & Decay Rate as DVs)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Value Sensitivity** | | | **Decay Rate** | | |
| *Predictors* | *Estimates* | *CI* | *p* | *Estimates* | *CI* | *p* |
| (Intercept) | 0.23 | 0.220 – 0.239 | **<0.001** | 0.399 | 0.386 – 0.413 | **<0.001** |
| session [51h TSD] | -0.006 | -0.018 – 0.007 | 0.368 | -0.013 | -0.030 – 0.004 | 0.139 |
| session [75h TSD] | -0.069 | -0.081 – -0.056 | **<0.001** | -0.037 | -0.054 – -0.020 | **<0.001** |
| **Random Effects** | | | | | | |
| σ2 | 0 | | | 0 | | |
| τ00 | 0.00 PtID | | | 0.00 PtID | | |
| ICC | 0.22 | | | 0.23 | | |
| N | 29 PtID | | | 29 PtID | | |
| Observations | 81 | | | 81 | | |
| Marginal R2 / Conditional R2 | 0.577 / 0.671 | | | 0.153 / 0.350 | | |

Highlighted effects are significant at *p* < .05.

## Regression model results (Explore Bonus, Explore Update, Consistency as DVs)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Exploration Bonus** | | | **Exploration Update (Learning Rate)** | | | **Consistency** | | |
| *Predictors* | *Estimates* | *CI* | *p* | *Estimates* | *CI* | *p* | *Estimates* | *CI* | *p* |
| (Intercept) | -3.974 | -4.022 – -3.926 | **<0.001** | 0.797 | 0.786 – 0.808 | **<0.001** | 1.839 | 1.822 – 1.855 | **<0.001** |
| session [51h TSD] | -0.105 | -0.165 – -0.044 | **0.001** | 0.018 | 0.004 – 0.031 | **0.01** | 0.021 | 0.000 – 0.043 | **0.046** |
| session [75h TSD] | -0.16 | -0.220 – -0.099 | **<0.001** | 0.025 | 0.011 – 0.038 | **<0.001** | 0.02 | -0.001 – 0.041 | 0.065 |
| **Random Effects** | | | | | | | | | |
| σ2 | 0.01 | | | 0 | | | 0 | | |
| τ00 | 0.00 PtID | | | 0.00 PtID | | | 0.00 PtID | | |
| ICC | 0.26 | | | 0.31 | | | 0.24 | | |
| N | 29 PtID | | | 29 PtID | | | 29 PtID | | |
| Observations | 81 | | | 81 | | | 81 | | |
| Marginal R2 / Conditional R2 | 0.210 / 0.419 | | | 0.111 / 0.385 | | | 0.047 / 0.275 | | |

Highlighted effects are significant at *p* < .05.

## Contrasts with Bonferroni Correction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Contrast** | **Estimate** | **SE** | **df** | **t.ratio** | **p.value** |
| ***Value Sensitivity*** |  |  |  |  |  |
| Baseline - 51h TSD | 0.005726 | 0.00634 | 54.46645 | 0.903182 | 1 |
| Baseline - 75h TSD | 0.068617 | 0.00634 | 54.46645 | 10.82303 | <.001 |
| 51h TSD - 75h TSD | 0.062891 | 0.006489 | 51.41287 | 9.691235 | <.001 |
| ***Decay Rate*** |  |  |  |  |  |
| Baseline - 51h TSD | 0.012783 | 0.008561 | 54.44318 | 1.4931 | 0.424 |
| Baseline - 75h TSD | 0.03671 | 0.008561 | 54.44318 | 4.288001 | <.001 |
| 51h TSD - 75h TSD | 0.023927 | 0.00876 | 51.38899 | 2.731367 | 0.026 |
| ***Exploration Bonus*** |  |  |  |  |  |
| Baseline - 51h TSD | 0.104937 | 0.030408 | 54.37624 | 3.450935 | 0.003 |
| Baseline - 75h TSD | 0.159672 | 0.030408 | 54.37624 | 5.250935 | <.001 |
| 51h TSD - 75h TSD | 0.054735 | 0.031089 | 51.3257 | 1.760616 | 0.253 |
| ***Exploration Update*** |  |  |  |  |  |
| Baseline - 51h TSD | -0.01777 | 0.00677 | 54.27386 | -2.62429 | 0.034 |
| Baseline - 75h TSD | -0.02469 | 0.00677 | 54.27386 | -3.64662 | 0.002 |
| 51h TSD - 75h TSD | -0.00692 | 0.006913 | 51.2414 | -1.00118 | 0.964 |
| ***Consistency*** |  |  |  |  |  |
| Baseline - 51h TSD | -0.02148 | 0.010619 | 54.43141 | -2.02307 | 0.144 |
| Baseline - 75h TSD | -0.01986 | 0.010619 | 54.43141 | -1.87034 | 0.200 |
| 51h TSD - 75h TSD | 0.001622 | 0.010864 | 51.37731 | 0.149274 | 1 |

Highlighted contrasts are significant at *p* < .05.