

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
## v dplyr      1.2.0      v readr      2.1.6
## v forcats    1.0.1      v stringr   1.6.0
## v ggplot2    4.0.2      v tibble    3.3.1
## v lubridate  1.9.5      v tidyr     1.3.2
## v purrr      1.2.1
## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()     masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(brms)
```

```
## Loading required package: Rcpp
## Loading 'brms' package (version 2.23.0). Useful instructions
## can be found by typing help('brms'). A more detailed introduction
## to the package is available through vignette('brms_overview').
##
## Attaching package: 'brms'
##
## The following object is masked from 'package:stats':
##
##     ar
```

```
library(bayesplot)
```

```
## This is bayesplot version 1.15.0
## - Online documentation and vignettes at mc-stan.org/bayesplot
## - bayesplot theme set to bayesplot::theme_default()
##   * Does _not_ affect other ggplot2 plots
##   * See ?bayesplot_theme_set for details on theme setting
##
## Attaching package: 'bayesplot'
##
## The following object is masked from 'package:brms':
##
##     rhat
```

```
library(loo)
```

```
## This is loo version 2.9.0
## - Online documentation and vignettes at mc-stan.org/loo
## - As of v2.0.0 loo defaults to 1 core but we recommend using as many as possible. Use the 'cores' argument
```

```
options(mc.cores = parallel::detectCores())
rstan::rstan_options(auto_write = TRUE)
```

```
df_p1 <- read.csv("/Users/debarpita/Desktop/arjun/trial_wise_dataset_post.csv")
df_p2 <- read.csv("/Users/debarpita/Desktop/arjun/trial_wise_dataset_pre.csv")

df <- bind_rows(df_p1, df_p2)
```

```
df <- df %>%
  filter(!is.na(Reward), Reward != 0)
df <- df %>%
  group_by(Participant_ID, stim_cat, env) %>%
  arrange(patch_id, .by_group = TRUE) %>%
  mutate(patch_number = patch_id) %>%
  ungroup()

# Remove patches with zero cumulative reward
df <- df %>%
  group_by(Participant_ID, stim_cat, env, patch_number) %>%
  filter(min(TotalCumulativeReward, na.rm = TRUE) > 0) %>%
  ungroup()

# Z-score predictors
df <- df %>%
  mutate(
    patch_number_z = scale(patch_number)[,1],
    trait_anxiety_score_z = scale(trait_anxiety_score)[,1]
  )

summary(df$TotalCumulativeReward)
```

```
##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##      91      1769    3231     3840    5449    11883
```

```
df %>%
  group_by(stim_cat, env) %>%
  summarise(
    n = n(),
    min_cum = min(TotalCumulativeReward, na.rm = TRUE),
    max_cum = max(TotalCumulativeReward, na.rm = TRUE),
    mean_cum = mean(TotalCumulativeReward, na.rm = TRUE),
    .groups = "drop"
  )
```

```
## # A tibble: 4 x 6
##   stim_cat  env      n min_cum max_cum mean_cum
##   <chr>    <int> <int>   <int>   <int>   <dbl>
## 1 post      1  1417    182  11883  4970.
## 2 post      2  1335    184  11840  5360.
## 3 pre       1  1309     91   6217  2488.
## 4 pre       2  1097     91   4514  2144.
```

Model 1: Learning Across Patches Do participants increase cumulative reward across patches within each environment, and does stimulation alter the rate of reward growth? Because cumulative reward is strictly positive and right-skewed, we use a Gamma regression with log link.

```

model1 <- brm(
  TotalCumulativeReward ~ patch_number_z * stim_cat + env +
    (1 | Participant_ID),
  data = df,
  family = Gamma(link = "log"),
  chains = 4,
  iter = 4000,
  warmup = 1500,
  cores = 4,
  seed = 123
)

```

```
## Compiling Stan program...
```

```
## Trying to compile a simple C file
```

```

## Running /Library/Frameworks/R.framework/Resources/bin/R CMD SHLIB foo.c
## using C compiler: 'Apple clang version 17.0.0 (clang-1700.6.3.2)'
## using SDK: 'MacOSX26.2.sdk'
## clang -arch arm64 -std=gnu2x -I"/Library/Frameworks/R.framework/Resources/include" -DNDEBUG -I"/Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/StanHeaders/include" -c foo.c -o foo.o
## In file included from <built-in>:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/StanHeaders/include:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen/include:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen/include/Eigen/src/Core/Matrix.h:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen/include/Eigen/src/Core/MatrixBase.h:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen/include/Eigen/src/Core/Matrix.h:1:
## 679 | #include <cmath>
##      |          ~~~~~~
## 1 error generated.
## make: *** [foo.o] Error 1

```

```
## Start sampling
```

```
summary(model1)
```

```

## Family: gamma
## Links: mu = log
## Formula: TotalCumulativeReward ~ patch_number_z * stim_cat + env + (1 | Participant_ID)
## Data: df (Number of observations: 5158)
## Draws: 4 chains, each with iter = 4000; warmup = 1500; thin = 1;
## total post-warmup draws = 10000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
## Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)      0.47      0.08      0.34      0.66 1.00      1224      2214
##
## Regression Coefficients:
## Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## Intercept          10.53      0.11      10.31      10.75 1.00      976
## patch_number_z       1.14      0.02       1.10       1.17 1.00     3027
## stim_catpre         -1.05      0.01      -1.08      -1.02 1.00     4556
## env                 -1.36      0.02      -1.40      -1.31 1.00     3412

```

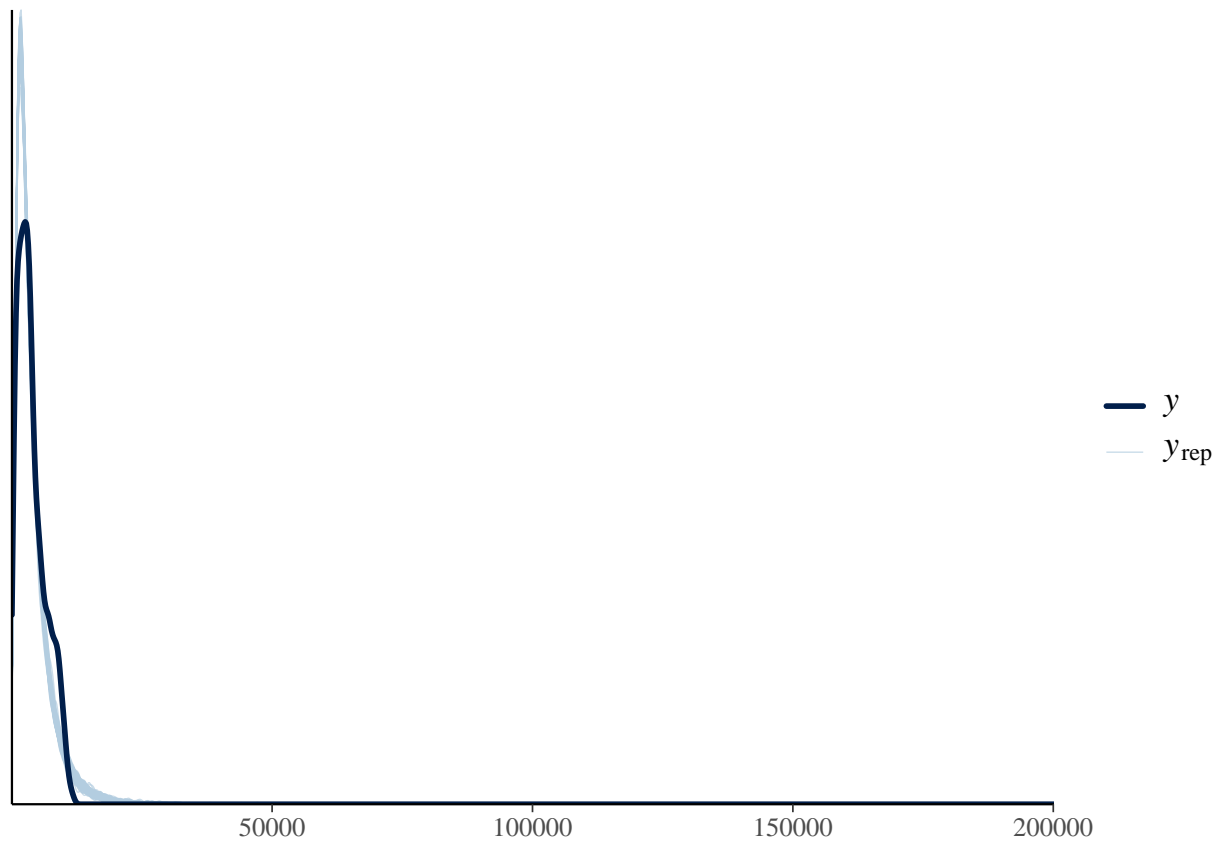
```
## patch_number_z:stim_catpre    -0.34      0.02    -0.38    -0.31 1.00      3792
##                               Tail_ESS
## Intercept                     1455
## patch_number_z                4262
## stim_catpre                   5216
## env                           4497
## patch_number_z:stim_catpre    4963
##
## Further Distributional Parameters:
##      Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## shape      4.57      0.09    4.40    4.74 1.00      4500      4782
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
```

beta\_patch\_number\_z > 0: Cumulative reward increases across patches 4% increase

```
exp(fixef(model1))
```

```
##              Estimate Est.Error      Q2.5      Q97.5
## Intercept      3.746086e+04  1.116933 3.011070e+04 4.664710e+04
## patch_number_z  3.122599e+00  1.018267 3.016704e+00 3.235720e+00
## stim_catpre     3.503953e-01  1.013836 3.412160e-01 3.599415e-01
## env            2.572681e-01  1.024756 2.453699e-01 2.698190e-01
## patch_number_z:stim_catpre 7.085548e-01 1.015845 6.869153e-01 7.310267e-01
```

```
pp_check(model1, type = "dens_overlay", ndraws = 100)
```

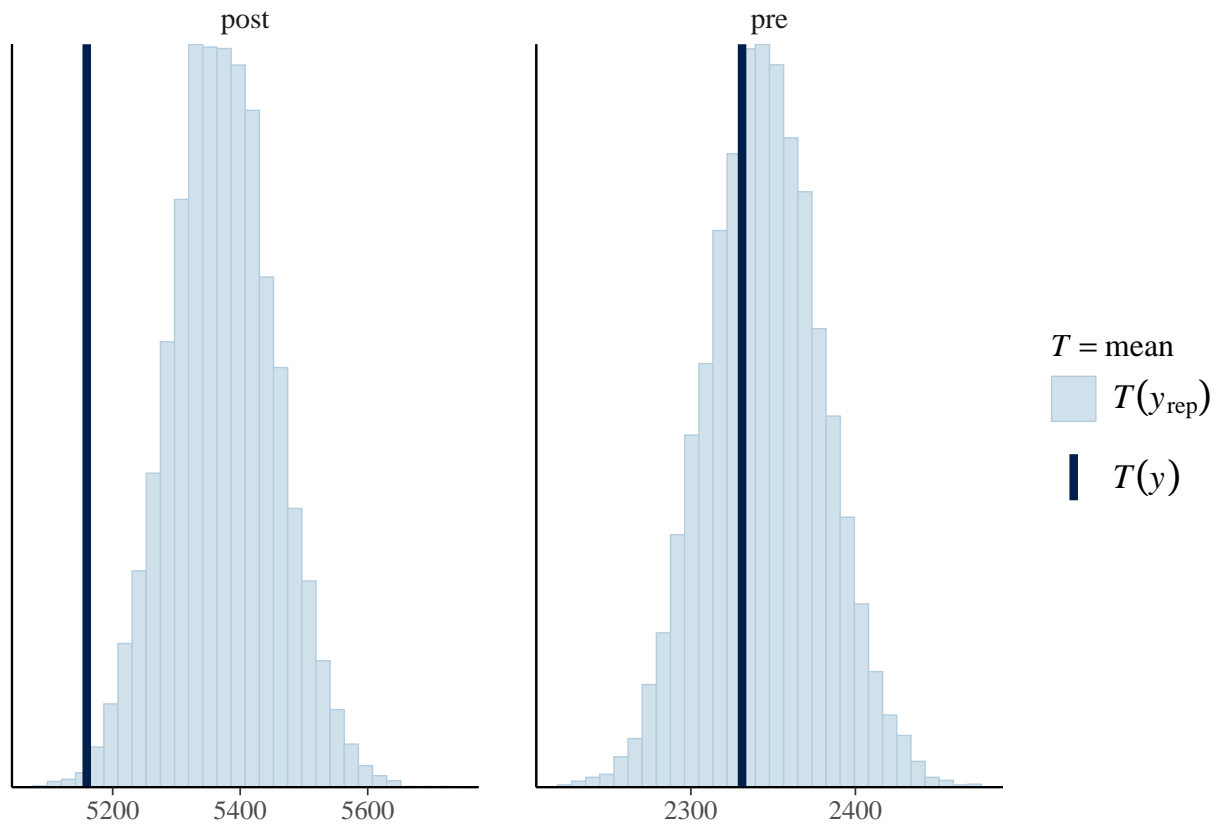


```
pp_check(model1, type = "stat_grouped", group = "stim_cat")
```

```
## Using all posterior draws for ppc type 'stat_grouped' by default.
```

```
## Note: in most cases the default test statistic 'mean' is too weak to detect anything of interest.
```

```
## 'stat_bin()' using 'bins = 30'. Pick better value 'binwidth'.
```



```
model2 <- brm(
  TotalCumulativeReward ~ patch_number_z * stim_cat *
    trait_anxiety_score_z + env +
    (1 | Participant_ID),
  data = df,
  family = Gamma(link = "log"),
  chains = 4,
  iter = 4000,
  warmup = 1500,
  cores = 4,
  seed = 123
)
```

```
## Compiling Stan program...
```

```
## recompiling to avoid crashing R session
```

```
## Trying to compile a simple C file
```

```
## Running /Library/Frameworks/R.framework/Resources/bin/R CMD SHLIB foo.c
```

```
## using C compiler: 'Apple clang version 17.0.0 (clang-1700.6.3.2)'
```

```
## using SDK: 'MacOSX26.2.sdk'
```

```
## clang -arch arm64 -std=gnu2x -I"/Library/Frameworks/R.framework/Resources/include" -DNDEBUG -I"/Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/StanHeaders/include/src" -c foo.c -o foo.o
```

```
## In file included from <built-in>:1:
```

```
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/StanHeaders/include/src:1:
```

```
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen.
## In file included from /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen.
## /Library/Frameworks/R.framework/Versions/4.5-arm64/Resources/library/RcppEigen/include/Eigen/src/Core
## 679 | #include <cmath>
##      | ~~~~~~
## 1 error generated.
## make: *** [foo.o] Error 1
```

```
## Start sampling
```

```
summary(model2)
```

```
## Family: gamma
## Links: mu = log
## Formula: TotalCumulativeReward ~ patch_number_z * stim_cat * trait_anxiety_score_z + env + (1 | Participant_ID)
## Data: df (Number of observations: 5158)
## Draws: 4 chains, each with iter = 4000; warmup = 1500; thin = 1;
##          total post-warmup draws = 10000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##          Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)      0.49      0.09      0.35      0.70 1.00      2592      4007
##
## Regression Coefficients:
##
##          Estimate Est.Error 1-95% CI
## Intercept          10.54      0.11      10.31
## patch_number_z        1.14      0.02       1.11
## stim_catpre         -1.05      0.01      -1.08
## trait_anxiety_score_z  0.01      0.11      -0.20
## env                 -1.37      0.02      -1.41
## patch_number_z:stim_catpre -0.34      0.02      -0.37
## patch_number_z:trait_anxiety_score_z -0.02      0.01      -0.04
## stim_catpre:trait_anxiety_score_z -0.04      0.01      -0.06
## patch_number_z:stim_catpre:trait_anxiety_score_z -0.03      0.02      -0.06
##
##          u-95% CI Rhat Bulk_ESS
## Intercept          10.77 1.00      2489
## patch_number_z        1.18 1.00       7767
## stim_catpre         -1.02 1.00     10761
## trait_anxiety_score_z  0.22 1.00       3540
## env                 -1.32 1.00       8770
## patch_number_z:stim_catpre -0.31 1.00       9509
## patch_number_z:trait_anxiety_score_z  0.01 1.00       8435
## stim_catpre:trait_anxiety_score_z -0.01 1.00     11198
## patch_number_z:stim_catpre:trait_anxiety_score_z  0.00 1.00       8400
##
##          Tail_ESS
## Intercept          4155
## patch_number_z        5753
## stim_catpre          7263
## trait_anxiety_score_z  4376
## env                 6752
## patch_number_z:stim_catpre  6995
## patch_number_z:trait_anxiety_score_z  6949
```

```
## stim_catpre:trait_anxiety_score_z          6479
## patch_number_z:stim_catpre:trait_anxiety_score_z    6868
##
## Further Distributional Parameters:
##      Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## shape      4.59      0.09    4.42    4.77 1.00   10817    6896
##
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
```

patch\_number\_z = 1.46- Participants clearly accumulate more reward over successive patches. Environment 2 has ~83% lower cumulative reward than Environment 1. patch\_number\_z:stim\_catpre = -0.30- The learning slope in pre-stim is 26% flatter than in post-stim Main anxiety effect: -0.01 -No overall anxiety effect on reward level stim × anxiety: -0.06 -Higher anxiety people have slightly lower cumulative reward in pre condition.

patch\_number\_z:stim\_catpre:trait\_anxiety\_score\_z = -0.05, CI excludes zero. In pre-stim condition, higher anxiety reduces learning slope. In post-stim condition, this anxiety-related reduction is attenuated. So stimulation may buffer anxiety-related learning deficits.

Random slope correlation = 0.95 -Participants who start with higher reward also show steeper learning slopes

```
pp_check(model2)
```

```
## Using 10 posterior draws for ppc type 'dens_overlay' by default.
```

