

```

# Load required packages
if (!requireNamespace("brms", quietly = TRUE)) {
  install.packages("brms")
}
library(tidyverse)

## -- Attaching core tidyverse packages ----- tidyverse 2.0.0 --
## v dplyr     1.2.0     v readr     2.1.6
## vforcats   1.0.1     v stringr   1.6.0
## v ggplot2   4.0.2     v tibble    3.3.1
## v lubridate 1.9.5     v tidyrr    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(rstan)

## Loading required package: StanHeaders
##
## rstan version 2.32.7 (Stan version 2.32.2)
##
## For execution on a local, multicore CPU with excess RAM we recommend calling
## options(mc.cores = parallel::detectCores()).
## To avoid recompilation of unchanged Stan programs, we recommend calling
## rstan_options(auto_write = TRUE)
## For within-chain threading using 'reduce_sum()' or 'map_rect()' Stan functions,
## change 'threads_per_chain' option:
## rstan_options(threads_per_chain = 1)
##
## Attaching package: 'rstan'
##
## The following object is masked from 'package:tidyrr':
##
##     extract

```

```

rstan_options(auto_write = TRUE)
options(mc.cores = parallel::detectCores())
library(brms)
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(cmdstanr)

## This is cmdstanr version 0.8.0
## - CmdStanR documentation and vignettes: mc-stan.org/cmdstanr
## - Use set_cmdstan_path() to set the path to CmdStan
## - Use install_cmdstan() to install CmdStan

library(lme4)

## Loading required package: Matrix
##
## Attaching package: 'Matrix'
##
## The following objects are masked from 'package:tidyverse':
##
##     expand, pack, unpack
##
## Attaching package: 'lme4'
##
## The following object is masked from 'package:brms':
##
##     ngrps

library(lmerTest)

##
## Attaching package: 'lmerTest'
##
## The following object is masked from 'package:lme4':
##
##     lmer
##
## The following object is masked from 'package:stats':
##
##     step

```

```

library(rstan)
library(posterior)

## This is posterior version 1.6.1
##
## Attaching package: 'posterior'
##
## The following object is masked from 'package:bayesplot':
##       rhat
##
## The following objects are masked from 'package:rstan':
##       ess_bulk, ess_tail
##
## The following objects are masked from 'package:stats':
##       mad, sd, var
##
## The following objects are masked from 'package:base':
##       %in%, match

```

```

library(performance)
library(sjPlot)

```

```

##
## Attaching package: 'sjPlot'
##
## The following object is masked from 'package:ggplot2':
##       set_theme

```

```

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")
library(dplyr)
df <- bind_rows(df_p1, df_p2)

```

```

summary(df$HandlingTime)

```

```

##      Min.    1st Qu.     Median      Mean    3rd Qu.      Max.
##  1.968    2.456    2.737    3.721    3.480   30.424

```

Turkey IQR outlier rule - removes extremely high outliers.

```

Q1 <- quantile(df$HandlingTime, 0.25, na.rm = TRUE)
Q3 <- quantile(df$HandlingTime, 0.75, na.rm = TRUE)
IQR <- Q3 - Q1
df <- df %>%
  filter(HandlingTime >= Q1 - 1.5 * IQR,
         HandlingTime <= Q3 + 1.5 * IQR)

```

```

df <- df %>%
  mutate(HandlingTime_safe = HandlingTime + 1e-6)
df <- df %>%
  mutate(across(c(Reward, trait_anxiety_score, TotalCumulativeReward),
    list(z = ~scale(.)[,1])))

```

```

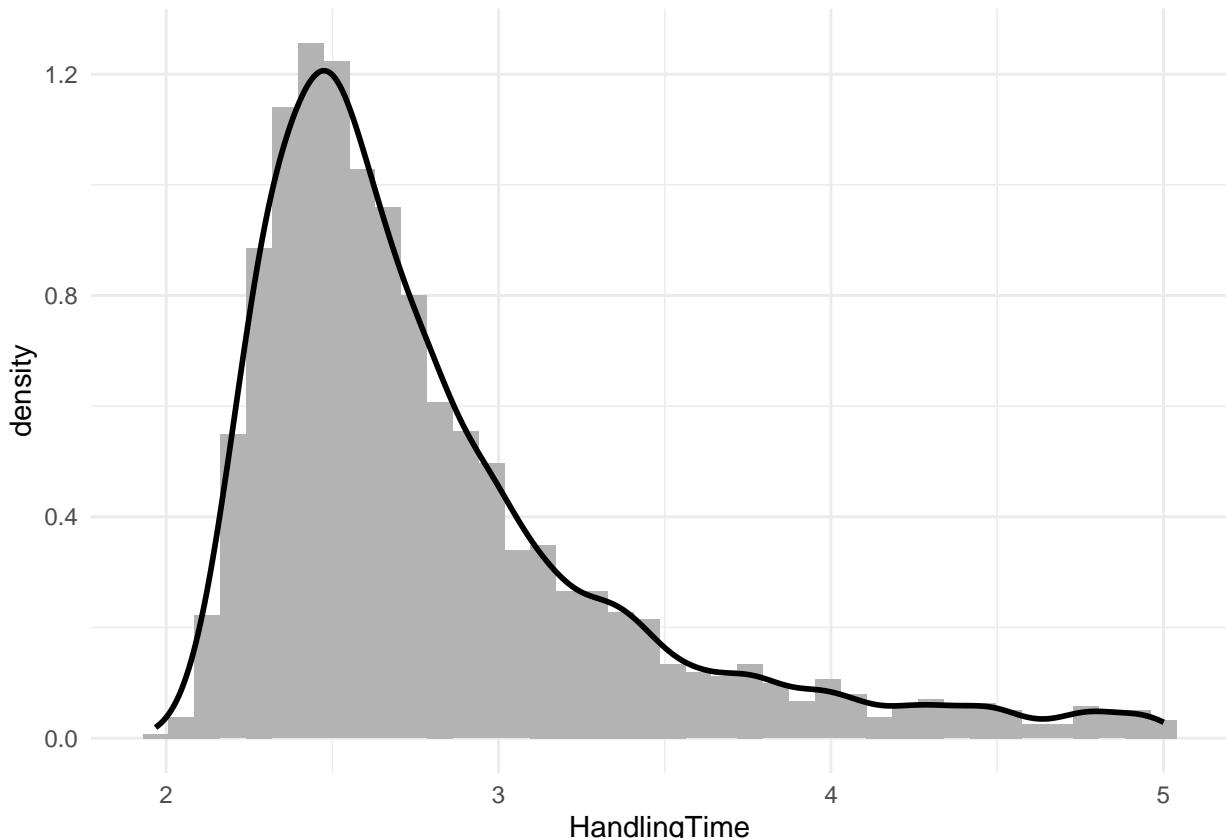
library(ggplot2)

ggplot(df, aes(x = HandlingTime)) +
  geom_histogram(aes(y = ..density..), bins = 40, fill = "grey70") +
  geom_density(size = 1) +
  theme_minimal()

```

## Warning: Using ‘size’ aesthetic for lines was deprecated in ggplot2 3.4.0.  
## i Please use ‘linewidth’ instead.  
## This warning is displayed once per session.  
## Call ‘lifecycle::last\_lifecycle\_warnings()’ to see where this warning was  
## generated.

## Warning: The dot-dot notation (‘..density..’) was deprecated in ggplot2 3.4.0.  
## i Please use ‘after\_stat(density)’ instead.  
## This warning is displayed once per session.  
## Call ‘lifecycle::last\_lifecycle\_warnings()’ to see where this warning was  
## generated.



Each participant has a different baseline handling time but the effect of stimulation is assumed to be the same for everyone

```
model_gamma <- brm(  
  HandlingTime_safe ~ stim + (1|Participant_ID),  
  data = df,  
  family = Gamma(link = "log"),  
  chains = 4,  
  iter = 3000,  
  warmup = 1000,  
  cores = 4  
)
```

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

```
## Start sampling
```

```
model_student <- brm(  
  HandlingTime_safe ~ stim + (1|Participant_ID),  
  data = df,  
  family = student(link = "log"),  
  chains = 4,  
  iter = 3000,  
  warmup = 1000,  
  cores = 4  
)
```

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

```
## Start sampling
```

```
## 4:                      70.353 seconds (Total)  
## Chain 4:
```

```
model_lognorm <- brm(  
  HandlingTime_safe ~ stim + (1|Participant_ID),  
  data = df,  
  family = lognormal(),  
  chains = 4,  
  iter = 3000,  
  warmup = 1000,  
  cores = 4  
)
```

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

```
## Start sampling
```

```
##                      70.353 seconds (Total)  
## Chain 4:
```

For interactions in Bayesian models, z-scoring is strongly recommended as it makes priors behave properly and improves convergence

```

df <- df %>%
  mutate(across(c(Reward, trait_anxiety_score,
                 TotalCumulativeReward),
               list(z = ~scale(.)[,1])))

summary(model_gamma)

## Family: gamma
## Links: mu = log
## Formula: HandlingTime_safe ~ stim + (1 | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##         total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.13      0.02     0.10     0.19 1.01       680      1119
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      1.10      0.03     1.04     1.16 1.00       551      1021
## stim        -0.09      0.00    -0.10    -0.09 1.00      3390      3692
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## shape        49.36      0.97    47.49    51.29 1.00      2670      3110
##
## 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).

```

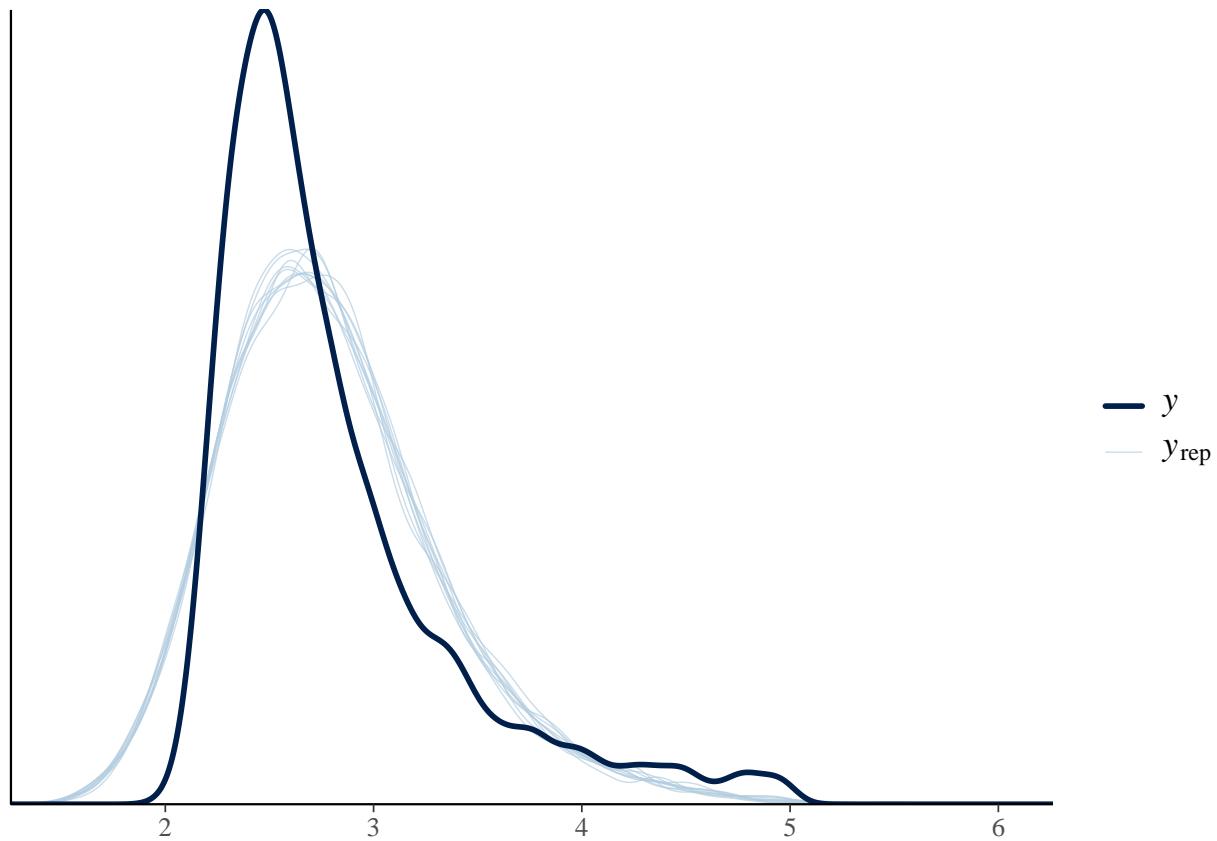
`sd(Intercept) = 0.14` between-person variability in baseline handling time.  $\exp(0.14) = 1.15$  this implies that a typical participant is about 15% faster or slower than the average person. High variability - people are very different from each other.  $\text{Estimate}(\text{Intercept}) = 1.10 \rightarrow \exp(1.10) = 3.00$  - The average handling time before stimulation. confidence interval doesn't include 0 which is why it is credible.  $\text{stim} = -0.09 \rightarrow \exp(-0.09) = 0.914$  Handling time is reduced by ~8.6% under stimulation. CI narrow which means model is confident about above effect and it is consistent across trials. Shape > 5: implies normal. Rhat is 1.00 so converged. Bulk\_ESS -> middle of the distribution. Tail\_ESS -> For the extreme values ess values greater than 400 so of no concern. stim error is within participant difference which is much smaller than intercept which is in between participants.

```

pp_check(model_gamma)

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

```



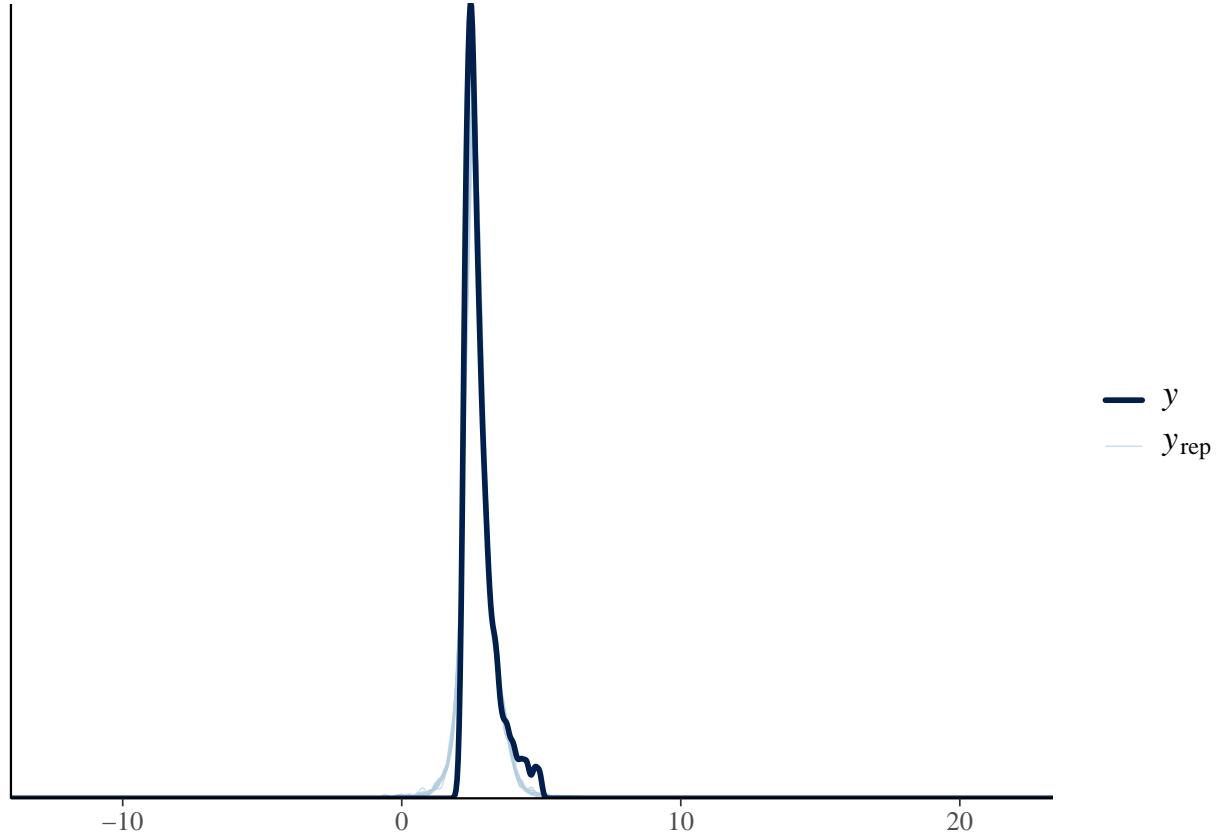
```
summary(model_student)

## Family: student
## Links: mu = log
## Formula: HandlingTime_safe ~ stim + (1 | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##         total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.13     0.02     0.10     0.19 1.00      784     1169
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      1.04     0.03     0.99     1.10 1.01      709     998
## stim        -0.07     0.00    -0.07    -0.06 1.00     3805    4048
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma        0.23     0.00     0.22     0.24 1.00     2481     3625
## nu          2.15     0.08     2.00     2.32 1.00     2505     3344
##
## 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).
```

```
pp_check(model_student)
```

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



```
summary(model_lognorm)
```

```
## Family: lognormal
##   Links: mu = identity
## Formula: HandlingTime_safe ~ stim + (1 | Participant_ID)
##   Data: df (Number of observations: 5079)
##   Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.13      0.02     0.10     0.18 1.01      636     1210
## 
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      1.09      0.03     1.03     1.14 1.02      551     805
```

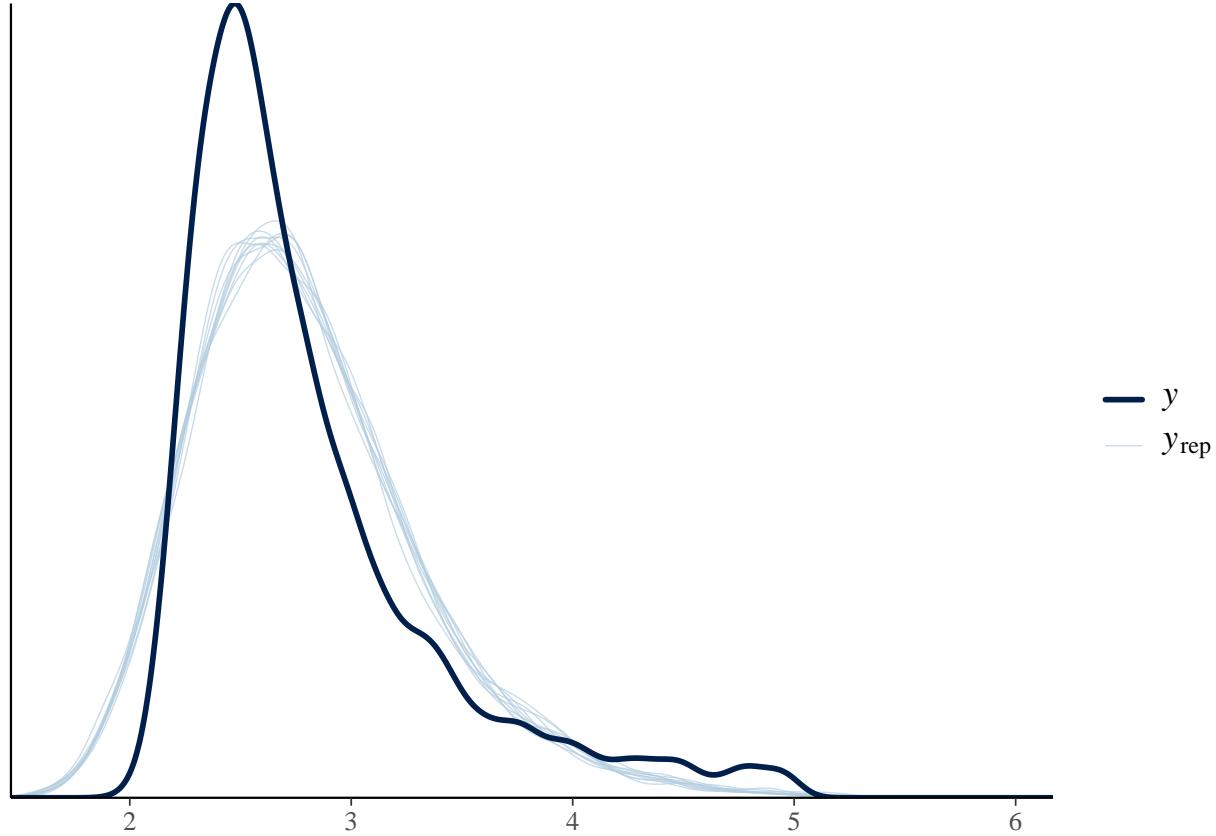
```

## stim      -0.09      0.00     -0.10    -0.08 1.00      3230      3545
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma      0.14      0.00      0.14      0.14 1.00      2169      2684
##
## 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).

```

```
pp_check(model_lognorm)
```

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



```
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' arg
##
## Attaching package: 'loo'

```

```

## The following object is masked from 'package:rstan':
##
##      loo

# Compute LOO for each model
loo_gamma    <- loo(model_gamma)
loo_student  <- loo(model_student)
loo_lognorm <- loo(model_lognorm)

# Compare models
loo_compare(loo_gamma, loo_student, loo_lognorm)

```

```

##           elpd_diff se_diff
## model_student     0.0      0.0
## model_lognorm   -41.6     39.8
## model_gamma     -201.7    45.9

```

elpd\_diff (Expected Log Predictive Density Difference) -> higher is better se\_diff (Standard Error of Difference) -> uncertainty in the comparison. If  $|elpd\_diff| > 2 \times se\_diff$  → strong evidence

Student and lognorm are clearly close competitors with student being the better model.

Each participant has their own baseline and their own stimulation effect. Lines are no longer parallel.

```

model_lognorm_own <- brm(
  HandlingTime_safe ~ stim + (1 + stim | Participant_ID),
  data = df,
  family = lognormal(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)

## Compiling Stan program...

## Start sampling

summary(model_lognorm_own)

## Family: lognormal
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim + (1 + stim | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##        total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##           Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.14      0.03     0.10     0.20 1.00     1501     2708
## sd(stim)         0.07      0.01     0.05     0.10 1.00     1729     3292

```

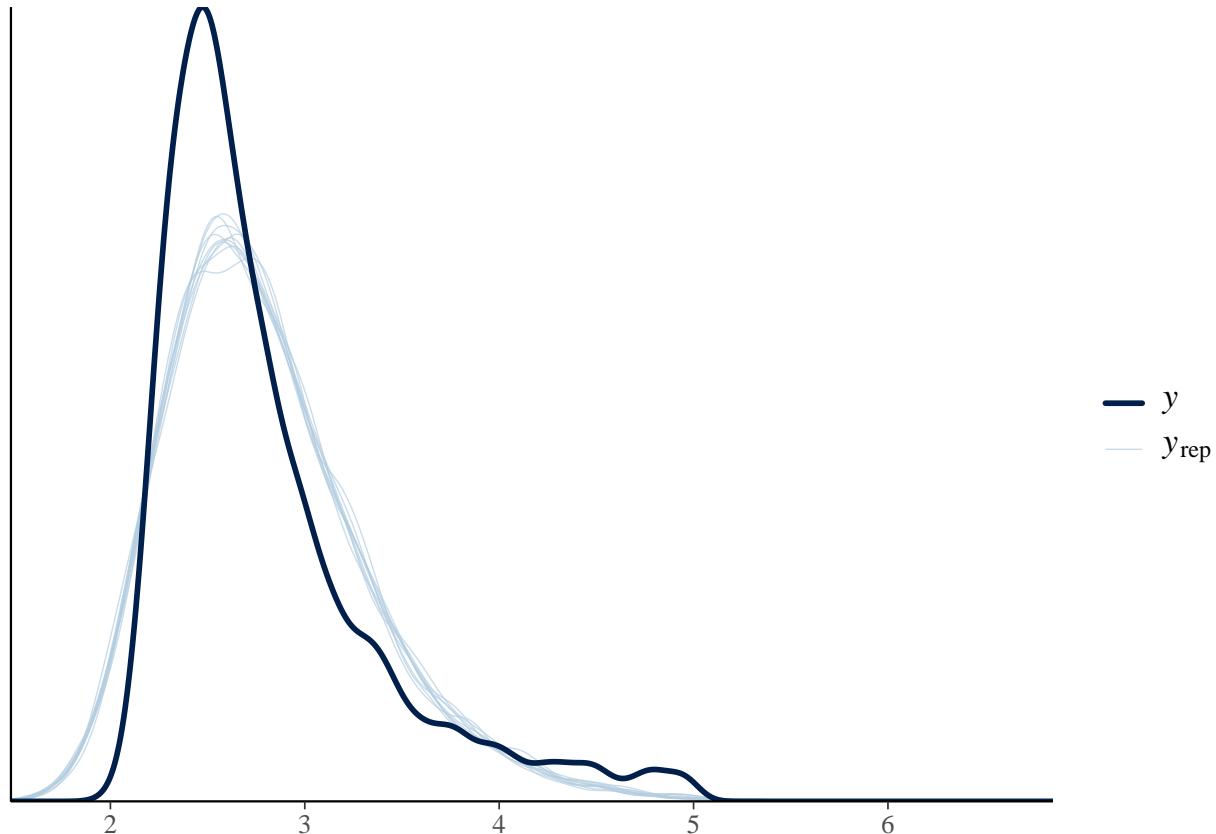
```

## cor(Intercept,stim)      -0.23      0.21     -0.61      0.22 1.00      2250      3477
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      1.09      0.03     1.02     1.15 1.00      1022      2006
## stim        -0.09      0.02    -0.12    -0.06 1.00      1924      3364
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma         0.14      0.00     0.13     0.14 1.00      9427      5738
##
## 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).

```

```
pp_check(model_lognorm_own)
```

## Using 10 posterior draws for ppc type 'dens\_overlay' by default.



```

model_student_own <- brm(
  HandlingTime_safe ~ stim + (1 + stim | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
  iter = 3000,

```

```

    warmup = 1000,
    cores = 4
)

## Compiling Stan program...

## Start sampling

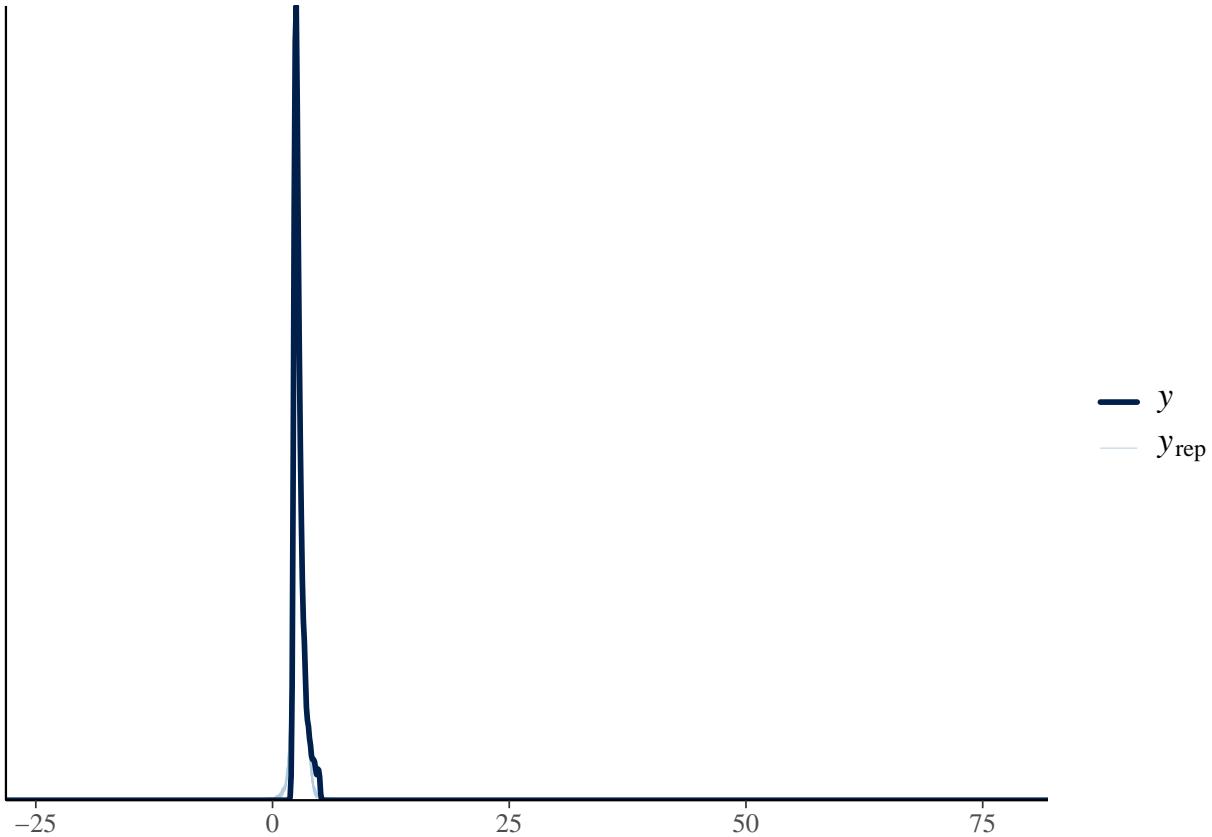
summary(model_student_own)

## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim + (1 + stim | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##         total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.44      0.08     0.32     0.63 1.00    1712    2959
## sd(stim)          0.17      0.03     0.12     0.25 1.00    1996    3609
## cor(Intercept,stim) -0.37      0.20    -0.72     0.07 1.00    2810    3828
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.89      0.10     2.70     3.08 1.00    1288    1962
## stim          -0.21      0.04    -0.29    -0.12 1.00    1785    2832
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma          0.22      0.00     0.21     0.23 1.00    5843    5248
## nu            2.14      0.08     1.99     2.31 1.00    5525    6082
##
## 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).

pp_check(model_student_own)

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

```



```

model_reward_log <- brm(
  HandlingTime_safe ~ Reward_z + (1 | Participant_ID),
  data = df,
  family = lognormal(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)

## Compiling Stan program...

## recompiling to avoid crashing R session

## Start sampling

## Warning: Bulk Effective Samples Size (ESS) is too low, indicating posterior means and medians may be
## Running the chains for more iterations may help. See
## https://mc-stan.org/misc/warnings.html#bulk-ess

summary(model_reward_log)

```

## Family: lognormal  
## Links: mu = identity

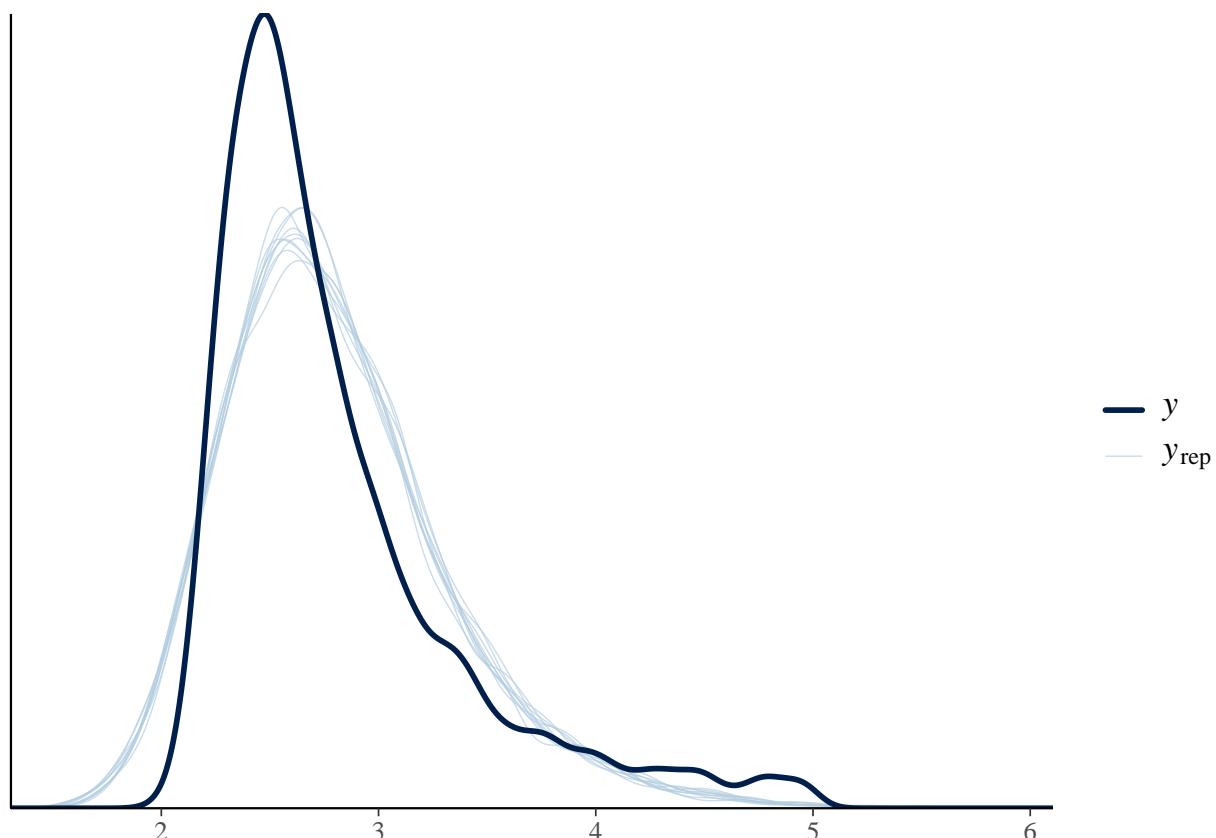
```

## Formula: HandlingTime_safe ~ Reward_z + (1 | Participant_ID)
##   Data: df (Number of observations: 5079)
##   Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.13     0.02     0.10     0.19 1.01      732     1261
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      1.04     0.03     0.98     1.10 1.01      400     659
## Reward_z       -0.03     0.00    -0.03    -0.02 1.00     5395    5038
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma         0.14     0.00     0.14     0.15 1.00     2604    3232
##
## 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).

pp_check(model_reward_log)

```

## Using 10 posterior draws for ppc type 'dens\_overlay' by default.



```

model_reward_student <- brm(
  HandlingTime_safe ~ Reward_z + (1 | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)

## Compiling Stan program...

## Start sampling

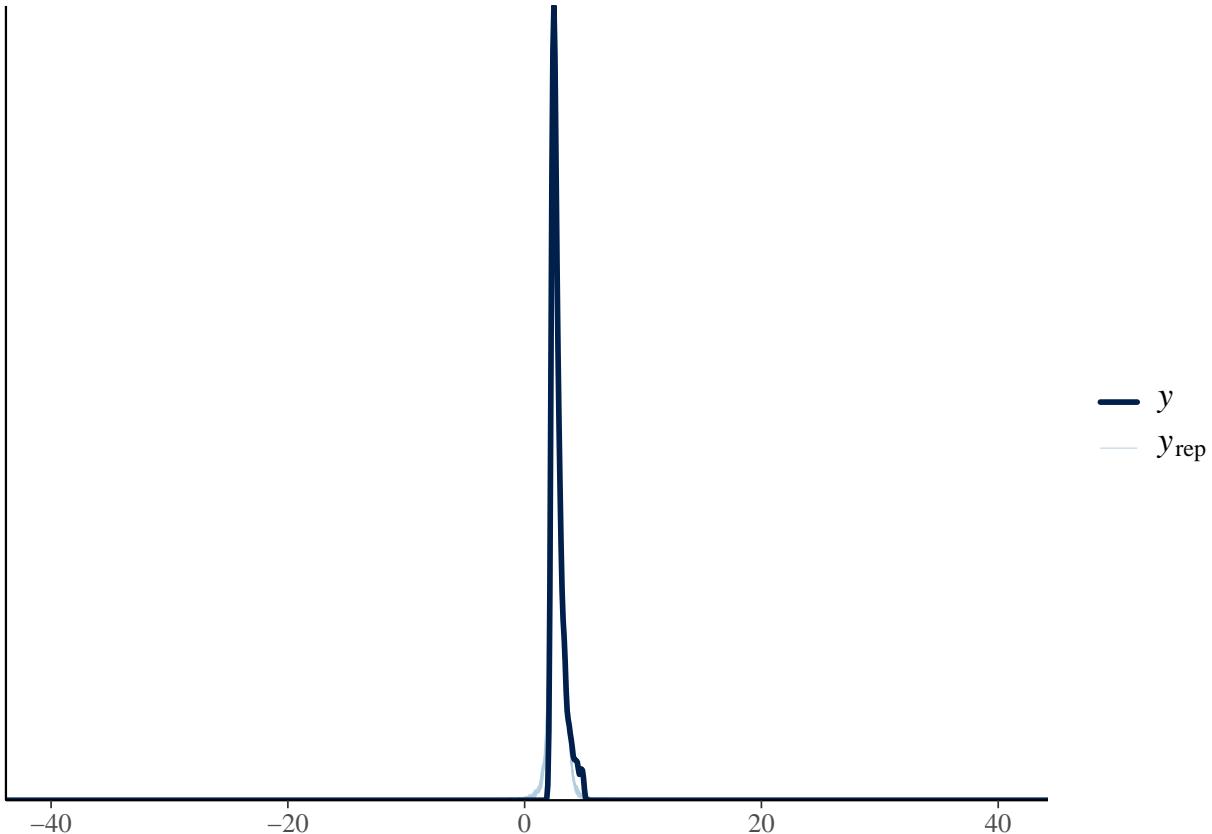
summary(model_reward_student)

## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ Reward_z + (1 | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##         total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.39      0.07     0.28     0.56 1.01      869     1578
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept      2.76      0.09     2.58     2.93 1.00      677     892
## Reward_z       -0.06      0.00    -0.07    -0.05 1.00      3925     3734
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma        0.23      0.00     0.22     0.24 1.00     2570     3233
## nu          2.11      0.08     1.96     2.28 1.00     2512     3206
##
## 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).

pp_check(model_reward_student)

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

```



```

model_stim_anx <- brm(
  HandlingTime_safe ~ stim * trait_anxiety_score_z + Reward_z +
    (1 + stim | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)

## Compiling Stan program...

## recompiling to avoid crashing R session

## Start sampling

summary(model_stim_anx)

## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim * trait_anxiety_score_z + Reward_z + (1 + stim | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;

```

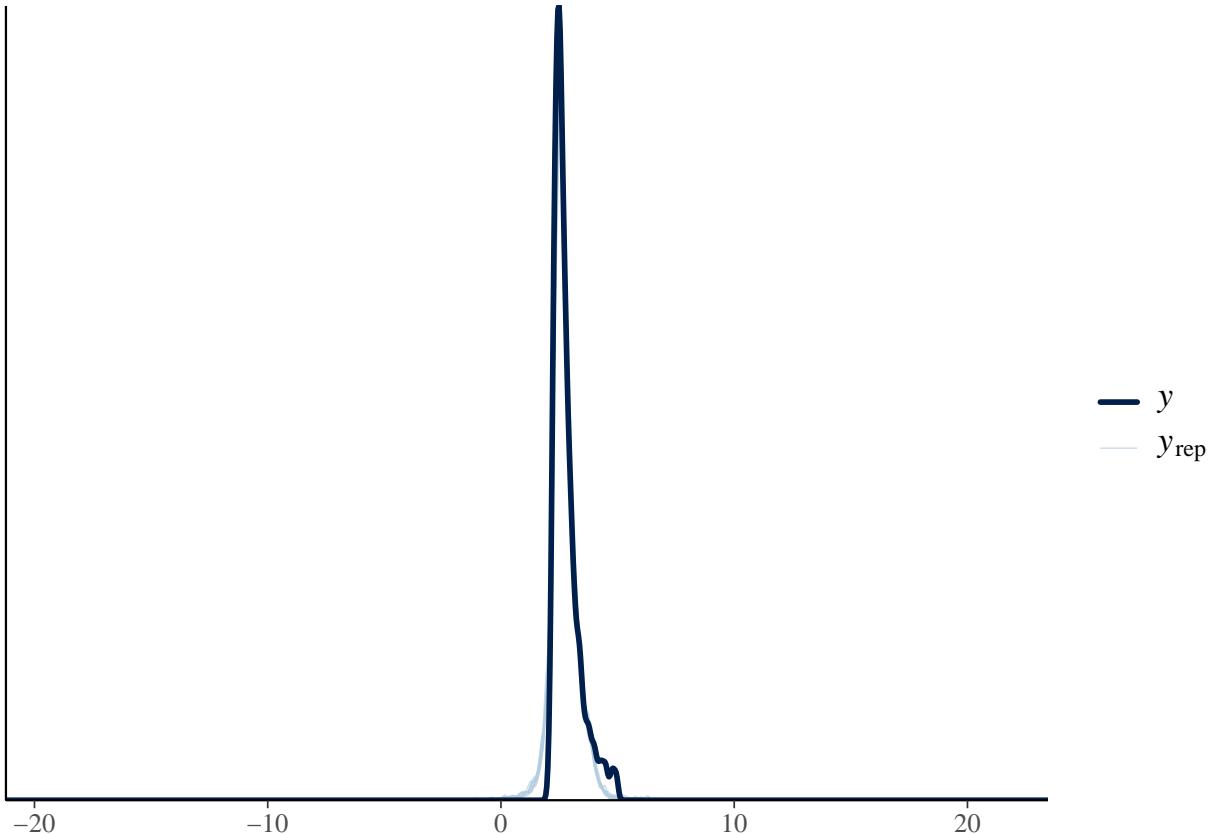
```

##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.43     0.08     0.31     0.61 1.00      2459     3860
## sd(stim)         0.18     0.03     0.12     0.26 1.00      2706     4548
## cor(Intercept,stim) -0.35     0.21    -0.71     0.10 1.00      4177     4246
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## Intercept          2.87     0.10     2.68     3.06 1.00      2467
## stim              -0.19     0.04    -0.27    -0.10 1.00      3501
## trait_anxiety_score_z -0.14     0.10    -0.33     0.05 1.00      3221
## Reward_z          -0.02     0.00    -0.03    -0.01 1.00      8408
## stim:trait_anxiety_score_z  0.03     0.04    -0.05     0.11 1.00      4255
##           Tail_ESS
## Intercept          3224
## stim              4360
## trait_anxiety_score_z 3724
## Reward_z          5736
## stim:trait_anxiety_score_z 4662
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma       0.22     0.00     0.21     0.23 1.00      7581     5916
## nu          2.13     0.09     1.97     2.30 1.00      7147     5803
##
## 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).

```

```
pp_check(model_stim_anx)
```

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



```

model_stim_anx_log <- brm(
  HandlingTime_safe ~ stim * trait_anxiety_score_z + Reward_z +
    (1 + stim | Participant_ID),
  data = df,
  family = lognormal,
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)

## Compiling Stan program...

## recompiling to avoid crashing R session

## Start sampling

summary(model_stim_anx_log)

## Family: lognormal
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim * trait_anxiety_score_z + Reward_z + (1 + stim | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;

```

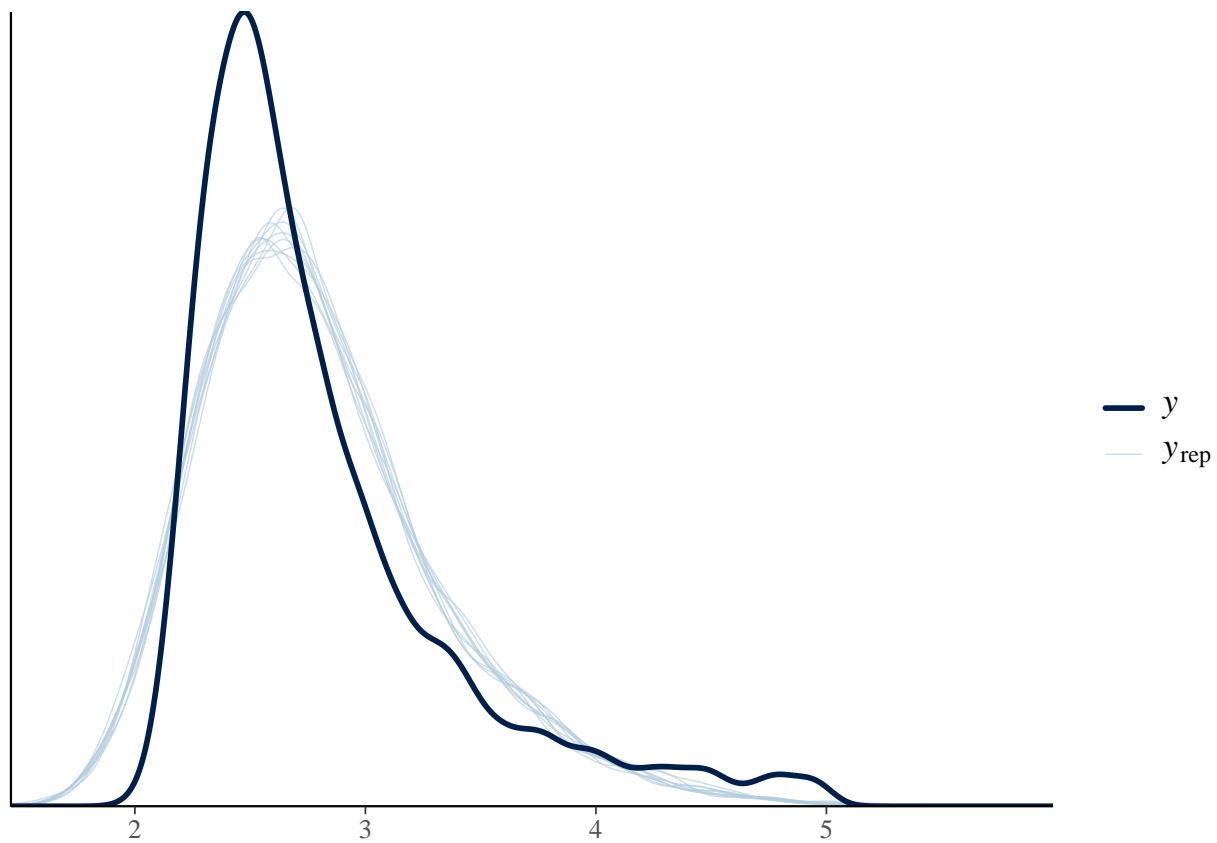
```

##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.14      0.02     0.10     0.20 1.00      2376     4071
## sd(stim)         0.07      0.01     0.05     0.10 1.00      2588     3727
## cor(Intercept,stim) -0.21     0.23    -0.60     0.26 1.00      3363     4445
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## Intercept          1.09      0.03     1.02     1.15 1.00      2145
## stim              -0.09      0.02    -0.12    -0.05 1.00      3278
## trait_anxiety_score_z -0.04      0.03    -0.10     0.02 1.00      2781
## Reward_z          -0.00      0.00    -0.01     0.00 1.00     11439
## stim:trait_anxiety_score_z  0.01      0.02    -0.02     0.04 1.00      3407
##           Tail_ESS
## Intercept          2818
## stim              4057
## trait_anxiety_score_z 3584
## Reward_z          5367
## stim:trait_anxiety_score_z 4561
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma       0.14      0.00     0.13     0.14 1.00      9724     5326
##
## 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).

```

```
pp_check(model_stim_anx_log)
```

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



```
df <- df %>%
  group_by(Participant_ID, stim_cat, env, patch_id) %>%
  mutate(trial_in_patch = row_number()) %>%
  ungroup()
```

```
model_stim_cum <- brm(
  HandlingTime_safe ~ stim * TotalCumulativeReward_z +
    (1 + stim | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)
```

```
## Compiling Stan program...

## recompiling to avoid crashing R session

## Start sampling

summary(model_stim_cum)
```

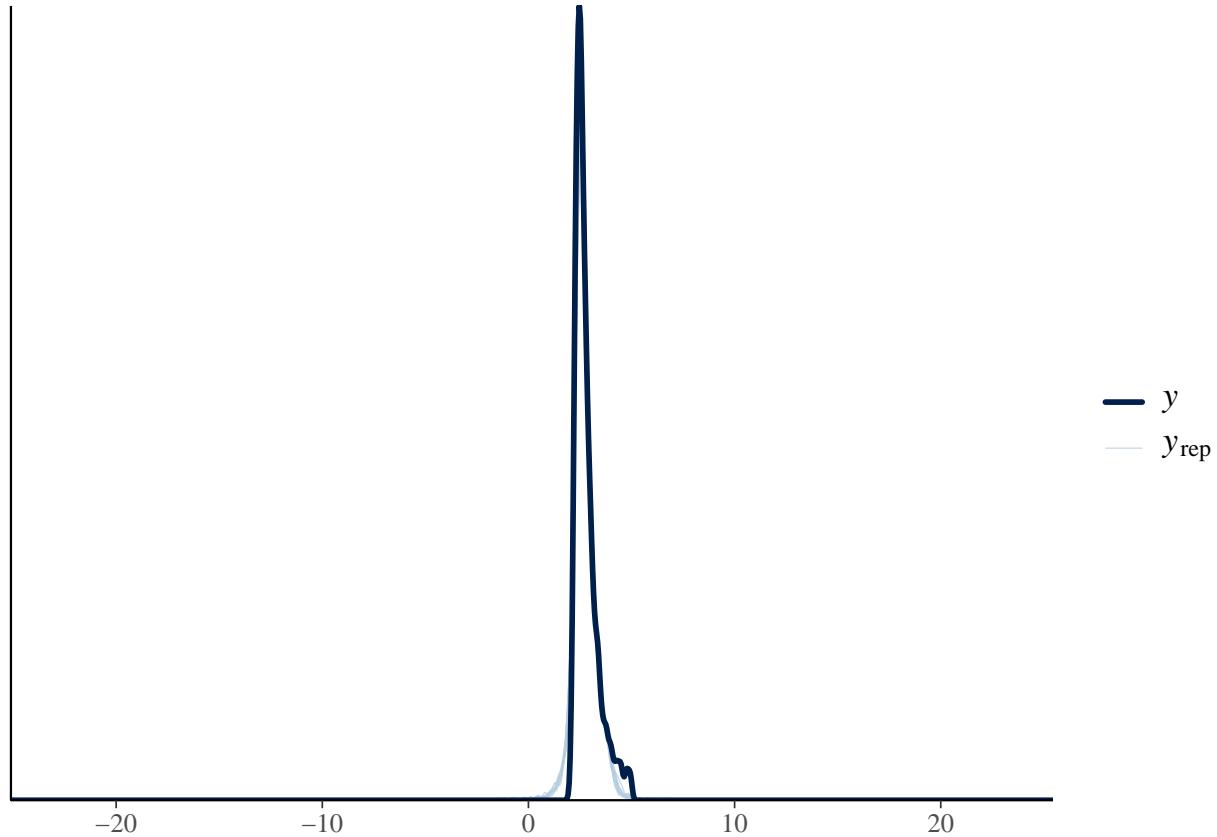
```

## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim * TotalCumulativeReward_z + (1 + stim | Participant_ID)
## Data: df (Number of observations: 5079)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)    0.43     0.08    0.31    0.61 1.00      1613     2802
## sd(stim)        0.17     0.03    0.12    0.24 1.00      1745     3475
## cor(Intercept,stim) -0.37     0.20   -0.72    0.06 1.00      2954     3867
##
## Regression Coefficients:
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## Intercept           2.83     0.10    2.65    3.03 1.00      956
## stim                -0.13     0.04   -0.21   -0.06 1.00     2149
## TotalCumulativeReward_z -0.10     0.01   -0.12   -0.07 1.00     5457
## stim:TotalCumulativeReward_z  0.06     0.01    0.03    0.08 1.00     5651
##             Tail_ESS
## Intercept           1631
## stim                 3175
## TotalCumulativeReward_z  5402
## stim:TotalCumulativeReward_z  5344
##
## Further Distributional Parameters:
##             Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma       0.22     0.00    0.21    0.23 1.00      6152     5548
## nu         2.17     0.09    2.01    2.35 1.00      5814     5064
##
## 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).

```

```
pp_check(model_stim_cum)
```

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



```

df <- df %>%
  group_by(Participant_ID, stim_cat, env) %>%
  mutate(
    AvgRewardRate_before = lag(AvgRewardRate)
  ) %>%
  ungroup()

df <- df %>%
  filter(!is.na(AvgRewardRate_before))

df <- df %>%
  mutate(
    trial_in_patch_z = scale(trial_in_patch)[,1],
    patch_id_z = scale(patch_id)[,1],
    AvgRewardRate_before_z = scale(AvgRewardRate_before)[,1]
  )

model_L1 <- brm(
  HandlingTime_safe ~ stim_cat * Reward_z +
    trial_in_patch_z +
    patch_id_z +
    (1 + stim_cat | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
)

```

```

    iter = 3000,
    warmup = 1000,
    cores = 4
)

## Compiling Stan program...

## recompiling to avoid crashing R session

## Start sampling

summary(model_L1)

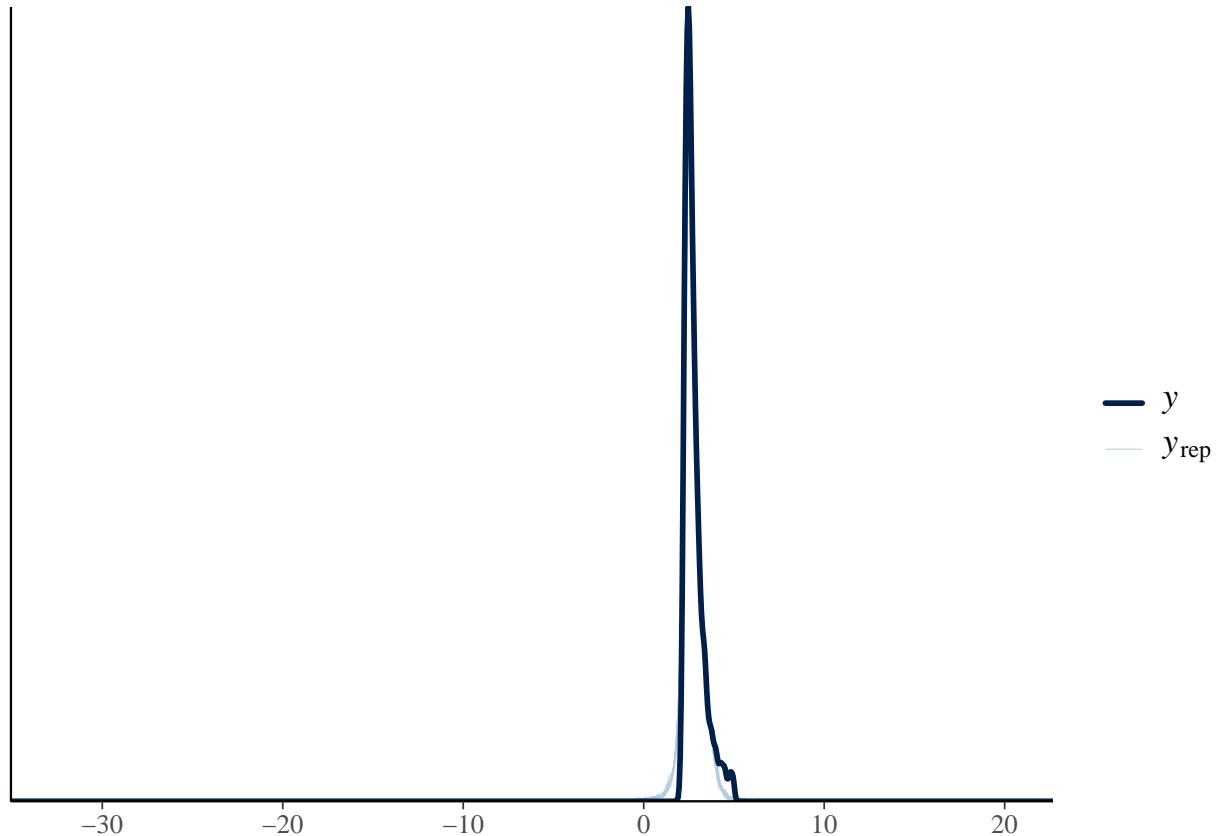
## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim_cat * Reward_z + trial_in_patch_z + patch_id_z + (1 + stim_cat | P
## Data: df (Number of observations: 4995)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##         total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)              0.39     0.07     0.29     0.55 1.00    1665
## sd(stim_catpre)           0.19     0.04     0.13     0.27 1.00    1918
## cor(Intercept,stim_catpre) 0.01     0.24    -0.45     0.47 1.00    2257
##                               Tail_ESS
## sd(Intercept)                2889
## sd(stim_catpre)              3370
## cor(Intercept,stim_catpre)   3490
##
## Regression Coefficients:
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## Intercept                  2.69     0.09     2.52     2.87 1.01    944
## stim_catpre                 0.17     0.04     0.09     0.26 1.00    1874
## Reward_z                   -0.02     0.01    -0.04    -0.01 1.00    5277
## trial_in_patch_z            -0.02     0.01    -0.03    -0.00 1.00    5449
## patch_id_z                  -0.07     0.01    -0.08    -0.06 1.00    7265
## stim_catpre:Reward_z        -0.04     0.01    -0.07    -0.02 1.00    6836
##                               Tail_ESS
## Intercept                  1560
## stim_catpre                 3101
## Reward_z                   5419
## trial_in_patch_z            5370
## patch_id_z                  6360
## stim_catpre:Reward_z        5321
##
## Further Distributional Parameters:
##                               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma          0.21     0.00     0.20     0.22 1.00    5181    5522
## nu             2.16     0.09     1.99     2.34 1.00    5306    4874
##

```

```
## 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).
```

```
pp_check(model_L1)
```

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



```
model_L2 <- brm(  
  HandlingTime_safe ~ stim_cat * Reward_z +  
    trial_in_patch_z +  
    patch_id_z +  
    AvgRewardRate_before_z +  
    (1 + stim_cat | Participant_ID),  
  data = df,  
  family = student(),  
  chains = 4,  
  iter = 3000,  
  warmup = 1000,  
  cores = 4  
)
```

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

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

```

## Start sampling

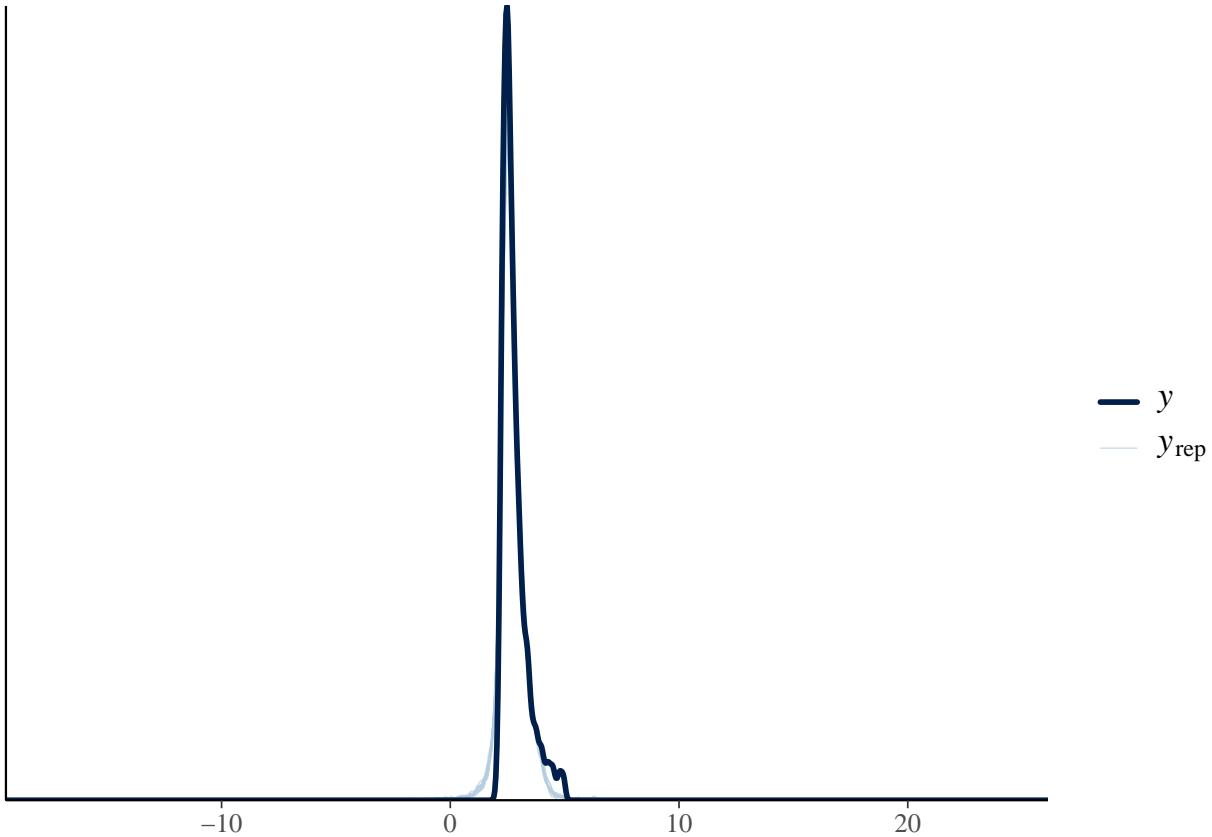
summary(model_L2)

## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim_cat * Reward_z + trial_in_patch_z + patch_id_z + AvgRewardRate_bef
## Data: df (Number of observations: 4995)
## Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##                                     Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)                  0.38     0.07     0.28     0.55 1.00    1596
## sd(stim_catpre)                0.18     0.04     0.12     0.26 1.00    1650
## cor(Intercept,stim_catpre)    0.04     0.23    -0.42     0.47 1.00    2152
##                                     Tail_ESS
## sd(Intercept)                  2398
## sd(stim_catpre)                3450
## cor(Intercept,stim_catpre)    3795
##
## Regression Coefficients:
##                                     Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS
## Intercept                      2.70     0.09     2.53     2.87 1.00    1070
## stim_catpre                     0.14     0.04     0.05     0.22 1.00    2003
## Reward_z                        -0.02    0.01    -0.03    -0.01 1.00    5688
## trial_in_patch_z                -0.01    0.01    -0.02     0.00 1.00    5455
## patch_id_z                      -0.07    0.01    -0.08    -0.06 1.00    6589
## AvgRewardRate_before_z          -0.03    0.01    -0.04    -0.01 1.00    6223
## stim_catpre:Reward_z            -0.04    0.01    -0.07    -0.02 1.00    7685
##                                     Tail_ESS
## Intercept                      1836
## stim_catpre                     3371
## Reward_z                        5381
## trial_in_patch_z                5600
## patch_id_z                      6128
## AvgRewardRate_before_z          5472
## stim_catpre:Reward_z            5178
##
## Further Distributional Parameters:
##                                     Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma      0.21     0.00     0.20     0.22 1.00    6409    5716
## nu         2.17     0.09     2.00     2.34 1.00    6283    5527
##
## 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).

pp_check(model_L2)

```

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



```

model_L3 <- brm(
  HandlingTime_safe ~ stim_cat * AvgRewardRate_before_z +
    trial_in_patch_z +
    patch_id_z +
    (1 + stim_cat | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)

## Compiling Stan program...

## recompiling to avoid crashing R session

## Start sampling

summary(model_L3)

## Family: student
## Links: mu = identity
## Formula: HandlingTime_safe ~ stim_cat * AvgRewardRate_before_z + trial_in_patch_z + patch_id_z + (1 ...

```

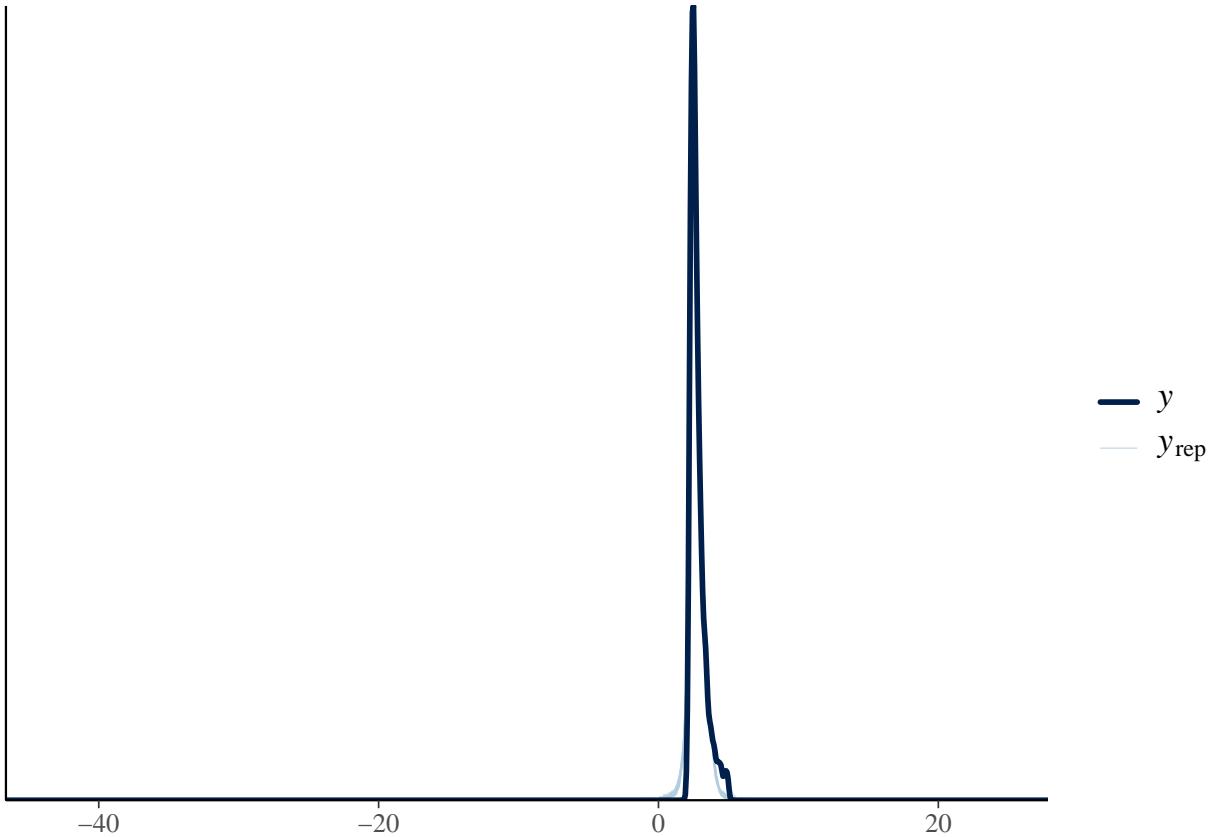
```

##      Data: df (Number of observations: 4995)
##      Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##              total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##                                     Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)                  0.40     0.07    0.29    0.56 1.00    1695
## sd(stim_catpre)                0.15     0.03    0.10    0.22 1.00    1659
## cor(Intercept,stim_catpre)   -0.23     0.23   -0.63    0.25 1.00    2557
##                                     Tail_ESS
## sd(Intercept)                  2689
## sd(stim_catpre)                3152
## cor(Intercept,stim_catpre)   3809
##
## Regression Coefficients:
##                                     Estimate Est.Error 1-95% CI u-95% CI Rhat
## Intercept                      2.67     0.09    2.49    2.84 1.00
## stim_catpre                   -0.06     0.05   -0.16    0.04 1.00
## AvgRewardRate_before_z        -0.01     0.01   -0.03    0.01 1.00
## trial_in_patch_z                 0.01     0.00    0.00    0.02 1.00
## patch_id_z                     -0.09     0.01   -0.10   -0.08 1.00
## stim_catpre:AvgRewardRate_before_z -0.30     0.04   -0.37   -0.23 1.00
##                                     Bulk_ESS Tail_ESS
## Intercept                      907     1434
## stim_catpre                   2464     3731
## AvgRewardRate_before_z       6562     6074
## trial_in_patch_z             10036    6030
## patch_id_z                   6091     5988
## stim_catpre:AvgRewardRate_before_z 4578     4975
##
## Further Distributional Parameters:
##                                     Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma            0.21     0.00    0.21    0.22 1.00    5526    5864
## nu              2.21     0.09    2.04    2.40 1.00    5831    5823
##
## 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).

```

```
pp_check(model_L3)
```

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



```
model_L4 <- brm(
  HandlingTime_safe ~ stim_cat * AvgRewardRate_before_z +
    trial_in_patch_z +
    patch_id_z +
    trait_anxiety_score_z +
    (1 + stim_cat | Participant_ID),
  data = df,
  family = student(),
  chains = 4,
  iter = 3000,
  warmup = 1000,
  cores = 4
)
```

```
## Compiling Stan program...
## recompiling to avoid crashing R session
```

```
## Start sampling
```

```
summary(model_L4)
```

```
## Family: student
## Links: mu = identity
```

```

## Formula: HandlingTime_safe ~ stim_cat * AvgRewardRate_before_z + trial_in_patch_z + patch_id_z + tra
##   Data: df (Number of observations: 4995)
##   Draws: 4 chains, each with iter = 3000; warmup = 1000; thin = 1;
##          total post-warmup draws = 8000
##
## Multilevel Hyperparameters:
## ~Participant_ID (Number of levels: 21)
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS
## sd(Intercept)                      0.39     0.07    0.28    0.55 1.00    1841
## sd(stim_catpre)                   0.15     0.03    0.10    0.23 1.00    1845
## cor(Intercept,stim_catpre)      -0.30     0.22   -0.67    0.18 1.00    3324
##                                         Tail_ESS
## sd(Intercept)                     2825
## sd(stim_catpre)                  3503
## cor(Intercept,stim_catpre)      3966
##
## Regression Coefficients:
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat
## Intercept                           2.67     0.08    2.49    2.83 1.00
## stim_catpre                         -0.07     0.05   -0.17    0.03 1.00
## AvgRewardRate_before_z              -0.01     0.01   -0.03    0.01 1.00
## trial_in_patch_z                   0.01     0.00    0.00    0.02 1.00
## patch_id_z                          -0.09     0.01   -0.10   -0.08 1.00
## trait_anxiety_score_z             -0.13     0.08   -0.29    0.03 1.01
## stim_catpre:AvgRewardRate_before_z -0.30     0.04   -0.37   -0.23 1.00
##                                         Bulk_ESS Tail_ESS
## Intercept                           1771     2376
## stim_catpre                         3827     4893
## AvgRewardRate_before_z              6874     5419
## trial_in_patch_z                  10080    6121
## patch_id_z                          7984     6539
## trait_anxiety_score_z              1841     2890
## stim_catpre:AvgRewardRate_before_z 6270     5570
##
## Further Distributional Parameters:
##                                         Estimate Est.Error 1-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma      0.21     0.00    0.21    0.22 1.00    7603    5817
## nu         2.21     0.09    2.03    2.39 1.00    7555    5652
##
## 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).

```

```
pp_check(model_L4)
```

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

