E3 rate

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This notebook takes response rates by subject, log-transforms them, and runs a Bayesian version of a mixed effects model.

```
set.seed(15000)
```

Load the data.

```
data <- read_csv('../data/E3/response_rate_by_sub.csv', show_col_types = FALSE)
```

Change musician and scramble into a factor.

```
data %<>% mutate(Musician = factor(Musician, levels = c('Yes', 'No')),
                 scramble = factor(scramble, levels = c('Intact', '8B', '2B', '1B')))
```

Set Intact as reference level.

```
contrasts(data$scramble) <- contr.treatment(4)
```

Set the musician/non-musician contrast.

```
contrasts(data$Musician) <- c(-1,1)
print(contrasts(data$Musician))
```

```
##     [,1]
## Yes   -1
## No     1
```

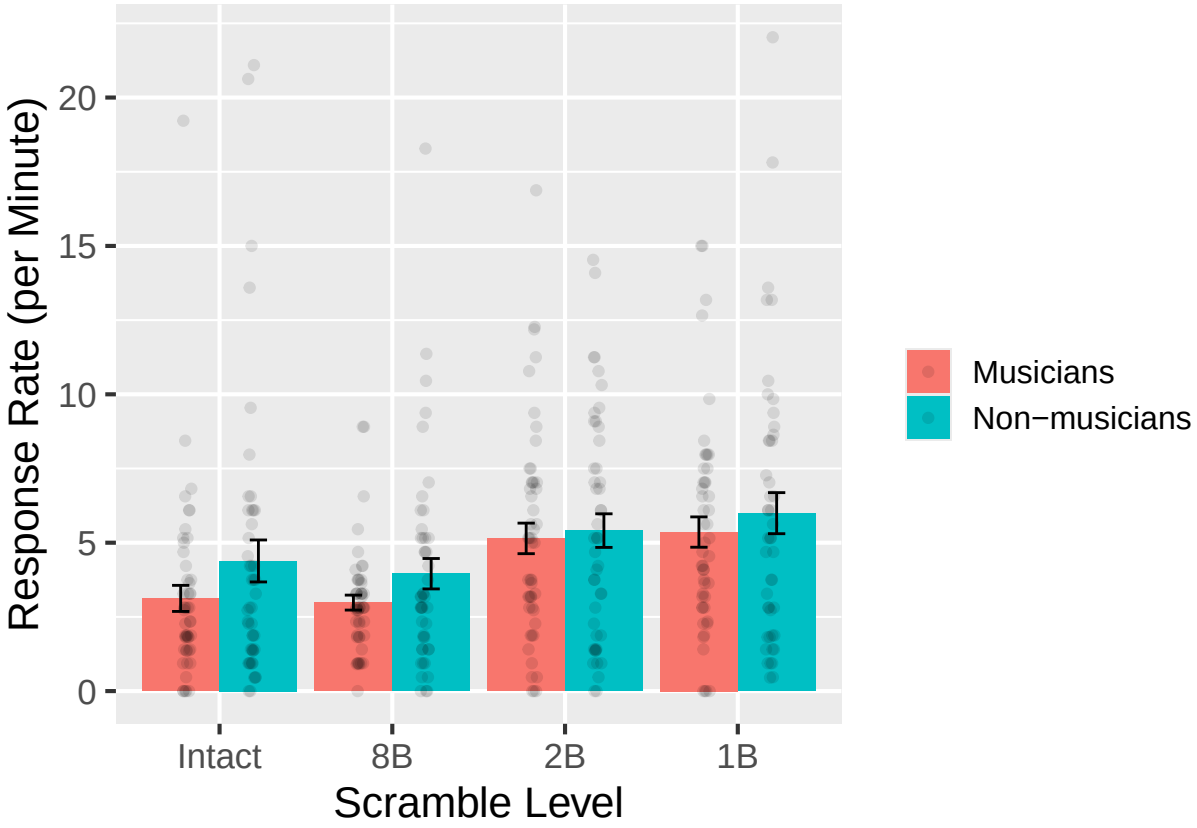
Check normality of the true response rate data. (Ignoring stimulus set.)

```
data %>%
  group_by(Musician, scramble) %>%
  shapiro_test(mean_response_rate)
```

```
## # A tibble: 8 x 5
##   Musician scramble variable           statistic            p
##   <fct>    <fct>    <chr>                  <dbl>        <dbl>
## 1 Yes      Intact   mean_response_rate     0.724 0.0000000283
## 2 Yes      8B       mean_response_rate     0.863 0.0000429
## 3 Yes      2B       mean_response_rate     0.941 0.0162
## 4 Yes      1B       mean_response_rate     0.929 0.00575
## 5 No       Intact   mean_response_rate     0.744 0.000000135
## 6 No       8B       mean_response_rate     0.839 0.0000157
## 7 No       2B       mean_response_rate     0.948 0.0401
## 8 No       1B       mean_response_rate     0.894 0.000530
```

```
data %>%
  ggplot(aes(x = scramble, y = mean_response_rate, fill = Musician)) +
  geom_bar(position = "dodge", stat = "summary", fun = mean) +
  geom_errorbar(position = position_dodge(width = 0.9), width = 0.2, stat = "summary") +
  geom_point(position = position_jitterdodge(jitter.width = 0.1), alpha = 0.1) +
  theme_gray(base_size = 16) +
  xlab('Scramble Level') +
  ylab('Response Rate (per Minute)') +
  scale_fill_discrete(name="", labels=c('Musicians', 'Non-musicians')) +
  theme(legend.text = element_text(size = 12))
```

```
## No summary function supplied, defaulting to `mean_se()`
```


Response Rate (per Minute)
20
15
10
5
0
Intact
8B
2B
1B
Scramble Level
Musicians
Non−musicians

Log-transform the rates and check for normality.

```
data %<>% mutate(log_rate = log(1 + mean_response_rate))
# add 1 so rates that are zero transform to 0 (rather than negative infinity)
```

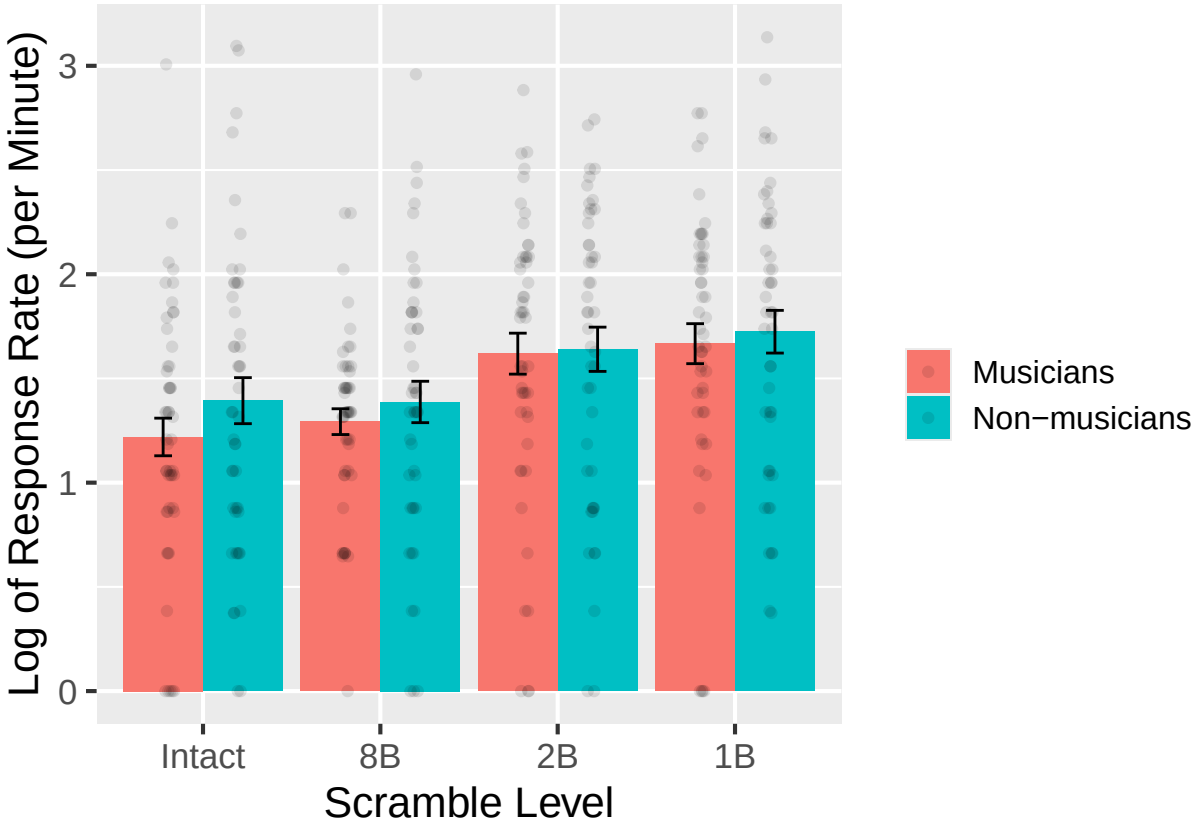
```
data %>%
  group_by(Musician, scramble) %>%
  shapiro_test(log_rate)
```

```
## # A tibble: 8 x 5
##   Musician scramble variable statistic       p
##   <fct>    <fct>    <chr>        <dbl>   <dbl>
## 1 Yes      Intact   log_rate     0.963 0.130
## 2 Yes      8B       log_rate     0.947 0.0284
## 3 Yes      2B       log_rate     0.943 0.0193
## 4 Yes      1B       log_rate     0.913 0.00153
## 5 No       Intact   log_rate     0.976 0.457
## 6 No       8B       log_rate     0.982 0.674
## 7 No       2B       log_rate     0.946 0.0319
## 8 No       1B       log_rate     0.973 0.358
```

Some of these are worse than others. Visualize:

```
data %>%
  ggplot(aes(x = scramble, y = log_rate, fill = Musician)) +
  geom_bar(position = "dodge", stat = "summary", fun = mean) +
  geom_errorbar(position = position_dodge(width = 0.9), width = 0.2, stat = "summary") +
  geom_point(position = position_jitterdodge(jitter.width = 0.1), alpha = 0.1) +
  theme_gray(base_size = 16) +
  xlab('Scramble Level') +
  ylab('Log of Response Rate (per Minute)') +
  scale_fill_discrete(name="", labels=c('Musicians', 'Non-musicians')) +
  theme(legend.text = element_text(size = 12))
```

```
## No summary function supplied, defaulting to `mean_se()`
```




```
#ggsave('log_rate.png', width = 7, height = 5)
```

It seems like this lack of normality is driven by the zero rates.

```
get_prior(log_rate ~ Musician + scramble + (1|exp_subject_id), data = data)
```

```
##                   prior     class      coef          group resp dpar nlpar lb
##                  (flat)         b
##                  (flat)         b Musician1
##                  (flat)         b scramble2
##                  (flat)         b scramble3
##                  (flat)         b scramble4
##  student_t(3, 1.5, 2.5) Intercept
##    student_t(3, 0, 2.5)        sd                                          0
##    student_t(3, 0, 2.5)        sd           exp_subject_id                 0
##    student_t(3, 0, 2.5)        sd Intercept exp_subject_id                 0
##    student_t(3, 0, 2.5)     sigma                                          0
##  ub       source
##         default
##     (vectorized)
##     (vectorized)
##     (vectorized)
##     (vectorized)
##          default
##          default
##     (vectorized)
##     (vectorized)
##          default
```

```
these_priors <- c(
  set_prior('normal(0, 0.5)', coef = "Musician1"), # don't necessarily expect a difference between grou
  set_prior('normal(0, 0.5)', coef = "scramble2"), # intact vs 8B
  set_prior('normal(0, 0.5)', coef = "scramble3"), # intact vs 2B
  set_prior('normal(0, 0.5)', coef = "scramble4") # intact vs 1B
)
```

```
brm_log_rate <- brm(log_rate ~ Musician + scramble + (1|exp_subject_id), data = data,
                    prior = these_priors,
                    save_pars = save_pars(all = TRUE),
                    iter = 20000, refresh = 0,
                    file = 'models/E3_log_rate')
```

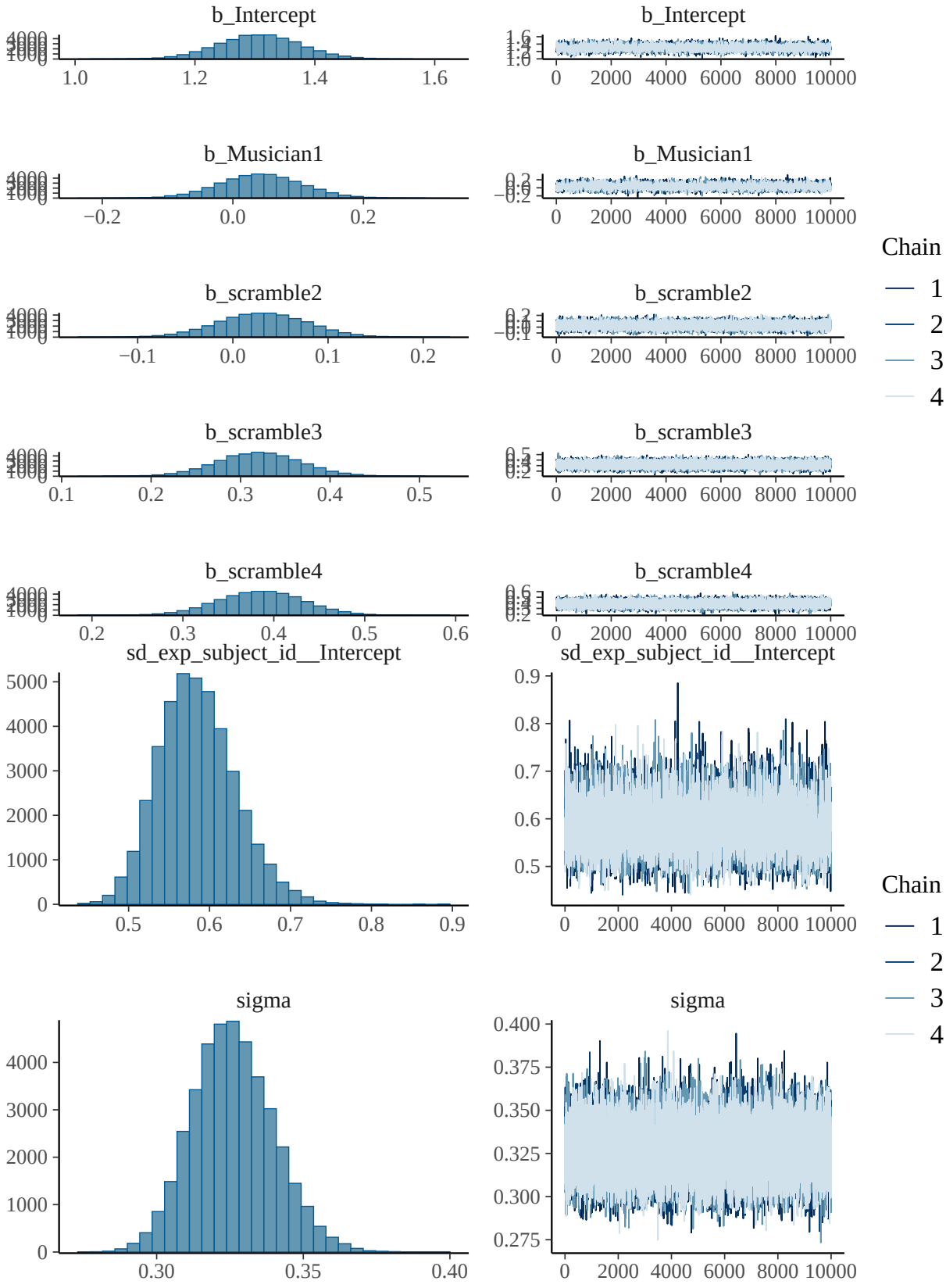
```
## Compiling Stan program...
```

```
## 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 16.0.0 (clang-1600.0.26.6)'
## using SDK: 'MacOSX15.2.sdk'
## clang -arch arm64 -I"/Library/Frameworks/R.framework/Resources/include" -DNDEBUG   -I"/Library/Framew
## In file included from <built-in>:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeade
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/
## /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include/Eigen/src/Core
##   679 | #include <cmath>
##       |          ^~~~~~
## 1 error generated.
## make: *** [foo.o] Error 1
```

```
## Start sampling
```

```
plot(brm_log_rate)
```



```r
print(summary(brm_log_rate), digits = 4)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: log_rate ~ Musician + scramble + (1 | exp_subject_id)
##    Data: data (Number of observations: 380)
##   Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~exp_subject_id (Number of levels: 95)
##               Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## sd(Intercept)   0.5849    0.0474   0.5005   0.6861 1.0005     5899    11676
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## Intercept   1.3073    0.0685   1.1729   1.4420 1.0014     4194     8832
## Musician1   0.0429    0.0627  -0.0799   0.1664 1.0012     3209     6536
## scramble2   0.0313    0.0469  -0.0606   0.1228 1.0000    28358    29264
## scramble3   0.3207    0.0468   0.2289   0.4132 1.0001    28158    29971
## scramble4   0.3859    0.0469   0.2935   0.4771 1.0000    28591    28847
##
## Further Distributional Parameters:
##       Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## sigma   0.3260    0.0138   0.3004   0.3545 1.0000    31495    30490
##
## 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).
```

```r
emm_log_rate <- emmeans(brm_log_rate, specs = c("scramble", "Musician"))
summary(emm_log_rate)
```

```
##  scramble Musician emmean lower.HPD upper.HPD
##  Intact   Yes        1.26      1.09      1.45
##  8B       Yes        1.30      1.12      1.47
##  2B       Yes        1.59      1.41      1.76
##  1B       Yes        1.65      1.47      1.82
##  Intact   No         1.35      1.17      1.54
##  8B       No         1.38      1.19      1.57
##  2B       No         1.67      1.49      1.86
##  1B       No         1.74      1.55      1.92
##
## Point estimate displayed: median
## HPD interval probability: 0.95
```

```r
emm_log_rate_s <- emmeans(brm_log_rate, specs = "scramble")
summary(emm_log_rate_s)
```

```
##  scramble emmean lower.HPD upper.HPD
##  Intact     1.31      1.17      1.44
##  8B         1.34      1.20      1.47
##  2B         1.63      1.49      1.76
##  1B         1.69      1.56      1.83
##
## Results are averaged over the levels of: Musician
## Point estimate displayed: median
## HPD interval probability: 0.95
```

```r
contrast(emm_log_rate_s, method = "pairwise")
```

```
##  contrast    estimate lower.HPD upper.HPD
##  Intact - 8B  -0.0312    -0.121    0.0624
##  Intact - 2B  -0.3208    -0.412   -0.2284
##  Intact - 1B  -0.3863    -0.476   -0.2927
##  8B - 2B      -0.2894    -0.382   -0.1968
##  8B - 1B      -0.3547    -0.449   -0.2641
##  2B - 1B      -0.0652    -0.158    0.0274
##
## Results are averaged over the levels of: Musician
## Point estimate displayed: median
## HPD interval probability: 0.95
```

```r
log_rate_BF <- describe_posterior(brm_log_rate,
                                  estimate = "median", dispersion = TRUE,
                                  ci = .95, ci_method = "HDI",
                                  test = c("bayes_factor"))
print(log_rate_BF, digits = 4)
```

```
## Summary of Posterior Distribution
##
## Parameter   | Median |    MAD |        95% CI |       BF |  Rhat |        ESS
## ------------------------------------------------------------------------------
## (Intercept) | 1.3075 | 0.0681 | [ 1.17, 1.44] | 3.51e+19 | 1.001 |  4186.0000
## Musician1   | 0.0427 | 0.0624 | [-0.08, 0.16] |    0.157 | 1.001 |  3199.0000
## scramble2   | 0.0312 | 0.0470 | [-0.06, 0.12] |    0.117 | 1.000 | 28320.0000
## scramble3   | 0.3208 | 0.0465 | [ 0.23, 0.41] | 5.50e+06 | 1.000 | 28127.0000
## scramble4   | 0.3863 | 0.0470 | [ 0.29, 0.48] | 5.03e+07 | 1.000 | 28556.0000
```

Compare the full model to a model without scramble condition.

```
brm_log_rate_null <- brm(log_rate ~ Musician + (1|exp_subject_id), data = data,
                         prior = set_prior('normal(0, 0.5)', class = 'b'),
                         save_pars = save_pars(all = TRUE),
                         iter = 20000, refresh = 0,
                         file = 'models/E3_log_rate_null')
```

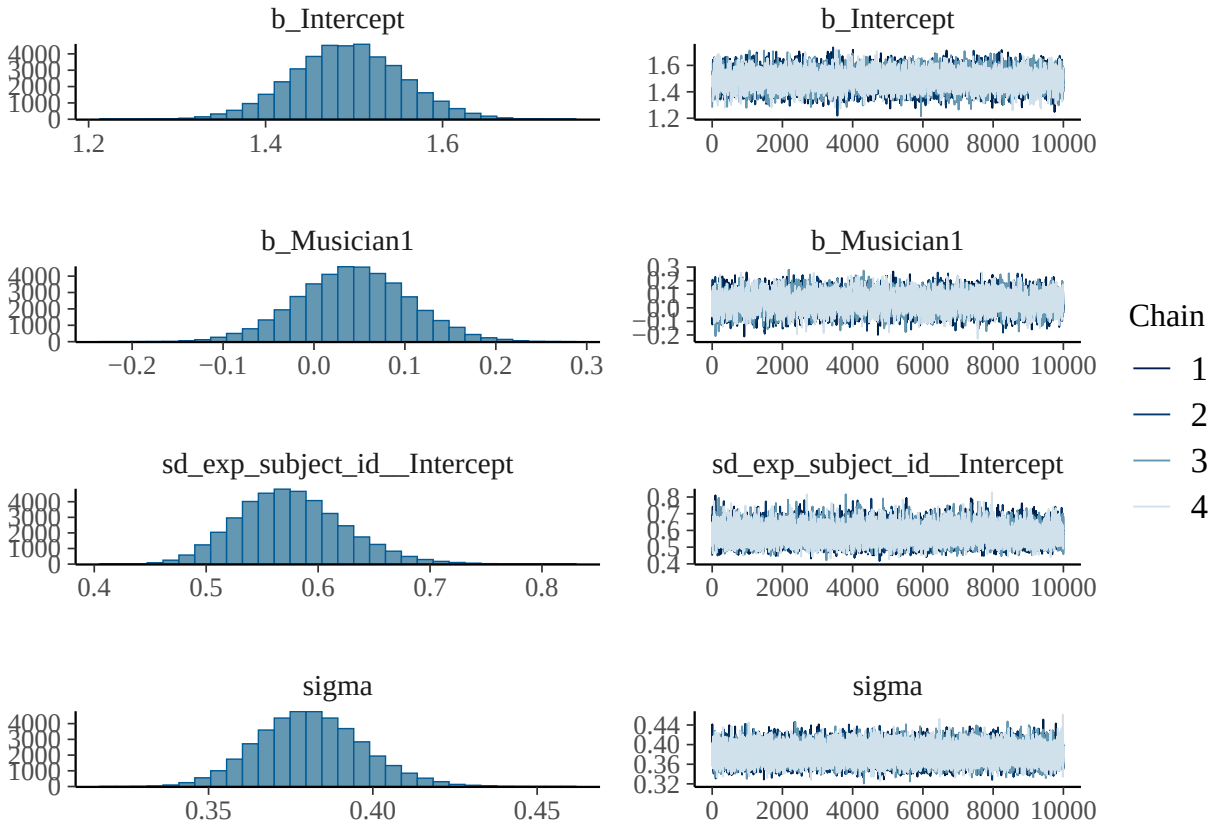
```
## Compiling Stan program...
```

```
## 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 16.0.0 (clang-1600.0.26.6)'
## using SDK: 'MacOSX15.2.sdk'
## clang -arch arm64 -I"/Library/Frameworks/R.framework/Resources/include" -DNDEBUG   -I"/Library/Framew
## In file included from <built-in>:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeade
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/
## /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include/Eigen/src/Core
##   679 | #include <cmath>
##       |          ^~~~~~
## 1 error generated.
## make: *** [foo.o] Error 1
```

```
## Start sampling
```

```
plot(brm_log_rate_null)
```



```r
print(summary(brm_log_rate_null), digits = 4)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: log_rate ~ Musician + (1 | exp_subject_id)
##    Data: data (Number of observations: 380)
##   Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~exp_subject_id (Number of levels: 95)
##               Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## sd(Intercept)   0.5763    0.0482   0.4909   0.6796 1.0004     8462    14860
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## Intercept   1.4924    0.0622   1.3702   1.6157 1.0002     5632    11148
## Musician1   0.0435    0.0613  -0.0784   0.1637 1.0005     6158    11569
##
## Further Distributional Parameters:
##       Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## sigma   0.3811    0.0160   0.3510   0.4143 1.0002    38097    30501
##
## 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).
```

```r
BF_log_rate <- bayes_factor(brm_log_rate, brm_log_rate_null)
```

```
## Iteration: 1
## Iteration: 2
## Iteration: 3
## Iteration: 4
## Iteration: 5
## Iteration: 1
## Iteration: 2
## Iteration: 3
## Iteration: 4
## Iteration: 5
```

```r
print(BF_log_rate)
```

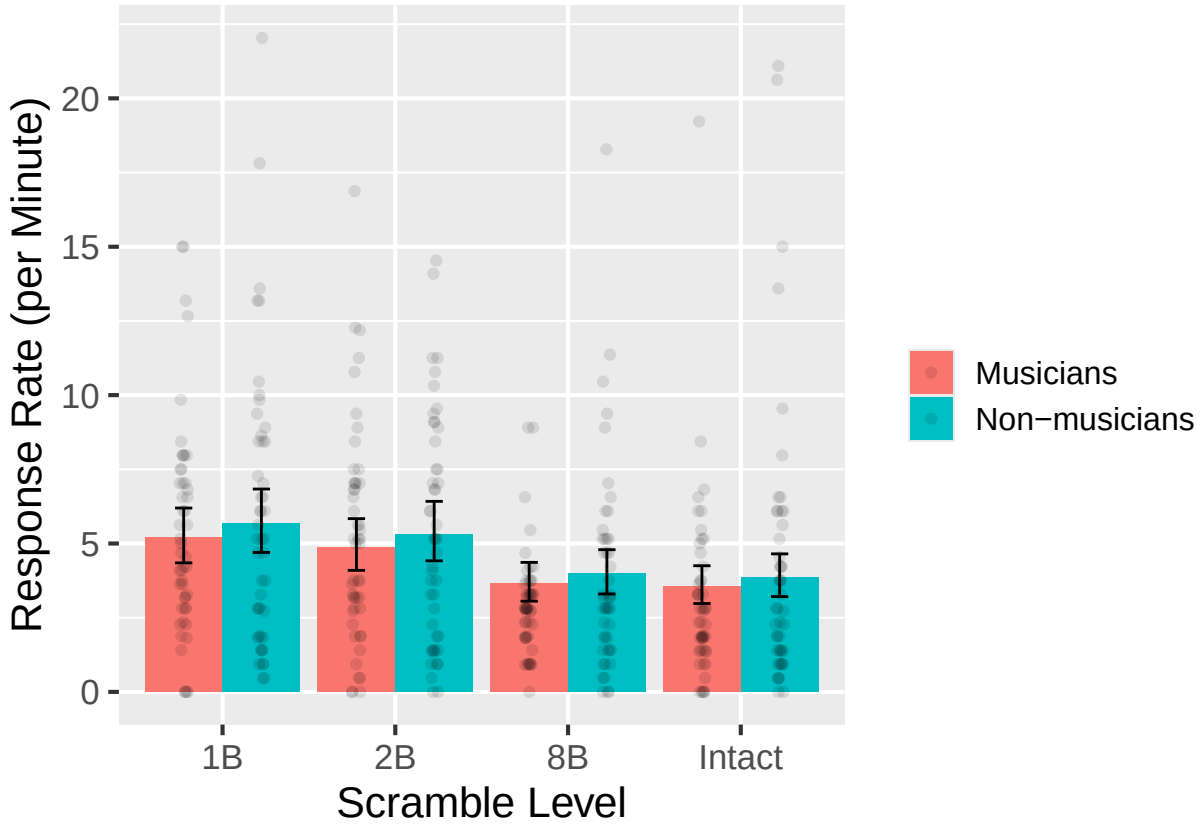
```
## Estimated Bayes factor in favor of brm_log_rate over brm_log_rate_null: 25281540448092340.00000
```

Visualize with posterior estimates and 95% CrI

```
posterior_est <- as.data.frame(emm_log_rate)
```

```
ggplot() +
  geom_col(aes(x = scramble, y = exp(emmean), fill = Musician), data = posterior_est,
           position = "dodge") +
  geom_errorbar(aes(x = scramble, ymin = exp(lower.HPD), ymax = exp(upper.HPD), fill = Musician),
                data = posterior_est, position = position_dodge(width = 0.9), width = 0.2) +
  geom_point(aes(x = scramble, y = mean_response_rate, fill = Musician), data = data,
             position = position_jitterdodge(dodge.width = 0.9, jitter.width = 0.1), alpha = 0.1) +
  theme_gray(base_size = 16) +
  scale_x_discrete(limits = rev) +
  xlab('Scramble Level') +
  ylab('Response Rate (per Minute)') +
  scale_fill_discrete(name="", labels=c('Musicians', 'Non-musicians')) +
  theme(legend.text = element_text(size = 12))
```

```
## Warning in geom_errorbar(aes(x = scramble, ymin = exp(lower.HPD), ymax =
## exp(upper.HPD), : Ignoring unknown aesthetics: fill
```




```
ggsave('../figures/Fig3_rate.png', width = 7, height = 5)
```