

# E3 alignment

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This notebook analyzes alignment values using a Bayesian approach.

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

Load the data.

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

Check number of subjects per group.

```
length(unique(filter(data, Musician == 'Yes')$sub))
```

```
## [1] 49
```

```
length(unique(filter(data, Musician == 'No')$sub))
```

```
## [1] 46
```

Make sure non-musicians and musicians are labelled with different numbers.

```
data %>% mutate(sub = ifelse(Musician == 'Yes', sub, sub + 49))
```

Pivot the data longer.

```
data %>% pivot_longer(cols = -c(Musician, sub, scramble),
                        names_to = 'level', values_to = 'value')
```

For comparisons across levels, look at nested structure only (levels 2, 4, 8, 16).

```
data_nested <- data %>%
  filter(!level %in% c(1,3,5))
```

Make group, scramble, and level into factors and set contrasts.

```
data %>% mutate(
  Musician = factor(Musician, levels = c('Yes', 'No')),
  scramble = factor(scramble, levels = c('Intact', '8B', '2B', '1B')),
  level = factor(level, levels = c(1,2,3,4,5,8,16), ordered = TRUE)
)

contrasts(data$scramble) <- contr.treatment(4) # Intact as reference
contrasts(data$level) <- contr.treatment(7, base = 6) # 8-bar as reference
contrasts(data$Musician) <- c(-1,1)

data_nested %>% mutate(
  Musician = factor(Musician, levels = c('Yes', 'No')),
  scramble = factor(scramble, levels = c('Intact', '8B', '2B', '1B')),
  level = factor(level, levels = c(2,4,8,16), ordered = TRUE)
)
```

```

contrasts(data_nested$scramble) <- contr.treatment(4) # Intact as reference
contrasts(data_nested$level) <- contr.treatment(4, base = 3) # 8-bar as reference
contrasts(data_nested$Musician) <- c(-1,1)

```

Check normality of the data.

```

data %>%
  group_by(scramble, level) %>%
  shapiro_test(value)

```

```

## # A tibble: 28 x 5
##   scramble level variable statistic      p
##   <fct>    <ord> <chr>     <dbl>    <dbl>
## 1 Intact    1     value     0.747 1.67e-11
## 2 Intact    2     value     0.813 1.29e- 9
## 3 Intact    3     value     0.956 3.13e- 3
## 4 Intact    4     value     0.918 1.83e- 5
## 5 Intact    5     value     0.929 6.93e- 5
## 6 Intact    8     value     0.891 9.46e- 7
## 7 Intact   16     value     0.801 5.55e-10
## 8 8B        1     value     0.945 5.66e- 4
## 9 8B        2     value     0.965 1.19e- 2
## 10 8B       3     value     0.958 4.22e- 3
## # i 18 more rows

```

Visualize.

```

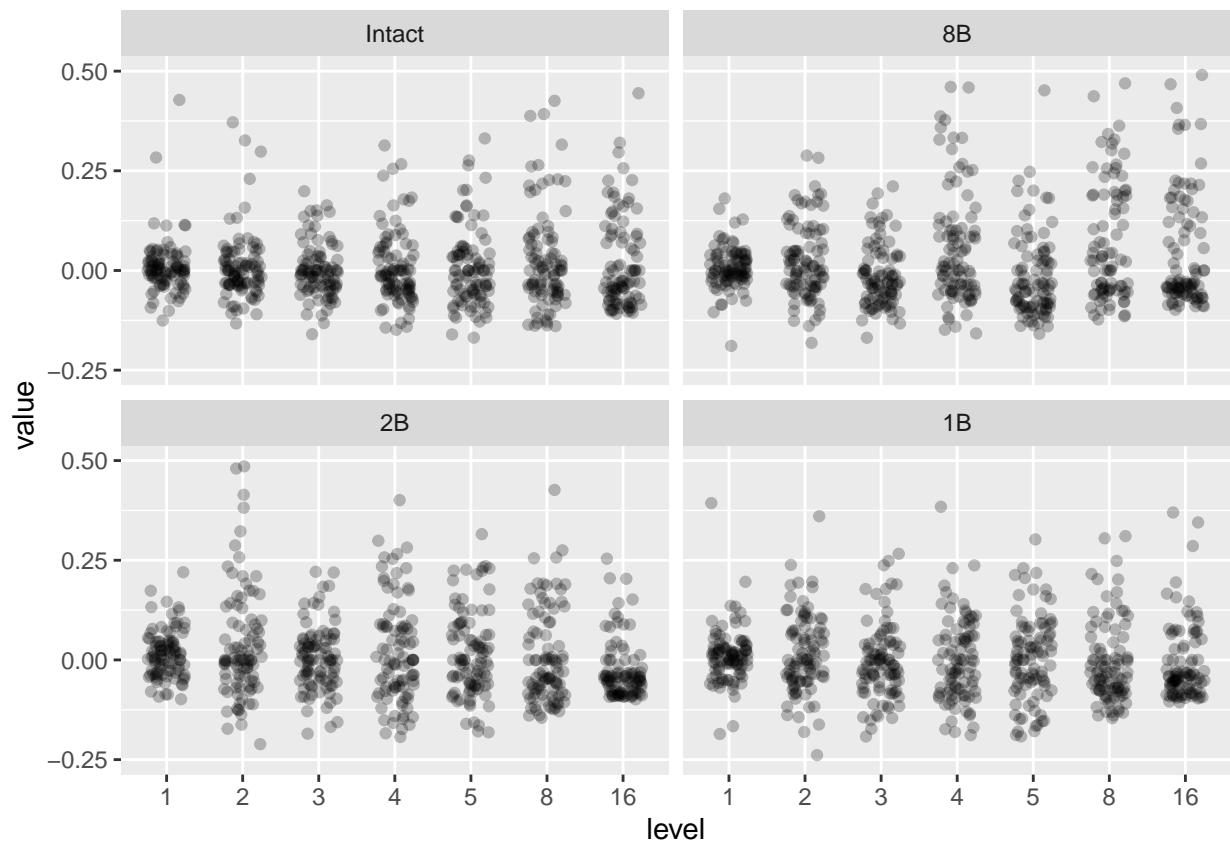
data %>%
  ggplot(aes(x = level, y = value)) +
  geom_jitter(width = 0.25, alpha = 0.25) +
  facet_wrap(vars(scramble)) +
  ylim(-0.25, 0.5)

```

```

## Warning: Removed 16 rows containing missing values or values outside the scale range
## (`geom_point()`).

```



## Main analysis

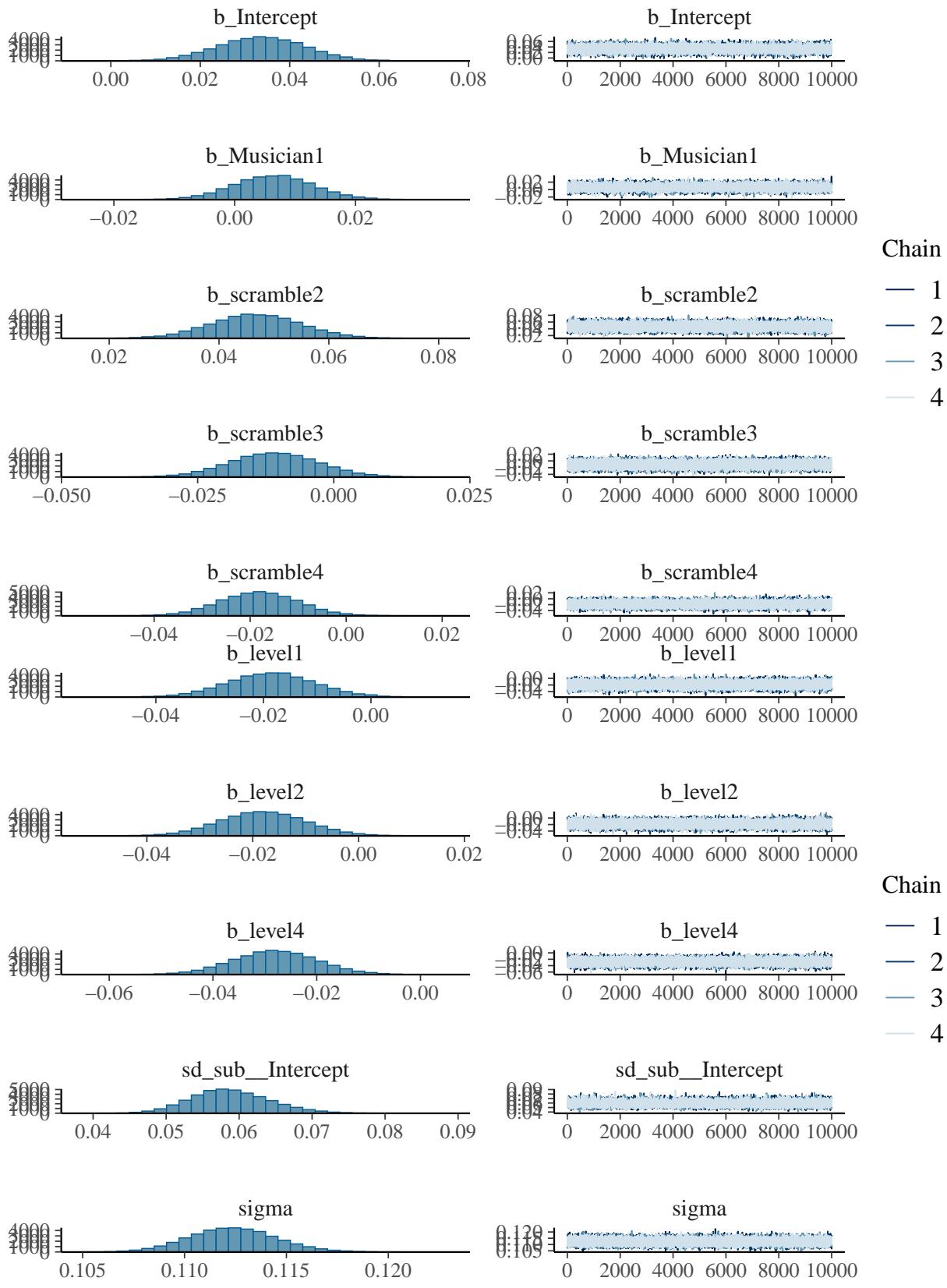
```
nested_3way <- brm(value ~ Musician + scramble + level + (1|sub), data = data_nested,
                     prior = c(
                       set_prior('normal(-0.1, 0.1)', coef = 'Musician1'),
                       set_prior('normal(0.1, 0.1)', coef = 'scramble2'),
                       set_prior('normal(-0.1, 0.1)', coef = 'scramble3'),
                       set_prior('normal(-0.1, 0.1)', coef = 'scramble4'),
                       set_prior('normal(-0.2, 0.1)', coef = 'level1'),
                       set_prior('normal(-0.1, 0.1)', coef = c('level2', 'level4'))
                     ),
                     save_pars = save_pars(all = TRUE), iter = 20000, refresh = 0,
                     file = 'models/E3_alignment_3way_noInt')

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from <built-in>:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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(nested_3way)
```



```
print(summary(nested_3way, robust = TRUE), digits = 4)
```

```

##  Family: gaussian
##  Links: mu = identity; sigma = identity
## Formula: value ~ Musician + scramble + level + (1 | sub)
## Data: data_nested (Number of observations: 1520)
## Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##         total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##           Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0586    0.0053   0.0490   0.0702 1.0004    14337    22747
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## Intercept    0.0338    0.0098   0.0145   0.0527 1.0002    25867    27643
## Musician1    0.0065    0.0066  -0.0064   0.0195 1.0001    17234    24158
## scramble2    0.0467    0.0082   0.0309   0.0629 1.0001    57972    34739
## scramble3   -0.0109    0.0082  -0.0268   0.0052 1.0001    58419    34958
## scramble4   -0.0181    0.0081  -0.0338  -0.0022 1.0001    55981    33746
## level1      -0.0186    0.0081  -0.0344  -0.0025 1.0003    54370    33407
## level2      -0.0181    0.0081  -0.0338  -0.0022 1.0002    54122    31299
## level4     -0.0280    0.0081  -0.0438  -0.0120 1.0001    56139    34039
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI   Rhat Bulk_ESS Tail_ESS
## sigma       0.1124    0.0021   0.1083   0.1166 1.0000    77932    28119
##
## 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).

```

```

nested_noMus <- brm(value ~ scramble + level + (1|sub), data = data_nested,
                     prior = c(
                       set_prior('normal(0.1, 0.1)', coef = 'scramble2'),
                       set_prior('normal(-0.1, 0.1)', coef = 'scramble3'),
                       set_prior('normal(-0.1, 0.1)', coef = 'scramble4'),
                       set_prior('normal(-0.2, 0.1)', coef = 'level1'),
                       set_prior('normal(-0.1, 0.1)', coef = c('level2', 'level4'))
                     ),
                     save_pars = save_pars(all = TRUE), iter = 20000, refresh = 0,
                     file = 'models/E3_alignment_2way_noMus')

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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

nested_noScram <- brm(value ~ Musician + level + (1|sub), data = data_nested,
                      prior = c(
                        set_prior('normal(-0.1, 0.1)', coef = 'Musician1'),
                        set_prior('normal(-0.2, 0.1)', coef = 'level1'),
                        set_prior('normal(-0.1, 0.1)', coef = c('level2', 'level4'))
                      ),
                      save_pars = save_pars(all = TRUE), iter = 20000, refresh = 0,
                      file = 'models/E3_alignment_2way_noScram')

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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
nested_noLevel <- brm(value ~ Musician + scramble + (1|sub), data = data_nested,
                       prior = c(
                           set_prior('normal(-0.1, 0.1)', coef = 'Musician1'),
                           set_prior('normal(0.1, 0.1)', coef = 'scramble2'),
                           set_prior('normal(-0.1, 0.1)', coef = 'scramble3'),
                           set_prior('normal(-0.1, 0.1)', coef = 'scramble4')
                       ),
                       save_pars = save_pars(all = TRUE), iter = 20000, refresh = 0,
                       file = 'models/E3_alignment_2way_noLevel')

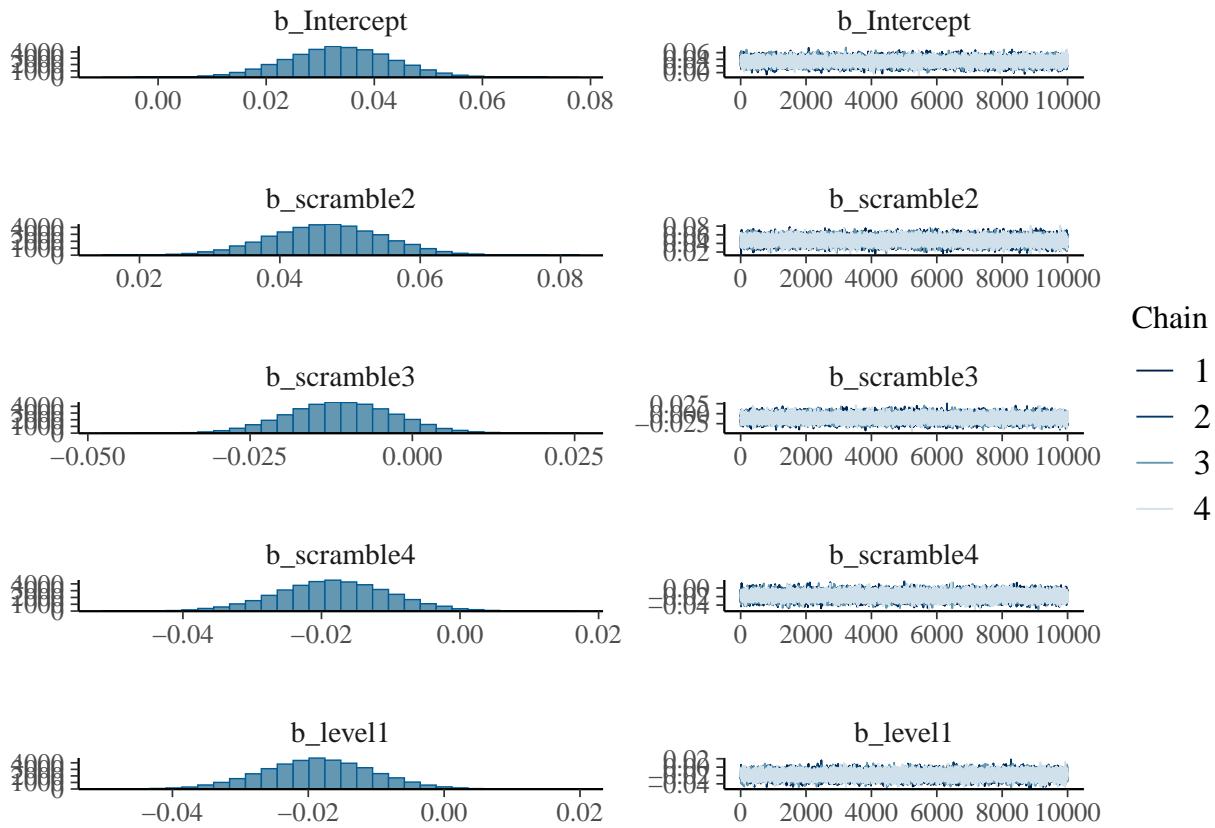
## Compiling Stan program...
## Trying to compile a simple C file
## Running /Library/Frameworks/R.framework/Resources/bin/R CMD SHLIB foo.c
## using C compiler: 'Apple clang version 16.0.0 (clang-1600.0.26.6)'
## using SDK: 'MacOSX15.2.sdk'
## clang -arch arm64 -I"/Library/Frameworks/R.framework/Resources/include" -DNDEBUG -I"/Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from <built-in>:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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

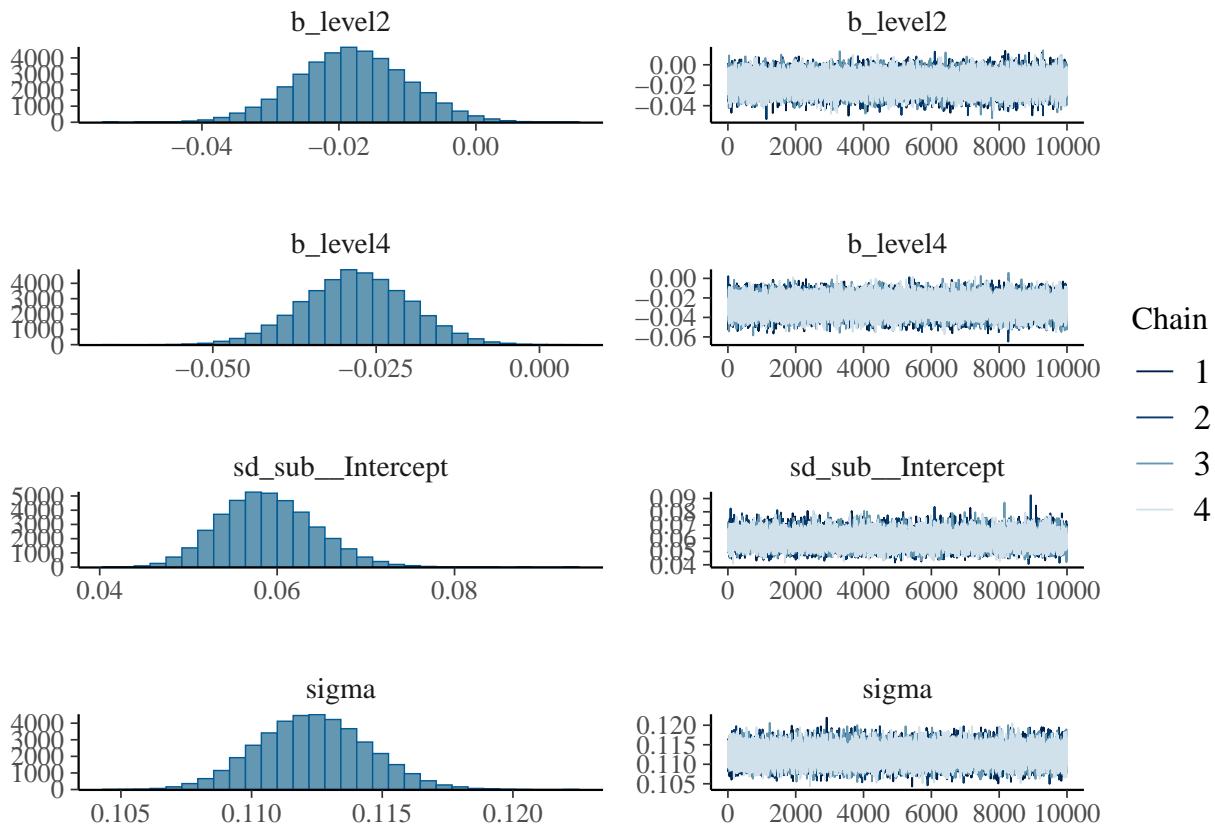
## Start sampling

```

Model without group:

```
plot(nested_noMus)
```





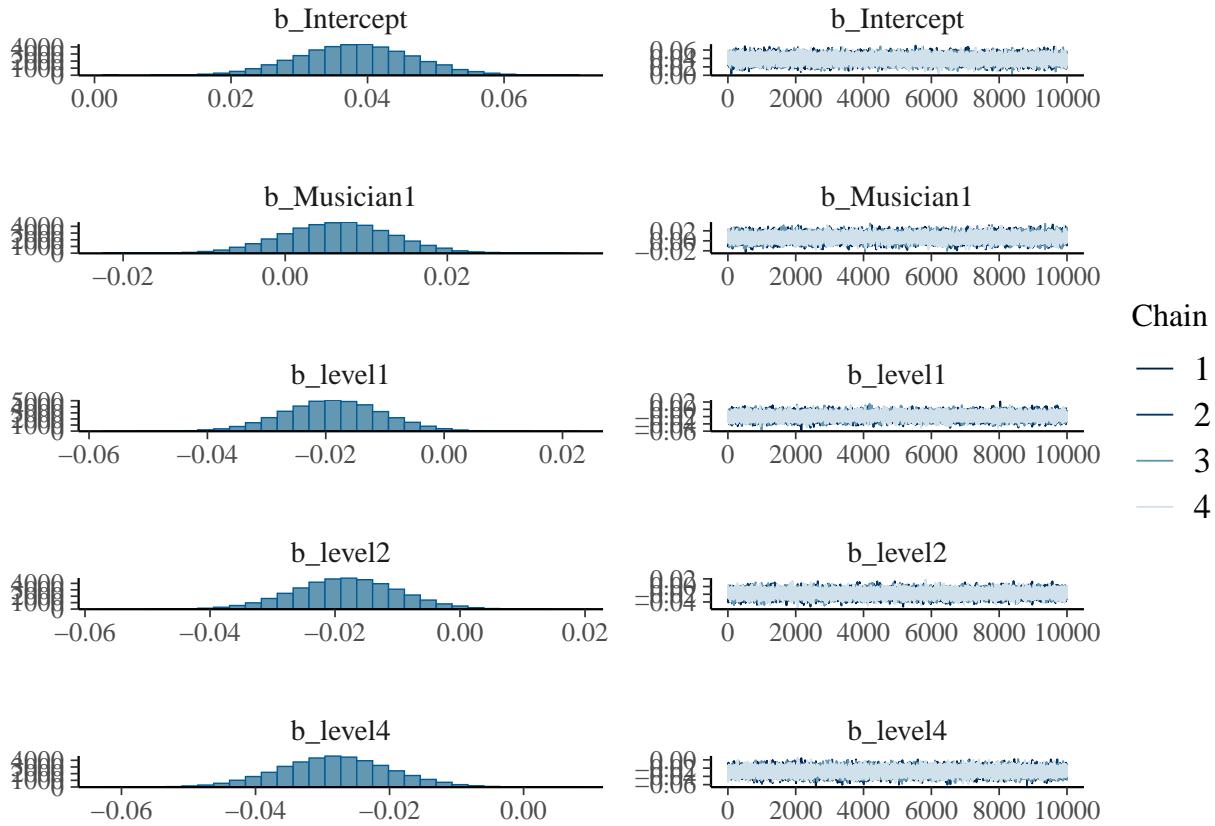
```
print(summary(nested_noMus, robust = TRUE), digits = 4)
```

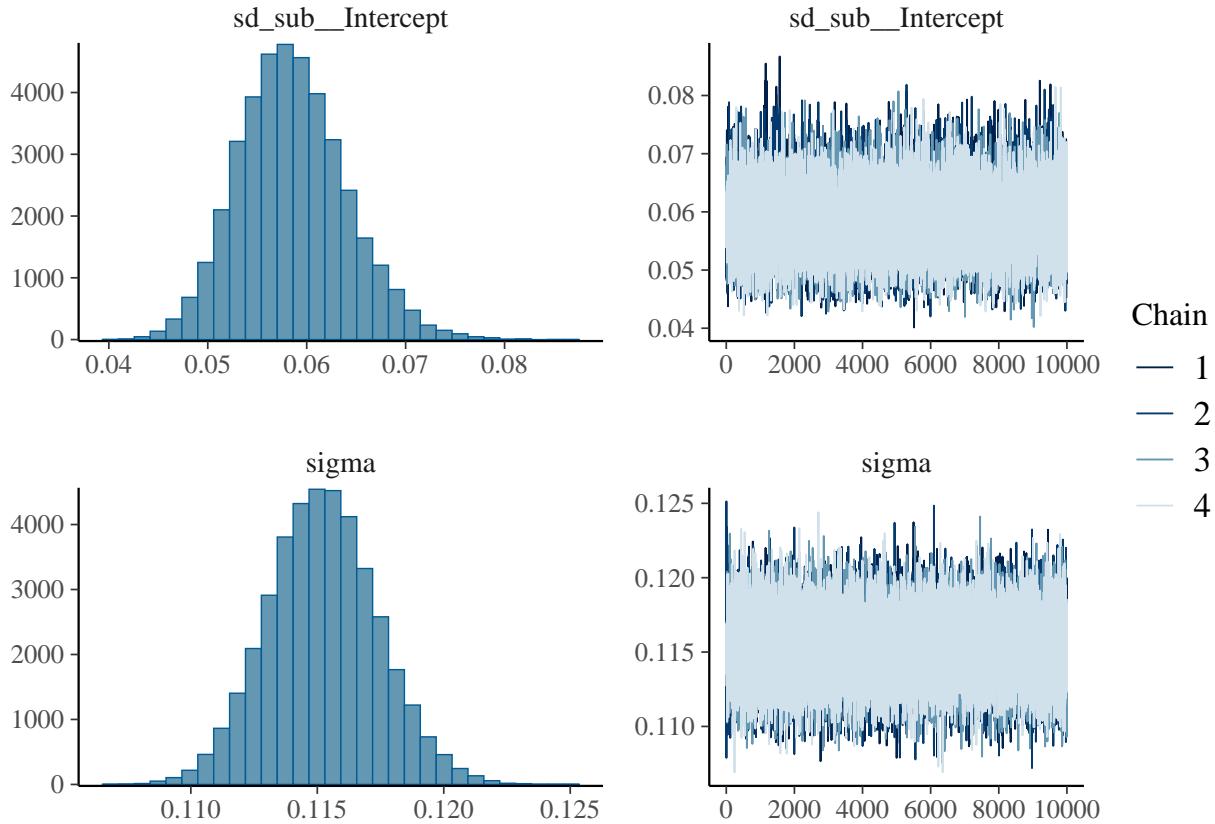
```
##  Family: gaussian
##  Links: mu = identity; sigma = identity
## Formula: value ~ scramble + level + (1 | sub)
##  Data: data_nested (Number of observations: 1520)
##  Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0587    0.0054   0.0491   0.0701 1.0002    14037    23235
## 
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## Intercept    0.0336    0.0097   0.0145   0.0525 1.0001    24556    29867
## scramble2    0.0468    0.0081   0.0308   0.0625 1.0001    58003    33390
## scramble3   -0.0109    0.0083  -0.0269   0.0051 1.0001    58659    32615
## scramble4   -0.0182    0.0081  -0.0342  -0.0022 1.0001    59353    33873
## level1     -0.0186    0.0080  -0.0347  -0.0029 1.0001    57372    34459
## level2     -0.0181    0.0081  -0.0341  -0.0021 1.0000    56656    34295
## level4     -0.0280    0.0081  -0.0441  -0.0121 1.0000    59380    34451
## 
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma       0.1123    0.0021   0.1083   0.1165 1.0002    76341    30110
## 
```

```
## 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).
```

Model without condition:

```
plot(nested_noScram)
```





```

print(summary(nested_noScram, robust = TRUE), digits = 4)

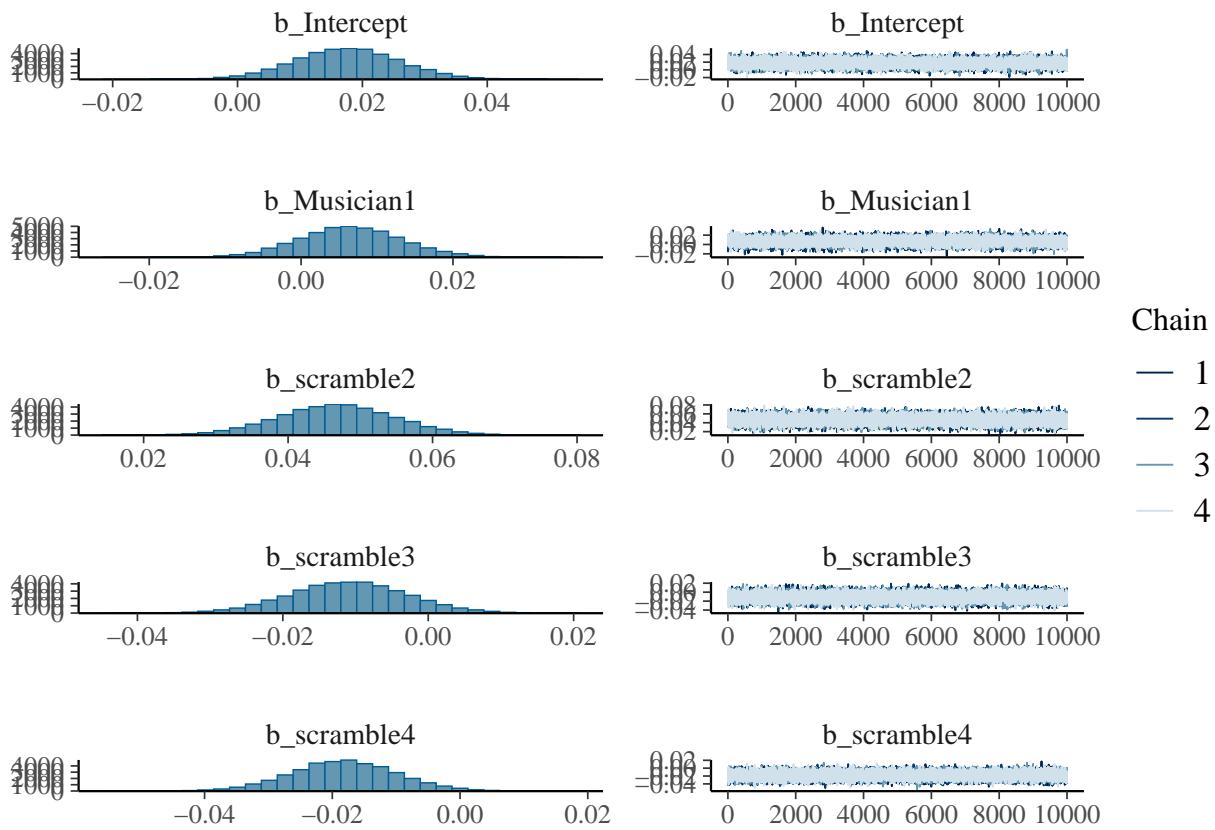
##  Family: gaussian
##  Links: mu = identity; sigma = identity
## Formula: value ~ Musician + level + (1 | sub)
##  Data: data_nested (Number of observations: 1520)
##  Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0583     0.0054   0.0486   0.0700 1.0006    14635    20415
## 
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## Intercept    0.0383     0.0084   0.0217   0.0549 1.0002    24002    29051
## Musician1    0.0065     0.0067  -0.0067   0.0197 1.0004    17858    24830
## level1      -0.0188     0.0083  -0.0350  -0.0025 1.0000    51979    33373
## level2      -0.0182     0.0083  -0.0346  -0.0019 1.0000    53303    32663
## level4      -0.0281     0.0082  -0.0443  -0.0118 1.0002    53965    34107
## 
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma       0.1152     0.0022   0.1110   0.1196 1.0002    75562    28996
## 
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential

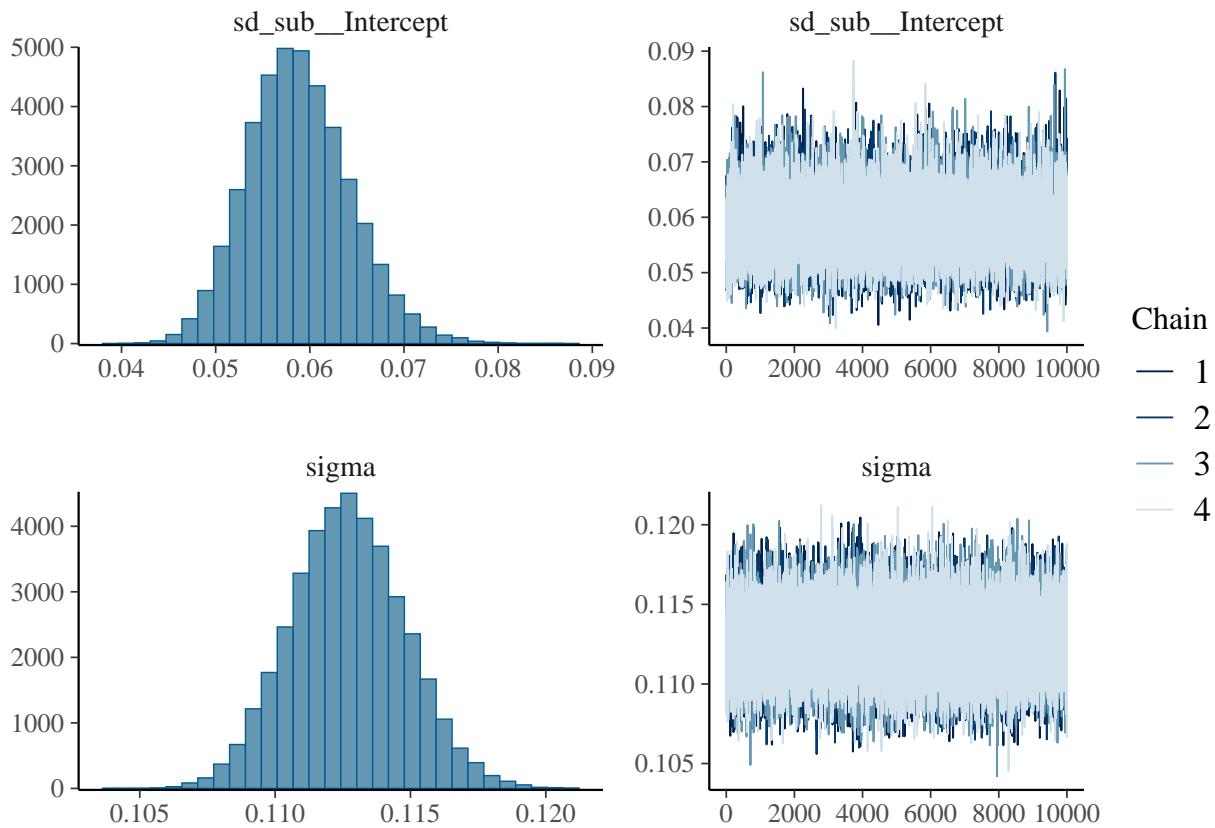
```

```
## scale reduction factor on split chains (at convergence, Rhat = 1).
```

Model without level:

```
plot(nested_noLevel)
```





```

print(summary(nested_noLevel, robust = TRUE), digits = 4)

##  Family: gaussian
##  Links: mu = identity; sigma = identity
## Formula: value ~ Musician + scramble + (1 | sub)
##  Data: data_nested (Number of observations: 1520)
##  Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept) 0.0586     0.0054   0.0489   0.0703 1.0001    13852    20224
## 
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## Intercept  0.0175     0.0083   0.0013   0.0339 1.0001    21467    26436
## Musician1  0.0065     0.0067  -0.0066   0.0199 1.0001    17396    24702
## scramble2  0.0467     0.0080   0.0308   0.0626 1.0001    54562    33000
## scramble3 -0.0109     0.0081  -0.0269   0.0050 1.0001    54652    33244
## scramble4 -0.0182     0.0081  -0.0342  -0.0021 1.0000    54782    33731
## 
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma      0.1127     0.0021   0.1087   0.1169 1.0001    71235    28807
## 
## 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).
```

## Main effect of group

```
BF_nested_mus <- bayes_factor(nested_3way, nested_noMus)

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

print(BF_nested_mus)

## Estimated Bayes factor in favor of nested_3way over nested_noMus: 0.06540
```

Strong evidence against a main effect of group.

## Main effect of condition

```
BF_nested_scram <- bayes_factor(nested_3way, nested_noScram)

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

print(BF_nested_scram)

## Estimated Bayes factor in favor of nested_3way over nested_noScram: 2024356222439.07056
```

Very strong evidence for a main effect of condition.

## Main effect of level

```
BF_nested_level <- bayes_factor(nested_3way, nested_noLevel)

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

print(BF_nested_level)
```

```
## Estimated Bayes factor in favor of nested_3way over nested_noLevel: 0.00990
Moderate evidence against a main effect of level.
```

## Interactions

Does adding an interaction between condition and level improve the model? (Without group)

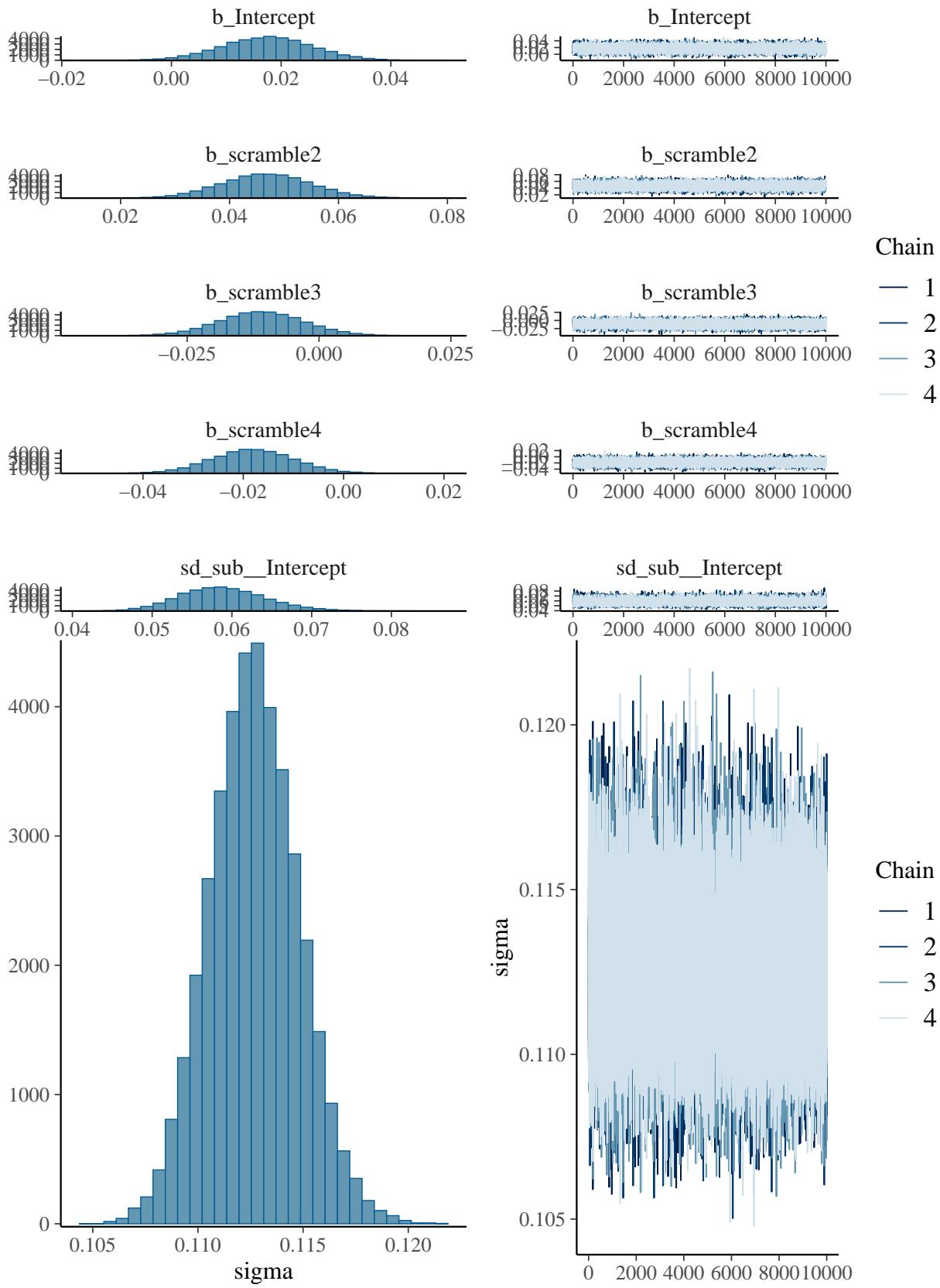
```
nested_justScram <- brm(value ~ scramble + (1|sub), data = data_nested,
  prior = c(
    set_prior('normal(0.1, 0.1)', coef = 'scramble2'),
    set_prior('normal(-0.1, 0.1)', coef = 'scramble3'),
    set_prior('normal(-0.1, 0.1)', coef = 'scramble4')
  ),
  save_pars = save_pars(all = TRUE),
  iter = 20000, refresh = 0,
  file = 'models/E3_alignment_justScram')

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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(nested_justScram)
```



```

print(summary(nested_justScram, robust = TRUE), digits = 4)

## Family: gaussian
## Links: mu = identity; sigma = identity
## Formula: value ~ scramble + (1 | sub)
## Data: data_nested (Number of observations: 1520)
## Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##         total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0587   0.0053   0.0491   0.0703 1.0001    14224   21149
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## Intercept    0.0175   0.0083   0.0011   0.0337 1.0000    22171   27682
## scramble2    0.0468   0.0081   0.0311   0.0628 1.0000    55488   34803
## scramble3   -0.0109   0.0080  -0.0268   0.0050 1.0000    55625   34567
## scramble4   -0.0181   0.0081  -0.0341  -0.0022 1.0000    56807   35534
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma       0.1126   0.0021   0.1086   0.1169 1.0001    71395   29102
##
## 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).

```

```

nested_2way_levelScram <- brm(value ~ scramble + scramble:level + (1|sub), data = data_nested,
                                prior = c(
                                    set_prior('normal(0, 0.1)', class = 'b'), # all interactions
                                    set_prior('normal(0.1, 0.1)', coef = 'scramble2'),
                                    set_prior('normal(-0.1, 0.1)', coef = 'scramble3'),
                                    set_prior('normal(-0.1, 0.1)', coef = 'scramble4')
                                ),
                                save_pars = save_pars(all = TRUE),
                                iter = 20000, refresh = 0,
                                file = 'models/E3_alignment_2way_levelScramInt')

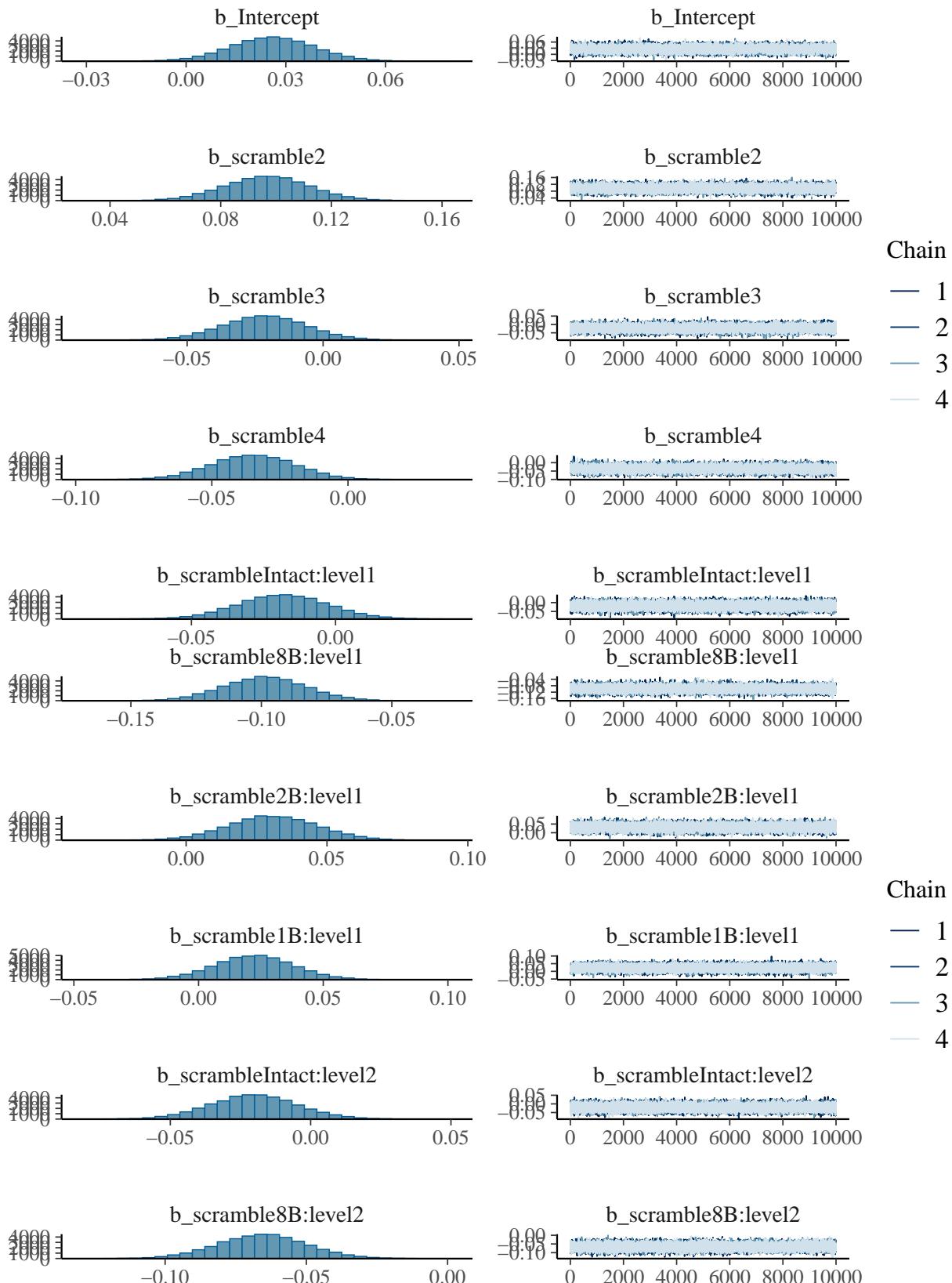
## Compiling Stan program...

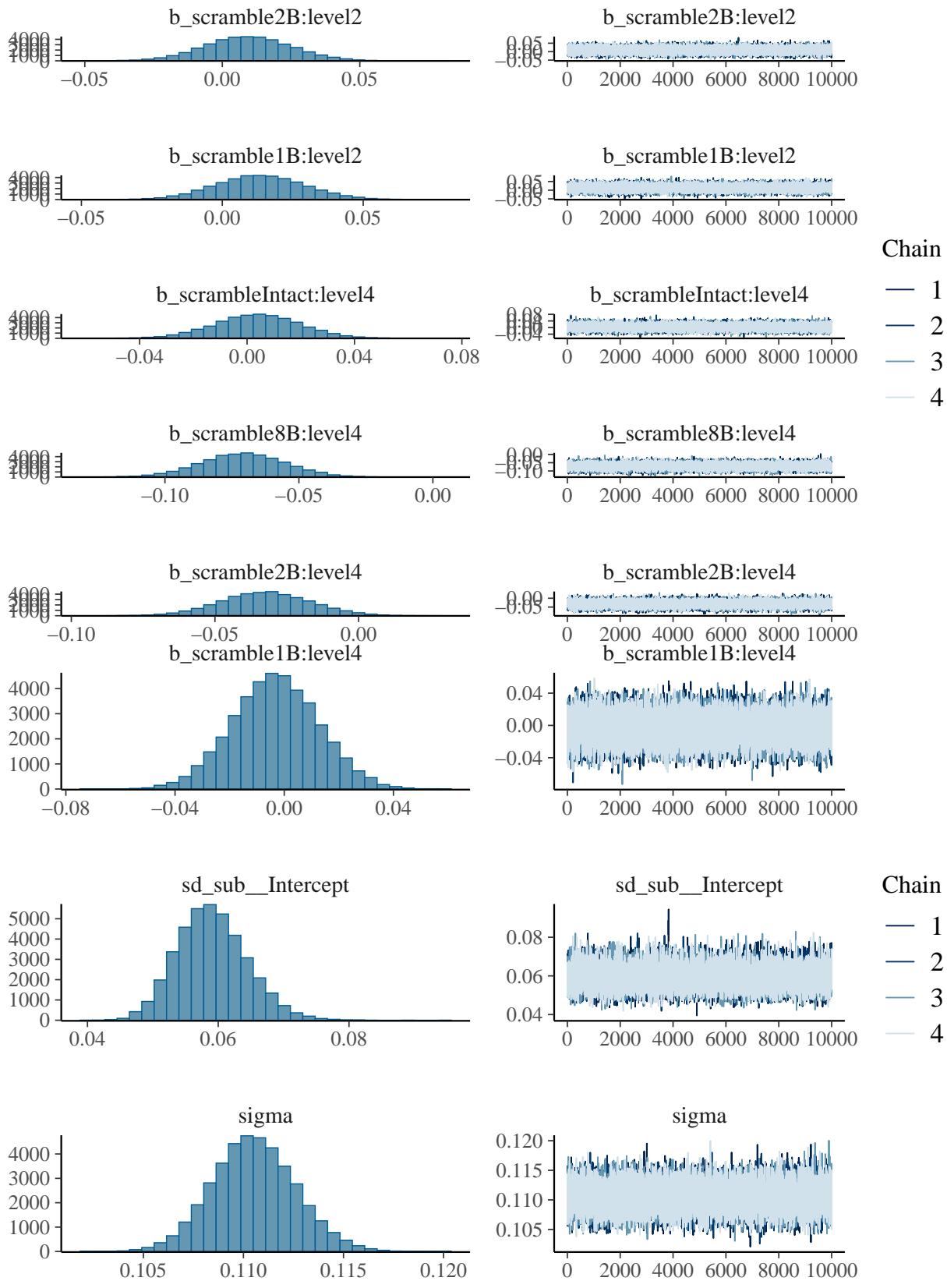
## Trying to compile a simple C file

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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(nested_2way_levelScram)

```





```
print(summary(nested_2way_levelScram, robust = TRUE), digits = 4)
```

```

## Family: gaussian
## Links: mu = identity; sigma = identity
## Formula: value ~ scramble + scramble:level + (1 | sub)
## Data: data_nested (Number of observations: 1520)
## Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##         total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0588   0.0053   0.0494   0.0702 1.0002    13371    22948
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS
## Intercept        0.0260   0.0125   0.0014   0.0506 1.0002    18081
## scramble2        0.0968   0.0154   0.0668   0.1268 1.0000    22695
## scramble3       -0.0215   0.0154  -0.0517   0.0087 1.0002    22790
## scramble4       -0.0349   0.0156  -0.0654  -0.0049 1.0000    23553
## scrambleIntact:level1 -0.0182   0.0157  -0.0488   0.0127 1.0001    30875
## scramble8B:level1 -0.0987   0.0157  -0.1294  -0.0678 1.0001    40909
## scramble2B:level1  0.0308   0.0157   0.0004   0.0616 1.0000    39658
## scramble1B:level1  0.0223   0.0156  -0.0089   0.0531 1.0000    40740
## scrambleIntact:level2 -0.0202   0.0153  -0.0506   0.0105 1.0000    30593
## scramble8B:level2 -0.0655   0.0156  -0.0966  -0.0349 1.0000    40463
## scramble2B:level2  0.0093   0.0156  -0.0210   0.0401 1.0001    40491
## scramble1B:level2  0.0134   0.0158  -0.0170   0.0446 1.0003    39625
## scrambleIntact:level4  0.0039   0.0157  -0.0271   0.0343 1.0000    31221
## scramble8B:level4  -0.0708   0.0157  -0.1017  -0.0402 1.0002    39616
## scramble2B:level4  -0.0324   0.0155  -0.0628  -0.0013 1.0000    40106
## scramble1B:level4  -0.0032   0.0158  -0.0340   0.0280 1.0001    40599
##             Tail_ESS
## Intercept      26660
## scramble2      28932
## scramble3      28577
## scramble4      28453
## scrambleIntact:level1 31986
## scramble8B:level1 33245
## scramble2B:level1 33687
## scramble1B:level1 34627
## scrambleIntact:level2 32469
## scramble8B:level2 32793
## scramble2B:level2 32326
## scramble1B:level2 33769
## scrambleIntact:level4 31552
## scramble8B:level4 33521
## scramble2B:level4 33395
## scramble1B:level4 34191
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma     0.1105   0.0021   0.1066   0.1147 1.0002    62485    29728
##
## 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).
BF_nested_2way_levelScram <- bayes_factor(nested_2way_levelScram, nested_justScram)

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

print(BF_nested_2way_levelScram)

## Estimated Bayes factor in favor of nested_2way_levelScram over nested_justScram: 8599.77367
```

Strong evidence for an interaction between condition and level.

Check the other interactions.

```
nested_justLevel <- brm(value ~ level + (1|sub), data = data_nested,
                         prior = c(
                           set_prior('normal(-0.2, 0.1)', coef = 'level1'),
                           set_prior('normal(-0.1, 0.1)', coef = c('level2', 'level4'))
                         ),
                         save_pars = save_pars(all = TRUE),
                         iter = 20000, refresh = 0,
                         file = 'models/E3_alignment_justLevel')

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include/Eigen/src/Core
## /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

nested_2way_musScram <- brm(value ~ scramble + scramble:Musician + (1|sub), data = data_nested,
                               prior = c(
                                 set_prior('normal(0, 0.1)', class = 'b'), # all interactions
                                 set_prior('normal(0.1, 0.1)', coef = 'scramble2'),
                                 set_prior('normal(-0.1, 0.1)', coef = 'scramble3'),
                                 set_prior('normal(-0.1, 0.1)', coef = 'scramble4')
                               ),
                               save_pars = save_pars(all = TRUE),
                               iter = 20000, refresh = 0,
                               file = 'models/E3_alignment_2way_musScramInt')

## 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/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include"
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include/Eigen/src/Core
## /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

nested_2way_musLevel <- brm(value ~ level + level:Musician + (1|sub), data = data_nested,
                           prior = c(
                             set_prior('normal(0, 0.1)', class = 'b'), # all interactions
                             set_prior('normal(-0.2, 0.1)', coef = 'level1'),
                             set_prior('normal(-0.1, 0.1)', coef = c('level2', 'level4'))
                           ),
                           save_pars = save_pars(all = TRUE),
                           iter = 20000, refresh = 0,
                           file = 'models/E3_alignment_2way_musLevelInt')

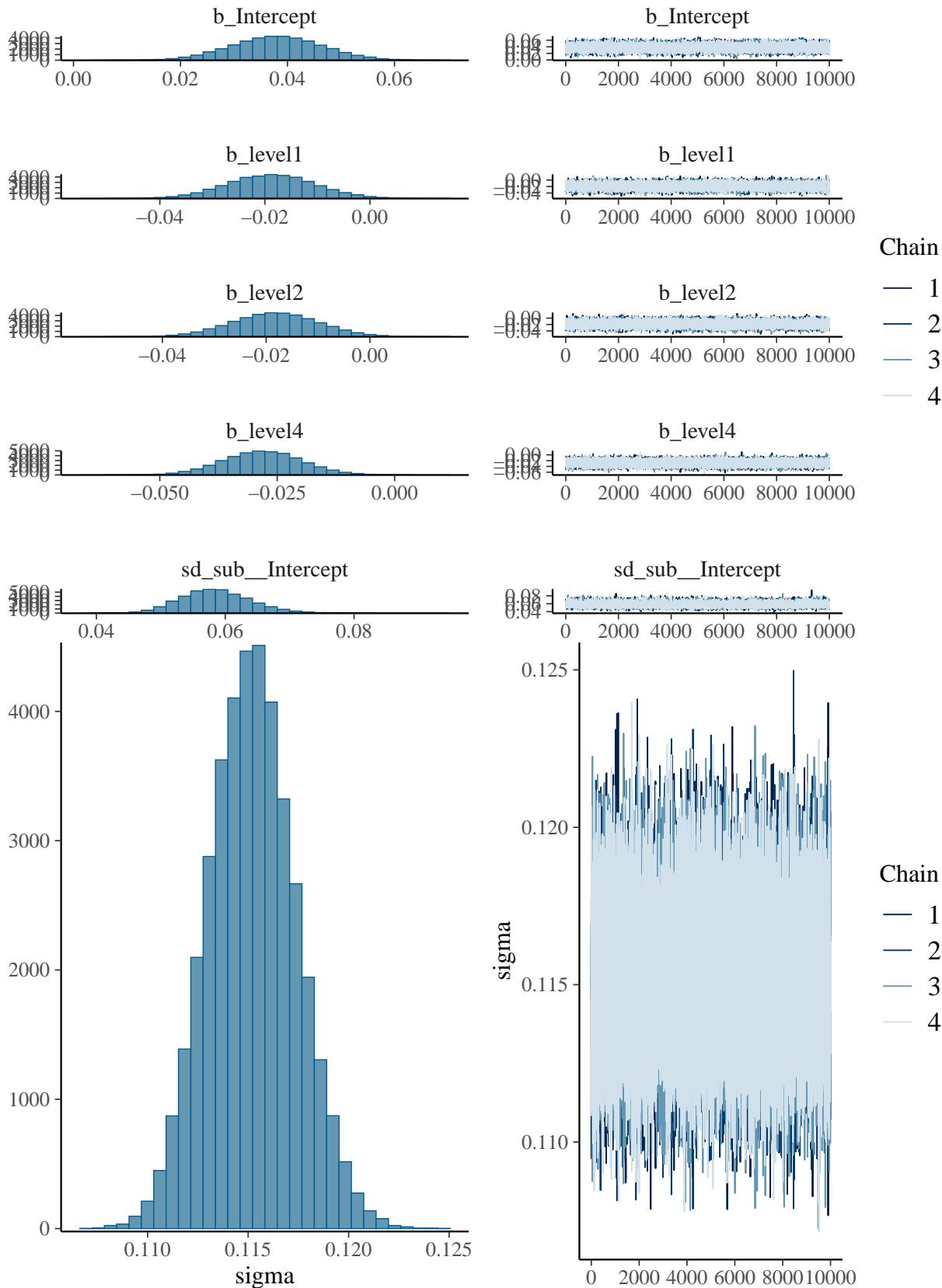
## Compiling Stan program...
## Trying to compile a simple C file

## 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/Frameworks/R.framework/Resources/include"
## In file included from <built-in>:1:
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/StanHeaders/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## In file included from /Library/Frameworks/R.framework/Versions/4.3-arm64/Resources/library/RcppEigen/include
## /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(nested_justLevel)
```



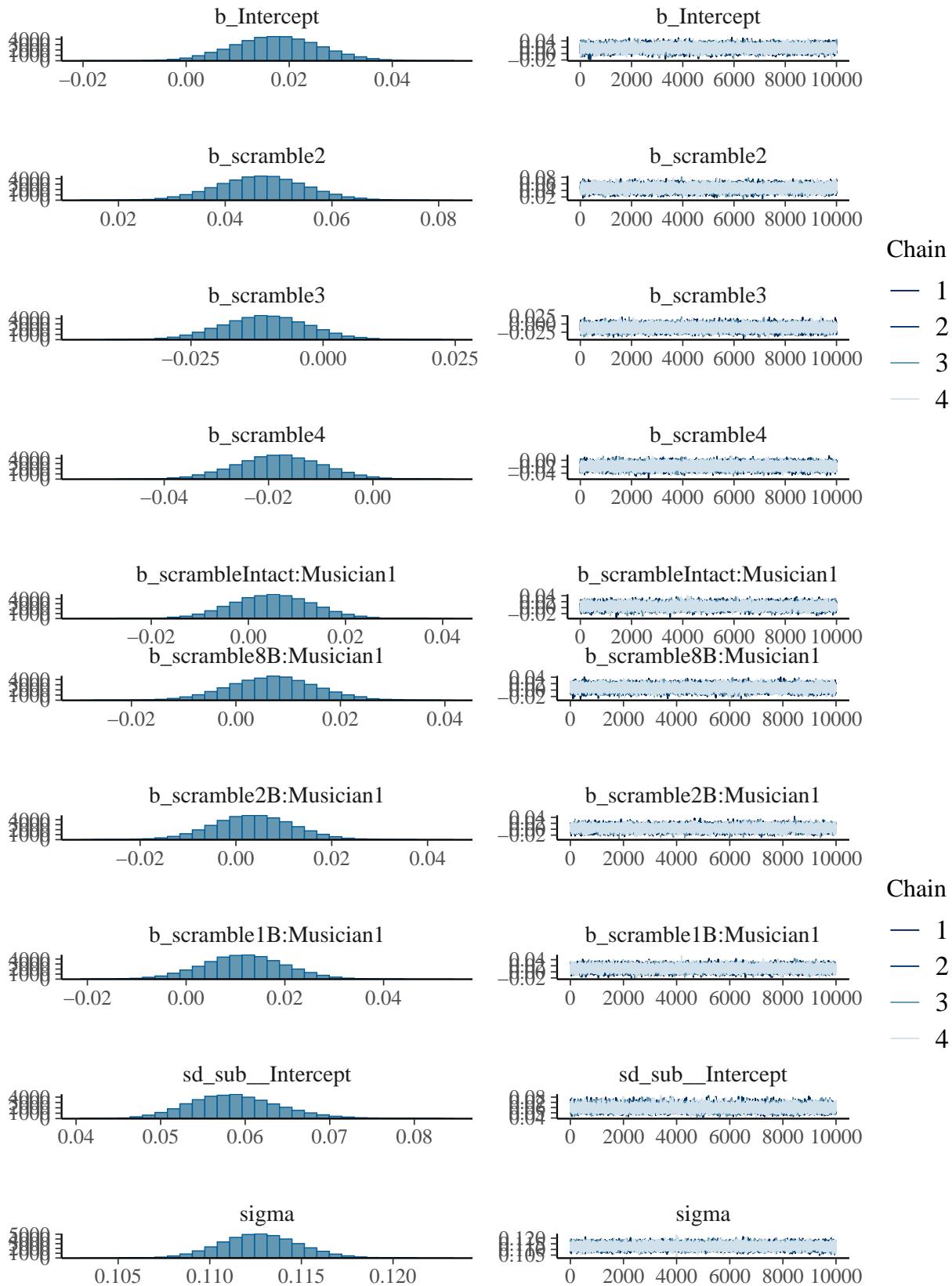
```

print(summary(nested_justLevel, robust = TRUE), digits = 4)

## Family: gaussian
## Links: mu = identity; sigma = identity
## Formula: value ~ level + (1 | sub)
## Data: data_nested (Number of observations: 1520)
## Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##         total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0583   0.0053   0.0488   0.0700 1.0004    14801   22846
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## Intercept    0.0380   0.0085   0.0216   0.0546 1.0002    23162   29745
## level1      -0.0188   0.0084  -0.0351  -0.0023 1.0001    57036   33309
## level2      -0.0182   0.0083  -0.0346  -0.0021 1.0000    57470   34969
## level4      -0.0281   0.0083  -0.0444  -0.0118 1.0001    57109   34719
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma       0.1152   0.0022   0.1111   0.1196 1.0002    76264   28811
##
## 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).

```

```
plot(nested_2way_musScram)
```



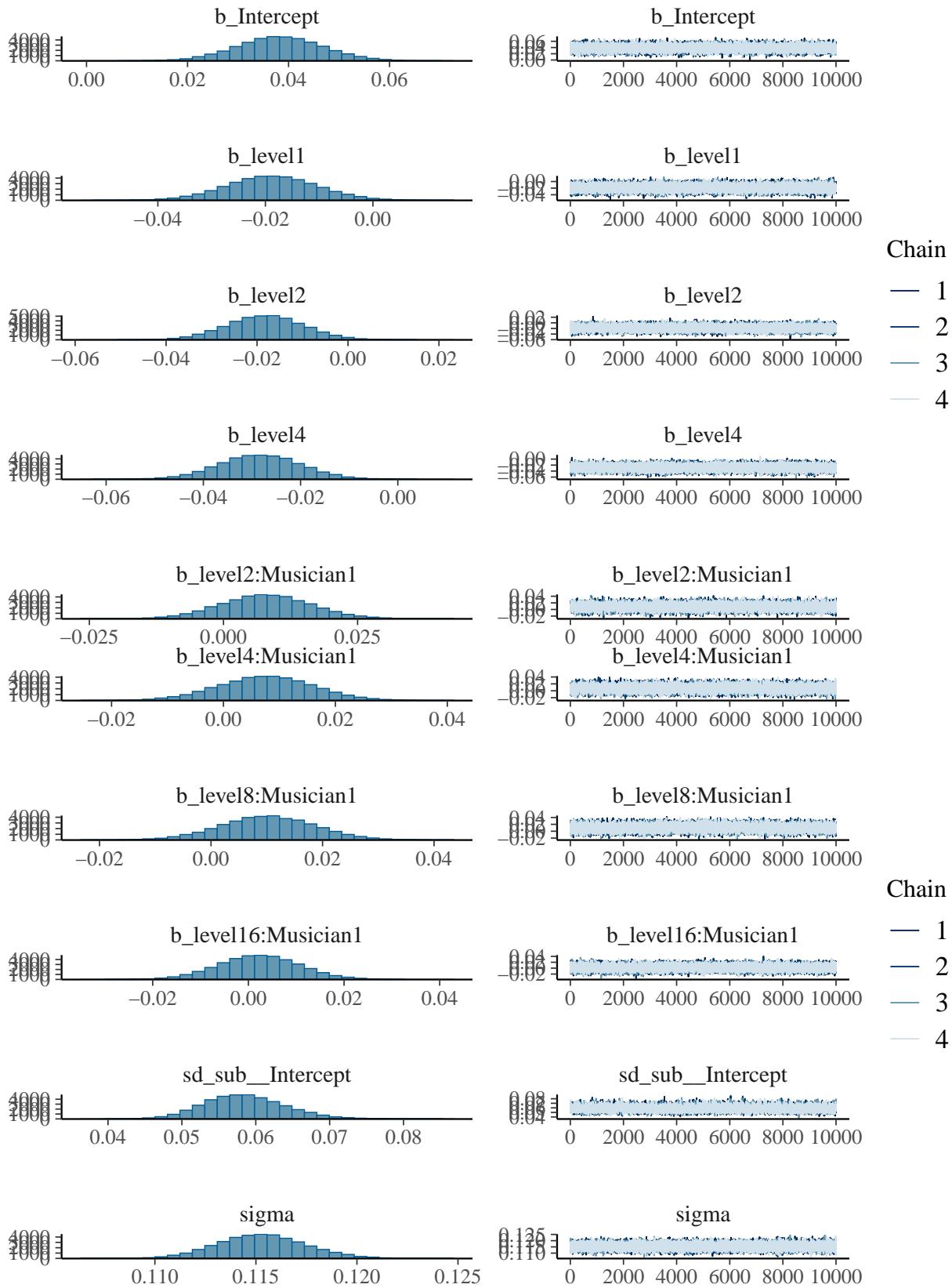
```

print(summary(nested_2way_musScram, robust = TRUE), digits = 4)

##  Family: gaussian
##  Links: mu = identity; sigma = identity
## Formula: value ~ scramble + scramble:Musician + (1 | sub)
##   Data: data_nested (Number of observations: 1520)
##   Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0585   0.0053   0.0491   0.0702 1.0002    14497    21353
##
## Regression Coefficients:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS
## Intercept      0.0176   0.0084   0.0013   0.0341 1.0002    23728
## scramble2       0.0468   0.0082   0.0308   0.0629 1.0000    54166
## scramble3      -0.0109   0.0081  -0.0268   0.0050 1.0000    58805
## scramble4      -0.0180   0.0082  -0.0339  -0.0020 1.0001    55242
## scrambleIntact:Musician1  0.0049   0.0084  -0.0113   0.0213 1.0002    19839
## scramble8B:Musician1     0.0071   0.0083  -0.0092   0.0234 1.0002    19455
## scramble2B:Musician1    0.0036   0.0083  -0.0126   0.0200 1.0000    19528
## scramble1B:Musician1    0.0117   0.0082  -0.0046   0.0279 1.0001    19864
##
## Tail_ESS
## Intercept      27731
## scramble2       33397
## scramble3       33812
## scramble4       32586
## scrambleIntact:Musician1  26489
## scramble8B:Musician1    27799
## scramble2B:Musician1    26490
## scramble1B:Musician1    28014
##
## Further Distributional Parameters:
##             Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma     0.1127   0.0021   0.1087   0.1170 1.0000    65620    28142
##
## 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).

```

```
plot(nested_2way_musLevel)
```



```

print(summary(nested_2way_musLevel, robust = TRUE), digits = 4)

##  Family: gaussian
##  Links: mu = identity; sigma = identity
## Formula: value ~ level + level:Musician + (1 | sub)
##   Data: data_nested (Number of observations: 1520)
##   Draws: 4 chains, each with iter = 20000; warmup = 10000; thin = 1;
##          total post-warmup draws = 40000
##
## Multilevel Hyperparameters:
## ~sub (Number of levels: 95)
##           Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sd(Intercept)  0.0583   0.0054   0.0486   0.0699 1.0001    15064   22199
##
## Regression Coefficients:
##           Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## Intercept      0.0383   0.0084   0.0220   0.0549 1.0000    23277   27371
## level1        -0.0188   0.0083  -0.0352  -0.0024 1.0000    56609   33054
## level2        -0.0182   0.0083  -0.0345  -0.0019 1.0000    54879   33586
## level4        -0.0283   0.0084  -0.0447  -0.0120 1.0000    55606   32433
## level2:Musician1  0.0079   0.0084  -0.0084   0.0246 1.0003    18037   26526
## level4:Musician1  0.0076   0.0085  -0.0093   0.0240 1.0002    18436   26200
## level8:Musician1  0.0102   0.0084  -0.0063   0.0267 1.0000    18141   27646
## level16:Musician1 0.0023   0.0084  -0.0143   0.0188 1.0003    18410   26323
##
## Further Distributional Parameters:
##           Estimate Est.Error l-95% CI u-95% CI    Rhat Bulk_ESS Tail_ESS
## sigma     0.1153   0.0022   0.1111   0.1197 1.0001    73531   28797
##
## 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).

```

```

BF_nested_2way_musScram <- bayes_factor(nested_2way_musScram, nested_justScram)

## Iteration: 1
## Iteration: 2
## Iteration: 3
## Iteration: 4
## Iteration: 1
## Iteration: 2
## Iteration: 3
## Iteration: 4

print(formatC(BF_nested_2way_musScram$bf, format = 'e'))

## [1] "7.6484e-05"

BF_nested_2way_musLevel <- bayes_factor(nested_2way_musLevel, nested_justLevel)

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

print(formatC(BF_nested_2way_musLevel$bf, format = 'e'))

## [1] "7.7754e-05"

```

Very strong evidence against interactions between group and condition and group and level.