Bayesian Analyses for CircleTime

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Contents

1 About the Study

1.1 Introduction to Circle-Time

Circle-time is a group activity based on Applied Behavior Analysis (ABA) for children with Autism Spectrum Disorder (ASD) to prepare them for attending in traditional classroom activities alongside neurotically developed children. In circle-time, children sit together semicircular, and an instructor give them group instruction activities such as dance, yoga, labeling animals, finding objects, etc. The goal of circle-time is to improve children's learning behaviors, which are:

- Affect
- Communication
- Engagement
- Performance

In this study, we evaluate the efficacy of a social robot in delivering group instruction activities to children with ASD. Throughout the six month of experiment, Six children participants received 10 sessions of group instructions from a human instructor and 10 sessions from a Pepper humanoid social robot as a within-subject study design. To compare children learning behaviors between the human and the robot instructor conditions their activities were video recorded and coded for the sessions 1, 4, 7, and 10.

1.2 Research Questions

In this research, we address the following research questions:

1. How learning behaviors (Affect, Communication, Engagement, Performance) differ between conditions (Human, Robot)?

2. How is the correlation between learning behaviors (Affect, Communication, Engagement, Performance) and time (Session Number)?
3. How is the correlation between different learning behaviors (Affect, Communication, Engagement, Performance)?
4. Between the Affect, Communication, and Engagement learning behaviors, which one has more effective relationship with the Performance learning behavior (increasing performance is considered as the main objective)?

1.3 Study Design

For this longitudinal within-subject study with 6 participants we defined the following variables:

1.3.0.1 Independent Variables

- Instructor Conditions:

    - Human ~ 1
    - Robot ~ 2

- Time

    - Session 1 ~ 1
    - Session 4 ~ 2
    - Session 7 ~ 3
    - Session 10 ~ 4

1.3.0.2 Dependent Variables

- Affect
- Communication
- Engagement
- Performance

1.3.1 Data Collection

The evaluation of the learning behavior is based on the following continuous metrics:

1.3.1.1 Affect   children's happiness level was defined as:

- Positive
- Negative
- Neutral

A video was divided into 10 seconds intervals, and a human coder, focusing on one child in the group, labeled that interval as Positive if the child was showing positive affective behaviors (e.g., smiling, Clapping, laughing). An interval was labeled as Negative if the target child was showing negative affective behaviors (e.g., crying, whining, frowning). And, and an interval was labeled as Neutral if it was neither Positive or Negative. Percentage of each measurement is used for analysis as a continuous variable.

1.3.1.2 Communication Communication of the children was coded into 4 categories. Communication with:

- Instructor
- Instructor-Prompted
- Behavior Therapist (BT) or peers
- Indeterminate

1.3.1.3 Engagement Engagement was coded into 3 categories. Engagement with:

- Instructor or screen (On Target)
- BT or peers
- Off Target

1.3.1.4 Performance Children's performance was coded into two categories:

- Positive
- Negative

1.3.1.5 Inter-observer Agreement (IoA) At the beginning of the coding procedure, coders' understanding of the metrics had to be on the same page. We used Cohen's Kappa score to evaluate the IoA on the coding procedure. An individual coder was allowed to code independently only if their Cohen's Kappa IioA score was higher than 80%. All session ones and tens were double coded as well as the 30% of the session fours and sevens. For the sessions with lower than 80% agreement, coders went through coding together and came up with 100% agreement. We considered this conservative approach since we were looking into the highest reliability of data on our 6 participants.

2 Data Analysis

In order to investigate the research questions, we analyze the data from children's learning behaviors as follows:

2.1 Affect

We use Bayesian Model to analyze the Affect metric.For all analyses condition 1 indicates the human instructor while condition 2 indicates the robot instructor.

2.1.1 Positive Affect

```r
library(readr)
```

```
## Warning: package 'readr' was built under R version 4.3.2
```

```r
library(brms)
```

```
## Warning: package 'brms' was built under R version 4.3.2
```

```
## Loading required package: Rcpp


## Warning: package 'Rcpp' was built under R version 4.3.2


## Loading 'brms' package (version 2.20.4). 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
```

```r
CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16


## -- Column specification ---------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use 'spec()' to retrieve the full column specification for this data.
## i Specify the column types or set 'show_col_types = FALSE' to quiet this message.
```

```r
bmodel <- brm(Affect_Positive ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.7e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.27 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
```

```
## Chain 1:
## Chain 1:  Elapsed Time: 0.217 seconds (Warm-up)
## Chain 1:                0.108 seconds (Sampling)
## Chain 1:                0.325 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 7e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.258 seconds (Warm-up)
## Chain 2:                0.116 seconds (Sampling)
## Chain 2:                0.374 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.244 seconds (Warm-up)
## Chain 3:                0.096 seconds (Sampling)
## Chain 3:                0.34 seconds (Total)
```

```
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.261 seconds (Warm-up)
## Chain 4:                0.128 seconds (Sampling)
## Chain 4:                0.389 seconds (Total)
## Chain 4:


## Warning: There were 13 divergent transitions after warmup. See
## https://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
## to find out why this is a problem and how to eliminate them.


## Warning: Examine the pairs() plot to diagnose sampling problems


## Warning: Tail Effective Samples Size (ESS) is too low, indicating posterior variances and tail quant
## Running the chains for more iterations may help. See
## https://mc-stan.org/misc/warnings.html#tail-ess
```

```r
summary(bmodel)
```

```
## Warning: There were 13 divergent transitions after warmup. Increasing
## adapt_delta above 0.8 may help. See
## http://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup


##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Affect_Positive ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
```

```
##                 Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)       0.09      0.06     0.04     0.23 1.00      631      508
##
## Population-Level Effects:
##                 Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept           0.05      0.09    -0.13     0.23 1.00     1002     1054
## Condition           0.09      0.05    -0.01     0.19 1.00     1674     2087
## time                0.01      0.03    -0.05     0.07 1.00     1583     1902
## Condition:time     -0.01      0.02    -0.05     0.02 1.00     1571     2011
##
## Family Specific Parameters:
##        Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma      0.07      0.01     0.06     0.09 1.00     1541     1017
##
## 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(bmodel)
```
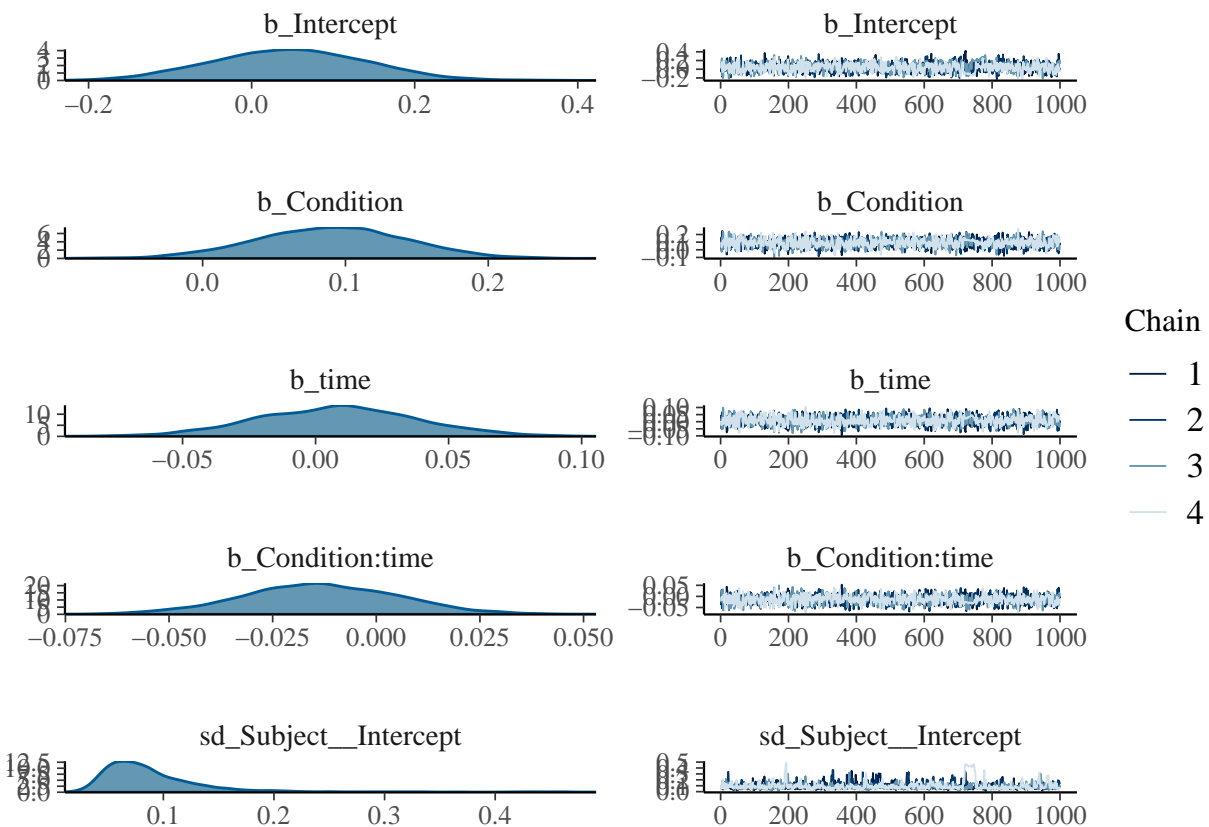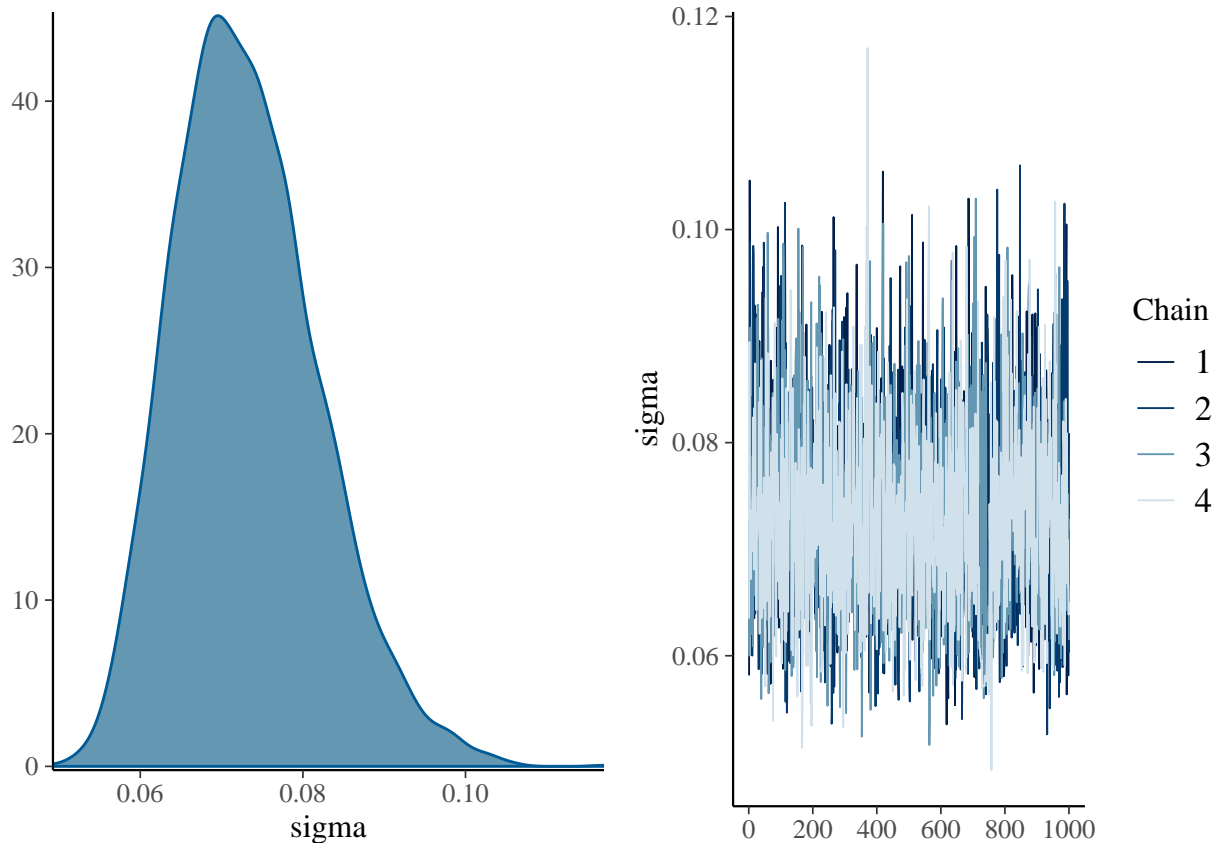
2.1.1.1 Reporting Affect Positive

Our Bayesian analysis of Affect_Positive explores the emotional responses of children in conditions involving human (Condition 1) versus robot instructors (Condition 2) across four pivotal sessions, representing sessions 1, 4, 7, and 10 in the context of a comprehensive longitudinal study spanning six months. The estimated standard deviation of intercepts across subjects is 0.08 (95% CI: 0.04, 0.20), indicating moderate variability in baseline levels of Affect_Positive among individuals. Examining population-level effects, the intercept is estimated at 0.04 (95% CI: -0.14, 0.21), representing the expected value of Affect_Positive when both Condition and time are zero. Positive effect sizes were observed for both Condition (0.09, 95% CI: -0.01, 0.20) and time (0.01, 95% CI: -0.05, 0.07), suggesting an increase in Affect_Positive during sessions with robot instructors compared to human instructors and a gradual rise over time. Interestingly, the interaction effect, represented by Condition:time, showed a slight decrease in the effect of Condition over time (-0.01, 95% CI: -0.05, 0.02). The estimated standard deviation of the residuals (sigma) was 0.07 (95% CI: 0.06, 0.09), capturing variability not explained by the fixed effects.

2.1.2 Negative Affect

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ----------------------------------------------------
## Delimiter: ","
```

```
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use 'spec()' to retrieve the full column specification for this data.
## i Specify the column types or set 'show_col_types = FALSE' to quiet this message.
```

```r
bmodel <- brm(Affect_Negative ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 3.5e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.35 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.407 seconds (Warm-up)
## Chain 1:                0.117 seconds (Sampling)
## Chain 1:                0.524 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 7e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
```

```
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.403 seconds (Warm-up)
## Chain 2:                0.115 seconds (Sampling)
## Chain 2:                0.518 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.437 seconds (Warm-up)
## Chain 3:                0.123 seconds (Sampling)
## Chain 3:                0.56 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 2.1e-05 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.21 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.455 seconds (Warm-up)
```

```
## Chain 4:                  0.115 seconds (Sampling)
## Chain 4:                  0.57 seconds (Total)
## Chain 4:


## Warning: There were 2 divergent transitions after warmup. See
## https://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
## to find out why this is a problem and how to eliminate them.


## Warning: Examine the pairs() plot to diagnose sampling problems
```

summary(bmodel)

```
## Warning: There were 2 divergent transitions after warmup. Increasing
## adapt_delta above 0.8 may help. See
## http://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup


##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Affect_Negative ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.01      0.01     0.00     0.03 1.00      957     1233
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.02      0.02    -0.02     0.06 1.00     2046     1891
## Condition         -0.01      0.01    -0.03     0.02 1.00     2078     2338
## time              -0.01      0.01    -0.02     0.01 1.00     2067     2264
## Condition:time     0.01      0.00    -0.00     0.01 1.00     1992     2155
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.02      0.00     0.01     0.02 1.00     2320     2577
##
## 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(bmodel)
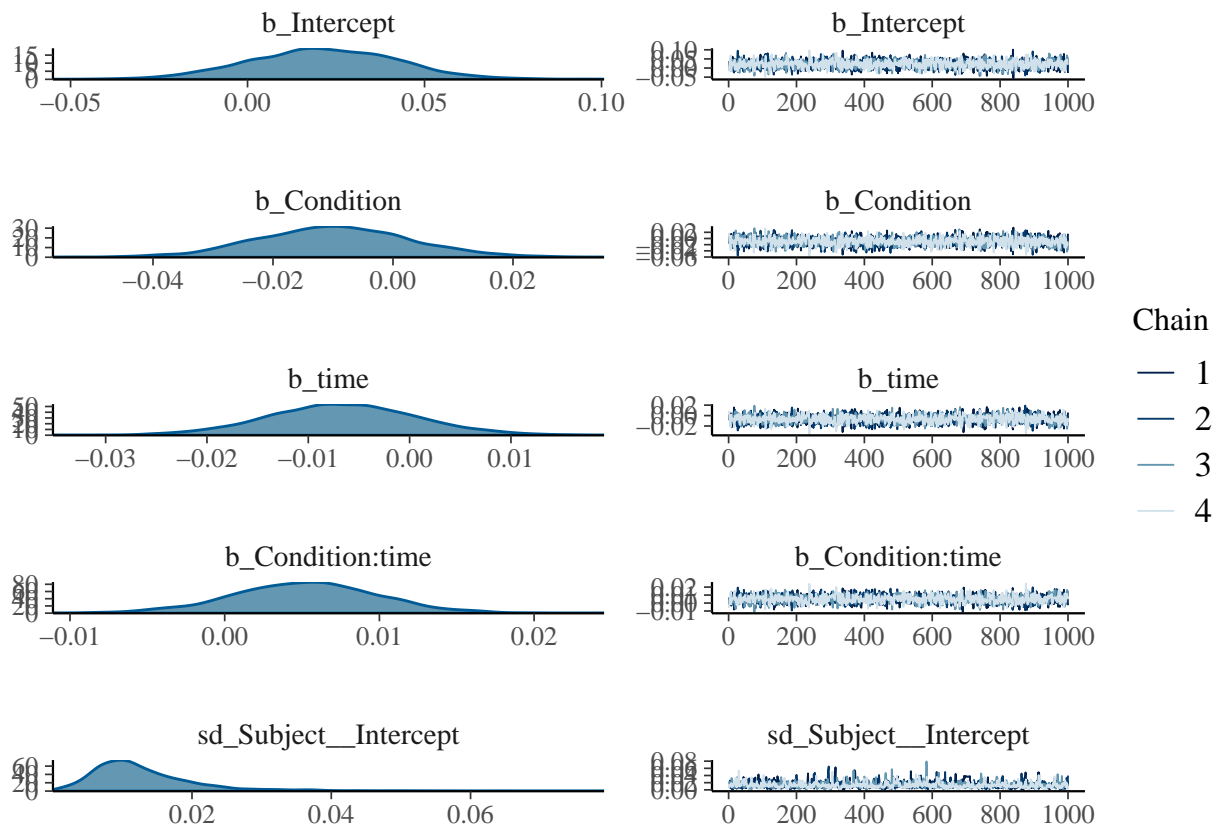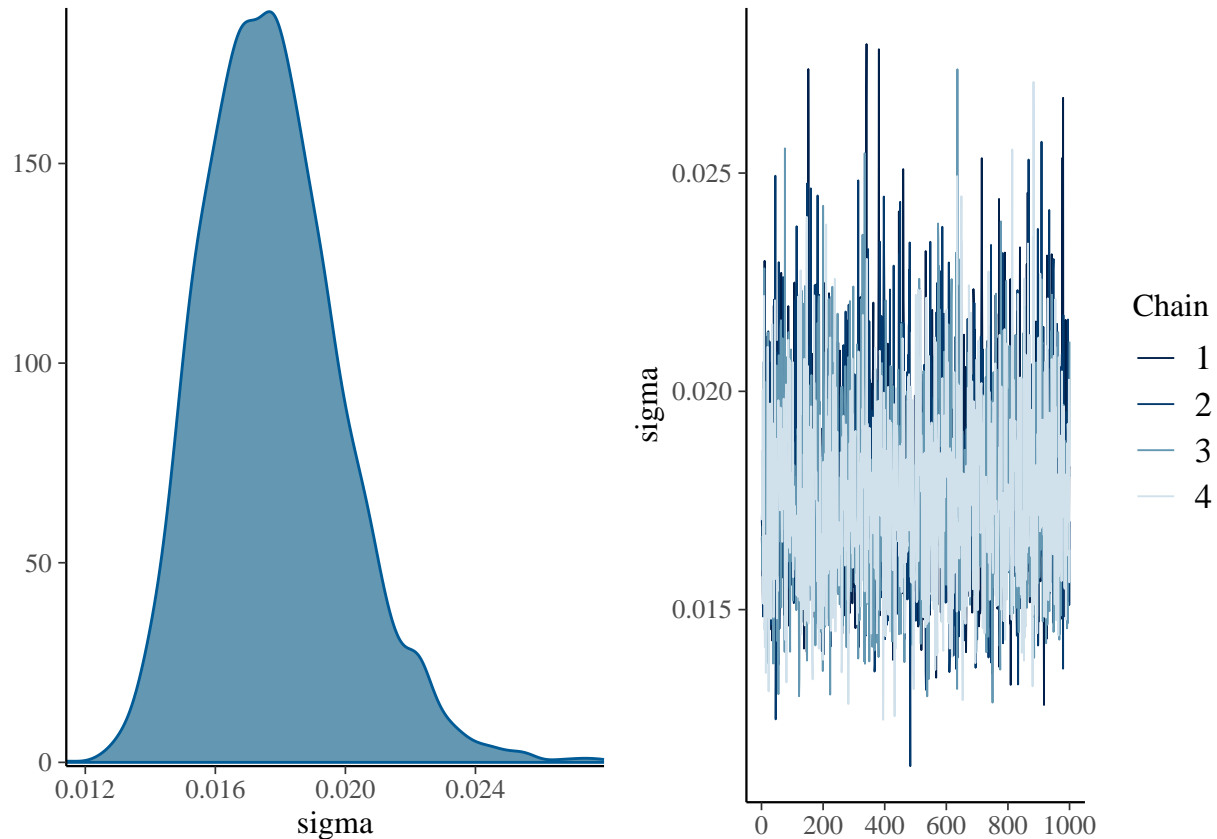
2.1.2.1 Reporting Negative Affect Our Bayesian analysis of Negative Affect delves into the emotional responses of children within conditions involving human (Condition 1) versus robot instructors (Condition 2) across four pivotal sessions, representing sessions 1, 4, 7, and 10 in the context of a comprehensive longitudinal study spanning six months. The estimated standard deviation of intercepts across subjects is 0.01 (95% CI: 0.00, 0.03), indicating minimal variability in baseline levels of Negative Affect among individuals. Exploring population-level effects, the intercept is estimated at 0.02 (95% CI: -0.02, 0.06), representing the expected value of Negative Affect when both Condition and time are zero. Negative effect sizes were observed for both Condition (-0.01, 95% CI: -0.03, 0.02) and time (-0.01, 95% CI: -0.02, 0.01), suggesting a decrease in Negative Affect during sessions with robot instructors compared to human instructors and a slight decline over time. The interaction effect, represented by Condition:time, showed a slight increase in the effect of Condition over time (0.01, 95% CI: -0.00, 0.01). The estimated standard deviation of the residuals (sigma) was 0.02 (95% CI: 0.01, 0.02), capturing variability not explained by the fixed effects.

2.1.3 Overall Affect (Positive - Negative)

The percentage of positive intervals in a session was subtracted by the percentage of negative intervals to obtain their overall affect during the session.

```r
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
```

14

```
## -- Column specification -----------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
bmodel <- brm(Affect_Overall ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling
```

```
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.7e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.27 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.236 seconds (Warm-up)
## Chain 1:                0.127 seconds (Sampling)
## Chain 1:                0.363 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 9e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
```

```
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.233 seconds (Warm-up)
## Chain 2:                0.159 seconds (Sampling)
## Chain 2:                0.392 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 8e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.256 seconds (Warm-up)
## Chain 3:                0.113 seconds (Sampling)
## Chain 3:                0.369 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
```

```
## Chain 4:
## Chain 4:  Elapsed Time: 0.237 seconds (Warm-up)
## Chain 4:                 0.11 seconds (Sampling)
## Chain 4:                 0.347 seconds (Total)
## Chain 4:
```

```
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Affect_Overall ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.09      0.05     0.04     0.21 1.00     1055     1306
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.03      0.10    -0.17     0.23 1.00     1653     1772
## Condition         0.10      0.06    -0.01     0.20 1.00     1751     2130
## time              0.01      0.03    -0.05     0.08 1.01     1590     2071
## Condition:time   -0.02      0.02    -0.06     0.02 1.01     1595     2050
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.08      0.01     0.06     0.10 1.00     2425     2614
##
## 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(bmodel)
```
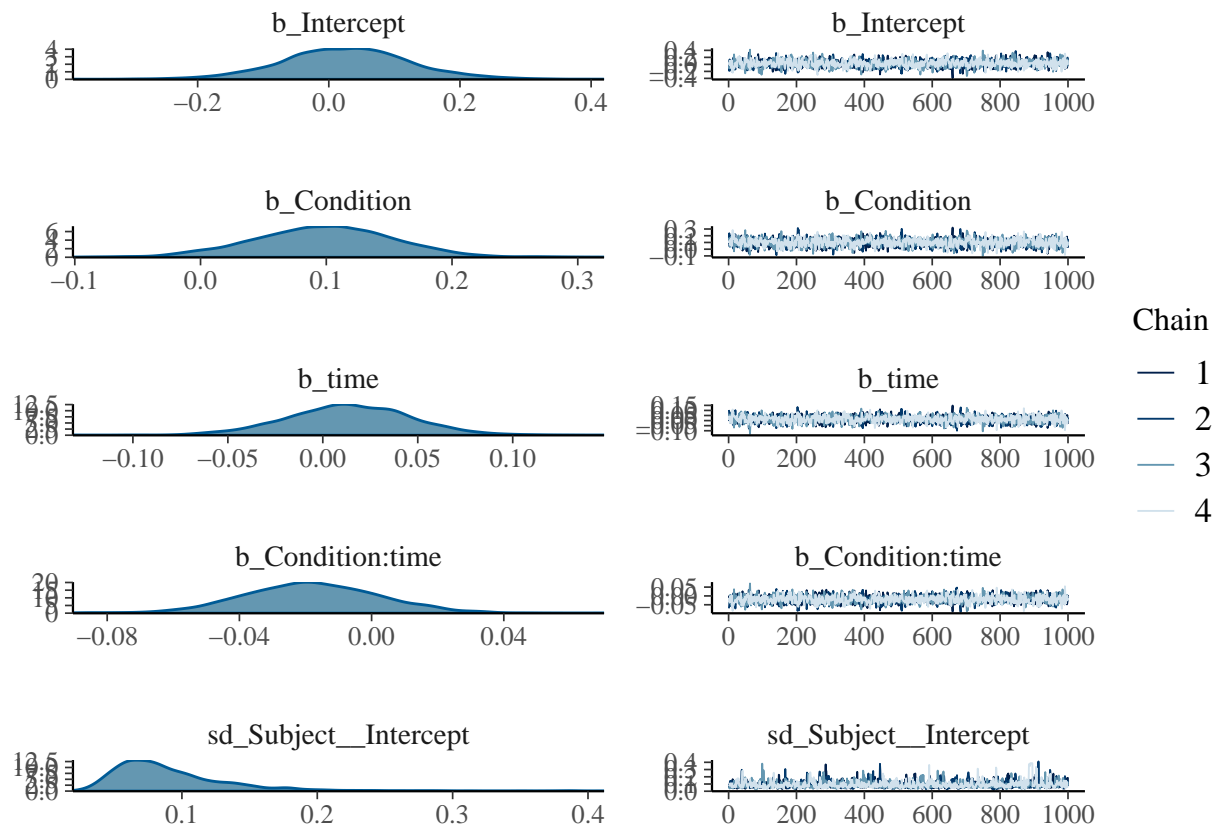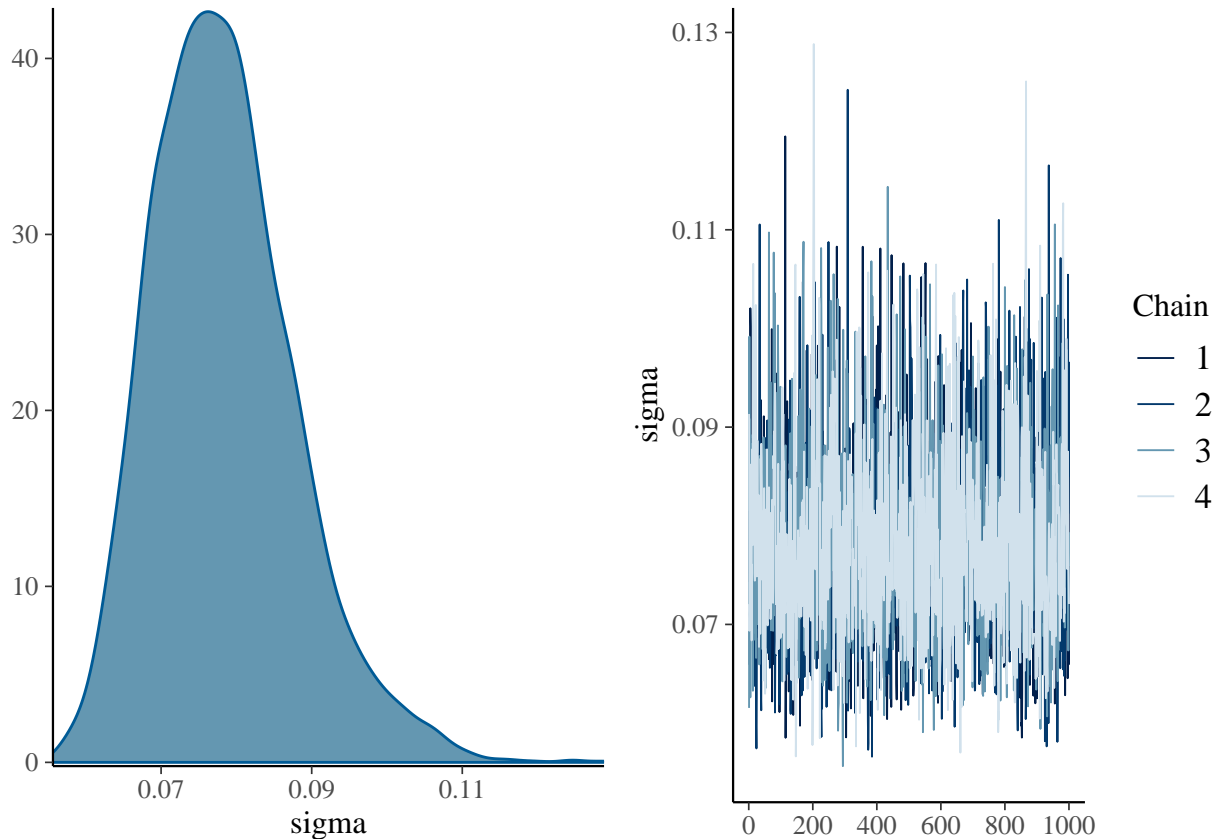
Reporting Overall Affect

Examining the overall affect, our Bayesian analysis considered the impact of instructional conditions (human vs. robot instructors) and time across four sessions (sessions 1, 4, 7, and 10) in a longitudinal study conducted over six months. The standard deviation of intercepts across subjects is estimated at 0.09 (95% CI: 0.04, 0.22), indicating variability in baseline overall affect among individuals. At the population level, the intercept is estimated at 0.02 (95% CI: -0.17, 0.21), representing the expected overall affect when both Condition and time are zero. The effect size for Condition (0.10, 95% CI: -0.01, 0.21) suggests a moderate increase in overall affect with robot instructors compared to human instructors. The effect of time (0.01, 95% CI: -0.05, 0.08) indicates a slight linear trend in overall affect over sessions. The interaction effect Condition:time (-0.02, 95% CI: -0.06, 0.02) suggests a slight decrease in the rate of change in overall affect for robot instructors compared to human instructors. The estimated standard deviation of the residuals (sigma) is 0.08 (95% CI: 0.06, 0.10), representing unexplained variability not captured by the fixed effects.

2.1.4 Neutral Affect

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ------------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
```

```
##
## i Use 'spec()' to retrieve the full column specification for this data.
## i Specify the column types or set 'show_col_types = FALSE' to quiet this message.
```

```
bmodel <- brm(Affect_Neutral ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.9e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.29 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.211 seconds (Warm-up)
## Chain 1:                0.11 seconds (Sampling)
## Chain 1:                0.321 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 8e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
```

```
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.255 seconds (Warm-up)
## Chain 2:                0.105 seconds (Sampling)
## Chain 2:                0.36 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 8e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.235 seconds (Warm-up)
## Chain 3:                0.127 seconds (Sampling)
## Chain 3:                0.362 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.279 seconds (Warm-up)
## Chain 4:                0.116 seconds (Sampling)
```

```
## Chain 4:                    0.395 seconds (Total)
## Chain 4:
```

```r
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Affect_Neutral ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.08      0.04     0.03     0.18 1.00     1130     1641
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.95      0.09     0.77     1.13 1.00     1625     2279
## Condition         -0.09      0.05    -0.19     0.01 1.00     2012     2381
## time              -0.01      0.03    -0.07     0.05 1.00     1902     2241
## Condition:time     0.01      0.02    -0.02     0.05 1.00     1912     2173
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.07      0.01     0.06     0.09 1.00     2512     2410
##
## 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
plot(bmodel)
```
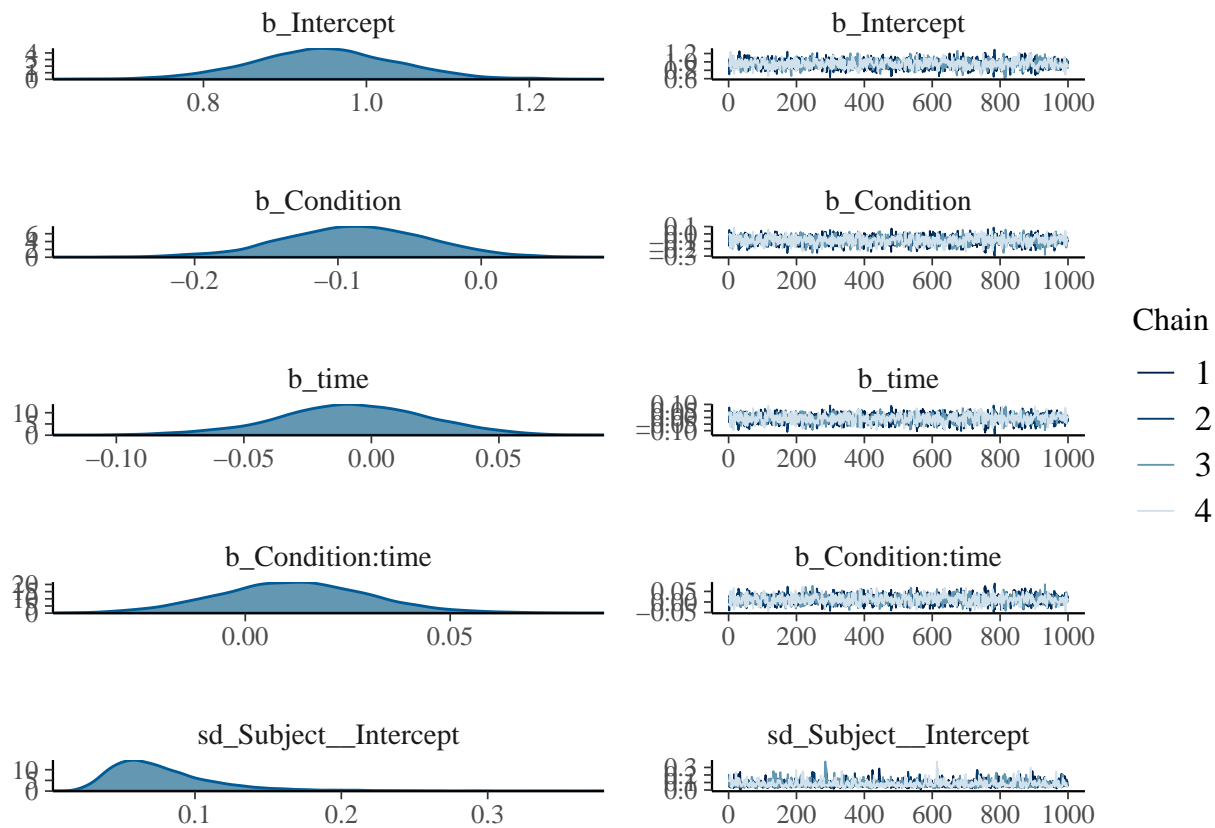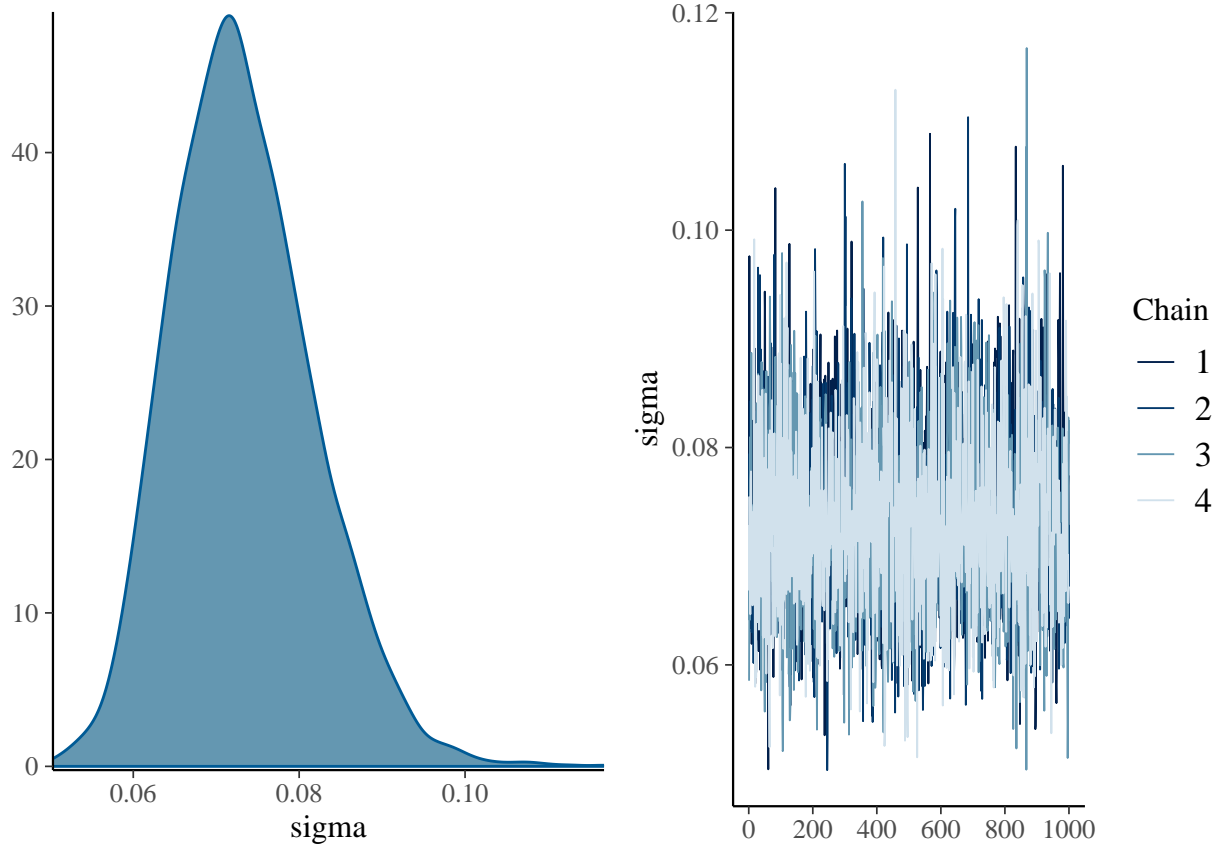
2.1.4.1 Reporting Neutral Affect Our Bayesian analysis of Neutral Affect explores the emotional responses of children across sessions involving human (Condition 1) versus robot instructors (Condition 2). These sessions are crucial, representing sessions 1, 4, 7, and 10, reflecting a longitudinal study spanning six months. The estimated standard deviation of intercepts across subjects is 0.08 (95% CI: 0.03, 0.20), indicative of some variability in baseline levels of Neutral Affect among individuals. Delving into population-level effects, the intercept is estimated at 0.95 (95% CI: 0.78, 1.13), representing the expected value of Neutral Affect when both Condition and time are zero. Noteworthy negative effect sizes were observed for Condition (-0.09, 95% CI: -0.19, 0.01), suggesting a decrease in Neutral Affect during sessions with robot instructors compared to human instructors. However, the effect size is not statistically significant, as the 95% CI encompasses zero. Additionally, time exhibited a slight negative effect (-0.01, 95% CI: -0.07, 0.05), suggesting a subtle decline in Neutral Affect over the sessions. The interaction effect, represented by Condition:time, showed a marginal increase in the effect of Condition over time (0.01, 95% CI: -0.02, 0.05). The estimated standard deviation of the residuals (sigma) was 0.07 (95% CI: 0.06, 0.09), capturing variability not explained by the fixed effects.

2.2 Communication

We use Bayesian Model to analyze the Communication metric.For all analyses condition 1 indicates the human instructor while condition 2 indicates the robot instructor.

2.2.1 Communication with Instructor

```r
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ---------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
bmodel <- brm(Communication_with_Instructor ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling
```

```
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.8e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.28 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.305 seconds (Warm-up)
## Chain 1:                0.122 seconds (Sampling)
## Chain 1:                0.427 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 8e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
```

```
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.325 seconds (Warm-up)
## Chain 2:                0.112 seconds (Sampling)
## Chain 2:                0.437 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 8e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.3 seconds (Warm-up)
## Chain 3:                0.123 seconds (Sampling)
## Chain 3:                0.423 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 8e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
```

```
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.287 seconds (Warm-up)
## Chain 4:                0.114 seconds (Sampling)
## Chain 4:                0.401 seconds (Total)
## Chain 4:


## Warning: There were 4 divergent transitions after warmup. See
## https://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
## to find out why this is a problem and how to eliminate them.


## Warning: Examine the pairs() plot to diagnose sampling problems


## Warning: Tail Effective Samples Size (ESS) is too low, indicating posterior variances and tail quant:
## Running the chains for more iterations may help. See
## https://mc-stan.org/misc/warnings.html#tail-ess
```

```r
summary(bmodel)
```

```
## Warning: There were 4 divergent transitions after warmup. Increasing
## adapt_delta above 0.8 may help. See
## http://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup


##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Communication_with_Instructor ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.04      0.03     0.00     0.11 1.02      400      217
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.06      0.06    -0.06     0.18 1.00     1117     1839
## Condition          0.04      0.04    -0.03     0.12 1.00     1489     1972
## time               0.03      0.02    -0.02     0.07 1.00     1615     2009
## Condition:time    -0.02      0.01    -0.05     0.01 1.00     1537     1935
##
## Family Specific Parameters:
##        Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma      0.05      0.01     0.04     0.07 1.00     2170     2685
##
```
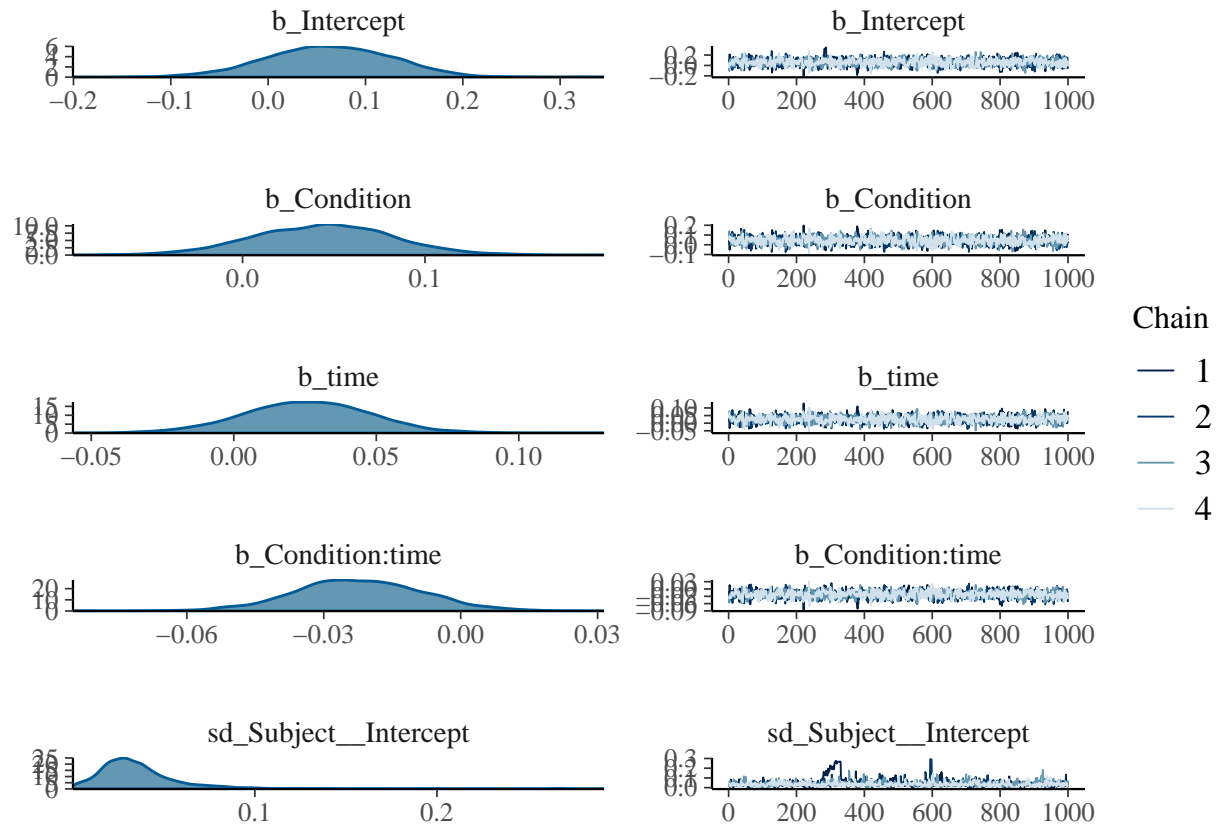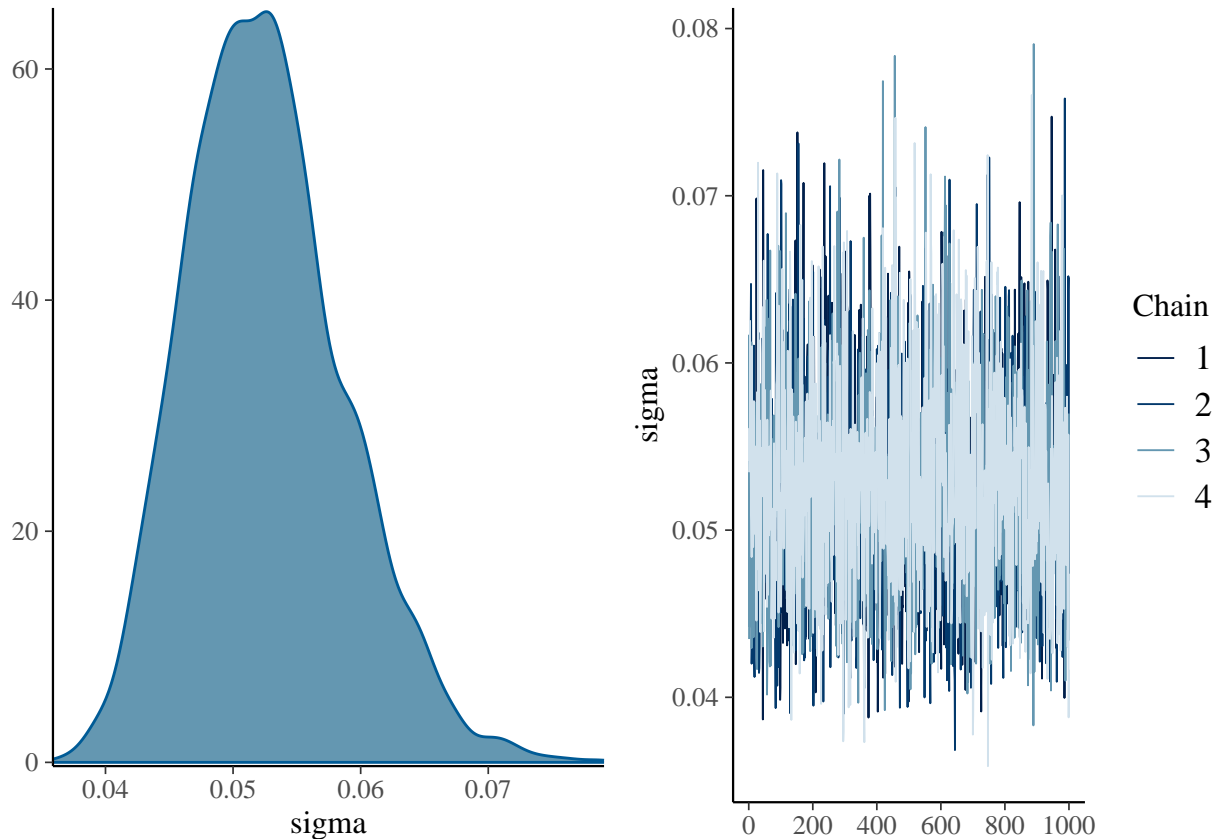
```
## Draws were sampled using sampling(NUTS). For each parameter, Bulk_ESS
## and Tail_ESS are effective sample size measures, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
```

```
plot(bmodel)
```

Reporting Communication with Instructors

Our Bayesian analysis of the 'Communication with Instructor' metric explores the dynamics of children's communication across sessions involving human (Condition 1) versus robot instructors (Condition 2). These sessions correspond to pivotal points in our longitudinal study, occurring at sessions 1, 4, 7, and 10, capturing the progression over a span of six months. The estimated standard deviation of intercepts across subjects is 0.04 (95% CI: 0.01, 0.09), indicating some variability in baseline communication levels among individuals. Examining population-level effects, the intercept is estimated at 0.06 (95% CI: -0.06, 0.18), representing the expected value of communication when both Condition and time are zero. A positive effect size for Condition (0.04, 95% CI: -0.03, 0.12) suggests a potential increase in communication during sessions with robot instructors compared to human instructors, but the effect size is not statistically significant, as the 95% CI encompasses zero. Time exhibits a positive effect (0.03, 95% CI: -0.02, 0.07), indicating a slight overall increase in communication over the sessions. The interaction effect, represented by Condition:time, shows a marginal decrease in the effect of Condition over time (-0.02, 95% CI: -0.05, 0.01). The estimated standard deviation of the residuals (sigma) is 0.05 (95% CI: 0.04, 0.07), capturing variability not accounted for by the fixed effects.

2.2.2 Prompted Communication with Instructor

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
```

```
## -- Column specification ----------------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
bmodel <- brm(Communication_with_Instructor_Prompted ~ Condition * time + (1 | Subject), data = CircleT
```

```
## Compiling Stan program...
## Start sampling
```

```
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.9e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.29 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.494 seconds (Warm-up)
## Chain 1:                0.123 seconds (Sampling)
## Chain 1:                0.617 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 8e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
```

```
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.47 seconds (Warm-up)
## Chain 2:                0.122 seconds (Sampling)
## Chain 2:                0.592 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 7e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.44 seconds (Warm-up)
## Chain 3:                0.125 seconds (Sampling)
## Chain 3:                0.565 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 7e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
```

```
## Chain 4:
## Chain 4:  Elapsed Time: 0.435 seconds (Warm-up)
## Chain 4:                 0.116 seconds (Sampling)
## Chain 4:                 0.551 seconds (Total)
## Chain 4:
```

```
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Communication_with_Instructor_Prompted ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.00      0.00     0.00     0.01 1.00     1695     2169
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.01      0.01    -0.02     0.04 1.00     2250     2204
## Condition         0.00      0.01    -0.01     0.02 1.00     2351     2163
## time              0.00      0.01    -0.01     0.01 1.00     2416     2291
## Condition:time   -0.00      0.00    -0.01     0.00 1.00     2429     2137
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.01      0.00     0.01     0.02 1.00     3781     2445
##
## 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(bmodel)
```
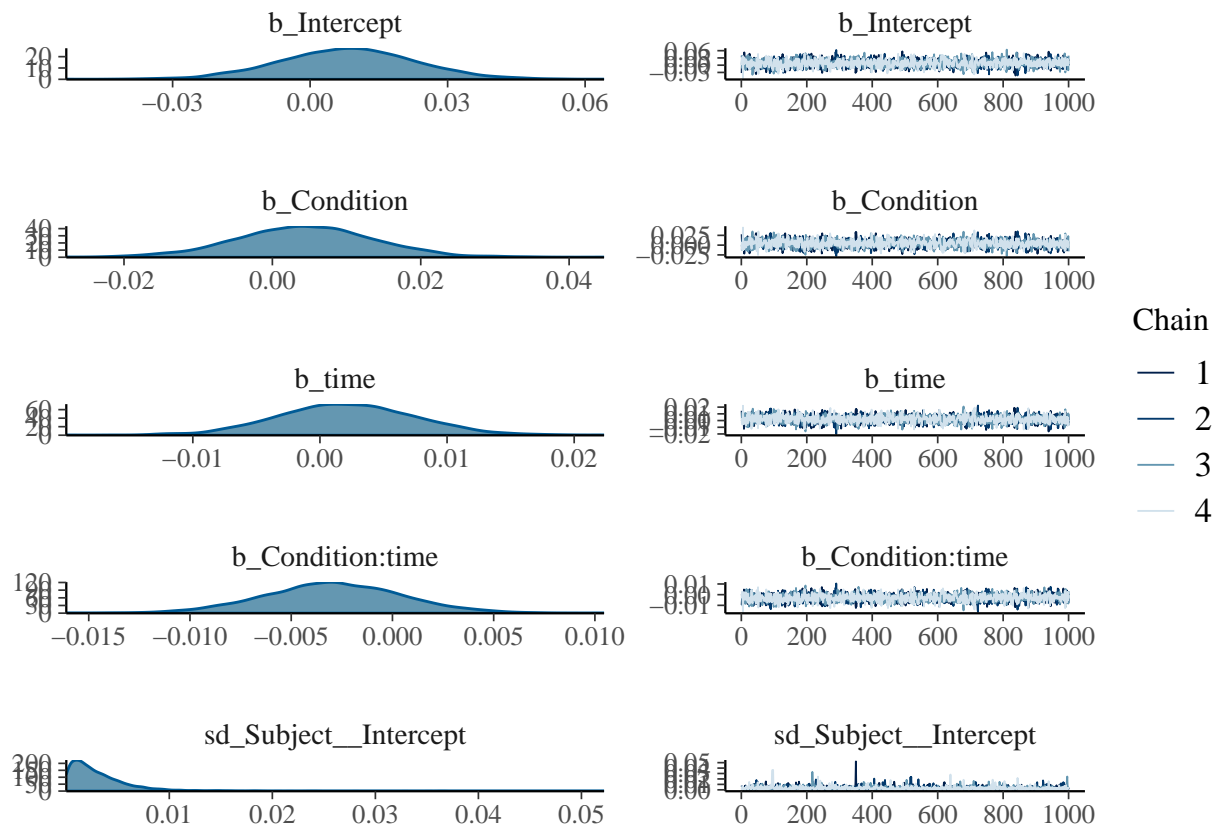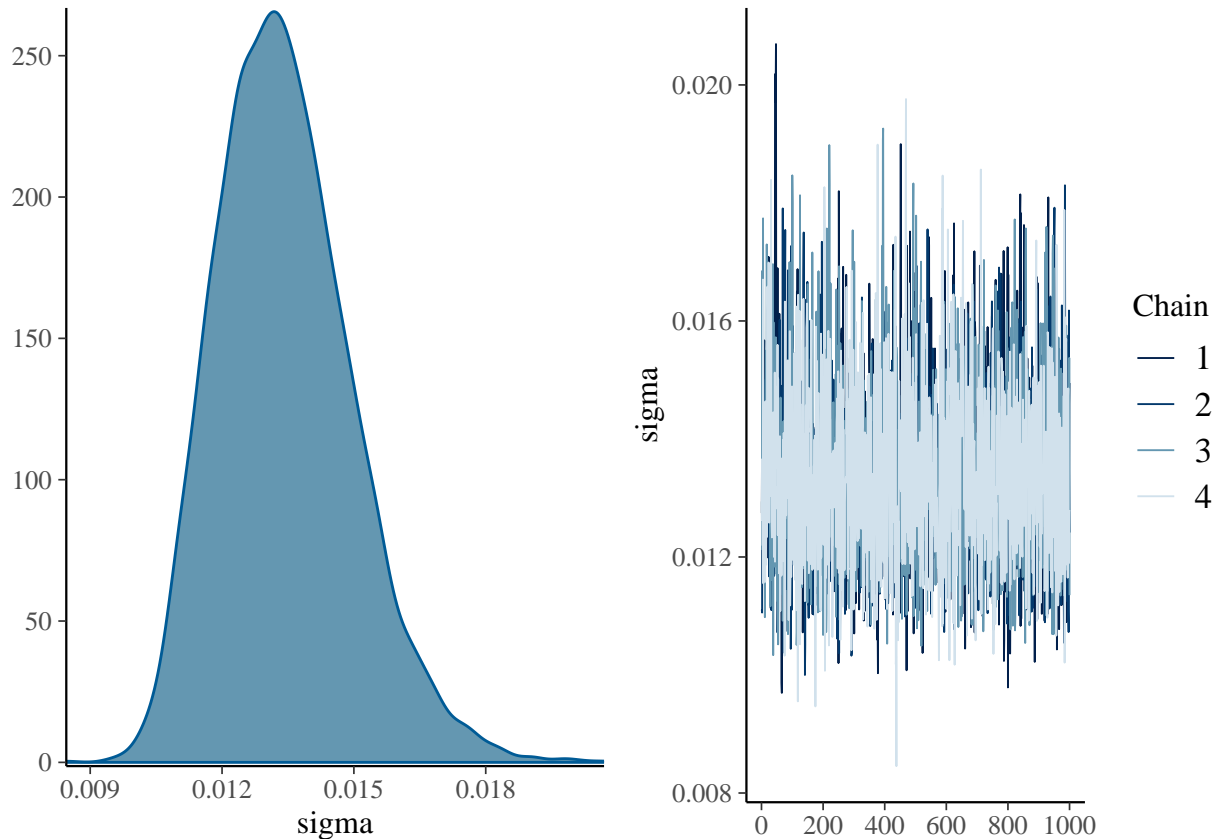
2.2.2.1 Reporting Prompted Communication with Instructor

In our Bayesian analysis of 'Prompted Communication with Instructor', the effect sizes for Condition (0.00, 95% CI: -0.01, 0.02), time (0.00, 95% CI: -0.01, 0.01), and the interaction effect Condition:time (-0.00, 95% CI: -0.01, 0.00) are all negligible, with 95% CIs spanning zero. The estimated standard deviation of the residuals (sigma) is 0.01 (95% CI: 0.01, 0.02), capturing variability not accounted for by the fixed effects. Convergence was achieved despite three divergent transitions after warmup, enhancing the robustness of our Bayesian analysis.

2.2.3 Communication with Behavioral Therapist

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ------------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
bmodel <- brm(Communication_with_Therapist ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.7e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.27 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.309 seconds (Warm-up)
## Chain 1:                0.106 seconds (Sampling)
## Chain 1:                0.415 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 1e-05 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.1 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.339 seconds (Warm-up)
## Chain 2:                0.092 seconds (Sampling)
```

```
## Chain 2:                     0.431 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.314 seconds (Warm-up)
## Chain 3:                0.132 seconds (Sampling)
## Chain 3:                0.446 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.355 seconds (Warm-up)
## Chain 4:                0.105 seconds (Sampling)
## Chain 4:                0.46 seconds (Total)
## Chain 4:


## Warning: There were 1 divergent transitions after warmup. See
```

```
## https://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
## to find out why this is a problem and how to eliminate them.
```

```
## Warning: Examine the pairs() plot to diagnose sampling problems
```

```r
summary(bmodel)
```

```
## Warning: There were 1 divergent transitions after warmup. Increasing
## adapt_delta above 0.8 may help. See
## http://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Communication_with_Therapist ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##         total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.02      0.02     0.00     0.08 1.00      868     1378
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.16      0.07     0.03     0.29 1.00     1805     2153
## Condition         -0.02      0.04    -0.10     0.06 1.00     1870     2004
## time              -0.03      0.02    -0.08     0.01 1.00     1835     1994
## Condition:time     0.01      0.01    -0.02     0.04 1.00     1816     1851
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.06      0.01     0.05     0.07 1.00     2960     2554
##
## 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).
```
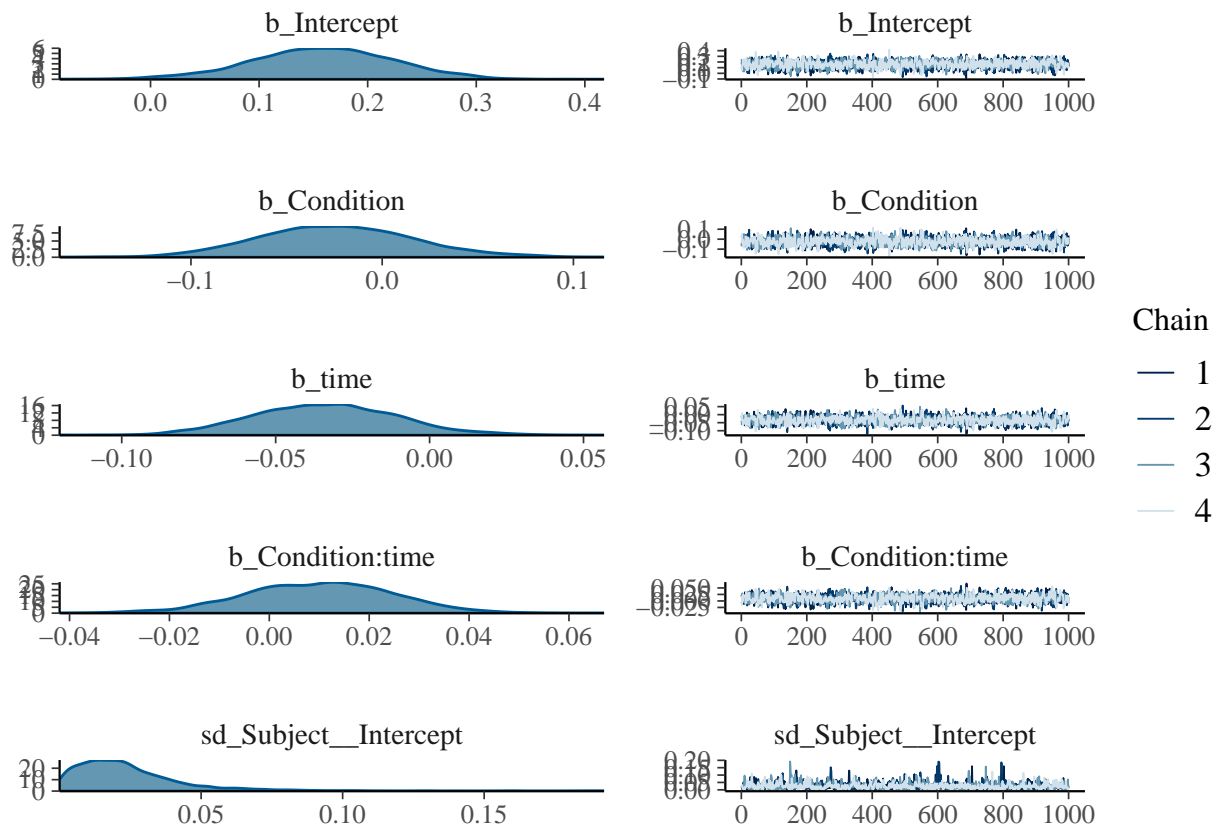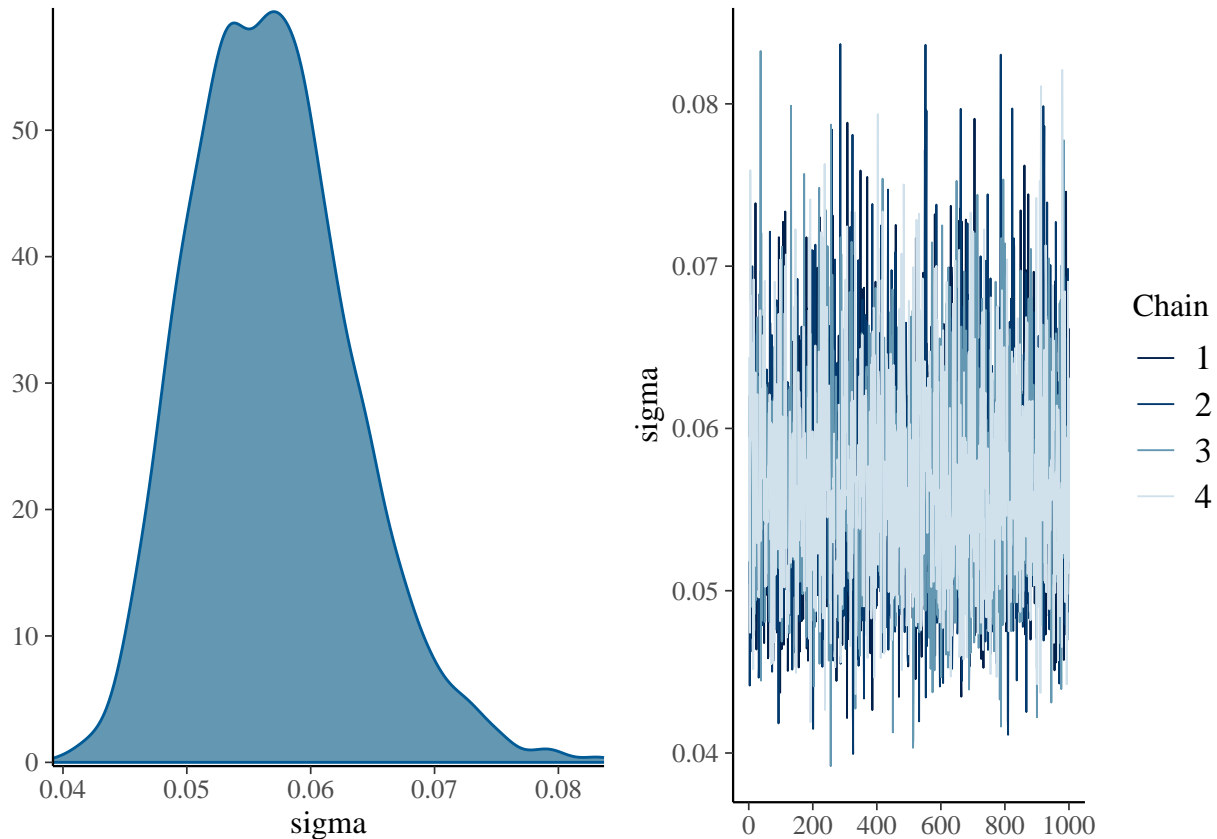
```r
plot(bmodel)
```

b_Intercept

b_Condition

b_time

b_Condition:time

sd_Subject__Intercept

Chain
— 1
— 2
— 3
— 4

2.2.3.1 Reporting Communication with Behavioral Therapist In our Bayesian analysis of 'Communication with Behavioral Therapist', the effect sizes for Condition (-0.02, 95% CI: -0.10, 0.05), time (-0.03, 95% CI: -0.08, 0.01), and the interaction effect Condition:time (0.01, 95% CI: -0.02, 0.04) are all relatively small, with 95% CIs spanning zero. The estimated standard deviation of the residuals (sigma) is 0.06 (95% CI: 0.05, 0.07), capturing variability not accounted for by the fixed effects. Our Bayesian analysis demonstrates convergence despite potential challenges, providing valuable insights into the intricate dynamics of children's communication with a behavioral therapist over the course of the longitudinal study.

2.2.4 Communication with Indeterminent

```r
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification --------------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use 'spec()' to retrieve the full column specification for this data.
## i Specify the column types or set 'show_col_types = FALSE' to quiet this message.
```

```r
bmodel <- brm(Communication_with_Indeterminent ~ Condition * time + (1 | Subject), data = CircleTimeData
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.9e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.29 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.355 seconds (Warm-up)
## Chain 1:                0.094 seconds (Sampling)
## Chain 1:                0.449 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 6e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.06 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.386 seconds (Warm-up)
## Chain 2:                0.114 seconds (Sampling)
```

```
## Chain 2:                    0.5 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 8e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.416 seconds (Warm-up)
## Chain 3:                0.128 seconds (Sampling)
## Chain 3:                0.544 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 8e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.426 seconds (Warm-up)
## Chain 4:                0.122 seconds (Sampling)
## Chain 4:                0.548 seconds (Total)
## Chain 4:
```

```r
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Communication_with_Indeterminent ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.01      0.01     0.00     0.03 1.00     1593     1692
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.06      0.05    -0.04     0.16 1.00     2279     2500
## Condition         0.01      0.03    -0.05     0.07 1.00     2262     2351
## time             -0.02      0.02    -0.06     0.01 1.00     2259     2540
## Condition:time    0.00      0.01    -0.02     0.03 1.00     2240     2362
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.04      0.01     0.04     0.06 1.00     3800     2614
##
## 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
plot(bmodel)
```
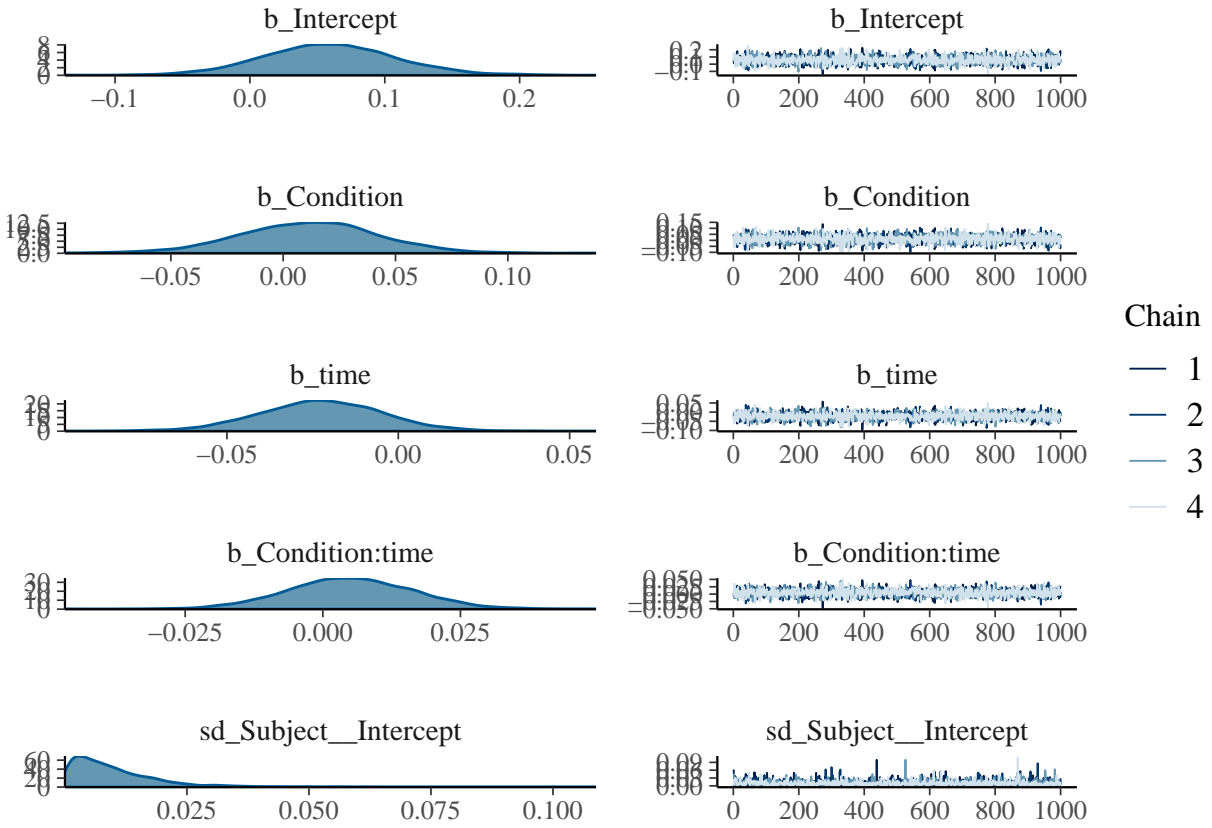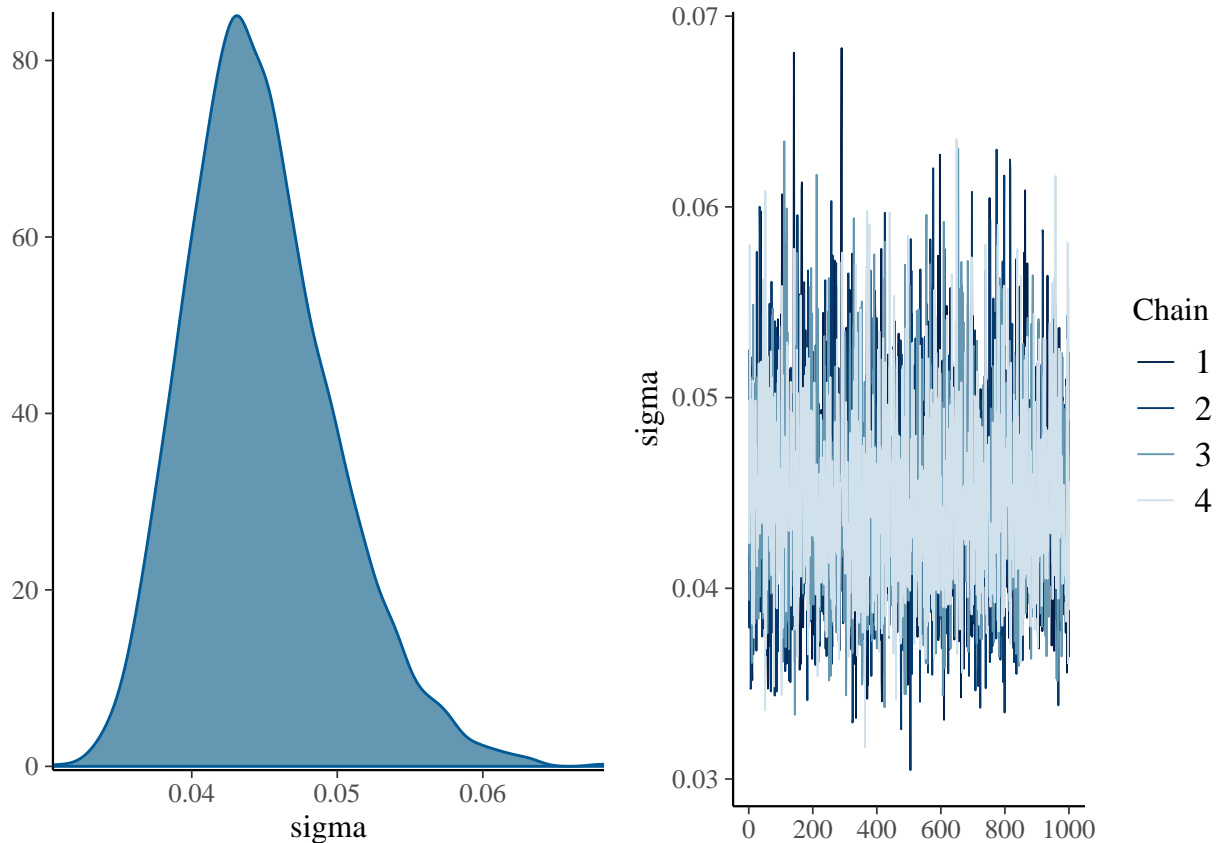
2.2.4.1 Reporting Communication with Indeterminent The effect sizes for Condition (0.01, 95% CI: -0.05, 0.07), time (-0.02, 95% CI: -0.06, 0.01), and the interaction effect Condition:time (0.01, 95% CI: -0.02, 0.03) are all modest, with 95% CIs encompassing zero. The estimated standard deviation of the residuals (sigma) is 0.04 (95% CI: 0.04, 0.06), capturing variability not explained by the fixed effects. Despite potential challenges, our Bayesian analysis demonstrates convergence, offering valuable insights into the intricate dynamics of children's communication with an indeterminate entity over the course of the longitudinal study.

2.3 Engagement

We use Bayesian Model to analyze the Engagement metric.For all analyses condition 1 indicates the human instructor while condition 2 indicates the robot instructor.

2.3.1 On-Target Engagement

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")


## Rows: 48 Columns: 16
## -- Column specification ------------------------------------------------
```

```
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use 'spec()' to retrieve the full column specification for this data.
## i Specify the column types or set 'show_col_types = FALSE' to quiet this message.
```

```
bmodel <- brm(Engagement_OnTarget ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 4e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.4 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.295 seconds (Warm-up)
## Chain 1:                0.113 seconds (Sampling)
## Chain 1:                0.408 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 9e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
```

```
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.31 seconds (Warm-up)
## Chain 2:                0.098 seconds (Sampling)
## Chain 2:                0.408 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.315 seconds (Warm-up)
## Chain 3:                0.111 seconds (Sampling)
## Chain 3:                0.426 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
```

```
## Chain 4:   Elapsed Time: 0.295 seconds (Warm-up)
## Chain 4:                 0.112 seconds (Sampling)
## Chain 4:                 0.407 seconds (Total)
## Chain 4:
```

```
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Engagement_OnTarget ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.02      0.02     0.00     0.07 1.00     1567     2074
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.67      0.09     0.49     0.85 1.00     2009     2417
## Condition         0.06      0.06    -0.06     0.17 1.00     1973     2205
## time              0.04      0.03    -0.02     0.11 1.00     1941     2172
## Condition:time   -0.02      0.02    -0.06     0.02 1.00     1858     2141
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.08      0.01     0.07     0.10 1.00     3276     3043
##
## 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(bmodel)
```
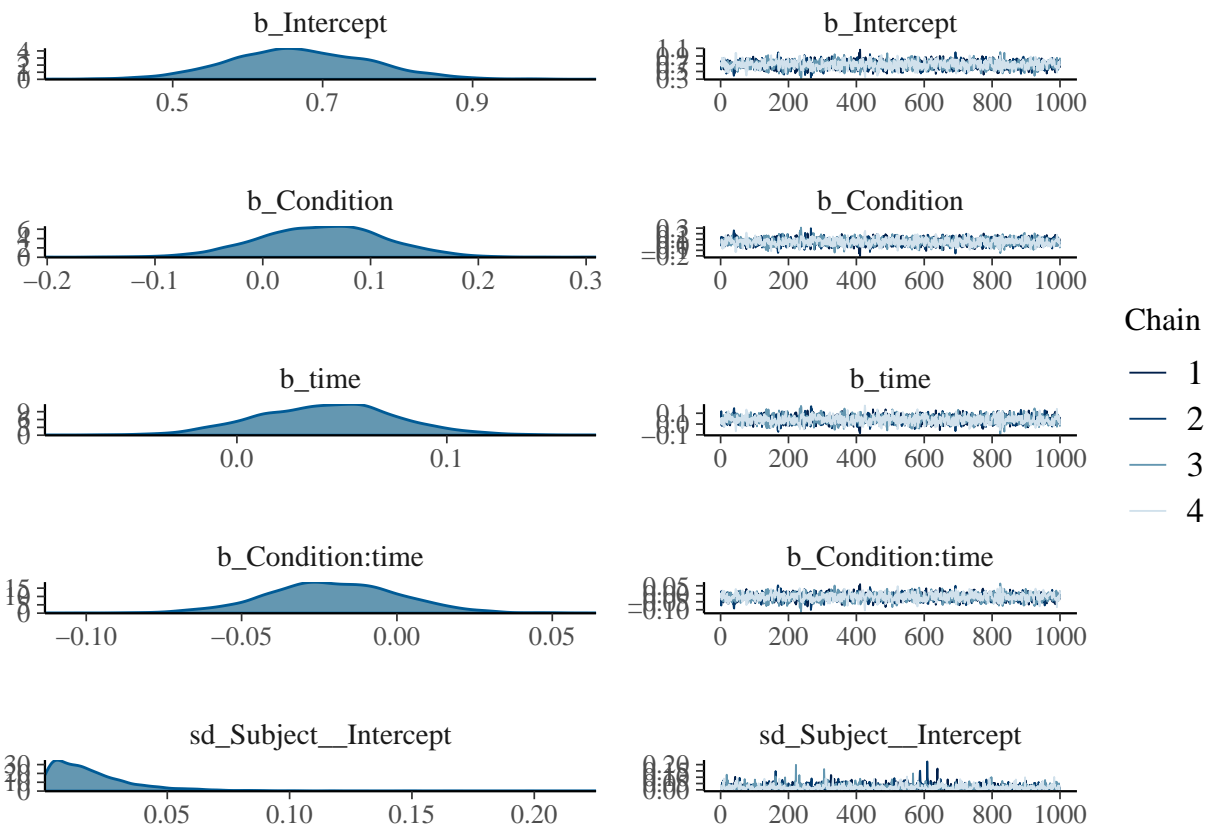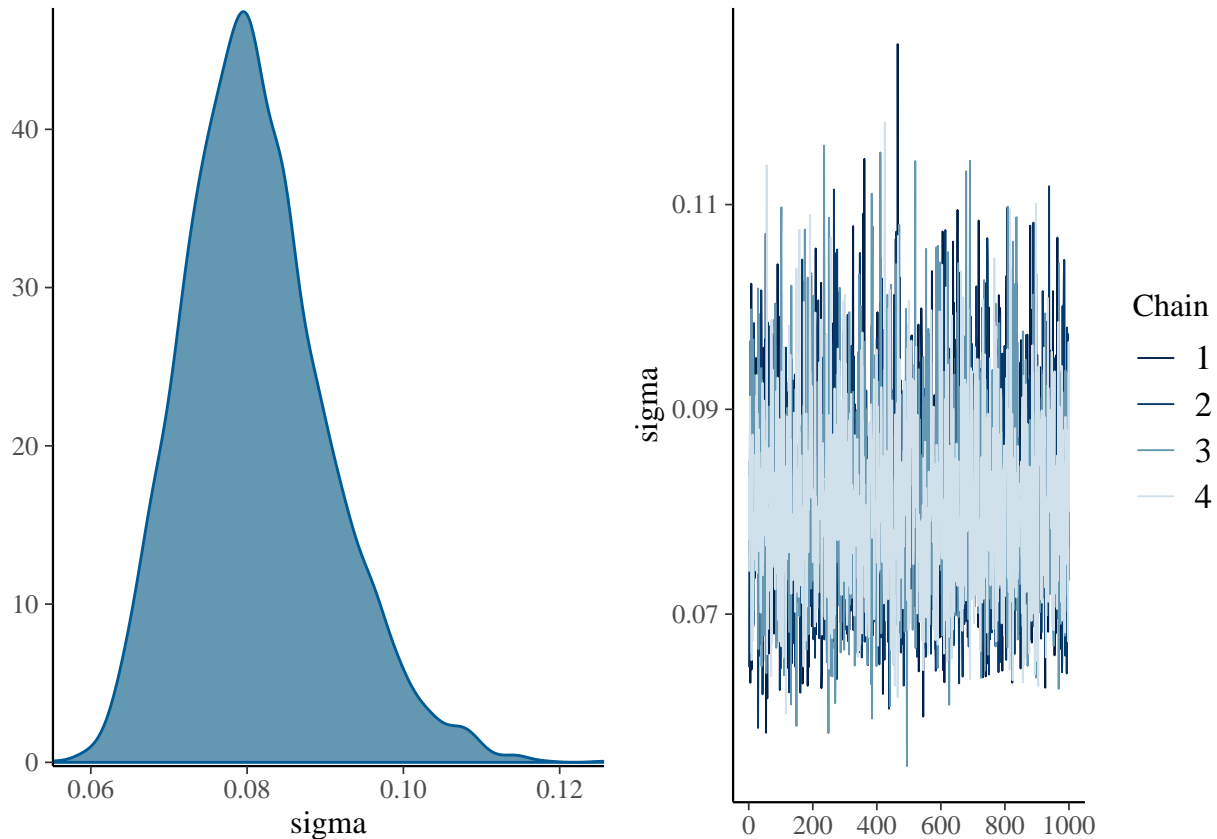
2.3.1.1 Reporting On-Target Engagement The effect size for Condition (0.06, 95% CI: -0.06, 0.18) is modest, indicating a slight difference in engagement with on-target between conditions. The effect of time (0.04, 95% CI: -0.02, 0.11) suggests a positive trend in engagement with on-target over sessions. The interaction effect Condition:time (-0.02, 95% CI: -0.07, 0.02) is subtle, with a 95% CI encompassing zero. The estimated standard deviation of the residuals (sigma) is 0.08 (95% CI: 0.07, 0.10), capturing variability not explained by the fixed effects. Our Bayesian analysis demonstrates convergence, providing valuable insights into the nuanced patterns of children's engagement with on-target behaviors over the course of the longitudinal study.

2.3.2 Engagement with Behavioral Therapist

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ------------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
bmodel <- brm(Engagement_Therapist ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.9e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.29 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.365 seconds (Warm-up)
## Chain 1:                0.125 seconds (Sampling)
## Chain 1:                0.49 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 7e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.42 seconds (Warm-up)
## Chain 2:                0.098 seconds (Sampling)
```

```
## Chain 2:                 0.518 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.419 seconds (Warm-up)
## Chain 3:                0.119 seconds (Sampling)
## Chain 3:                0.538 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.44 seconds (Warm-up)
## Chain 4:                0.128 seconds (Sampling)
## Chain 4:                0.568 seconds (Total)
## Chain 4:
```

```r
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Engagement_Therapist ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.01      0.01     0.00     0.03 1.00     1255     1752
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.05      0.03    -0.01     0.11 1.00     2281     2320
## Condition          0.01      0.02    -0.03     0.05 1.00     2211     2463
## time               0.00      0.01    -0.02     0.03 1.00     2174     2401
## Condition:time    -0.00      0.01    -0.02     0.01 1.00     2074     2230
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.03      0.00     0.02     0.04 1.00     3336     3033
##
## 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
plot(bmodel)
```
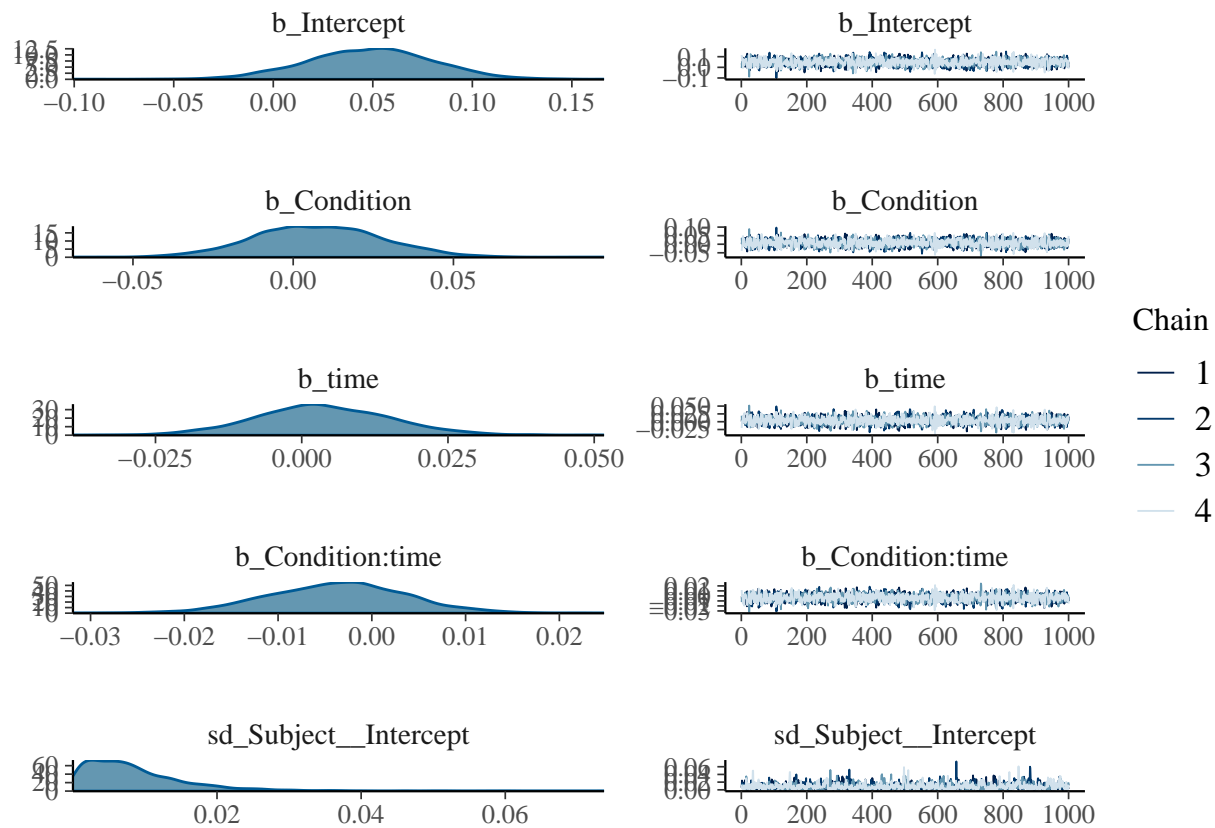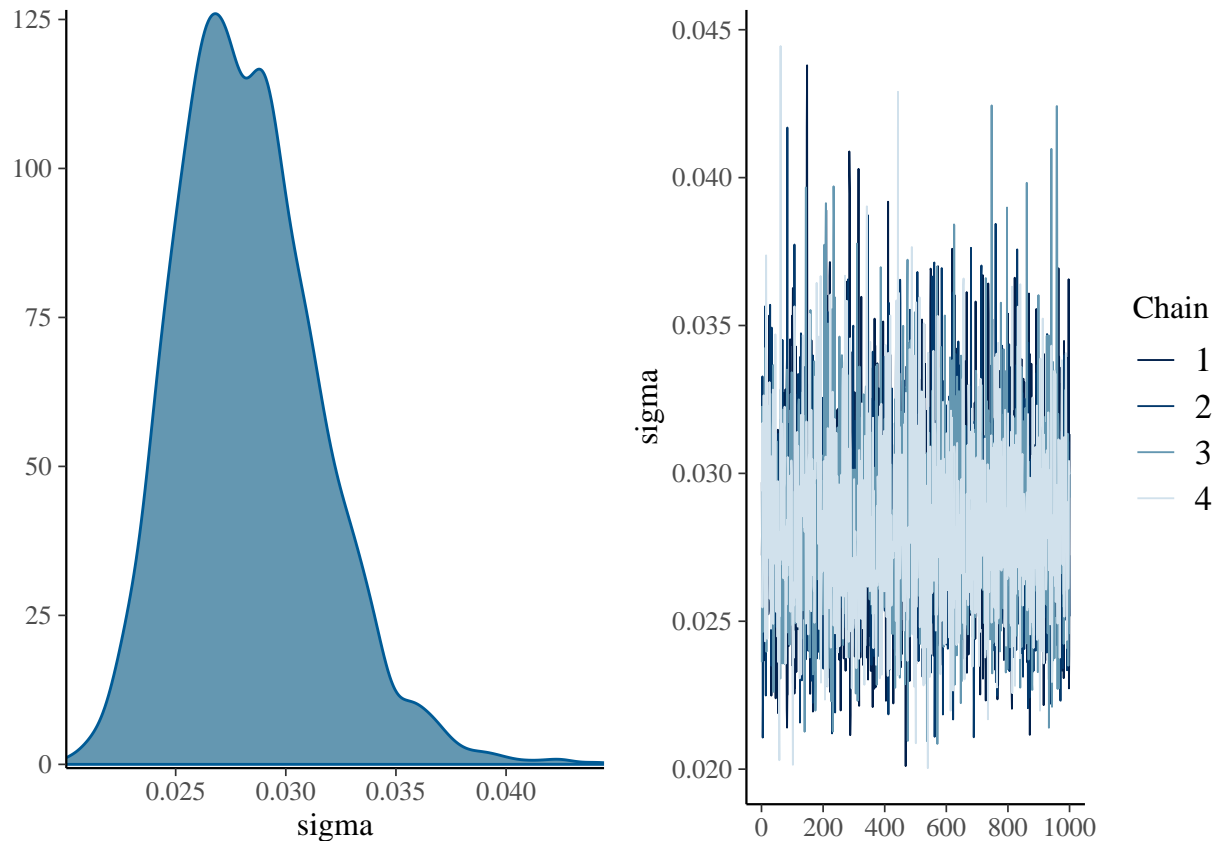
2.3.2.1 Reporting the Engagement with Behavioral Therapist

The effect size for Condition (0.01, 95% CI: -0.03, 0.05) suggests a small difference in engagement between conditions. The effect of time (0.00, 95% CI: -0.02, 0.03) indicates a subtle positive trend in engagement over sessions. The interaction effect Condition:time (-0.00, 95% CI: -0.02, 0.01) is negligible, with a 95% CI encompassing zero. The estimated standard deviation of the residuals (sigma) is 0.03 (95% CI: 0.02, 0.04), capturing variability not explained by the fixed effects. Our Bayesian analysis demonstrates convergence, providing valuable insights into the nuanced patterns of children's engagement with the behavioral therapist throughout the longitudinal study.

2.3.3 Engagement with Off-Target

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ---------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
bmodel <- brm(Engagement_OffTarget ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.8e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.28 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.27 seconds (Warm-up)
## Chain 1:                0.12 seconds (Sampling)
## Chain 1:                0.39 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 8e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.324 seconds (Warm-up)
## Chain 2:                0.116 seconds (Sampling)
```

```
## Chain 2:                   0.44 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.324 seconds (Warm-up)
## Chain 3:                0.098 seconds (Sampling)
## Chain 3:                0.422 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 8e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.287 seconds (Warm-up)
## Chain 4:                0.116 seconds (Sampling)
## Chain 4:                0.403 seconds (Total)
## Chain 4:
```

```r
summary(bmodel)
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Engagement_OffTarget ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.02      0.02     0.00     0.07 1.00     1368     1621
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.28      0.08     0.13     0.43 1.00     1818     2353
## Condition         -0.06      0.05    -0.16     0.03 1.00     1800     2267
## time              -0.05      0.03    -0.10     0.01 1.00     1784     2038
## Condition:time     0.02      0.02    -0.01     0.06 1.00     1851     2099
##
## Family Specific Parameters:
##        Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma      0.07      0.01     0.06     0.09 1.00     3058     2854
##
## 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
plot(bmodel)
```
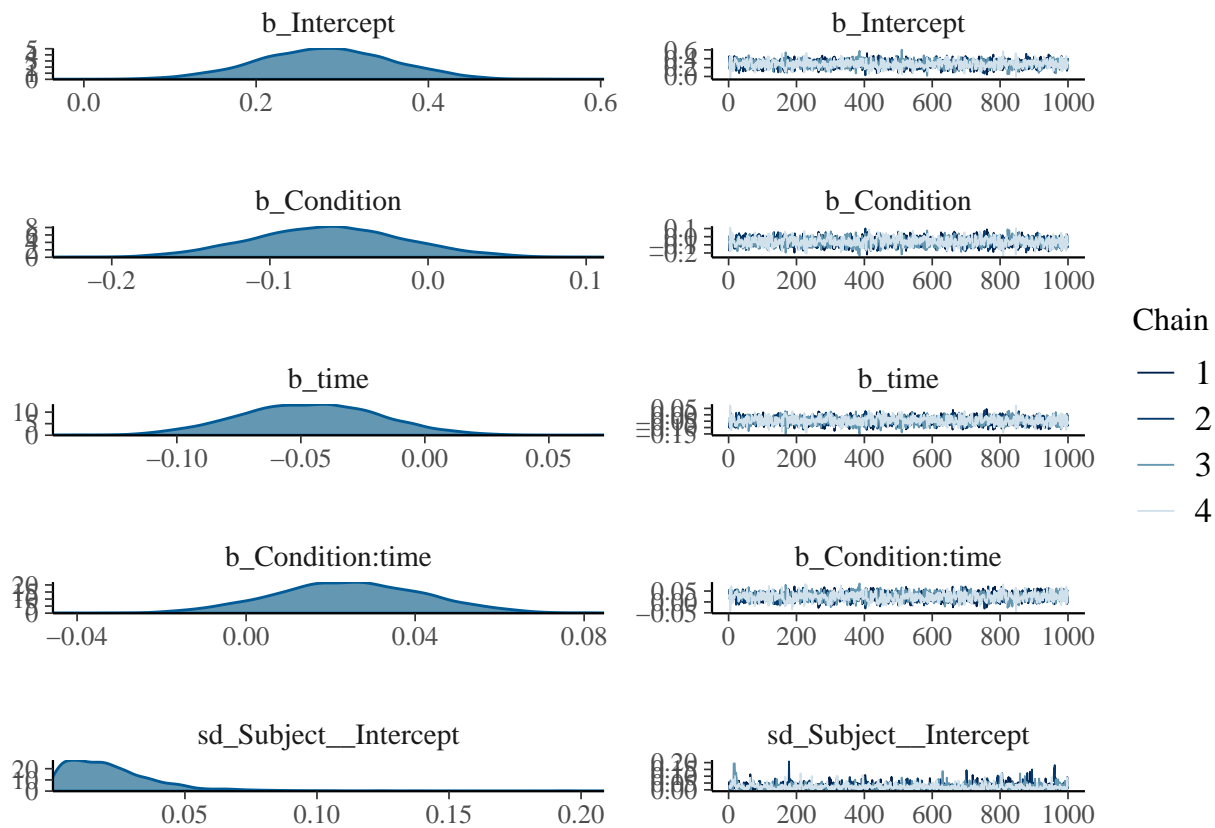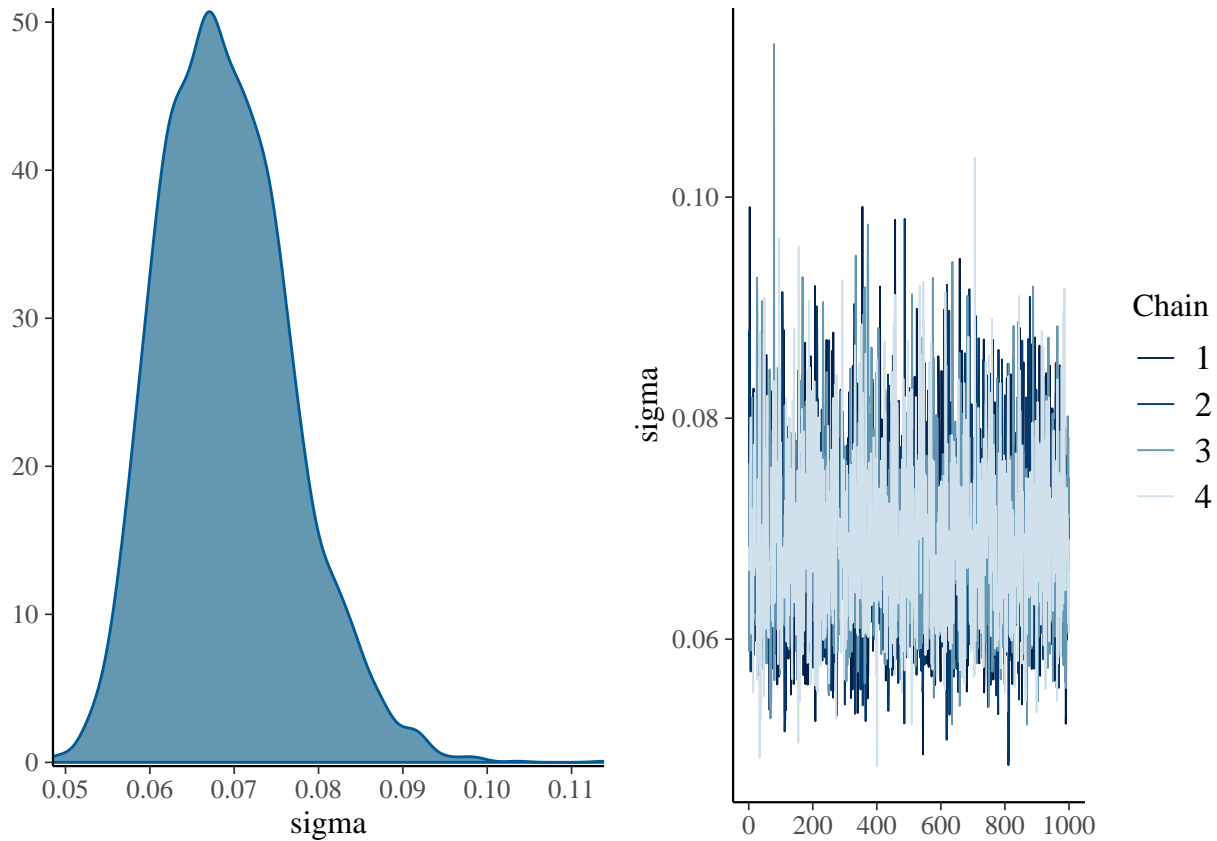
2.3.3.1 Reporting the Engagement with Off-Target The effect size for Condition (-0.06, 95% CI: -0.16, 0.04) indicates a moderate decrease in off-target engagement with robot instructors compared to human instructors. The effect of time (-0.05, 95% CI: -0.10, 0.01) suggests a decreasing trend in off-target engagement over sessions. The interaction effect Condition:time (0.02, 95% CI: -0.01, 0.06) indicates a slight increase in the rate of decrease for robot instructors compared to human instructors. The estimated standard deviation of the residuals (sigma) is 0.07 (95% CI: 0.06, 0.09), capturing variability not explained by the fixed effects. Our Bayesian analysis demonstrates convergence, providing valuable insights into the nuanced patterns of children's engagement with off-target behaviors throughout the longitudinal study.

2.4 Performance

We use Bayesian Model to analyze the Performance metric.For all analyses condition 1 indicates the human instructor while condition 2 indicates the robot instructor.

2.4.1 Positive Performance

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
```

```
## -- Column specification ---------------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```r
bmodel <- brm(Performance_Positive ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.7e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.27 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.237 seconds (Warm-up)
## Chain 1:                0.179 seconds (Sampling)
## Chain 1:                0.416 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 7e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
```

```
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.231 seconds (Warm-up)
## Chain 2:                0.231 seconds (Sampling)
## Chain 2:                0.462 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 9e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.271 seconds (Warm-up)
## Chain 3:                0.176 seconds (Sampling)
## Chain 3:                0.447 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 7e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
```

```
## Chain 4:
## Chain 4:   Elapsed Time: 0.231 seconds (Warm-up)
## Chain 4:                 0.188 seconds (Sampling)
## Chain 4:                 0.419 seconds (Total)
## Chain 4:
```

```
## Warning: There were 4 divergent transitions after warmup. See
## https://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
## to find out why this is a problem and how to eliminate them.
```

```
## Warning: Examine the pairs() plot to diagnose sampling problems
```

```
summary(bmodel)
```

```
## Warning: There were 4 divergent transitions after warmup. Increasing
## adapt_delta above 0.8 may help. See
## http://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
```

```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Performance_Positive ~ Condition * time + (1 | Subject)
##    Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##          total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.24      0.11     0.11     0.55 1.00      941     1491
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.88      0.15     0.57     1.18 1.00     1512     1930
## Condition         -0.08      0.07    -0.22     0.06 1.00     1727     1963
## time               0.00      0.04    -0.08     0.09 1.00     1683     1894
## Condition:time     0.01      0.03    -0.05     0.06 1.00     1646     1731
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.10      0.01     0.08     0.13 1.00     2185     1987
##
## 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).
```
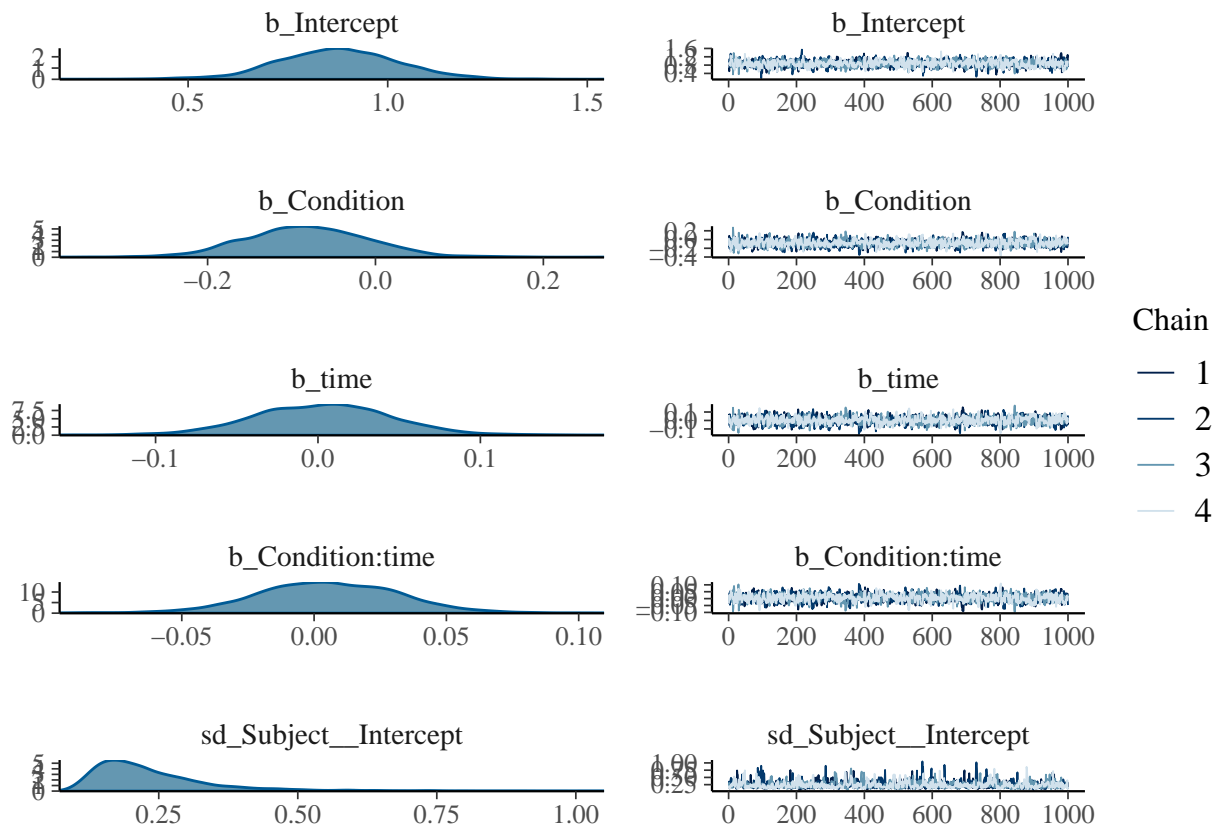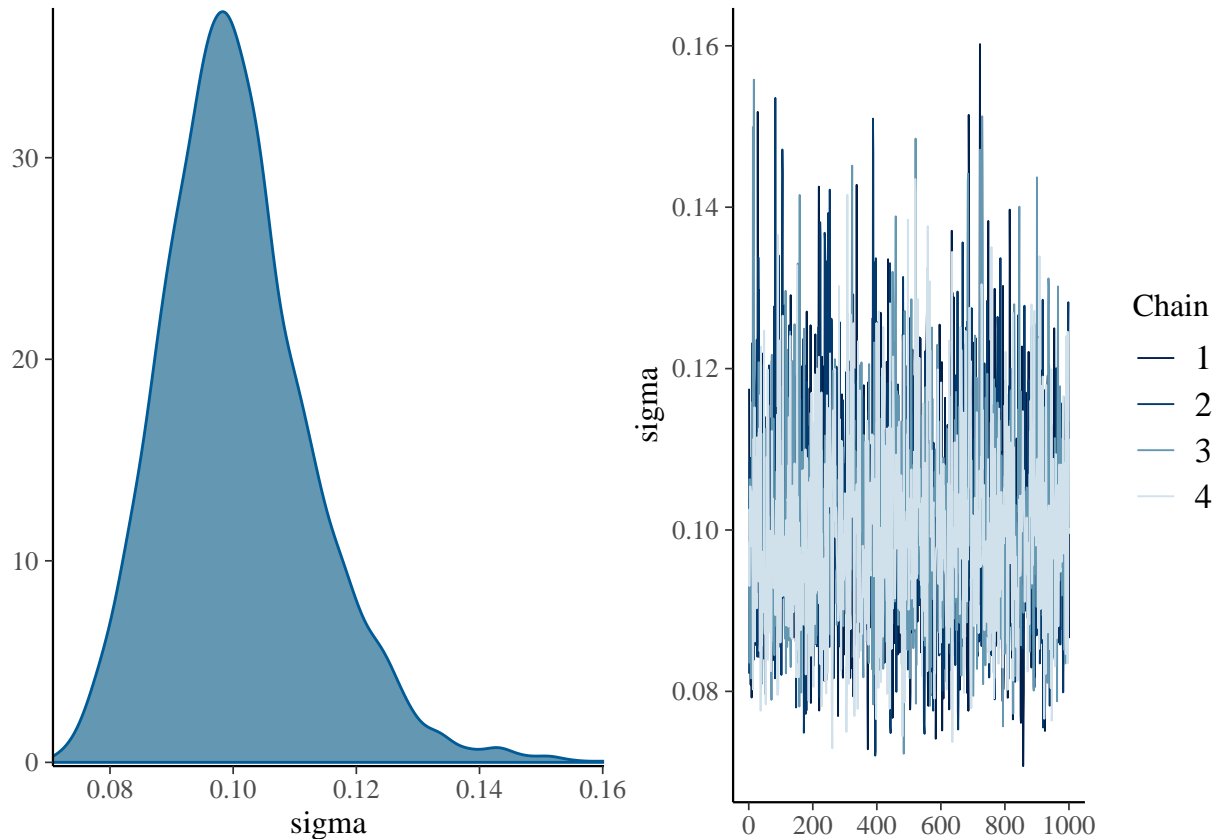
```
plot(bmodel)
```

b_Intercept   b_Intercept

b_Condition   b_Condition

b_time   b_time

b_Condition:time   b_Condition:time

sd_Subject__Intercept   sd_Subject__Intercept

Chain

— 1

— 2

— 3

— 4

2.4.1.1 Reporting the Positive Performance   The effect size for Condition (-0.08, 95% CI: -0.22, 0.06) suggests a moderate decrease in positive performance with robot instructors compared to human instructors. The effect of time (0.00, 95% CI: -0.08, 0.09) indicates no significant linear trend in positive performance over sessions. The interaction effect Condition:time (0.01, 95% CI: -0.05, 0.06) suggests a slight increase in the rate of positive performance for robot instructors compared to human instructors. The estimated standard deviation of the residuals (sigma) is 0.10 (95% CI: 0.08, 0.13), capturing variability not explained by the fixed effects. Our Bayesian analysis demonstrates convergence, providing nuanced insights into the dynamics of positive performance across sessions and instructional conditions.

2.4.2 Negative Performance

```
library(readr)
library(brms)

CircleTimeData <- read_csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData.csv")
```

```
## Rows: 48 Columns: 16
## -- Column specification ---------------------------------------------------
## Delimiter: ","
## dbl (16): Subject, Condition, time, Affect_Positive, Affect_Negative, Affect...
##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
bmodel <- brm(Performance_Negative ~ Condition * time + (1 | Subject), data = CircleTimeData)
```

```
## Compiling Stan program...
## Start sampling


##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 1).
## Chain 1:
## Chain 1: Gradient evaluation took 2.8e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.28 seconds.
## Chain 1: Adjust your expectations accordingly!
## Chain 1:
## Chain 1:
## Chain 1: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 1: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 1: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 1: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 1: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 1: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 1: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 1: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 1: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 1: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 1: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 1: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 1:
## Chain 1:  Elapsed Time: 0.218 seconds (Warm-up)
## Chain 1:                0.141 seconds (Sampling)
## Chain 1:                0.359 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 8e-06 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 2: Adjust your expectations accordingly!
## Chain 2:
## Chain 2:
## Chain 2: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 2: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 2: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 2: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 2: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 2: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 2: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 2: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 2: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 2: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 2: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 2: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 2:
## Chain 2:  Elapsed Time: 0.235 seconds (Warm-up)
## Chain 2:                0.165 seconds (Sampling)
```

```
## Chain 2:                     0.4 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 8e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.08 seconds.
## Chain 3: Adjust your expectations accordingly!
## Chain 3:
## Chain 3:
## Chain 3: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 3: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 3: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 3: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 3: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 3: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 3: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 3: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 3: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 3: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 3: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 3: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 3:
## Chain 3:  Elapsed Time: 0.239 seconds (Warm-up)
## Chain 3:                0.099 seconds (Sampling)
## Chain 3:                0.338 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 9e-06 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.09 seconds.
## Chain 4: Adjust your expectations accordingly!
## Chain 4:
## Chain 4:
## Chain 4: Iteration:    1 / 2000 [  0%]  (Warmup)
## Chain 4: Iteration:  200 / 2000 [ 10%]  (Warmup)
## Chain 4: Iteration:  400 / 2000 [ 20%]  (Warmup)
## Chain 4: Iteration:  600 / 2000 [ 30%]  (Warmup)
## Chain 4: Iteration:  800 / 2000 [ 40%]  (Warmup)
## Chain 4: Iteration: 1000 / 2000 [ 50%]  (Warmup)
## Chain 4: Iteration: 1001 / 2000 [ 50%]  (Sampling)
## Chain 4: Iteration: 1200 / 2000 [ 60%]  (Sampling)
## Chain 4: Iteration: 1400 / 2000 [ 70%]  (Sampling)
## Chain 4: Iteration: 1600 / 2000 [ 80%]  (Sampling)
## Chain 4: Iteration: 1800 / 2000 [ 90%]  (Sampling)
## Chain 4: Iteration: 2000 / 2000 [100%]  (Sampling)
## Chain 4:
## Chain 4:  Elapsed Time: 0.234 seconds (Warm-up)
## Chain 4:                0.159 seconds (Sampling)
## Chain 4:                0.393 seconds (Total)
## Chain 4:


## Warning: There were 323 divergent transitions after warmup. See
```

```
## https://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup
## to find out why this is a problem and how to eliminate them.


## Warning: Examine the pairs() plot to diagnose sampling problems


## Warning: The largest R-hat is 1.14, indicating chains have not mixed.
## Running the chains for more iterations may help. See
## https://mc-stan.org/misc/warnings.html#r-hat


## 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


## Warning: Tail Effective Samples Size (ESS) is too low, indicating posterior variances and tail quant:
## Running the chains for more iterations may help. See
## https://mc-stan.org/misc/warnings.html#tail-ess
```

```
summary(bmodel)
```

```
## Warning: Parts of the model have not converged (some Rhats are > 1.05). Be
## careful when analysing the results! We recommend running more iterations and/or
## setting stronger priors.


## Warning: There were 323 divergent transitions after warmup. Increasing
## adapt_delta above 0.8 may help. See
## http://mc-stan.org/misc/warnings.html#divergent-transitions-after-warmup


##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: Performance_Negative ~ Condition * time + (1 | Subject)
##     Data: CircleTimeData (Number of observations: 48)
##   Draws: 4 chains, each with iter = 2000; warmup = 1000; thin = 1;
##         total post-warmup draws = 4000
##
## Group-Level Effects:
## ~Subject (Number of levels: 6)
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sd(Intercept)     0.35      0.32     0.11     1.22 1.14       20       16
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.01      0.26    -0.56     0.38 1.13       22       14
## Condition         0.09      0.07    -0.05     0.22 1.05     1226     1906
## time              0.01      0.04    -0.07     0.08 1.04     1221     1810
## Condition:time   -0.01      0.02    -0.06     0.04 1.05     1292     1923
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## sigma     0.10      0.01     0.08     0.12 1.04      192      399
##
## 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).
```
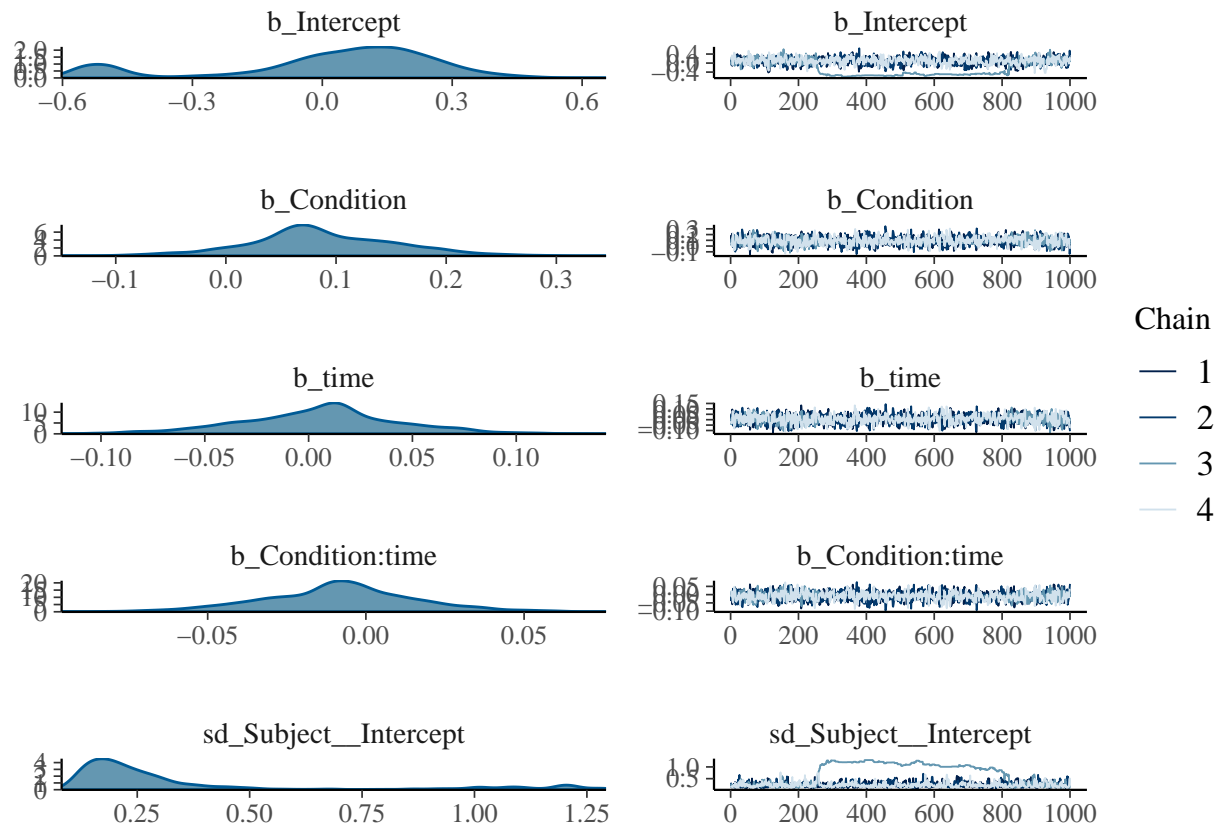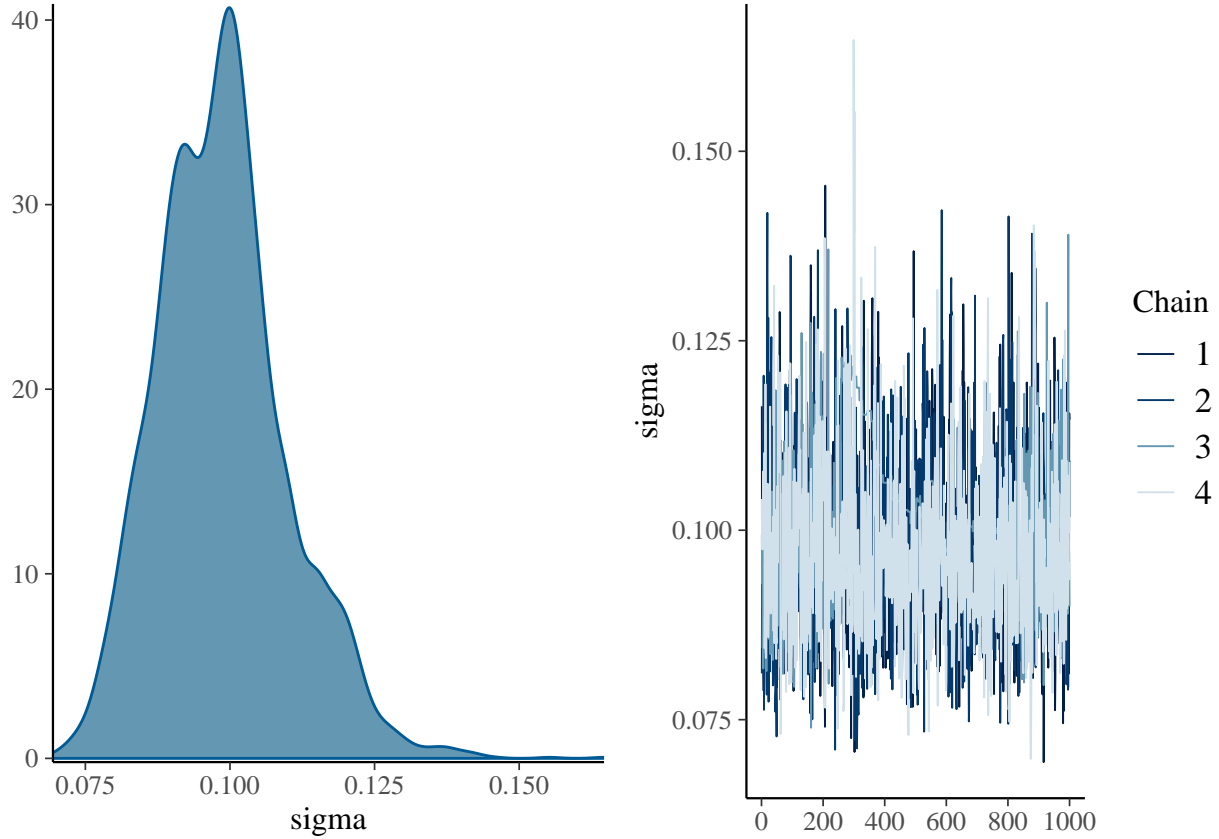
```
plot(bmodel)
```

2.4.2.1 Reporting the Negative Performance The effect size for Condition (0.09, 95% CI: -0.05, 0.22) suggests a modest increase in negative performance with robot instructors compared to human instructors. The effect of time (0.00, 95% CI: -0.08, 0.08) indicates no significant linear trend in negative performance over sessions. The interaction effect Condition:time (-0.01, 95% CI: -0.06, 0.04) suggests a slight decrease in the rate of negative performance for robot instructors compared to human instructors. The estimated standard deviation of the residuals (sigma) is 0.10 (95% CI: 0.08, 0.12), representing unexplained variability not captured by the fixed effects. Our Bayesian analysis, with confirmed convergence, provides nuanced insights into the dynamics of negative performance across sessions and instructional conditions.