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)?

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

```
library(readr)
```

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

```
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

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_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: 0.259 seconds (Warm-up)
## Chain 1:                0.109 seconds (Sampling)
## Chain 1:                0.368 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: 0.264 seconds (Warm-up)
## Chain 2:                0.106 seconds (Sampling)
## Chain 2:                0.37 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: 0.279 seconds (Warm-up)
## Chain 3:                0.113 seconds (Sampling)
## Chain 3:                0.392 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: 0.247 seconds (Warm-up)
## Chain 4:                0.107 seconds (Sampling)
## Chain 4:                0.354 seconds (Total)
## Chain 4:


## Warning: There were 3 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 3 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      0.04     0.04     0.20 1.00      943      802
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.04      0.09    -0.14     0.23 1.00     1414     1438
## Condition          0.09      0.05    -0.01     0.19 1.00     1678     2062
## time               0.01      0.03    -0.05     0.07 1.00     1649     2071
## Condition:time    -0.01      0.02    -0.05     0.02 1.00     1598     2063
##
## 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     2153     2489
##
```

```
## 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)
```
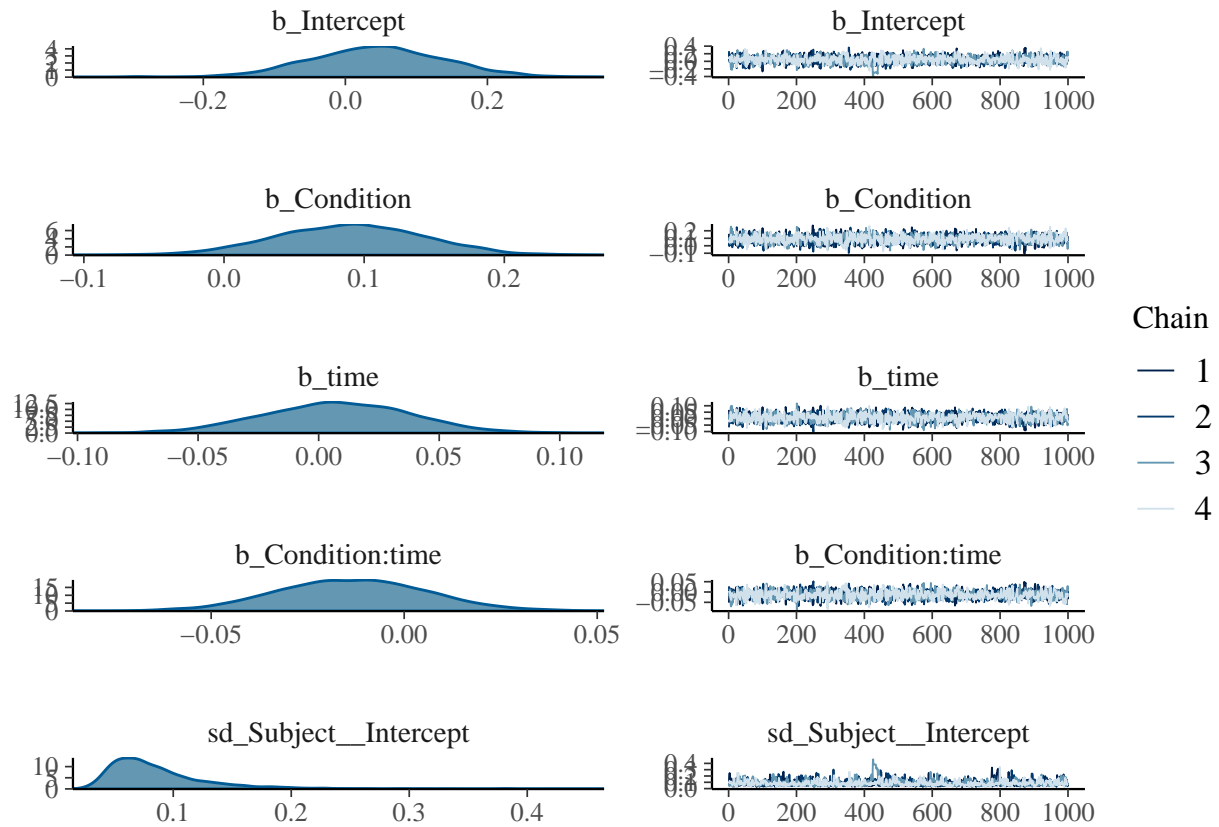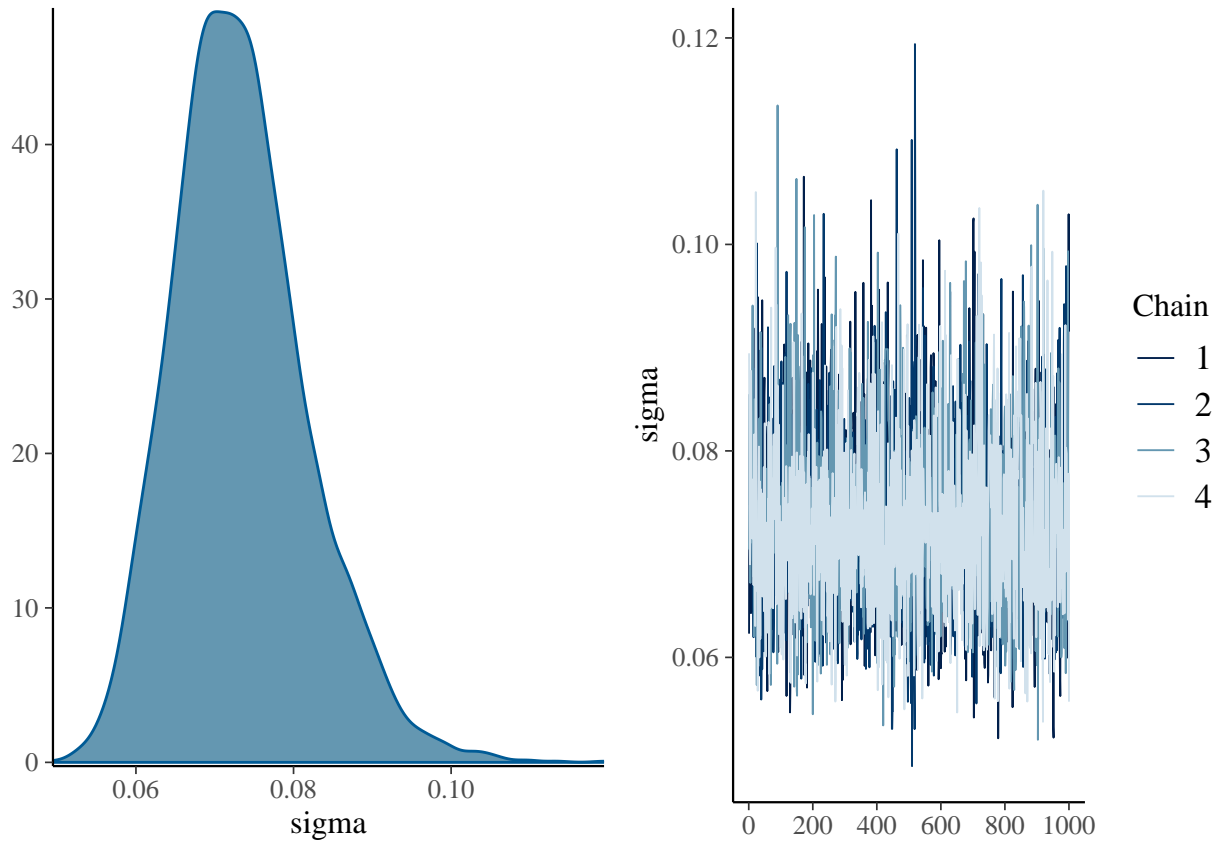
2.1.1.1 Reporting Affect Positive

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 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: 0.392 seconds (Warm-up)
## Chain 1:                0.136 seconds (Sampling)
## Chain 1:                0.528 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: 0.4 seconds (Warm-up)
## Chain 2:                0.132 seconds (Sampling)
## Chain 2:                0.532 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: 0.392 seconds (Warm-up)
## Chain 3:                0.113 seconds (Sampling)
## Chain 3:                0.505 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 1e-05 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.1 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: 0.422 seconds (Warm-up)
```

```
## Chain 4:                    0.125 seconds (Sampling)
## Chain 4:                    0.547 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
```

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: 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      808     1129
##
## 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     2522     2822
## Condition         -0.01      0.01    -0.03     0.02 1.00     2645     2635
## time              -0.01      0.01    -0.02     0.01 1.00     2702     2895
## Condition:time     0.01      0.00    -0.00     0.01 1.00     2622     2587
##
## 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     2708     2105
##
## 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)
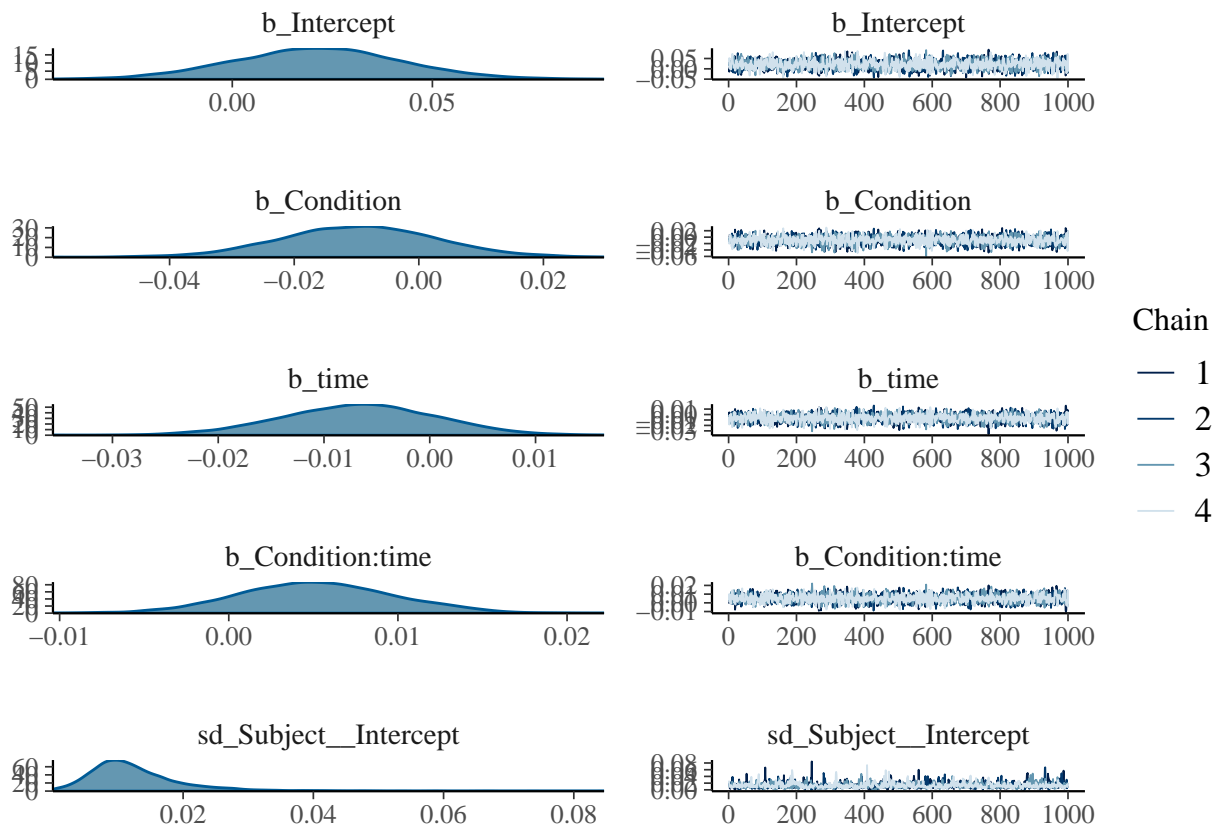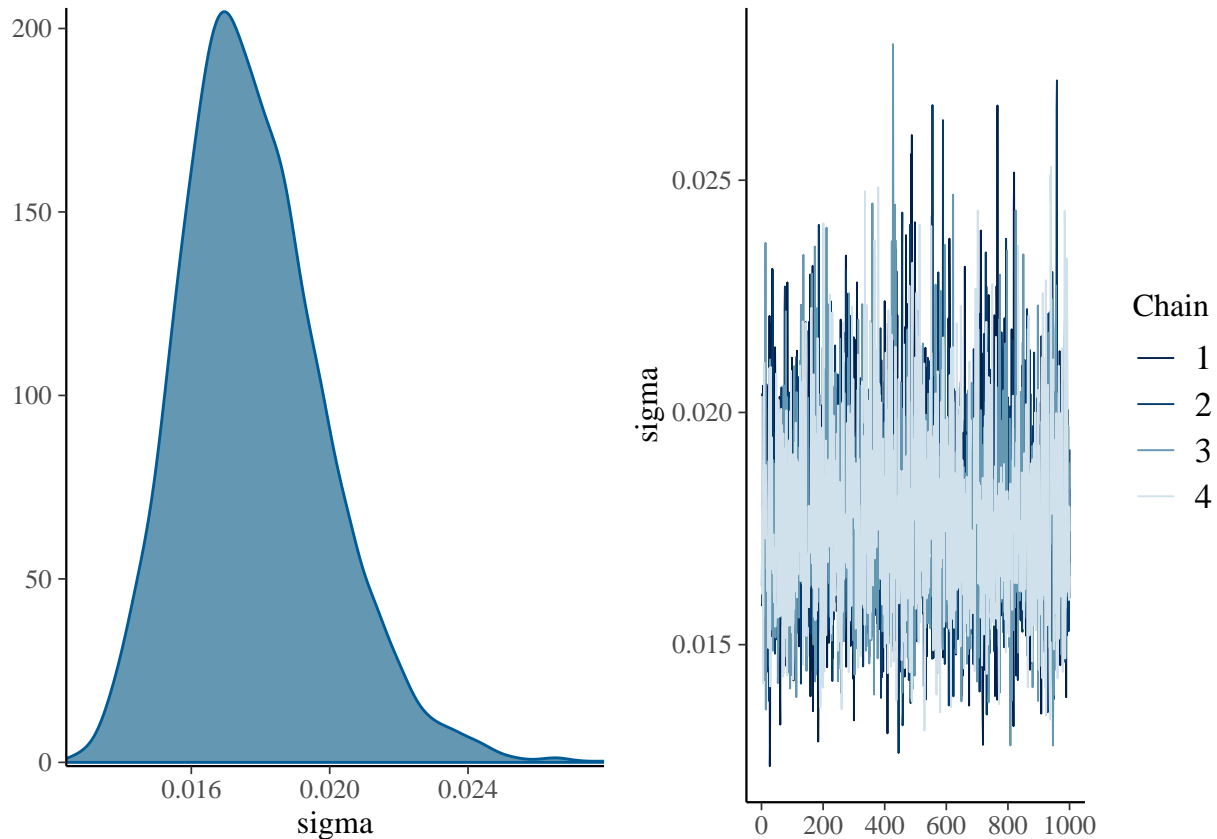
2.1.2.1 Reporting Negative Affect Our Bayesian analysis of Negative Affect delves into the emotional responses of children within conditions involving human (Condition 1) versus robot instructors (Condition 2) across four pivotal sessions, representing sessions 1, 4, 7, and 10 in the context of a comprehensive 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.

```
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_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 2.8e-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: 0.259 seconds (Warm-up)
## Chain 1:                0.103 seconds (Sampling)
## Chain 1:                0.362 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: 0.257 seconds (Warm-up)
## Chain 2:                0.124 seconds (Sampling)
## Chain 2:                0.381 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: 0.237 seconds (Warm-up)
## Chain 3:                0.114 seconds (Sampling)
## Chain 3:                0.351 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: 0.241 seconds (Warm-up)
## Chain 4:                 0.121 seconds (Sampling)
## Chain 4:                 0.362 seconds (Total)
## Chain 4:
```

```r
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     1002     1645
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.02      0.10    -0.16     0.21 1.00     1435     2093
## Condition         0.10      0.06    -0.01     0.21 1.00     1618     2000
## time              0.01      0.03    -0.05     0.08 1.00     1609     2138
## Condition:time   -0.02      0.02    -0.06     0.02 1.00     1548     1987
##
## 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     2686     2548
##
## 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)
```
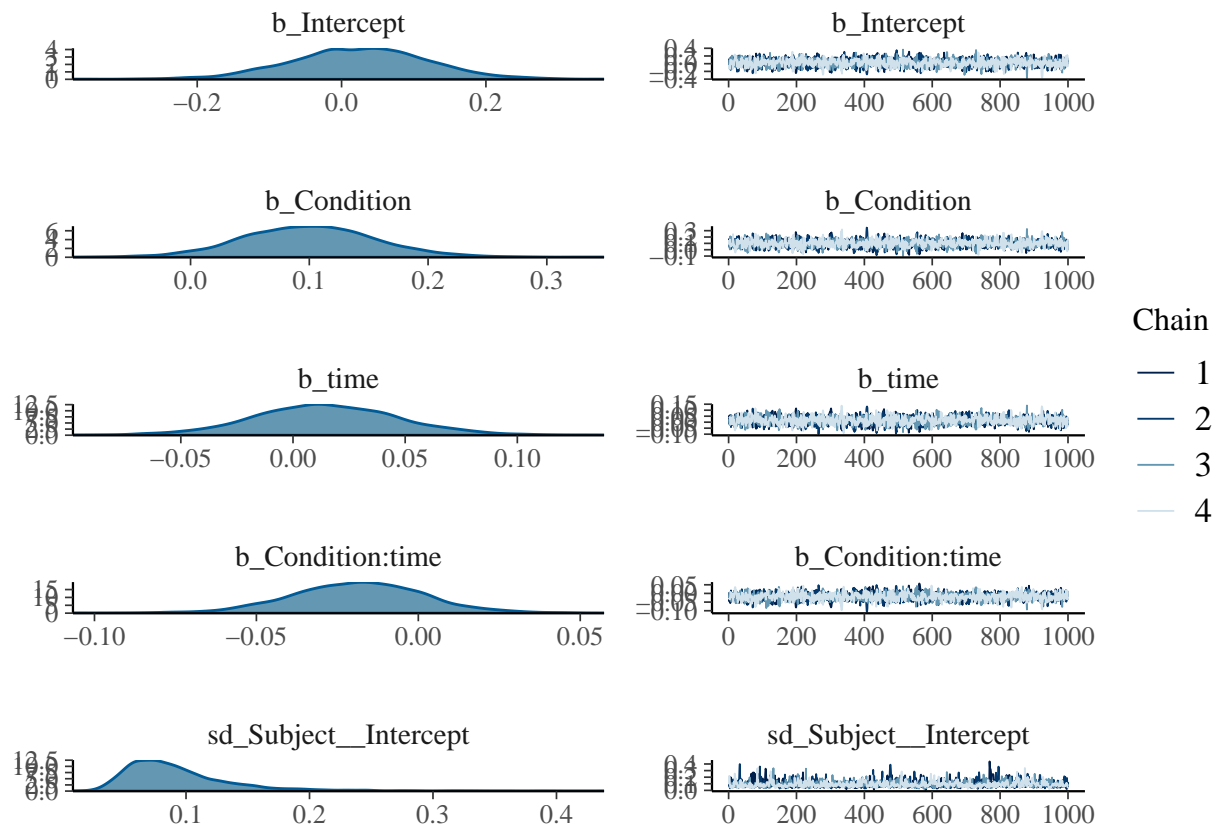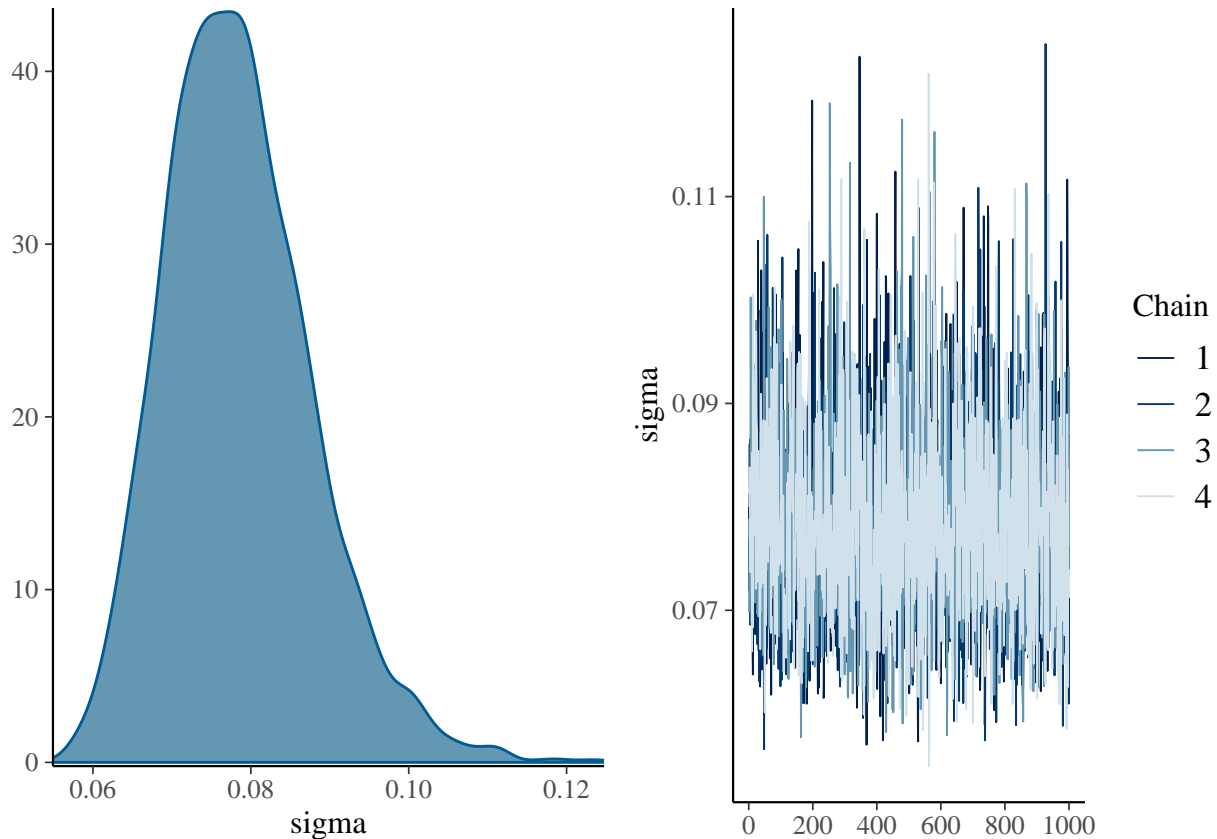
Reporting Overall Affect

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...
```

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```
##
## 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_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 2.8e-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: 0.255 seconds (Warm-up)
## Chain 1:                0.129 seconds (Sampling)
## Chain 1:                0.384 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: 0.273 seconds (Warm-up)
## Chain 2:                0.196 seconds (Sampling)
## Chain 2:                0.469 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: 0.251 seconds (Warm-up)
## Chain 3:                0.109 seconds (Sampling)
## Chain 3:                0.36 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 1e-05 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.1 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)
```
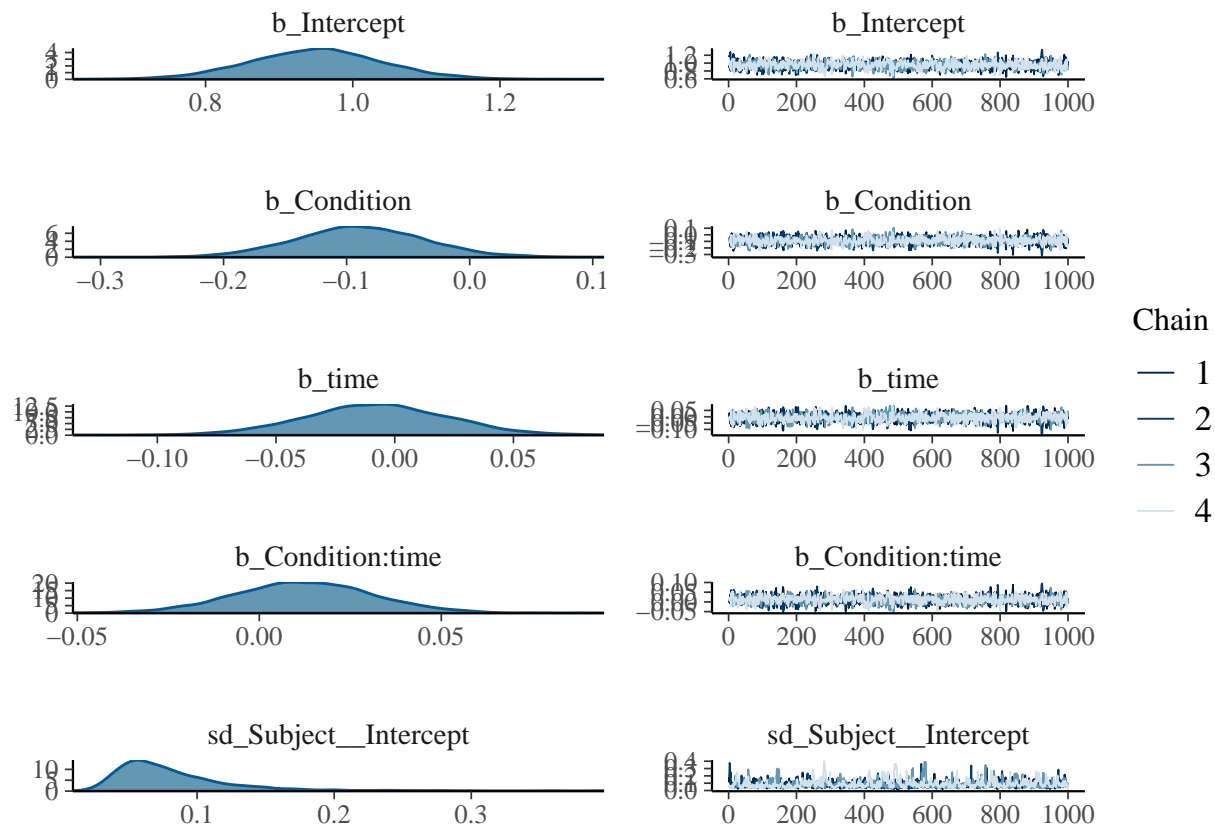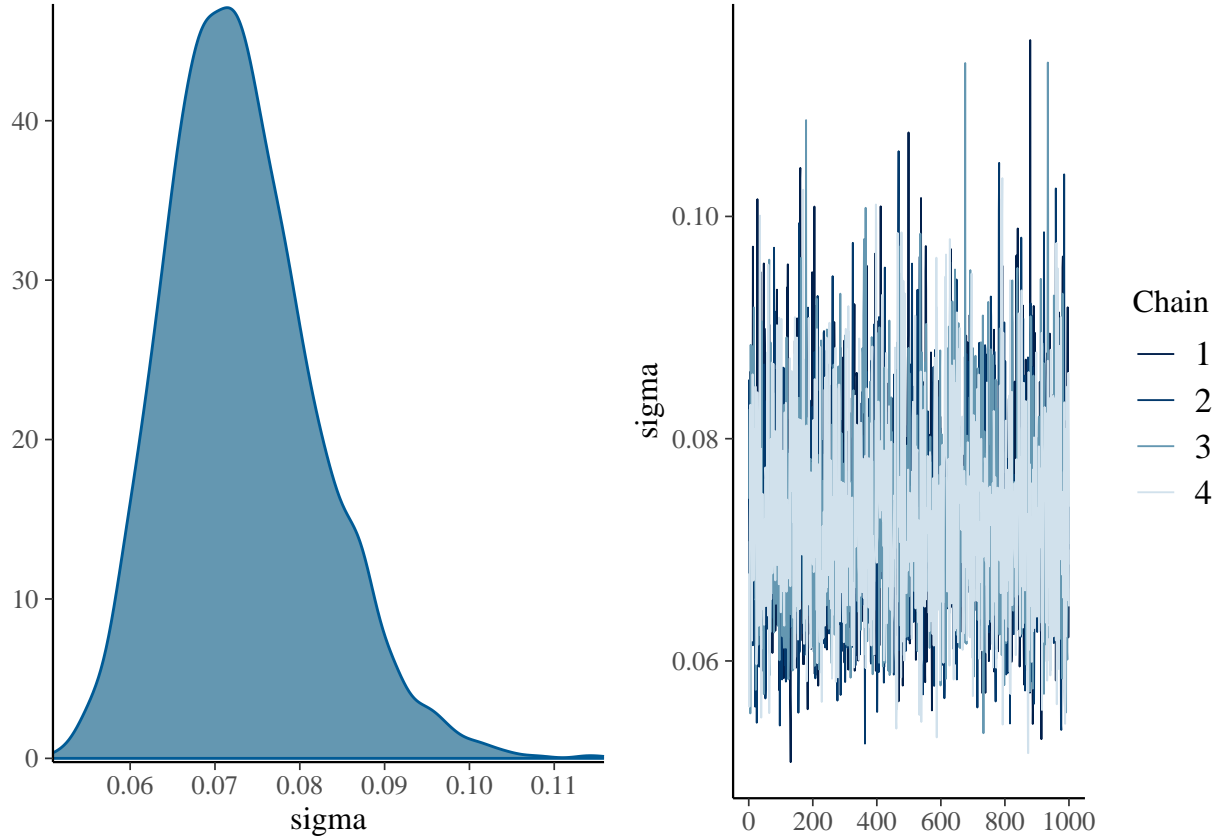
```
## Chain 4:                    0.395 seconds (Total)
## Chain 4:
```

```
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      0.05     0.03     0.22 1.01      818      932
##
## 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     1674     1928
## Condition        -0.09      0.05    -0.19     0.02 1.00     1857     2165
## time             -0.01      0.03    -0.07     0.05 1.00     1802     2075
## Condition:time    0.01      0.02    -0.03     0.05 1.00     1795     2019
##
## 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     2216     2551
##
## 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

2.1.4.1 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

```
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(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 2.9e-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: 0.338 seconds (Warm-up)
## Chain 1:                0.109 seconds (Sampling)
## Chain 1:                0.447 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: 0.349 seconds (Warm-up)
## Chain 2:                0.126 seconds (Sampling)
## Chain 2:                0.475 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: 0.367 seconds (Warm-up)
## Chain 3:                0.088 seconds (Sampling)
## Chain 3:                0.455 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: 0.351 seconds (Warm-up)
## Chain 4:                0.104 seconds (Sampling)
## Chain 4:                0.455 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
```

`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_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      0.02     0.01     0.09 1.00      621     1184
##
## 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     1526     1772
## Condition         0.04      0.04    -0.03     0.12 1.00     1613     1964
## time              0.03      0.02    -0.02     0.07 1.00     1681     1808
## Condition:time   -0.02      0.01    -0.05     0.00 1.00     1625     1879
##
## 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     2417     2424
##
## 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).
```
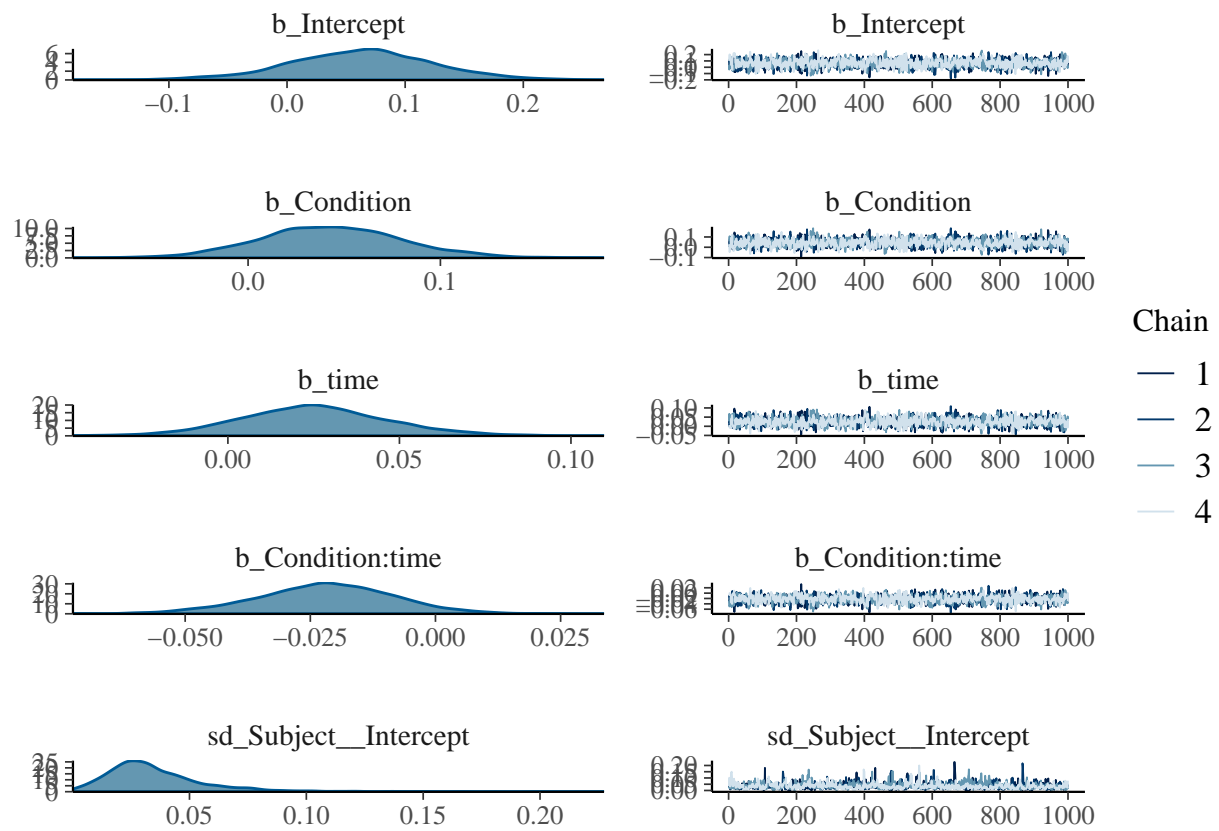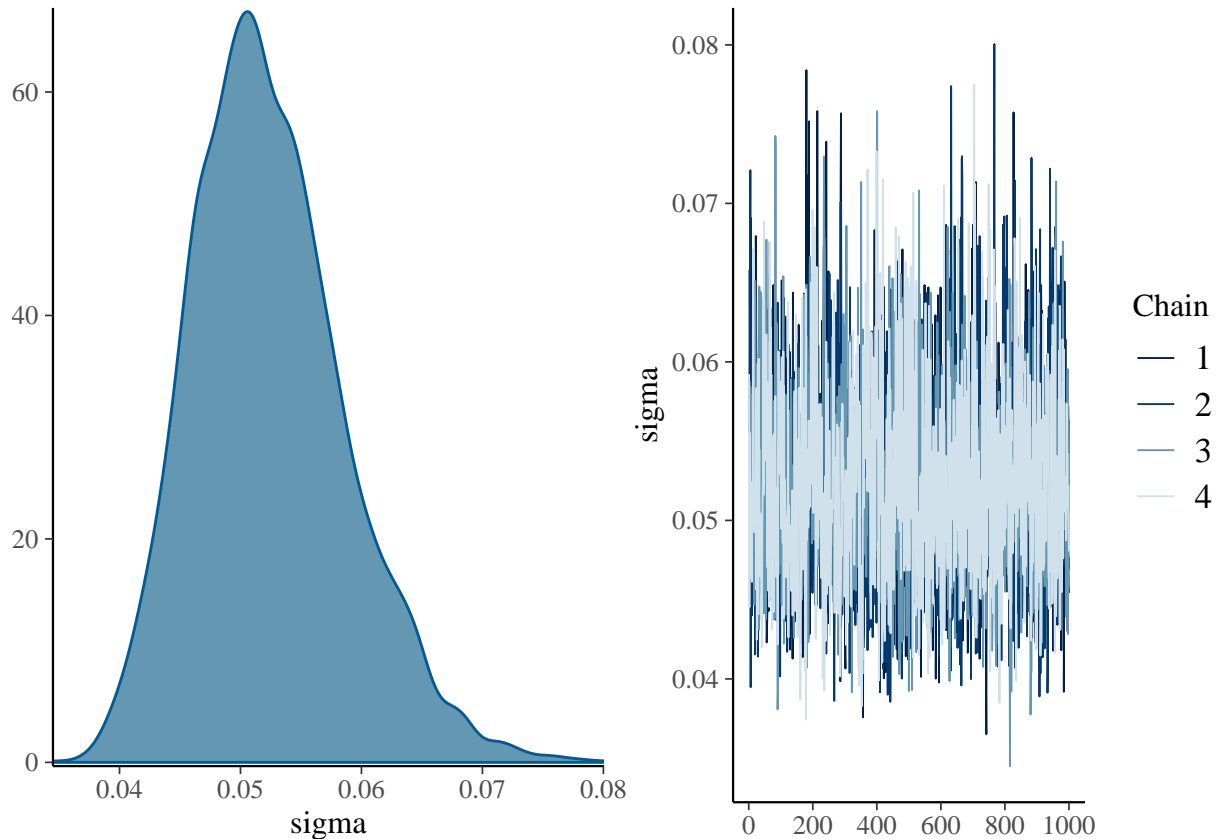
```
plot(bmodel)
```


b_Intercept

b_Condition

b_time

b_Condition:time

sd_Subject__Intercept

Chain
— 1
— 2
— 3
— 4

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 3.1e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.31 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: 0.464 seconds (Warm-up)
## Chain 1:                0.129 seconds (Sampling)
## Chain 1:                0.593 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: 0.501 seconds (Warm-up)
## Chain 2:                0.137 seconds (Sampling)
## Chain 2:                0.638 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: 0.447 seconds (Warm-up)
## Chain 3:                0.13 seconds (Sampling)
## Chain 3:                0.577 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 1e-05 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.1 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: 0.46 seconds (Warm-up)
## Chain 4:                 0.136 seconds (Sampling)
## Chain 4:                 0.596 seconds (Total)
## Chain 4:
```

```r
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     1686     1694
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.01      0.02    -0.02     0.04 1.00     2706     2829
## Condition          0.00      0.01    -0.01     0.02 1.00     2776     2819
## time               0.00      0.01    -0.01     0.01 1.00     2671     2656
## Condition:time    -0.00      0.00    -0.01     0.00 1.00     2709     2642
##
## 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     3717     3000
##
## 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)
```
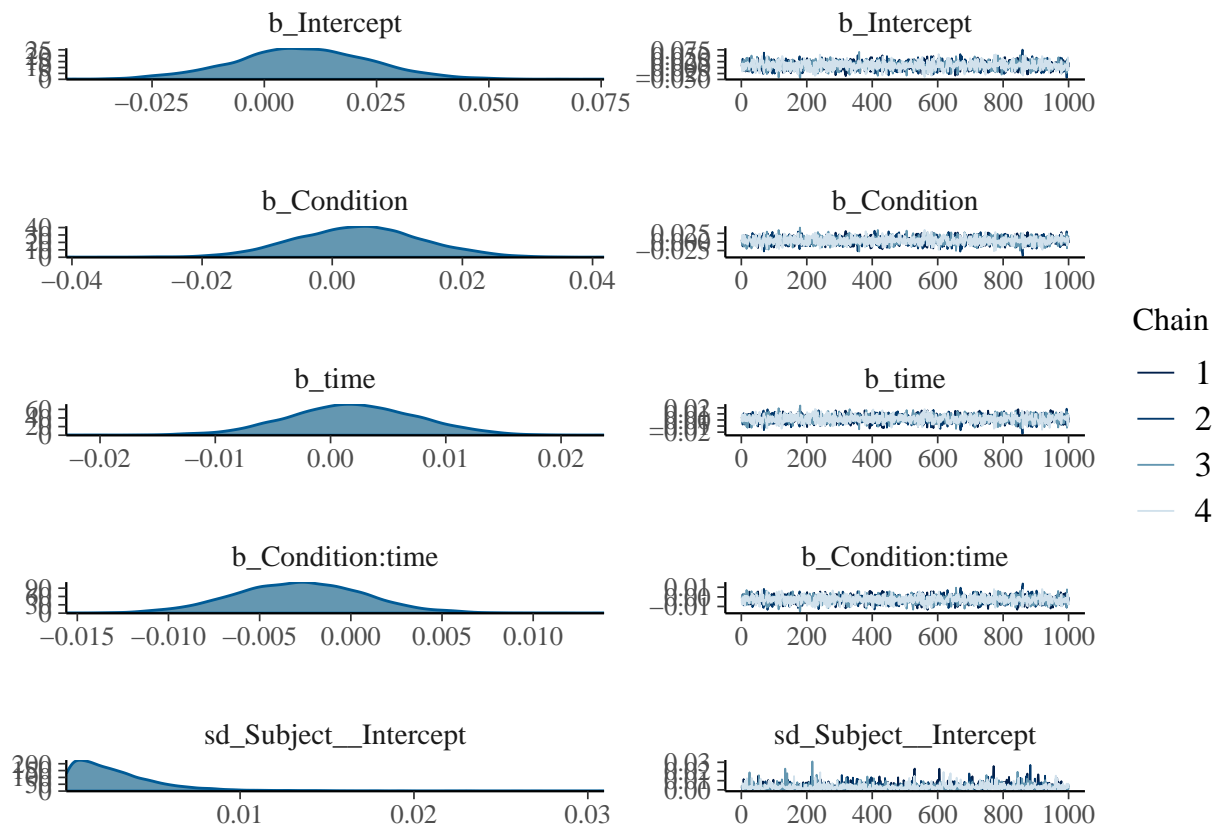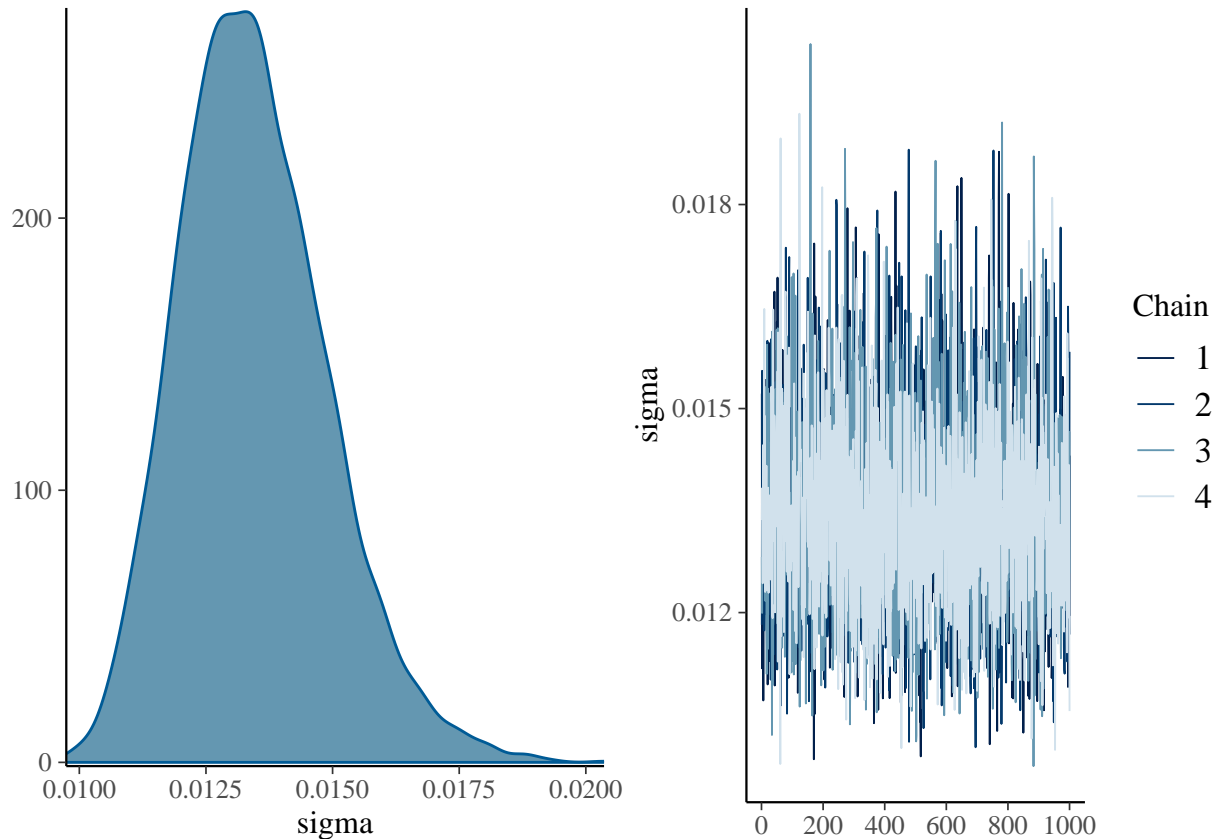
2.2.2.1 Reporting Prompted Communication with Instructor
In our Bayesian analysis of 'Prompted Communication with Instructor', the effect sizes for Condition (0.00, 95% CI: -0.01, 0.02), time (0.00, 95% CI: -0.01, 0.01), and the interaction effect Condition:time (-0.00, 95% CI: -0.01, 0.00) are all negligible, 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 2.8e-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: 0.276 seconds (Warm-up)
## Chain 1:                0.11 seconds (Sampling)
## Chain 1:                0.386 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: 0.367 seconds (Warm-up)
## Chain 2:                0.119 seconds (Sampling)
```

```
## Chain 2:                    0.486 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: 0.351 seconds (Warm-up)
## Chain 3:                0.115 seconds (Sampling)
## Chain 3:                0.466 seconds (Total)
## Chain 3:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 4).
## Chain 4:
## Chain 4: Gradient evaluation took 1e-05 seconds
## Chain 4: 1000 transitions using 10 leapfrog steps per transition would take 0.1 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: 0.335 seconds (Warm-up)
## Chain 4:                0.124 seconds (Sampling)
## Chain 4:                0.459 seconds (Total)
## Chain 4:
```

```
summary(bmodel)
```

```
##  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     0.07 1.00     1123     1812
##
## 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     1816     2343
## Condition         -0.03      0.04    -0.10     0.05 1.00     1765     2279
## time              -0.04      0.02    -0.08     0.01 1.00     1741     1996
## Condition:time     0.01      0.01    -0.02     0.04 1.01     1703     1845
##
## 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     2871     2835
##
## 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)
```
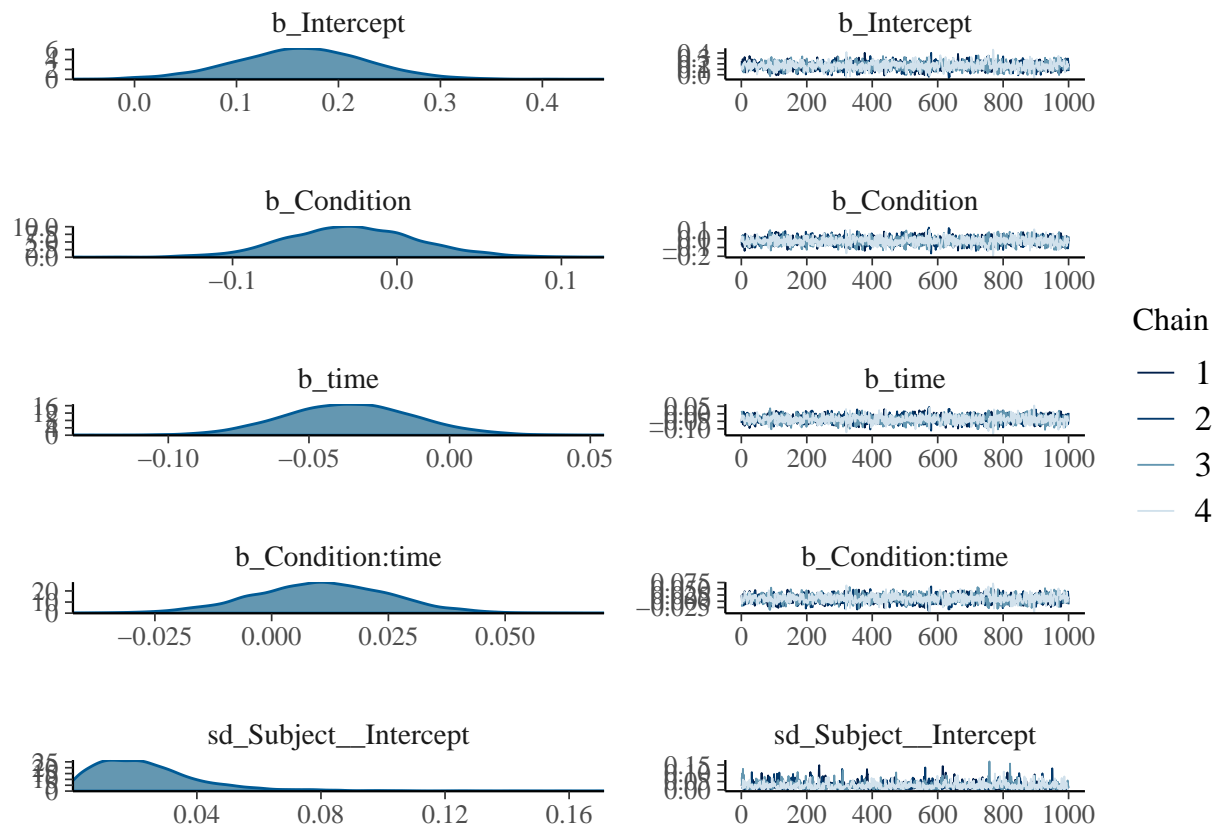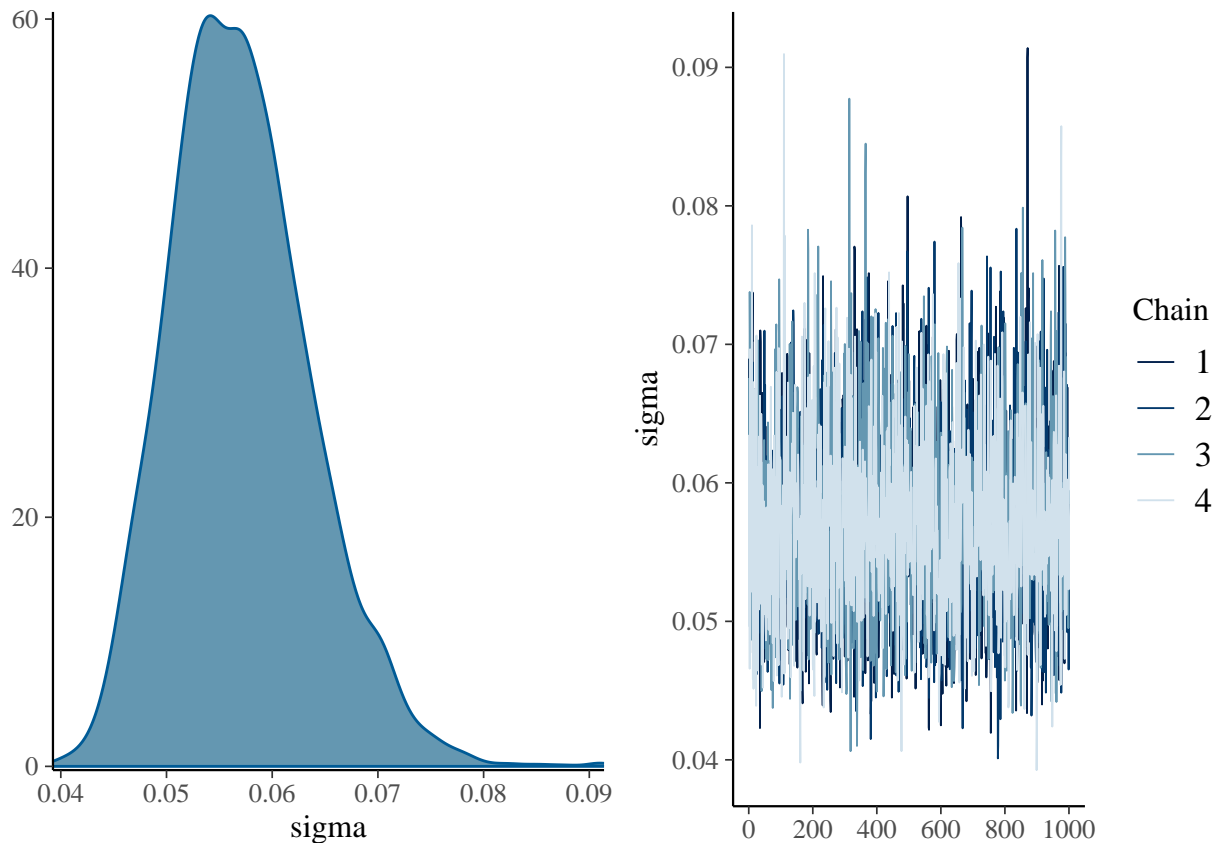
2.2.3.1 Reporting Communication with Behavioral Therapist In our Bayesian analysis of 'Communication with Behavioral Therapist', the effect sizes for Condition (-0.02, 95% CI: -0.10, 0.05), time (-0.03, 95% CI: -0.08, 0.01), and the interaction effect Condition:time (0.01, 95% CI: -0.02, 0.04) are all 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.
```

```
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 3.1e-05 seconds
## Chain 1: 1000 transitions using 10 leapfrog steps per transition would take 0.31 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: 0.404 seconds (Warm-up)
## Chain 1:                0.097 seconds (Sampling)
## Chain 1:                0.501 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: 0.389 seconds (Warm-up)
## Chain 2:                0.112 seconds (Sampling)
```
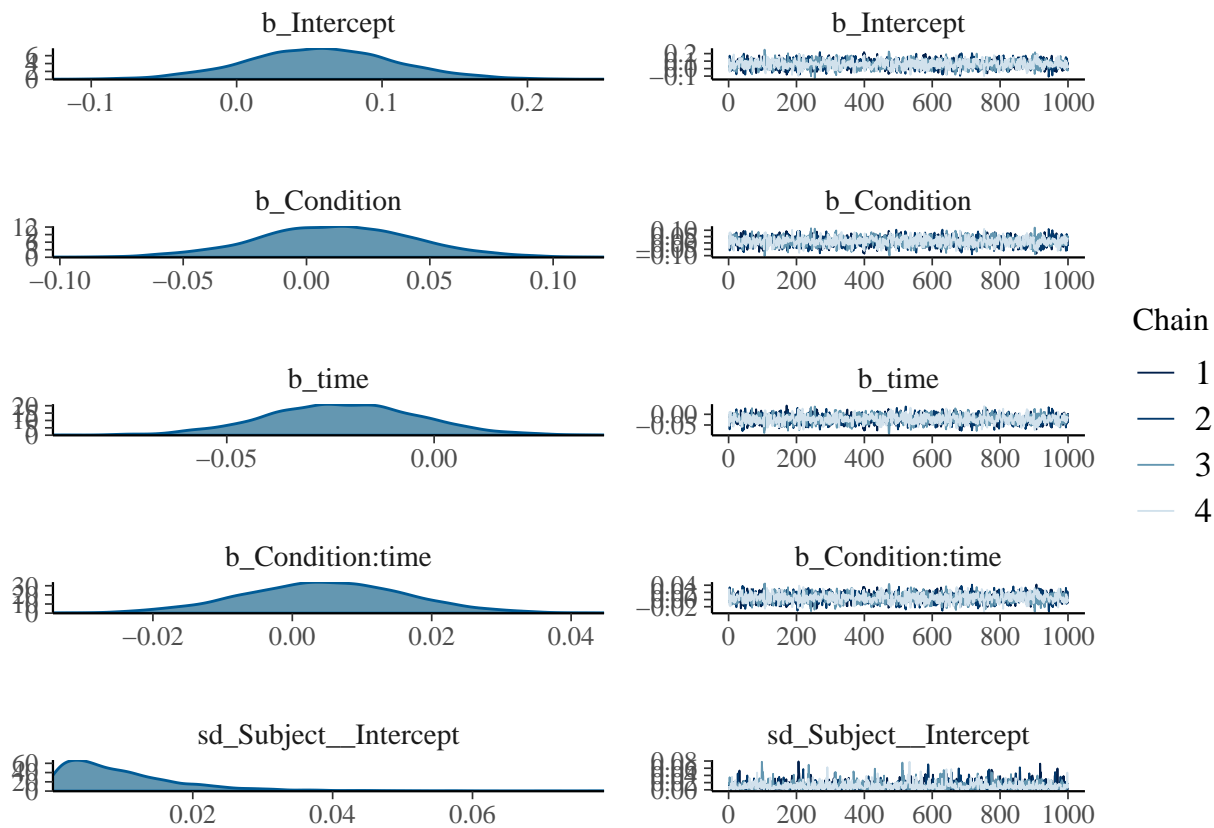
```
## Chain 2:                    0.501 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 7e-06 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.07 seconds.
## Chain 3: Adjust your 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: 0.402 seconds (Warm-up)
## Chain 3:                    0.116 seconds (Sampling)
## Chain 3:                    0.518 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: 0.399 seconds (Warm-up)
## Chain 4:                    0.122 seconds (Sampling)
## Chain 4:                    0.521 seconds (Total)
## Chain 4:
```
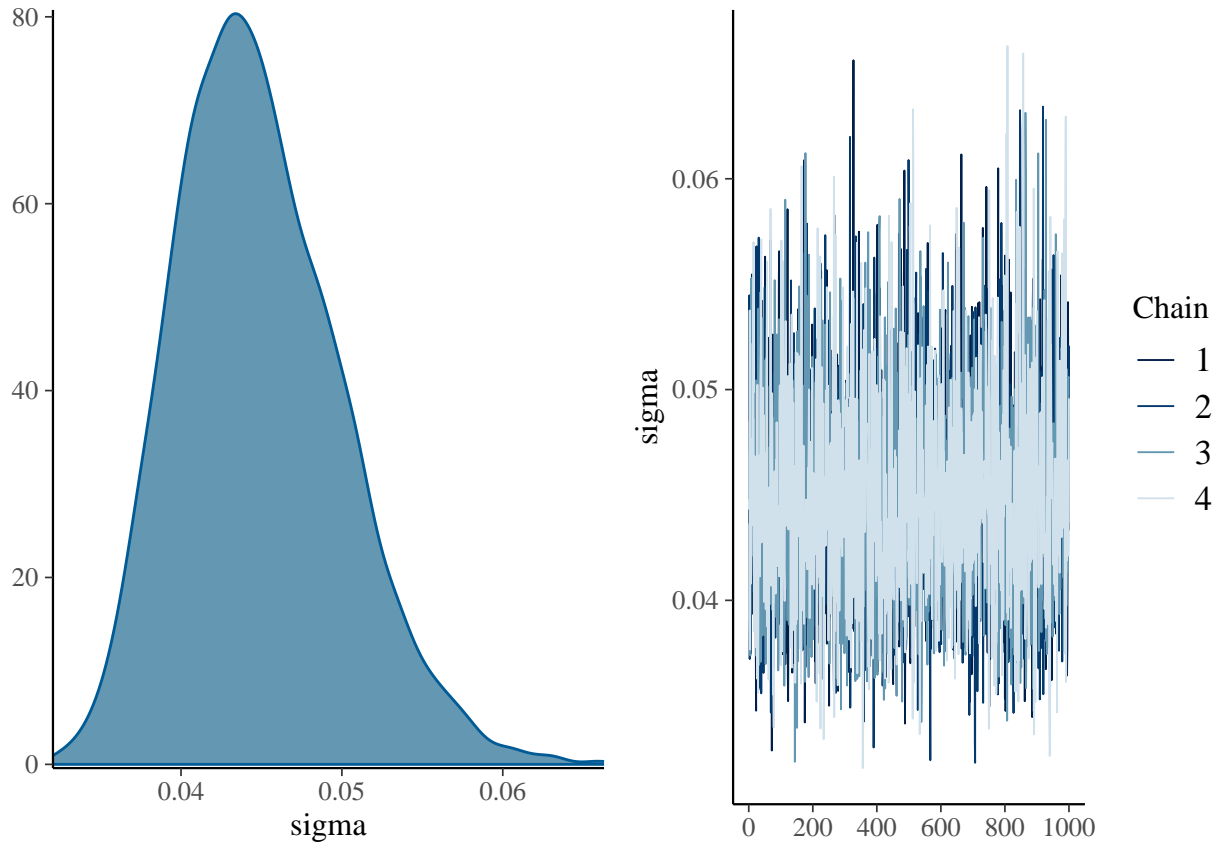
```
summary(bmodel)
```

```
##  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     0.04 1.01     1504     1902
##
## 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     1756     2007
## Condition          0.01      0.03    -0.05     0.08 1.00     1778     2328
## time              -0.02      0.02    -0.06     0.01 1.00     1694     2220
## Condition:time     0.00      0.01    -0.02     0.03 1.00     1658     2223
##
## 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     3551     3236
##
## 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

2.2.4.1 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 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:                0.12 seconds (Sampling)
## Chain 1:                0.425 seconds (Total)
## Chain 1:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 2).
## Chain 2:
## Chain 2: Gradient evaluation took 1.1e-05 seconds
## Chain 2: 1000 transitions using 10 leapfrog steps per transition would take 0.11 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: 0.3 seconds (Warm-up)
## Chain 2:                0.12 seconds (Sampling)
## Chain 2:                0.42 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: 0.321 seconds (Warm-up)
## Chain 3:                0.098 seconds (Sampling)
## Chain 3:                0.419 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: 0.318 seconds (Warm-up)
## Chain 4:                 0.097 seconds (Sampling)
## Chain 4:                 0.415 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     1267     1632
##
## 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     1888     2322
## Condition         0.06      0.06    -0.05     0.17 1.00     1848     2272
## time              0.04      0.03    -0.02     0.11 1.00     1838     2238
## Condition:time   -0.02      0.02    -0.06     0.02 1.00     1805     2208
##
## 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     3467     2279
##
## 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)
```
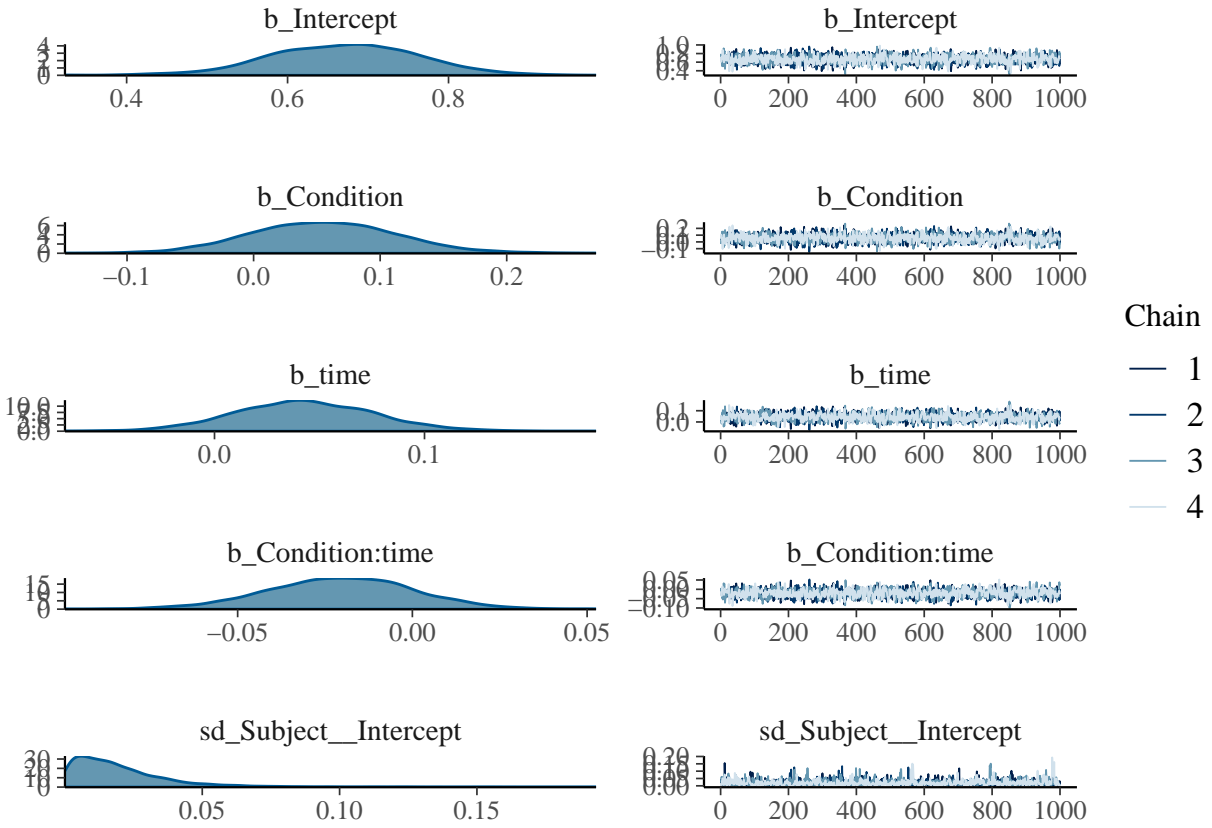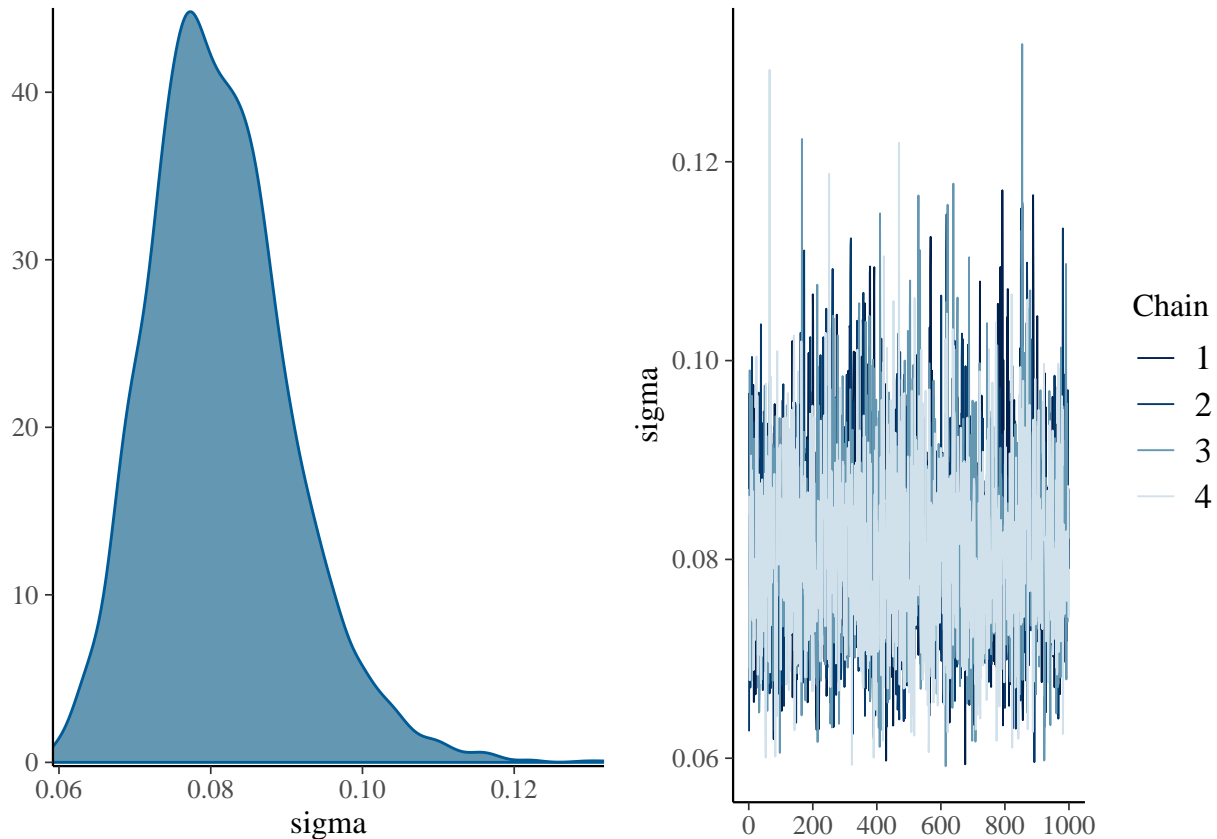
2.3.1.1 Reporting On-Target Engagement
The effect size for Condition (0.06, 95% CI: -0.06, 0.18) is modest, indicating a slight difference in engagement with on-target between conditions. The effect of time (0.04, 95% CI: -0.02, 0.11) suggests a positive trend in engagement with on-target over sessions. 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 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: 0.426 seconds (Warm-up)
## Chain 1:                0.119 seconds (Sampling)
## Chain 1:                0.545 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: 0.446 seconds (Warm-up)
## Chain 2:                0.116 seconds (Sampling)
```

```
## Chain 2:                     0.562 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: 0.436 seconds (Warm-up)
## Chain 3:                     0.112 seconds (Sampling)
## Chain 3:                     0.548 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: 0.414 seconds (Warm-up)
## Chain 4:                     0.128 seconds (Sampling)
## Chain 4:                     0.542 seconds (Total)
## Chain 4:
```

```
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      924     1111
##
## 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     2173     2407
## Condition          0.01      0.02    -0.03     0.05 1.00     2182     2359
## time               0.00      0.01    -0.02     0.03 1.00     2128     2420
## Condition:time    -0.00      0.01    -0.02     0.01 1.00     2112     2289
##
## 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     3081     2242
##
## 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)
```
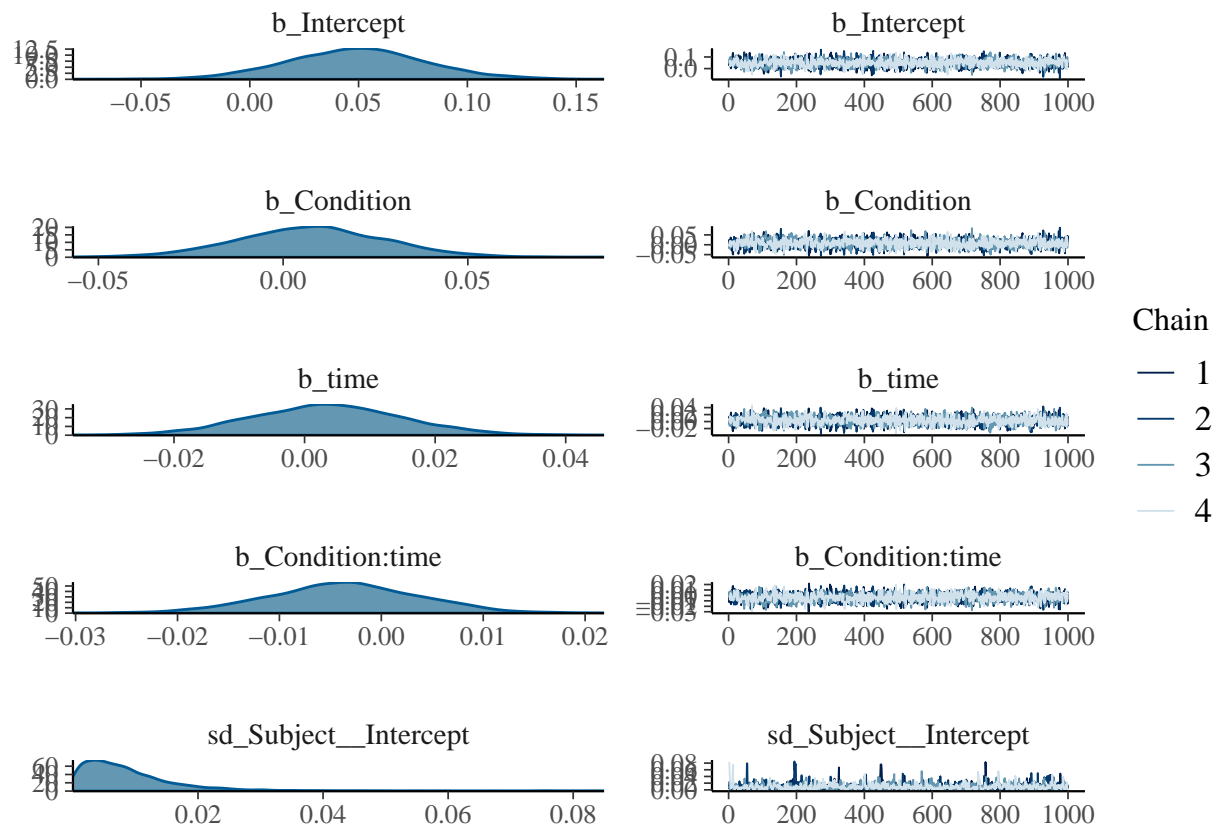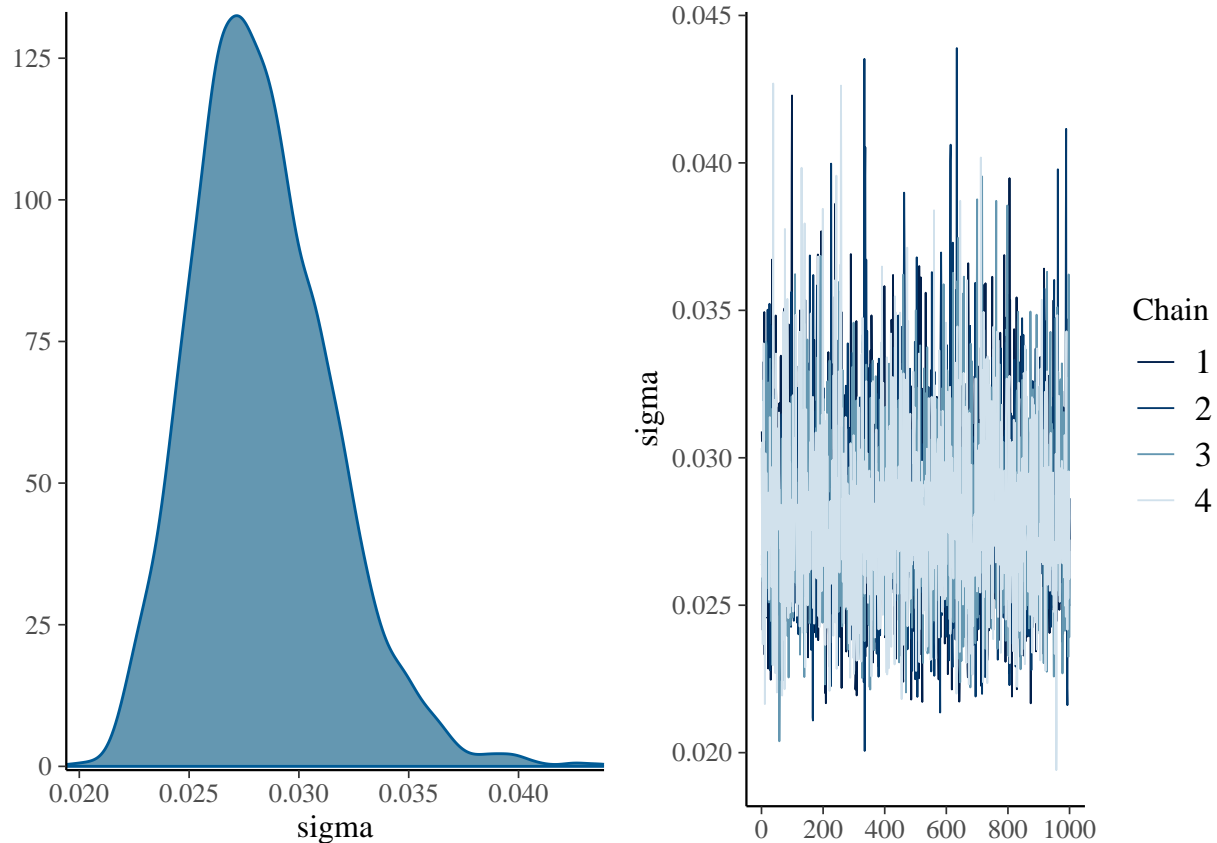
2.3.2.1 Reporting the Engagement with Behavioral Therapist
The effect size for Condition (0.01, 95% CI: -0.03, 0.05) suggests a small difference in engagement between conditions. The effect of time (0.00, 95% CI: -0.02, 0.03) indicates a subtle positive trend in engagement over sessions. The interaction 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

```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(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 2.9e-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: 0.344 seconds (Warm-up)
## Chain 1:                0.101 seconds (Sampling)
## Chain 1:                0.445 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: 0.337 seconds (Warm-up)
## Chain 2:                0.107 seconds (Sampling)
```

```
## Chain 2:                    0.444 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 1e-05 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.1 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: 0.286 seconds (Warm-up)
## Chain 3:                0.1 seconds (Sampling)
## Chain 3:                0.386 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: 0.348 seconds (Warm-up)
## Chain 4:                0.109 seconds (Sampling)
## Chain 4:                0.457 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     1270     1858
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.28      0.08     0.12     0.44 1.00     1678     1894
## Condition         -0.06      0.05    -0.16     0.04 1.00     1589     1898
## time              -0.05      0.03    -0.11     0.01 1.00     1624     1767
## Condition:time     0.02      0.02    -0.01     0.06 1.00     1528     1744
##
## 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     2836     2893
##
## 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)
```
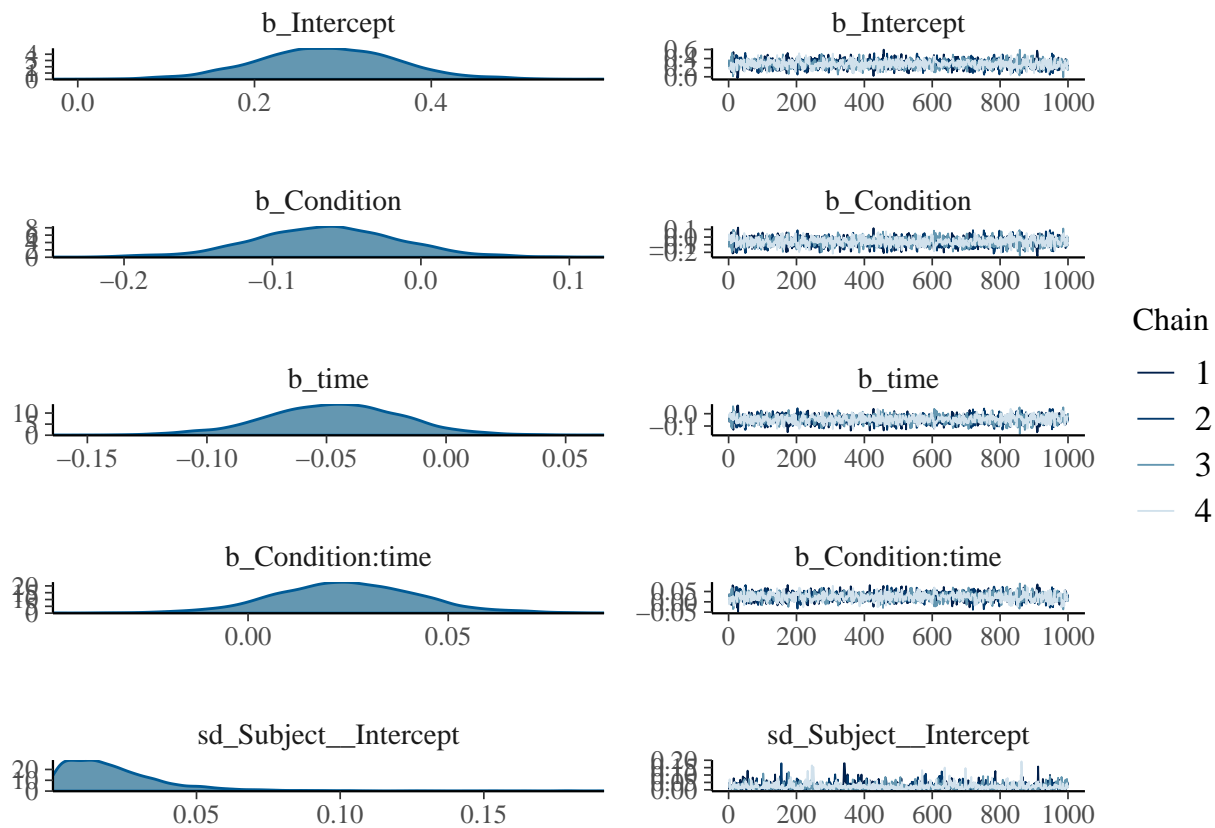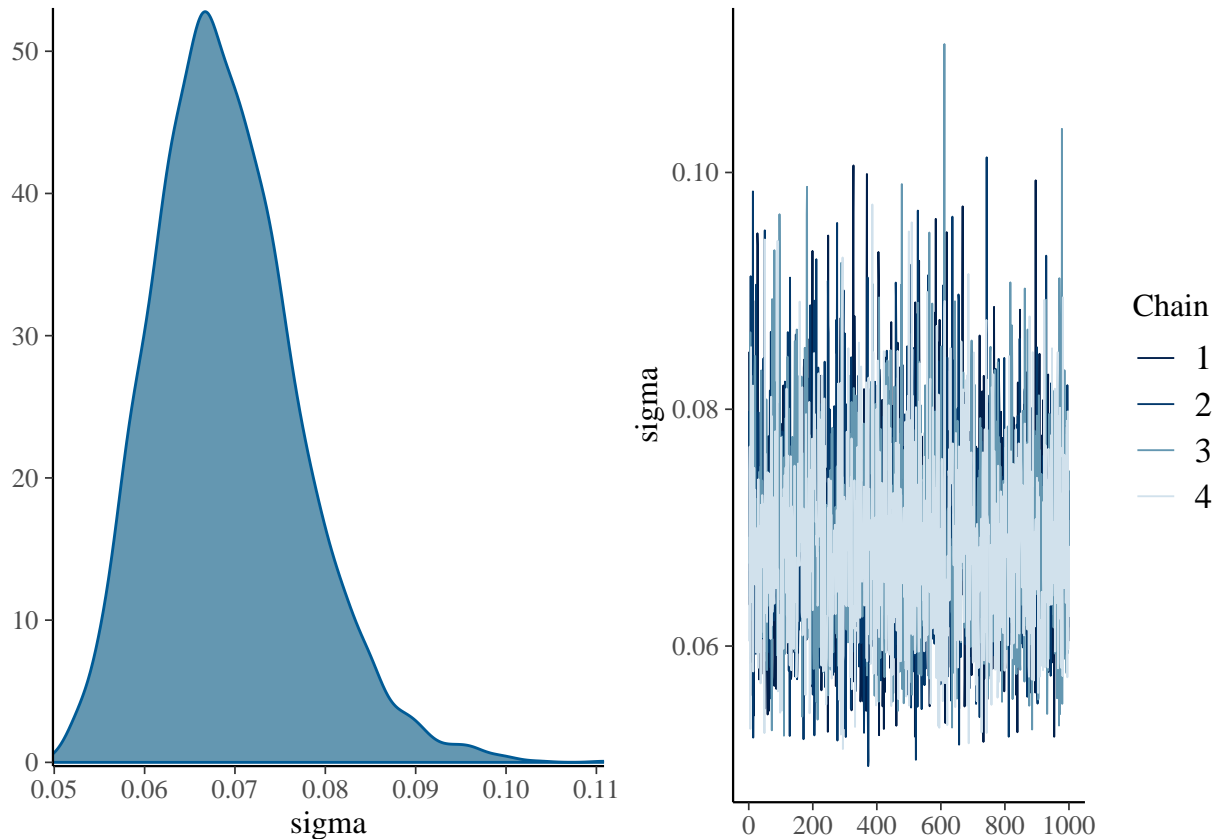
2.3.3.1 Reporting the Engagement with Off-Target The effect size for Condition (-0.06, 95% CI: -0.16, 0.04) indicates a moderate decrease in off-target engagement with robot instructors compared to human instructors. The effect of time (-0.05, 95% CI: -0.10, 0.01) suggests a decreasing trend in off-target 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 2.9e-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: 0.246 seconds (Warm-up)
## Chain 1:                0.191 seconds (Sampling)
## Chain 1:                0.437 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: 0.214 seconds (Warm-up)
## Chain 2:                0.151 seconds (Sampling)
## Chain 2:                0.365 seconds (Total)
## Chain 2:
##
## SAMPLING FOR MODEL 'anon_model' NOW (CHAIN 3).
## Chain 3:
## Chain 3: Gradient evaluation took 1.1e-05 seconds
## Chain 3: 1000 transitions using 10 leapfrog steps per transition would take 0.11 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: 0.226 seconds (Warm-up)
## Chain 3:                0.165 seconds (Sampling)
## Chain 3:                0.391 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: 0.218 seconds (Warm-up)
## Chain 4:                 0.174 seconds (Sampling)
## Chain 4:                 0.392 seconds (Total)
## Chain 4:


## Warning: There were 3 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 3 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)     0.25      0.13     0.11     0.61 1.00      842      724
##
## Population-Level Effects:
##               Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept         0.87      0.16     0.55     1.18 1.00     1111     1427
## Condition        -0.08      0.07    -0.22     0.06 1.00     1413     1994
## time              0.00      0.04    -0.08     0.08 1.00     1349     1829
## Condition:time    0.00      0.03    -0.05     0.06 1.00     1322     1622
##
## 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     2354     2179
##
## 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).
```
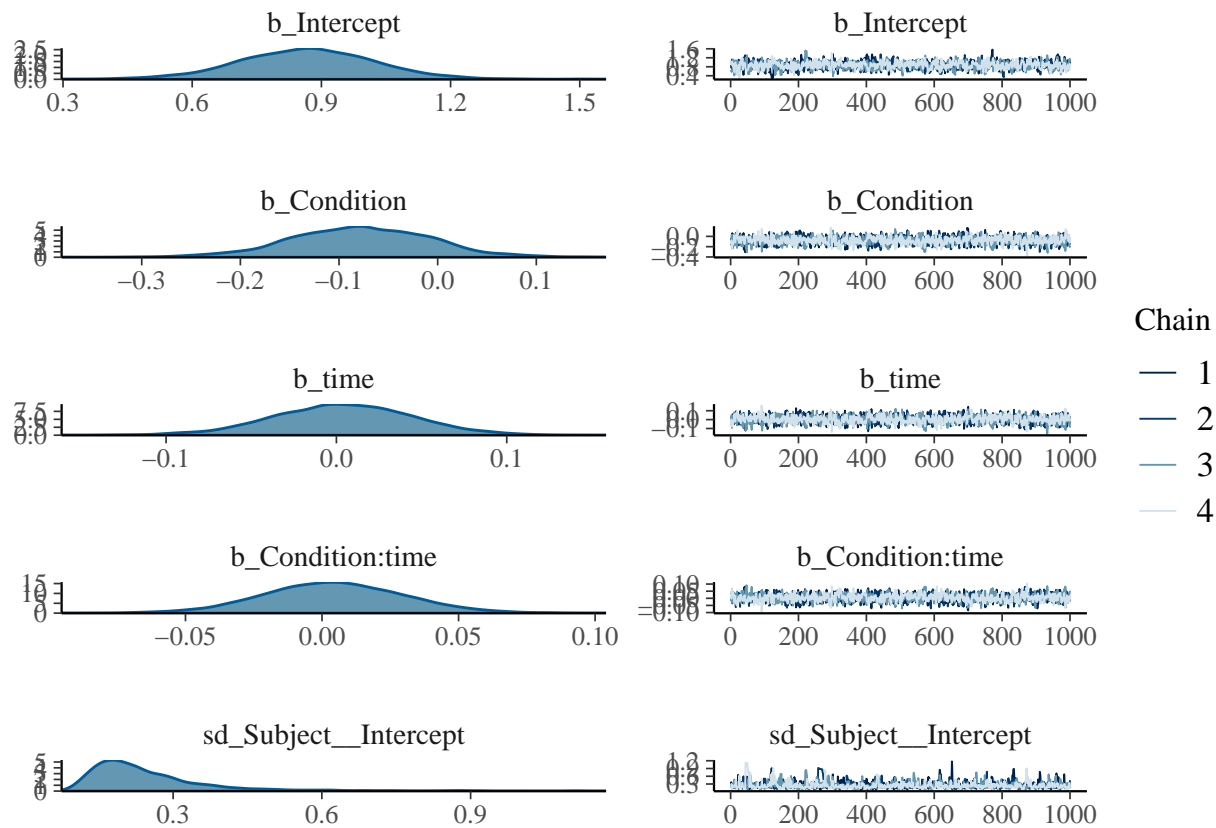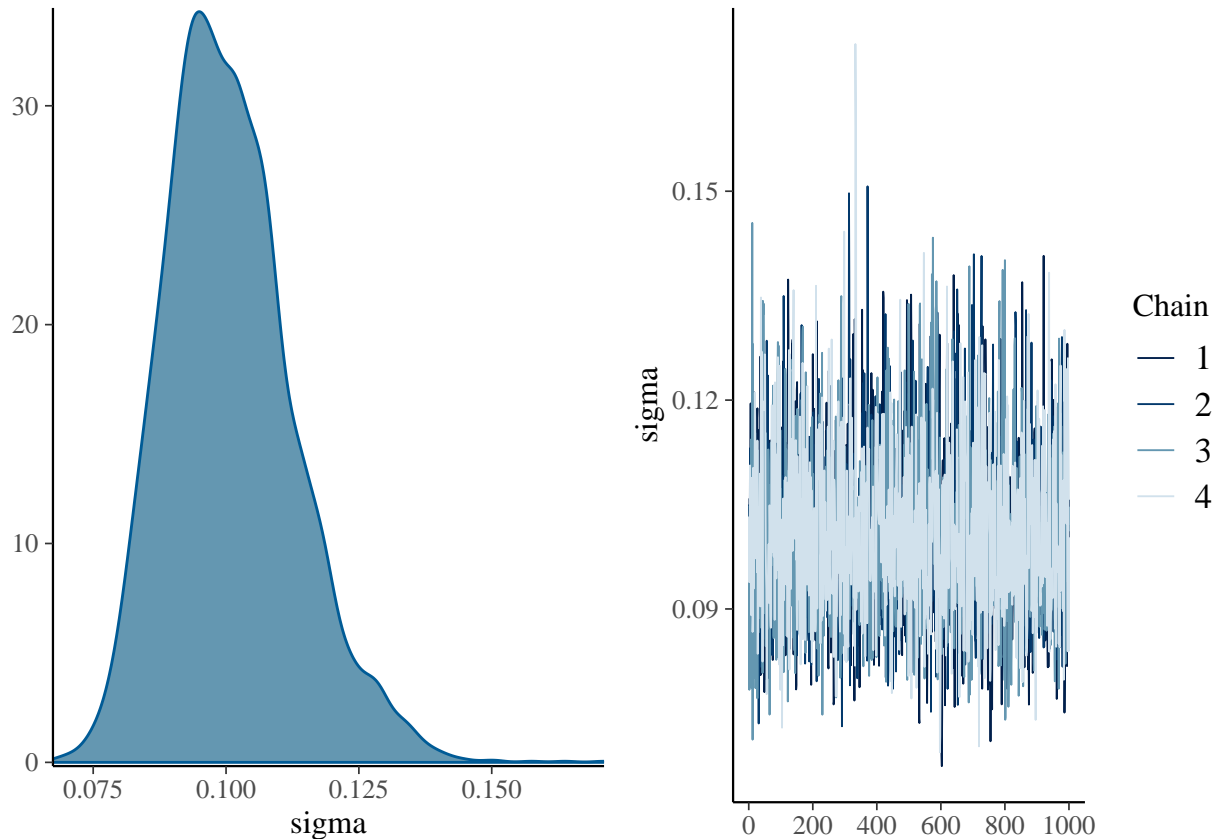
```
plot(bmodel)
```

2.4.1.1   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 2.7e-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: 0.241 seconds (Warm-up)
## Chain 1:                0.148 seconds (Sampling)
## Chain 1:                0.389 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: 0.254 seconds (Warm-up)
## Chain 2:                0.183 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 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: 0.247 seconds (Warm-up)
## Chain 3:                0.216 seconds (Sampling)
## Chain 3:                0.463 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: 0.243 seconds (Warm-up)
## Chain 4:                0.144 seconds (Sampling)
## Chain 4:                0.387 seconds (Total)
## Chain 4:
```

```
summary(bmodel)
```

```
##  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)     0.22      0.10     0.11     0.48 1.00      866     1312
##
## Population-Level Effects:
##                Estimate Est.Error l-95% CI u-95% CI Rhat Bulk_ESS Tail_ESS
## Intercept          0.11      0.14    -0.19     0.40 1.00     1416     1806
## Condition          0.09      0.07    -0.05     0.22 1.00     1878     2165
## time               0.00      0.04    -0.08     0.08 1.00     1869     2081
## Condition:time    -0.01      0.03    -0.06     0.04 1.00     1810     2027
##
## 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 1.00     2245     2336
##
## 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)
```
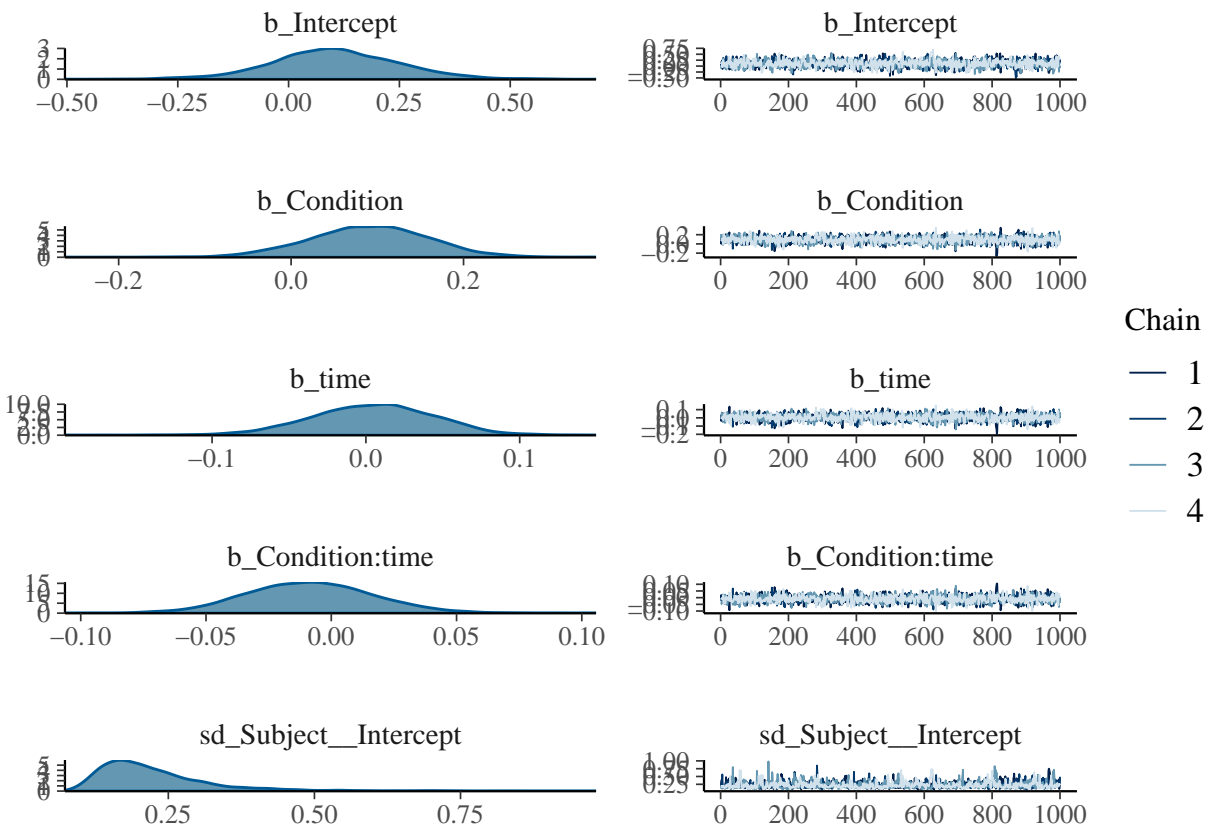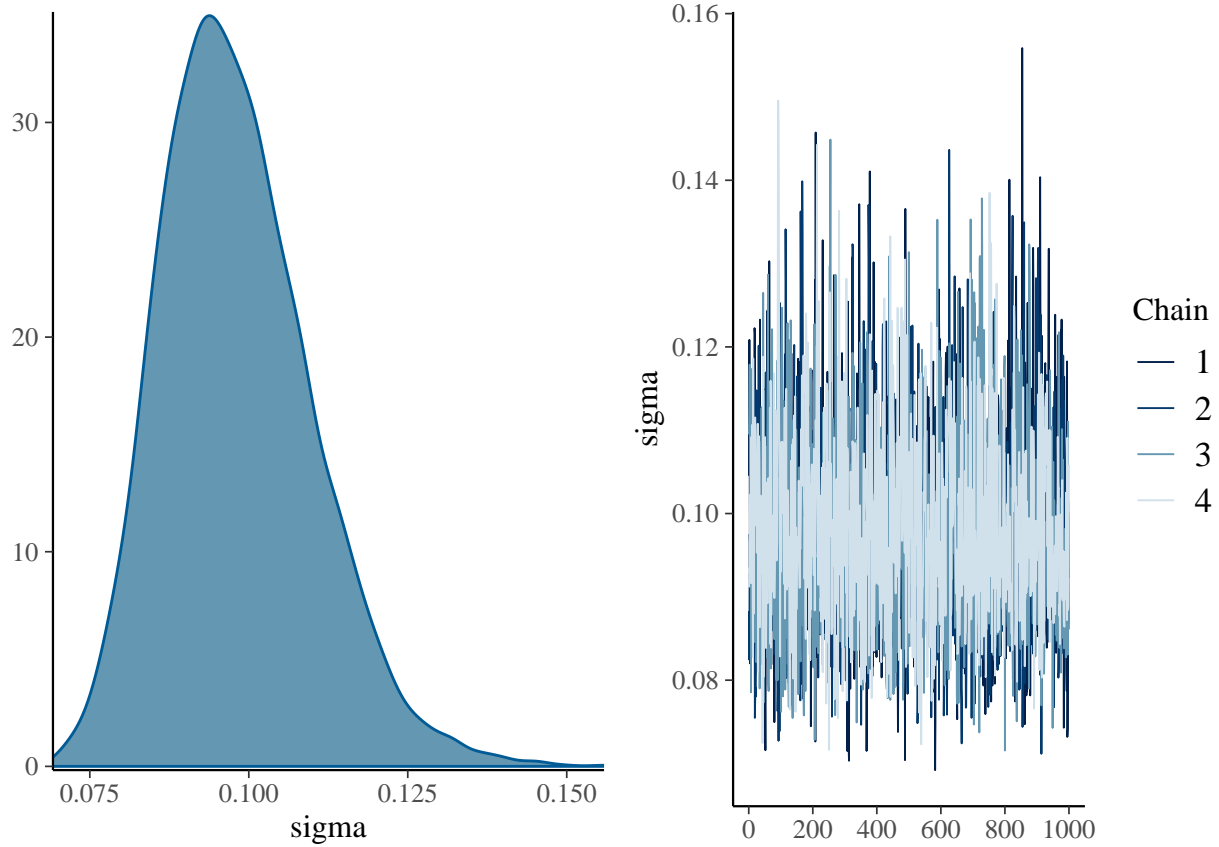
2.4.2.1 Reporting the Negative Performance The effect size for Condition (0.09, 95% CI: -0.05, 0.22) suggests a modest increase in negative performance with robot instructors compared to human instructors. The effect of time (0.00, 95% CI: -0.08, 0.08) indicates no significant linear trend in negative 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.