

GLMM Analysis for Circle Time

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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 Study Design

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

1.2.0.1 Independent Variables

- Instructor Conditions:
 - Human \sim 1
 - Robot \sim 2
- Time
 - Session 1 \sim 1
 - Session 4 \sim 2
 - Session 7 \sim 3
 - Session 10 \sim 4

1.2.0.2 Dependent Variables

- Affect
- Communication
- Engagement
- Performance

1.2.1 Data Collection

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

1.2.1.1 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.

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

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

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

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

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

- Positive
- Negative

1.2.1.5 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 IoA 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:

```
# Recommended Libraries
library(glmTMB)
library(ggplot2)
```

```
## Warning: package 'ggplot2' was built under R version 4.3.2
```

```
library(performance)
library(DHARMa)
```

```
## This is DHARMa 0.4.7. For overview type '?DHARMa'. For recent changes, type news(package = 'DHARMa')
```

```
library(emmeans)
```

```
## Welcome to emmeans.
## Caution: You lose important information if you filter this package's results.
## See '? untidy'
```

```
library(rlang)

# Load data
df <- read.csv("~/GitHub/Circle-Time-Data-Analyses/CircleTimeData-VBMAPP.csv")

# Fix factor labels
df$Condition <- factor(df$Condition, levels = c(1, 2), labels = c("Human", "Robot"))
```

```

# Apply beta regression transformation
epsilon <- 0.0001
vars <- c(
  "Affect_Positive", "Affect_Negative",
  "Communication_with_Instructor", "Communication_with_Instructor_Prompted",
  "Communication_with_Therapist", "Communication_with_Indeterminent",
  "Engagement_OnTarget", "Engagement_Therapist", "Engagement_OffTarget",
  "Performance_Positive"
)
for (v in vars) {
  df[[v]] <- (df[[v]] * (nrow(df) - 1) + epsilon) / nrow(df)
}

# Center time
df$time_c <- scale(df$time, center = TRUE, scale = FALSE)

# Modeling and plotting
model_outputs <- list()
slope_results <- list()

for (var in vars) {
  formula <- as.formula(paste0(var, " ~ Condition * time_c + Condition * VBMAPP + (1 | Subject)"))
  model <- glmmTMB(formula, data = df, family = beta_family())
  model_outputs[[var]] <- model

  # Simple slopes of time within Condition
  slope <- emtrends(model, pairwise ~ Condition, var = "time_c")
  slope_results[[var]] <- slope

  print(paste("==== Behavior:", var, "===="))
  print(summary(model))
  print("Simple slopes of time:")
  print(slope)

  # Plot with aes() using rlang::sym
  p <- ggplot(df, aes(x = time, y = !!sym(var), color = Condition, group = Condition)) +
    stat_summary(fun = mean, geom = "line") +
    stat_summary(fun.data = mean_cl_boot, geom = "errorbar", width = 0.2) +
    labs(title = paste(var, "over Time by Condition"))
  print(p)
}

```

```

## [1] "==== Behavior: Affect_Positive ====="
## Family: beta (logit)
## Formula:
## Affect_Positive ~ Condition * time_c + Condition * VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -120.1   -105.2     68.1   -136.1      40
##
## Random effects:
##

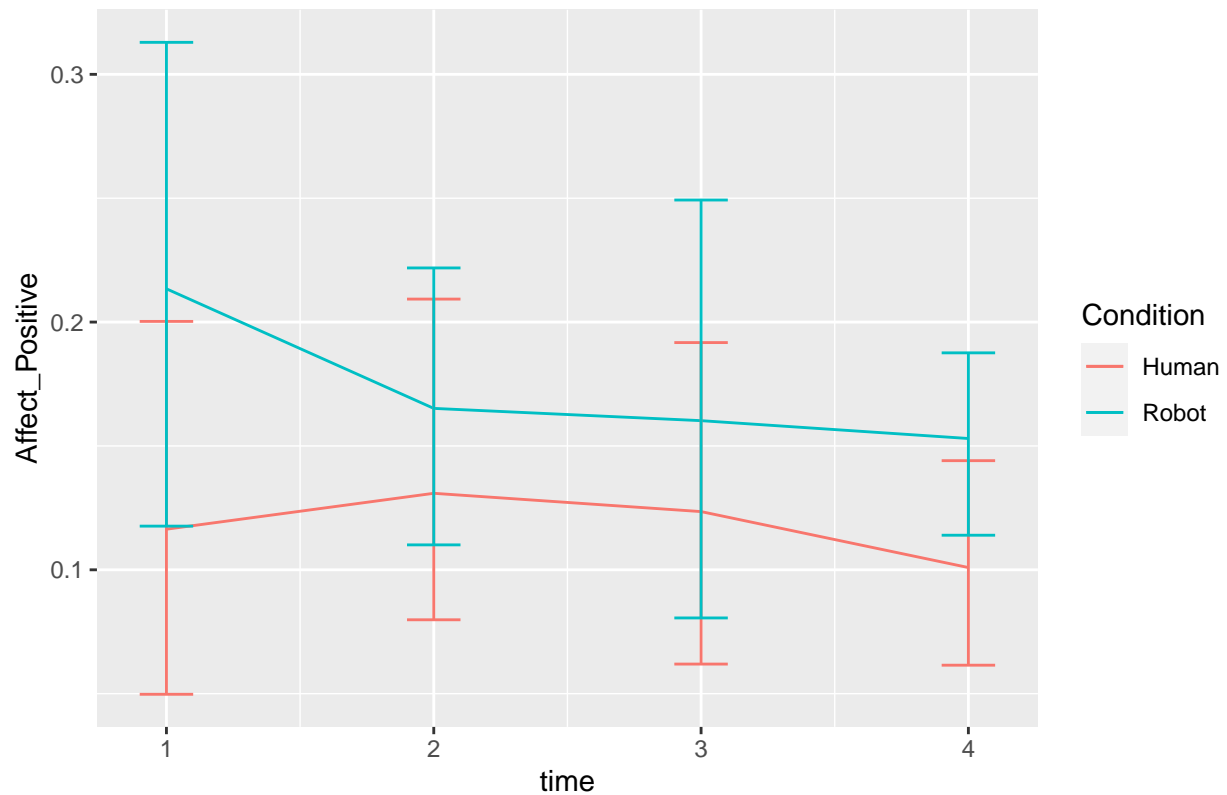
```

```

## Conditional model:
## Groups Name Variance Std.Dev.
## Subject (Intercept) 0.1158 0.3404
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 35.4
##
## Conditional model:
## Estimate Std. Error z value Pr(>|z|)
## (Intercept) 6.01310 3.19339 1.883 0.05970 .
## ConditionRobot -6.27818 2.34983 -2.672 0.00755 **
## time_c -0.04719 0.09014 -0.523 0.60063
## VBMAP -5.05437 1.99219 -2.537 0.01118 *
## ConditionRobot:time_c -0.06959 0.12115 -0.574 0.56570
## ConditionRobot:VBMAP 4.21557 1.47504 2.858 0.00426 **
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human -0.0472 0.0901 Inf -0.224 0.1295
## Robot -0.1168 0.0810 Inf -0.275 0.0419
##
## Confidence level used: 0.95
##
## $contrasts
## contrast estimate SE df z.ratio p.value
## Human - Robot 0.0696 0.121 Inf 0.574 0.5657

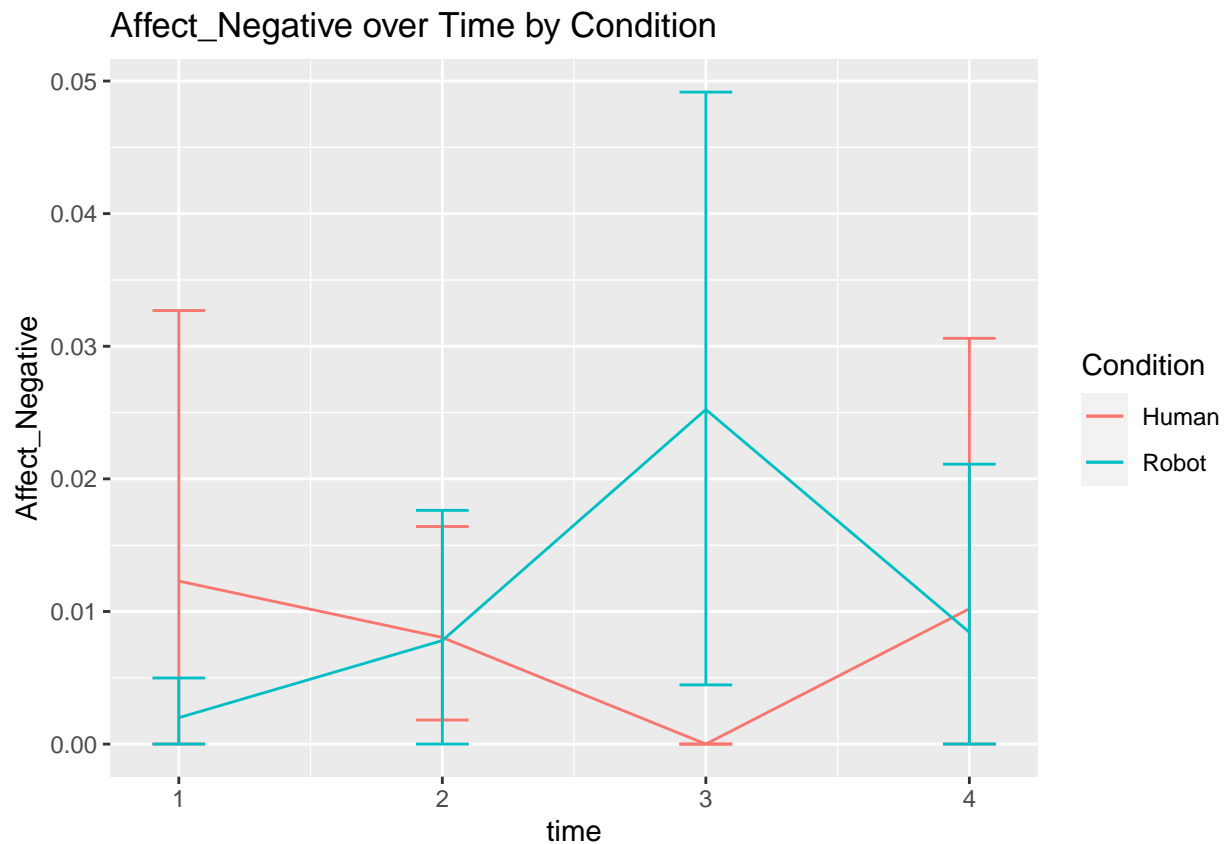
```

Affect_Positive over Time by Condition



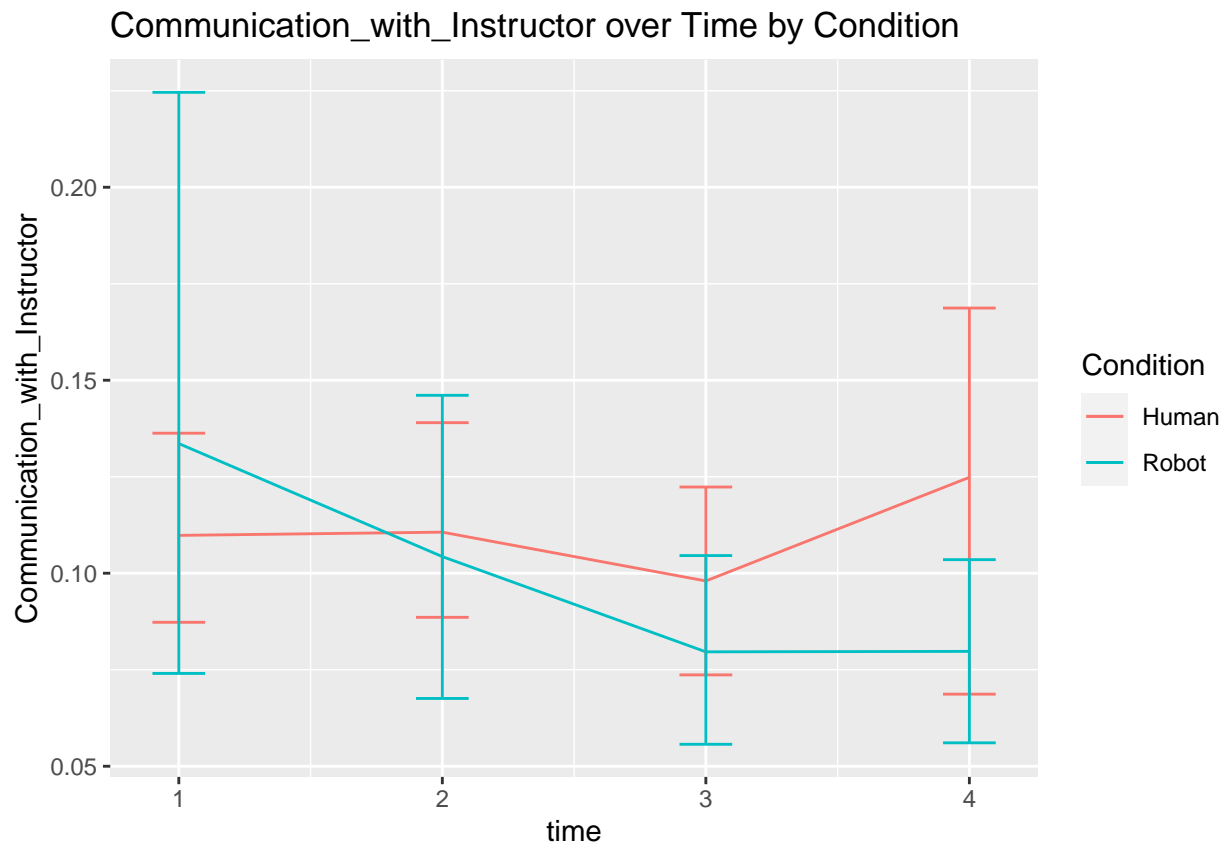
```
## [1] "==== Behavior: Affect_Negative ====="
## Family: beta ( logit )
## Formula:
## Affect_Negative ~ Condition * time_c + Condition * VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##    -654.7   -639.8    335.4   -670.7      40
##
## Random effects:
##
## Conditional model:
##   Groups  Name      Variance Std.Dev.
##   Subject (Intercept) 5.427e-09 7.367e-05
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 16.3
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    -6.29521    3.73329  -1.686   0.0918 .
## ConditionRobot    0.02179    5.41066   0.004   0.9968
## time_c         -0.12038    0.18291  -0.658   0.5104
## VBMAPP           0.92999    2.30321   0.404   0.6864
## ConditionRobot:time_c 0.17542    0.25106   0.699   0.4847
## ConditionRobot:VBMAPP 0.11049    3.35809   0.033   0.9738
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
##   Condition time_c.trend      SE df asymp.LCL asymp.UCL
##   Human          -0.120 0.183 Inf   -0.479    0.238
##   Robot           0.055 0.172 Inf   -0.282    0.392
##
## Confidence level used: 0.95
##
## $contrasts
##   contrast      estimate      SE df z.ratio p.value
##   Human - Robot  -0.175 0.251 Inf  -0.699  0.4847
```



```
## [1] "==== Behavior: Communication_with_Instructor ====="
## Family: beta (logit)
## Formula:
## Communication_with_Instructor ~ Condition * time_c + Condition *
##   VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -150.4   -135.4     83.2   -166.4       40
##
## Random effects:
##
```

```
## Conditional model:
## Groups Name Variance Std.Dev.
## Subject (Intercept) 0.06218 0.2494
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 51.8
##
## Conditional model:
## Estimate Std. Error z value Pr(>|z|)
## (Intercept) -3.839751 2.647106 -1.450 0.147
## ConditionRobot -0.253827 2.538371 -0.100 0.920
## time_c 0.001998 0.079652 0.025 0.980
## VBMAPP 1.081153 1.641104 0.659 0.510
## ConditionRobot:time_c -0.169855 0.116089 -1.463 0.143
## ConditionRobot:VBMAPP 0.066819 1.570527 0.043 0.966
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human 0.002 0.0797 Inf -0.154 0.15811
## Robot -0.168 0.0841 Inf -0.333 -0.00303
##
## Confidence level used: 0.95
##
## $contrasts
## contrast estimate SE df z.ratio p.value
## Human - Robot 0.17 0.116 Inf 1.463 0.1434
```

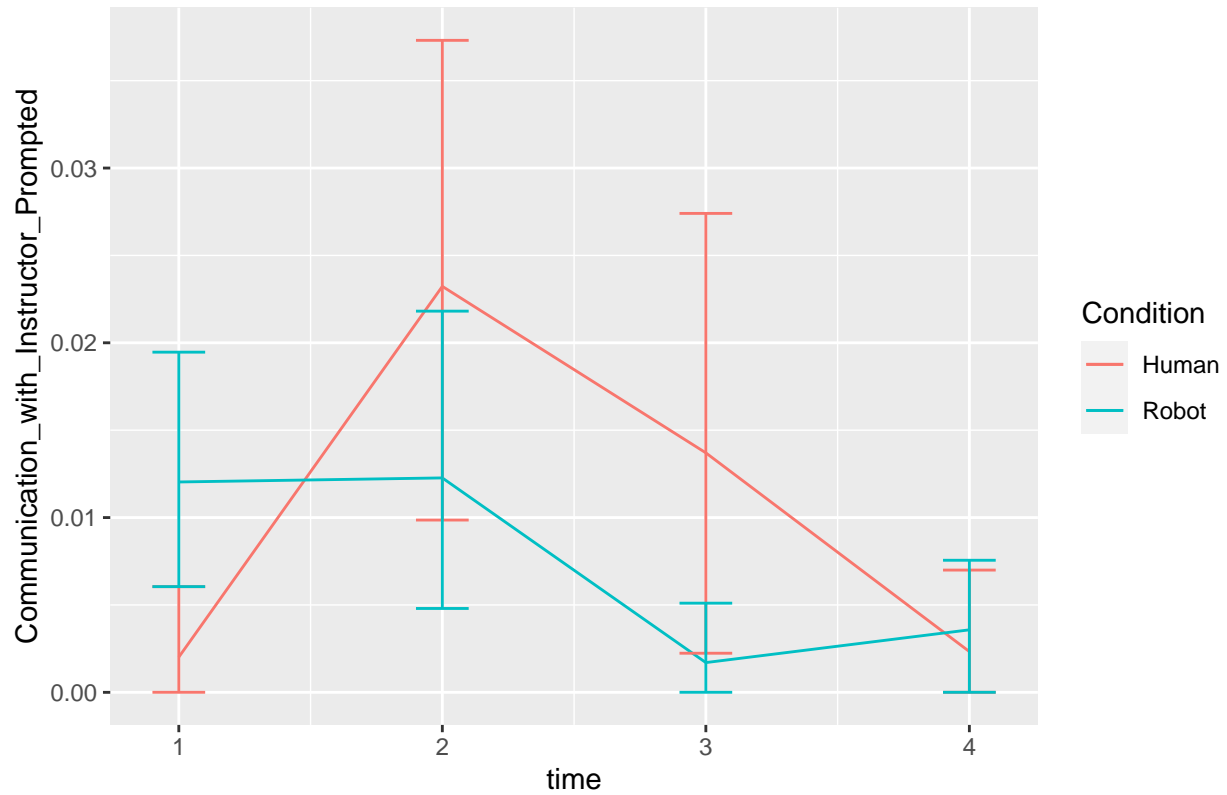



```

## [1] "==== Behavior: Communication_with_Instructor_Prompted ====="
## Family: beta (logit)
## Formula:
## Communication_with_Instructor_Prompted ~ Condition * time_c +
## Condition * VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -581.3   -566.3    298.7   -597.3      40
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 7.725e-13 8.789e-07
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 29.3
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   -11.22113    4.62119  -2.428  0.01517 *
## ConditionRobot    17.81288    5.88338   3.028  0.00246 **
## time_c         -0.02868    0.15310  -0.187  0.85143
## VBMAPP          3.83797    2.84698   1.348  0.17763
## ConditionRobot:time_c -0.33666    0.24156  -1.394  0.16342
## ConditionRobot:VBMAPP -10.91576    3.65587  -2.986  0.00283 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human      -0.0287 0.153 Inf    -0.329  0.27140
## Robot      -0.3653 0.187 Inf    -0.732  0.00101
##
## Confidence level used: 0.95
##
## $contrasts
## contrast      estimate SE df z.ratio p.value
## Human - Robot    0.337 0.242 Inf   1.394  0.1634

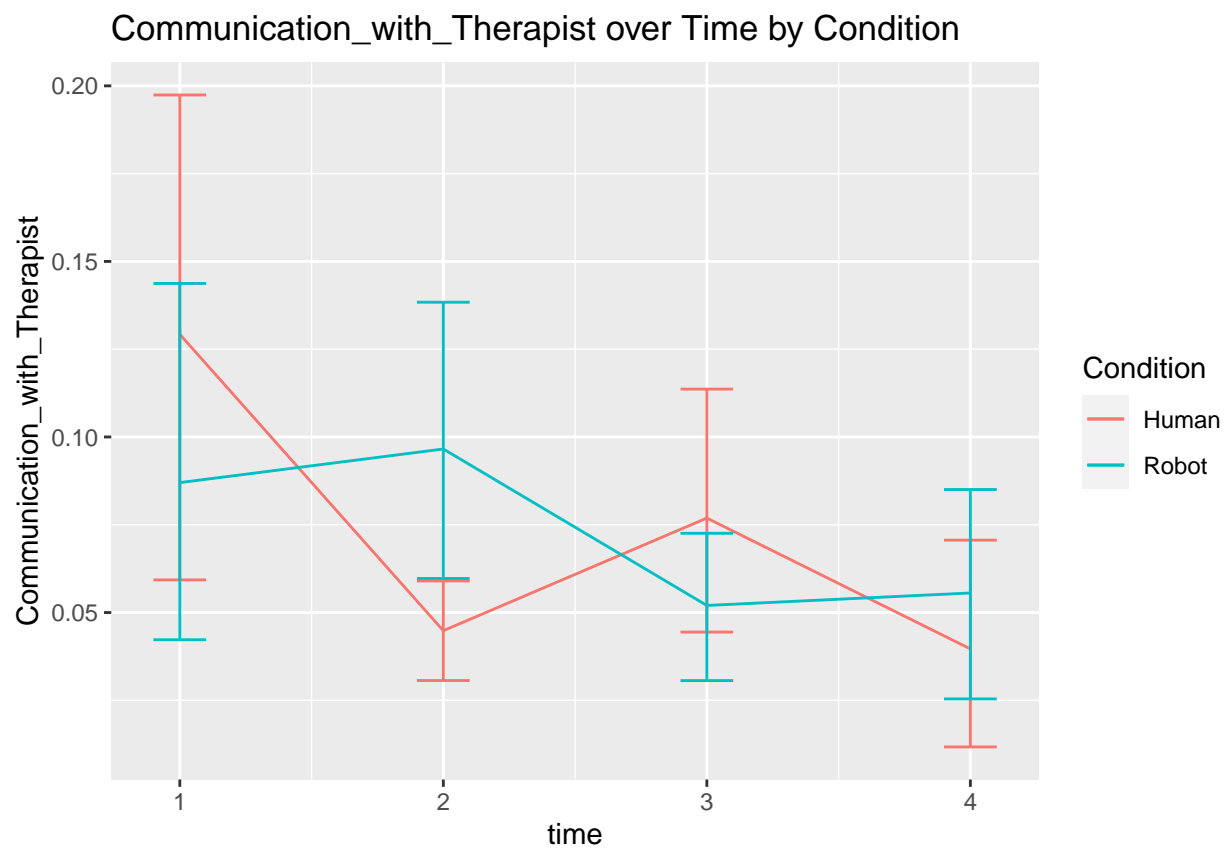
```

Communication_with_Instructor_Prompted over Time by Condition



```
## [1] "==== Behavior: Communication_with_Therapist ====="
## Family: beta ( logit )
## Formula:
## Communication_with_Therapist ~ Condition * time_c + Condition *
## VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -174.2   -159.2     95.1   -190.2      40
##
## Random effects:
##
## Conditional model:
##   Groups Name      Variance Std.Dev.
##   Subject (Intercept) 0.01416  0.119
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 19.5
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      5.8437    2.7466   2.128 0.033372 *
## ConditionRobot    -4.8675    3.8546  -1.263 0.206671
## time_c           -0.5438    0.1419  -3.833 0.000126 ***
## VBMAPP            -5.3687    1.7251  -3.112 0.001858 **
## ConditionRobot:time_c  0.2082    0.1872   1.112 0.265979
```

```
## ConditionRobot:VBMAPP 3.1113 2.4118 1.290 0.197029
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human -0.544 0.142 Inf -0.822 -0.2658
## Robot -0.336 0.142 Inf -0.614 -0.0576
##
## Confidence level used: 0.95
##
## $contrasts
## contrast estimate SE df z.ratio p.value
## Human - Robot -0.208 0.187 Inf -1.112 0.2660
```



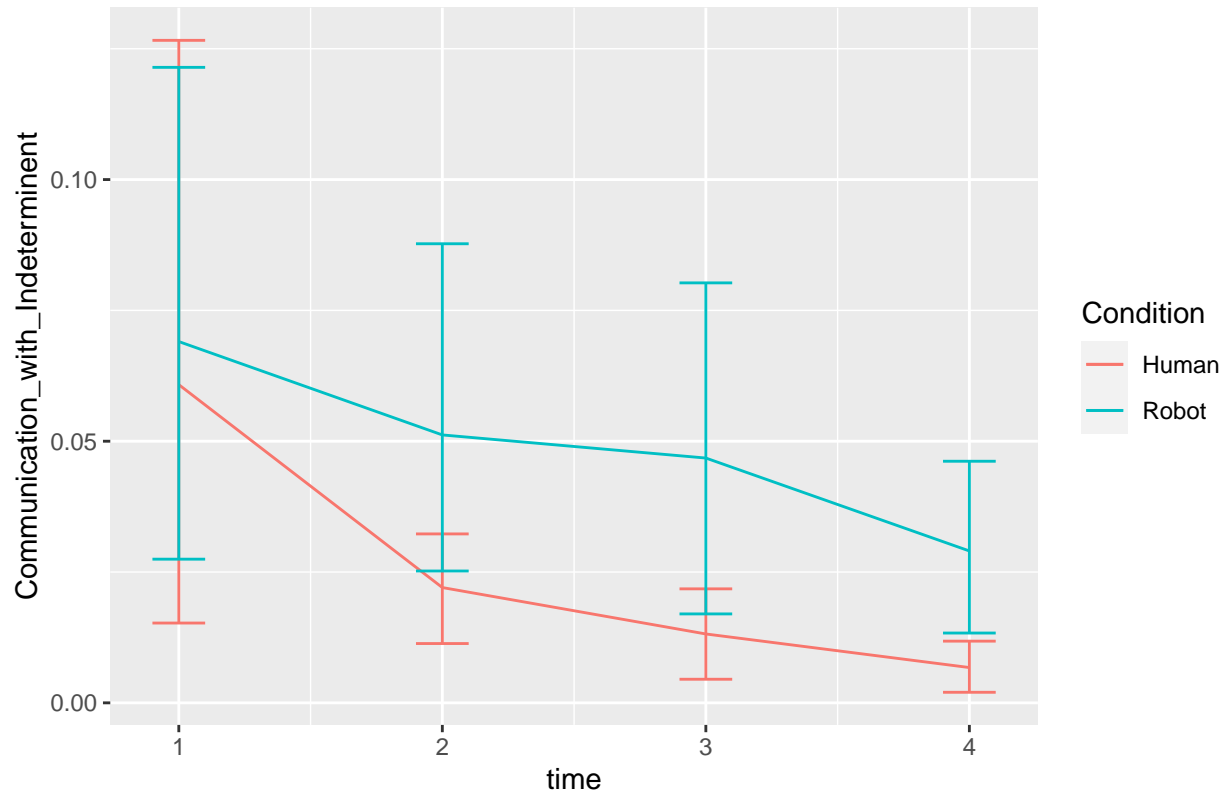
```
## [1] "==== Behavior: Communication_with_Indeterminent ====="
## Family: beta (logit)
## Formula:
## Communication_with_Indeterminent ~ Condition * time_c + Condition *
## VBMAPP + (1 | Subject)
## Data: df
##
## AIC BIC logLik -2*log(L) df.resid
## -288.2 -273.2 152.1 -304.2 40
##
## Random effects:
```

```

##
## Conditional model:
## Groups Name Variance Std.Dev.
## Subject (Intercept) 0.03274 0.1809
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 16.6
##
## Conditional model:
## Estimate Std. Error z value Pr(>|z|)
## (Intercept) 5.16222 3.75467 1.375 0.1692
## ConditionRobot -11.47056 5.24860 -2.186 0.0289 *
## time_c -0.27319 0.17144 -1.593 0.1110
## VBMAP -5.71030 2.35547 -2.424 0.0153 *
## ConditionRobot:time_c 0.04239 0.23497 0.180 0.8568
## ConditionRobot:VBMAP 7.80456 3.26442 2.391 0.0168 *
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human -0.273 0.171 Inf -0.609 0.0628
## Robot -0.231 0.164 Inf -0.552 0.0905
##
## Confidence level used: 0.95
##
## $contrasts
## contrast estimate SE df z.ratio p.value
## Human - Robot -0.0424 0.235 Inf -0.180 0.8568

```

Communication_with_Indeterminent over Time by Condition



```
## [1] "==== Behavior: Engagement_OnTarget ====="
## Family: beta ( logit )
## Formula:
## Engagement_OnTarget ~ Condition * time_c + Condition * VBMAP +
## (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##    -99.5   -84.5     57.7   -115.5      40
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 5.572e-11 7.465e-06
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 31.4
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      0.53469   1.60030   0.334   0.7383
## ConditionRobot      0.81212   2.28159   0.356   0.7219
## time_c            0.17198   0.07728   2.225   0.0261 *
## VBMAP             0.42642   0.99352   0.429   0.6678
## ConditionRobot:time_c -0.16225   0.10772  -1.506   0.1320
```

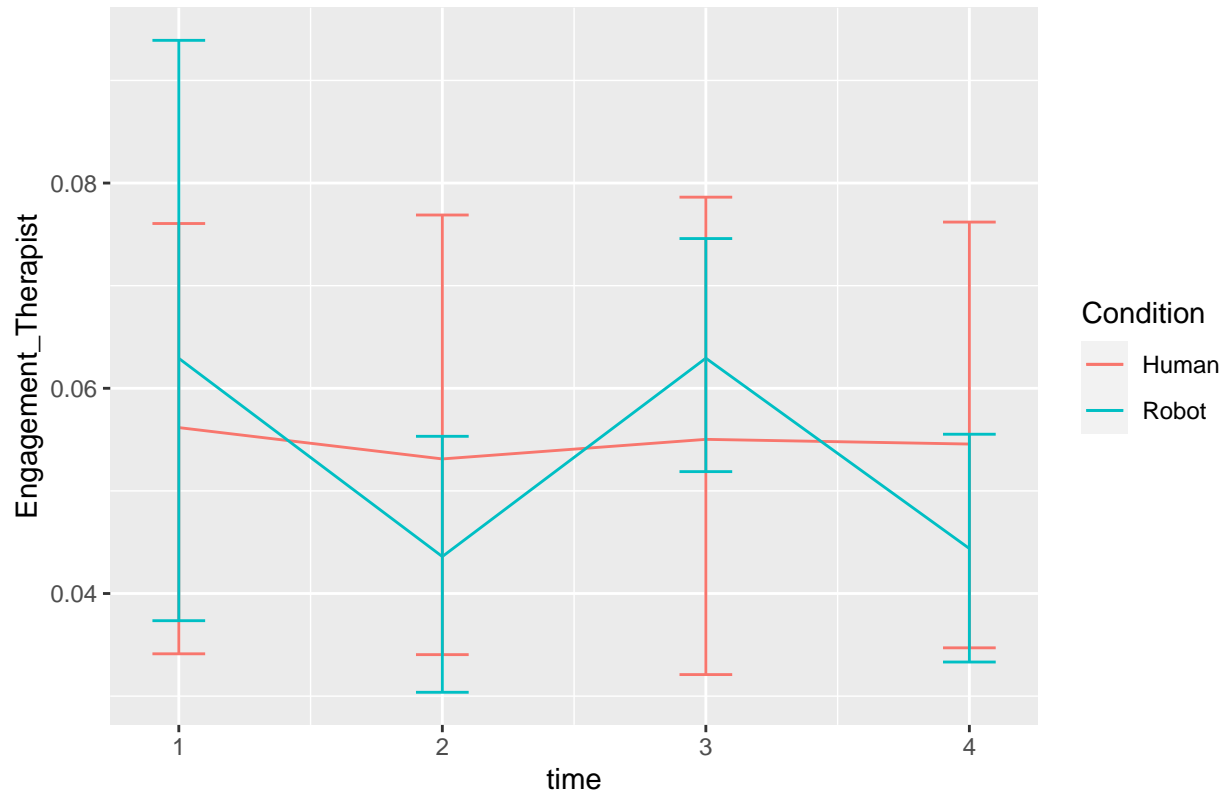
```
## ConditionRobot:VBMAPP -0.53438    1.41626  -0.377   0.7059
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
##   Condition time_c.trend      SE df asymp.LCL asymp.UCL
##   Human          0.17198 0.0773 Inf    0.0205   0.323
##   Robot           0.00973 0.0751 Inf   -0.1374   0.157
##
## Confidence level used: 0.95
##
## $contrasts
##   contrast      estimate      SE df z.ratio p.value
##   Human - Robot    0.162 0.108 Inf   1.506 0.1320
```



```
## [1] "==== Behavior: Engagement_Therapist ====="
## Family: beta ( logit )
## Formula:
## Engagement_Therapist ~ Condition * time_c + Condition * VBMAPP +
##   (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##    -206.9   -191.9    111.4   -222.9       40
##
## Random effects:
```

```
##
## Conditional model:
##   Groups   Name      Variance Std.Dev.
##   Subject (Intercept) 3.455e-10 1.859e-05
## Number of obs: 48, groups:  Subject, 6
##
## Dispersion parameter for beta family (): 76.9
##
## Conditional model:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)      -0.45397    1.82338  -0.249    0.803
## ConditionRobot    -0.21058    2.61027  -0.081    0.936
## time_c           -0.00490    0.08759  -0.056    0.955
## VBMAPP            -1.50391    1.13821  -1.321    0.186
## ConditionRobot:time_c -0.02194    0.12295  -0.178    0.858
## ConditionRobot:VBMAPP 0.13684    1.62866   0.084    0.933
## [1] "Simple slopes of time:"
## $emtrends
##   Condition time_c.trend      SE  df asymp.LCL asymp.UCL
##   Human          -0.0049 0.0876 Inf   -0.177    0.167
##   Robot          -0.0268 0.0863 Inf   -0.196    0.142
##
## Confidence level used: 0.95
##
## $contrasts
##   contrast      estimate      SE  df z.ratio p.value
##   Human - Robot   0.0219 0.123 Inf   0.178  0.8584
```

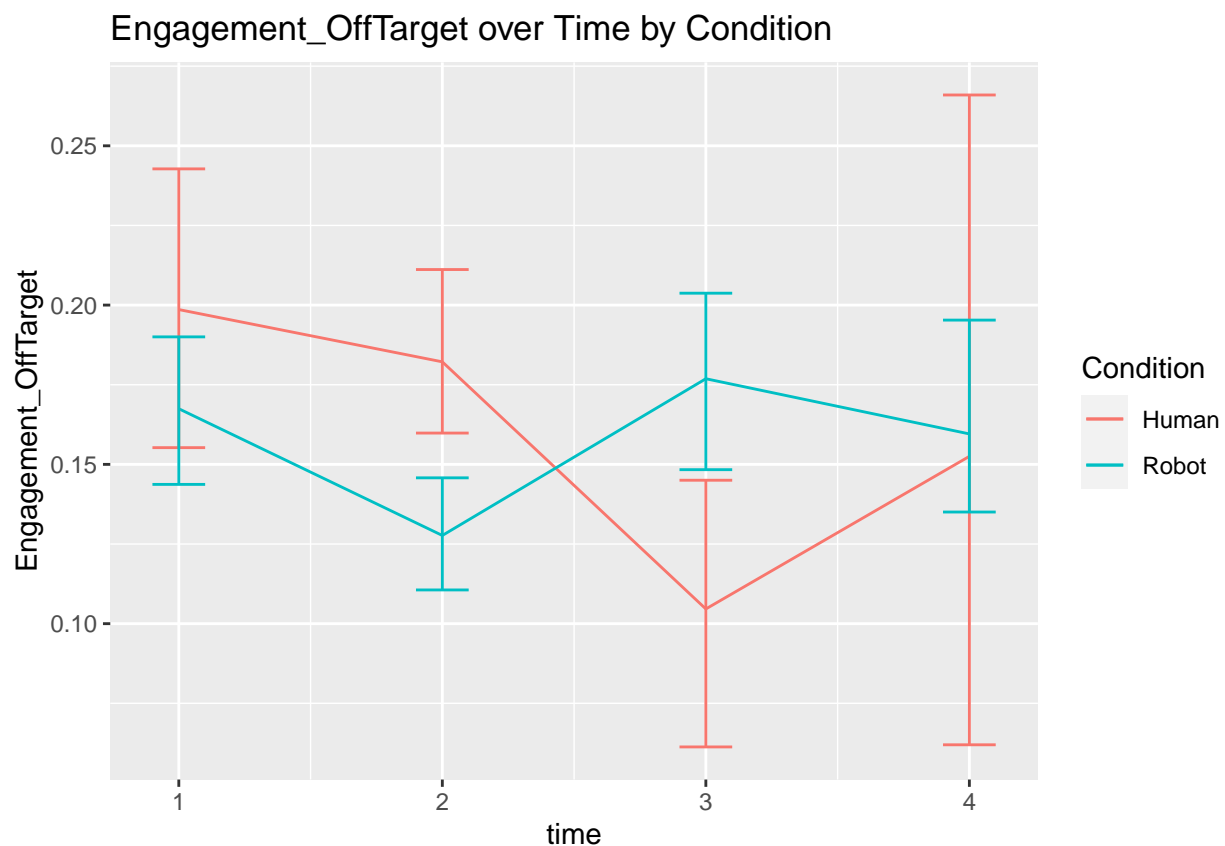
Engagement_Therapist over Time by Condition



```
## [1] "==== Behavior: Engagement_OffTarget ====="
## Family: beta ( logit )
## Formula:
## Engagement_OffTarget ~ Condition * time_c + Condition * VBMAPP +
## (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##    -115.1   -100.1     65.6   -131.1      40
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 2.345e-10 1.531e-05
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 30.4
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)   -1.89449    1.88725  -1.004  0.31546
## ConditionRobot -0.60091    2.65643  -0.226  0.82104
## time_c        -0.26905    0.09248  -2.909  0.00362 **
## VBMAPP         0.08467    1.16912   0.072  0.94227
## ConditionRobot:time_c 0.28367    0.12652   2.242  0.02495 *
```



```
## ConditionRobot:VBMAPP 0.46100 1.64638 0.280 0.77947
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human -0.2691 0.0925 Inf -0.450 -0.0878
## Robot 0.0146 0.0863 Inf -0.155 0.1838
##
## Confidence level used: 0.95
##
## $contrasts
## contrast estimate SE df z.ratio p.value
## Human - Robot -0.284 0.127 Inf -2.242 0.0250
```



```
## [1] "==== Behavior: Performance_Positive ====="
## Family: beta ( logit )
## Formula:
## Performance_Positive ~ Condition * time_c + Condition * VBMAPP +
## (1 | Subject)
## Data: df
##
## AIC BIC logLik -2*log(L) df.resid
## -79.8 -64.8 47.9 -95.8 40
##
## Random effects:
```

```

##
## Conditional model:
## Groups Name Variance Std.Dev.
## Subject (Intercept) 0.2101 0.4584
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 18.8
##
## Conditional model:
## Estimate Std. Error z value Pr(>|z|)
## (Intercept) -11.91777 4.15671 -2.867 0.00414 **
## ConditionRobot -1.33558 2.77109 -0.482 0.62983
## time_c 0.02756 0.10573 0.261 0.79435
## VBMAP 8.35390 2.59090 3.224 0.00126 **
## ConditionRobot:time_c 0.01900 0.14444 0.132 0.89533
## ConditionRobot:VBMAP 0.60602 1.74123 0.348 0.72781
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## [1] "Simple slopes of time:"
## $emtrends
## Condition time_c.trend SE df asymp.LCL asymp.UCL
## Human 0.0276 0.1060 Inf -0.180 0.235
## Robot 0.0466 0.0999 Inf -0.149 0.242
##
## Confidence level used: 0.95
##
## $contrasts
## contrast estimate SE df z.ratio p.value
## Human - Robot -0.019 0.144 Inf -0.132 0.8953

```

