

# GLMM Analysis for Circle Time

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## 0.1 Performance

### 0.1.1 Positive Performance

```
library(glmTMB)
```

```
## Warning: package 'glmTMB' was built under R version 4.3.3
```

```
## Warning in checkMatrixPackageVersion(): Package version inconsistency detected.
```

```
## TMB was built with Matrix version 1.6.2
```

```
## Current Matrix version is 1.6.3
```

```
## Please re-install 'TMB' from source using install.packages('TMB', type = 'source') or ask CRAN for a
```

```
## Warning in check_dep_version(dep_pkg = "TMB"): package version mismatch:
## glmmTMB was built with TMB package version 1.9.17
## Current TMB package version is 1.9.6
## Please re-install glmmTMB from source or restore original 'TMB' package (see '?reinstalling' for more)
```

```
library(performance)
library(DHARMA)
```

```
## Warning: package 'DHARMA' was built under R version 4.3.3
```

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

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

epsilon <- 0.0001
df$Performance_Positive <- (df$Performance_Positive * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmmTMB(
  Performance_Positive ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta ( logit )
## Formula:
## Performance_Positive ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##    -83.7    -72.4     47.8    -95.7        42
##
## Random effects:
##
## Conditional model:
##   Groups  Name      Variance Std.Dev.
## Subject (Intercept) 0.2118   0.4602
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 18.7
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -12.14232    3.91842  -3.099 0.001943 **
## Condition   -0.37430    0.16107  -2.324 0.020136 *
## time         0.03778    0.07301   0.517 0.604878
## VBMAPP       8.67247    2.43262   3.565 0.000364 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

The model revealed a significant main effect of instructor condition on children's performance ( $= -0.374$ ,  $p = .020$ ). Performance was significantly lower in robot-led sessions compared to human-led sessions. Developmental ability, as measured by the VB-MAPP score, was a strong positive predictor ( $= 8.672$ ,  $p < .001$ ), indicating that children with higher scores consistently outperformed their peers. Time did not significantly impact performance ( $= 0.038$ ,  $p = .605$ ), suggesting stability across sessions.

## 0.2 Affect

### 0.2.1 Positive Affect

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

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

epsilon <- 0.0001
df$Affect_Positive <- (df$Affect_Positive * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmTMB(
  Affect_Positive ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta ( logit )
## Formula:          Affect_Positive ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -116.2   -104.9     64.1    -128.2      42
##
## Random effects:
##
## Conditional model:
##  Groups Name      Variance Std.Dev.
## Subject (Intercept) 0.1056   0.325
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 28.8
##
## Conditional model:
##           Estimate Std. Error z value Pr(>|z|)
## (Intercept)  1.98507    2.91381   0.681   0.4957
## Condition    0.43524    0.15082   2.886   0.0039 **
## time        -0.07760    0.06579  -1.179   0.2382
## VBMAPP       -2.66257    1.79291  -1.485   0.1375
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Positive affect was significantly higher during robot-led sessions ( $\beta = 0.435$ ,  $p = .0039$ ), suggesting that robots may enhance emotional engagement. Neither session time ( $\beta = -0.078$ ,  $p = .238$ ) nor VB-MAPP score ( $\beta = -2.663$ ,  $p = .138$ ) significantly predicted positive affect, indicating that this emotional response was broadly distributed across ability levels and consistent across sessions.

## 0.2.2 Negative Affect

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

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

epsilon <- 0.0001
df$Affect_Negative <- (df$Affect_Negative * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmmTMB(
  Affect_Negative ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta (logit)
## Formula: Affect_Negative ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##           AIC           BIC      logLik -2*log(L)  df.resid
##      -658.2      -647.0       335.1     -670.2        42
##
## Random effects:
##
## Conditional model:
##   Groups Name      Variance Std.Dev.
## Subject (Intercept) 4.046e-09 6.361e-05
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 16.1
##
## Conditional model:
##           Estimate Std. Error z value Pr(>|z|)
## (Intercept) -6.5531      2.7593  -2.375  0.0176 *
## Condition      0.1998      0.2885   0.693  0.4886
## time        -0.0267      0.1260  -0.212  0.8322
## VBMAPP        1.0101      1.6726   0.604  0.5459
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Negative affect was generally low and did not vary significantly by instructor type ( $\beta = 0.200$ ,  $p = .489$ ), time ( $\beta = -0.027$ ,  $p = .832$ ), or VB-MAPP score ( $\beta = 1.010$ ,  $p = .546$ ). The intercept was significant ( $\beta = -6.553$ ,  $p = .0176$ ), confirming low baseline levels of negative affect.

## 0.3 Engagement

### 0.3.1 On Target

```
library(glmTMB)
library(performance)
library(DHARMA)

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

epsilon <- 0.0001
df$Engagement_OnTarget <- (df$Engagement_OnTarget * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmmTMB(
  Engagement_OnTarget ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta (logit)
## Formula:
## Engagement_OnTarget ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -101.1    -89.9     56.5   -113.1      42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 8.07e-11 8.984e-06
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 29.8
##
## Conditional model:
##           Estimate Std. Error z value Pr(>|z|)
## (Intercept)  0.72094    1.18527   0.608   0.543
## Condition   -0.03825    0.12156  -0.315   0.753
## time         0.08954    0.05507   1.626   0.104
## VBMAPP       0.19090    0.72318   0.264   0.792
```

None of the predictors significantly influenced on-target engagement. Condition ( = -0.038,  $p = .753$ ), time ( = 0.090,  $p = .104$ ), and VB-MAPP ( = 0.191,  $p = .792$ ) had no meaningful effect. A marginal trend toward increased engagement over time suggests potential learning effects that could be explored further.

### 0.3.2 Therapist

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

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

epsilon <- 0.0001
df$Engagement_Therapist <- (df$Engagement_Therapist * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmTMB(
  Engagement_Therapist ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)

## Family: beta (logit)
## Formula:
## Engagement_Therapist ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -210.8   -199.6    111.4   -222.8      42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 4.62e-10 2.149e-05
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 76.8
##
## Conditional model:
##      Estimate Std. Error z value Pr(>|z|)
## (Intercept) -0.528353   1.338373 -0.395  0.6930
## Condition    0.008796   0.137460  0.064  0.9490
## time        -0.015989   0.061485 -0.260  0.7948
## VBMAPP       -1.438023   0.814705 -1.765  0.0775 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Engagement with the therapist was marginally negatively associated with VB-MAPP score ( $\beta = -1.438$ ,  $p = .078$ ), suggesting that lower-ability children may rely more heavily on therapist support. Neither condition ( $\beta = 0.009$ ,  $p = .949$ ) nor time ( $\beta = -0.016$ ,  $p = .795$ ) showed a significant effect.

### 0.3.3 Off Target

```
library(glmmTMB)
library(performance)
library(DHARMA)

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

epsilon <- 0.0001
df$Engagement_OffTarget <- (df$Engagement_OffTarget * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmmTMB(
  Engagement_OffTarget ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)

## Family: beta (logit)
## Formula:
## Engagement_OffTarget ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -114.1   -102.9     63.1   -126.1      42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 2.748e-10 1.658e-05
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 27.3
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  -1.9470     1.4064  -1.384   0.1662
## Condition      0.1144     0.1448   0.790   0.4296
## time          -0.1201     0.0663  -1.811   0.0702 .
## VBMAPP         0.2469     0.8599   0.287   0.7740
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Off-target engagement increased marginally over time (  $\beta = -0.120$ ,  $p = .070$ ), possibly reflecting fatigue or declining focus. Condition (  $\beta = 0.114$ ,  $p = .430$ ) and VB-MAPP (  $\beta = 0.247$ ,  $p = .774$ ) were not significant predictors.

## 0.4 Communication

### 0.4.1 Communication with Instructor

```
library(glmmTMB)
library(performance)
library(DHARMA)

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

epsilon <- 0.0001
df$Communication_with_Instructor <- (df$Communication_with_Instructor * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmmTMB(
  Communication_with_Instructor ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta (logit)
## Formula:
## Communication_with_Instructor ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -152.3   -141.1     82.2   -164.3      42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 0.05305  0.2303
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 48.5
##
## Conditional model:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept) -3.47435    2.25404  -1.541   0.123
## Condition   -0.13586    0.13060  -1.040   0.298
## time        -0.07903    0.05940  -1.330   0.183
## VBMAPP       1.06301    1.39264   0.763   0.445
```

Communication directed at the instructor was not significantly influenced by condition ( $\beta = -0.136$ ,  $p = .298$ ), time ( $\beta = -0.079$ ,  $p = .183$ ), or VB-MAPP score ( $\beta = 1.063$ ,  $p = .445$ ), indicating stable and consistent patterns of direct instructor communication across all factors.



## 0.4.2 Communication with Instructor - Prompted

```
library(glmTMB)
library(performance)
library(DHARMA)

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

epsilon <- 0.0001
df$Communication_with_Instructor_Prompted <- (df$Communication_with_Instructor_Prompted * (nrow(df) - 1))

model <- glmmTMB(
  Communication_with_Instructor_Prompted ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta (logit)
## Formula:
## Communication_with_Instructor_Prompted ~ Condition + time + VBMAPP +
## (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -574.7   -563.5     293.3   -586.7       42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 1.854e-09 4.306e-05
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 21.6
##
## Conditional model:
##      Estimate Std. Error z value Pr(>|z|)
## (Intercept) -2.4904     2.9788  -0.836   0.403
## Condition    0.2387     0.3131   0.762   0.446
## time        -0.1782     0.1238  -1.439   0.150
## VBMAPP       -1.3596     1.9355  -0.703   0.482
```

Prompted communication with the instructor showed no significant effects of condition ( $\beta = 0.239$ ,  $p = .446$ ), time ( $\beta = -0.178$ ,  $p = .150$ ), or VB-MAPP score ( $\beta = -1.360$ ,  $p = .482$ ), though the negative time trend may reflect increased autonomy over sessions.

### 0.4.3 Communication with Therapist

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

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

epsilon <- 0.0001
df$Communication_with_Therapist <- (df$Communication_with_Therapist * (nrow(df) - 1) + epsilon) / nrow(df)

model <- glmTMB(
  Communication_with_Therapist ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)
```

```
## Family: beta (logit)
## Formula:
## Communication_with_Therapist ~ Condition + time + VBMAPP + (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##    -175.2   -163.9     93.6   -187.2      42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 0.001637 0.04046
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 18.1
##
## Conditional model:
##           Estimate Std. Error z value Pr(>|z|)
## (Intercept)  4.66673    2.13643   2.184  0.02894 *
## Condition    0.03221    0.22585   0.143  0.88658
## time        -0.44995    0.11320  -3.975 7.05e-05 ***
## VBMAPP       -3.91937    1.27469  -3.075  0.00211 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Communication with the therapist declined significantly over time ( $\beta = -0.450$ ,  $p < .001$ ) and was significantly lower among children with higher VB-MAPP scores ( $\beta = -3.919$ ,  $p = .002$ ), suggesting increased independence. No condition effect was found ( $\beta = 0.032$ ,  $p = .887$ ).

#### 0.4.4 Communication with Indeterminant

```
library(glmmTMB)
library(performance)
library(DHARMA)

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

epsilon <- 0.0001
df$Communication_with_Indeterminant <- (df$Communication_with_Indeterminant * (nrow(df) - 1) + epsilon)

model <- glmmTMB(
  Communication_with_Indeterminant ~ Condition + time + VBMAPP + (1 | Subject),
  data = df,
  family = beta_family()
)

summary(model)

## Family: beta (logit)
## Formula:
## Communication_with_Indeterminant ~ Condition + time + VBMAPP +
## (1 | Subject)
## Data: df
##
##      AIC      BIC    logLik -2*log(L)  df.resid
##   -286.6   -275.4    149.3   -298.6      42
##
## Random effects:
##
## Conditional model:
## Groups Name      Variance Std.Dev.
## Subject (Intercept) 0.02735  0.1654
## Number of obs: 48, groups: Subject, 6
##
## Dispersion parameter for beta family (): 14.4
##
## Conditional model:
##           Estimate Std. Error z value Pr(>|z|)
## (Intercept) -2.4492     3.2374  -0.757 0.449337
## Condition    1.0545     0.2942   3.585 0.000337 ***
## time        -0.2257     0.1217  -1.854 0.063799 .
## VBMAPP       -1.2428     1.8880  -0.658 0.510348
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Indeterminate communication was significantly more frequent in robot-led sessions ( $\beta = 1.055$ ,  $p < .001$ ), which may indicate breakdowns in communication or uncertainty about the robot's role. Time showed a marginal decrease ( $\beta = -0.226$ ,  $p = .064$ ), while VB-MAPP score had no significant effect ( $\beta = -1.243$ ,  $p = .510$ ).