Linear (Mixed Effects) Models for LDM

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Age-IQ Analysis

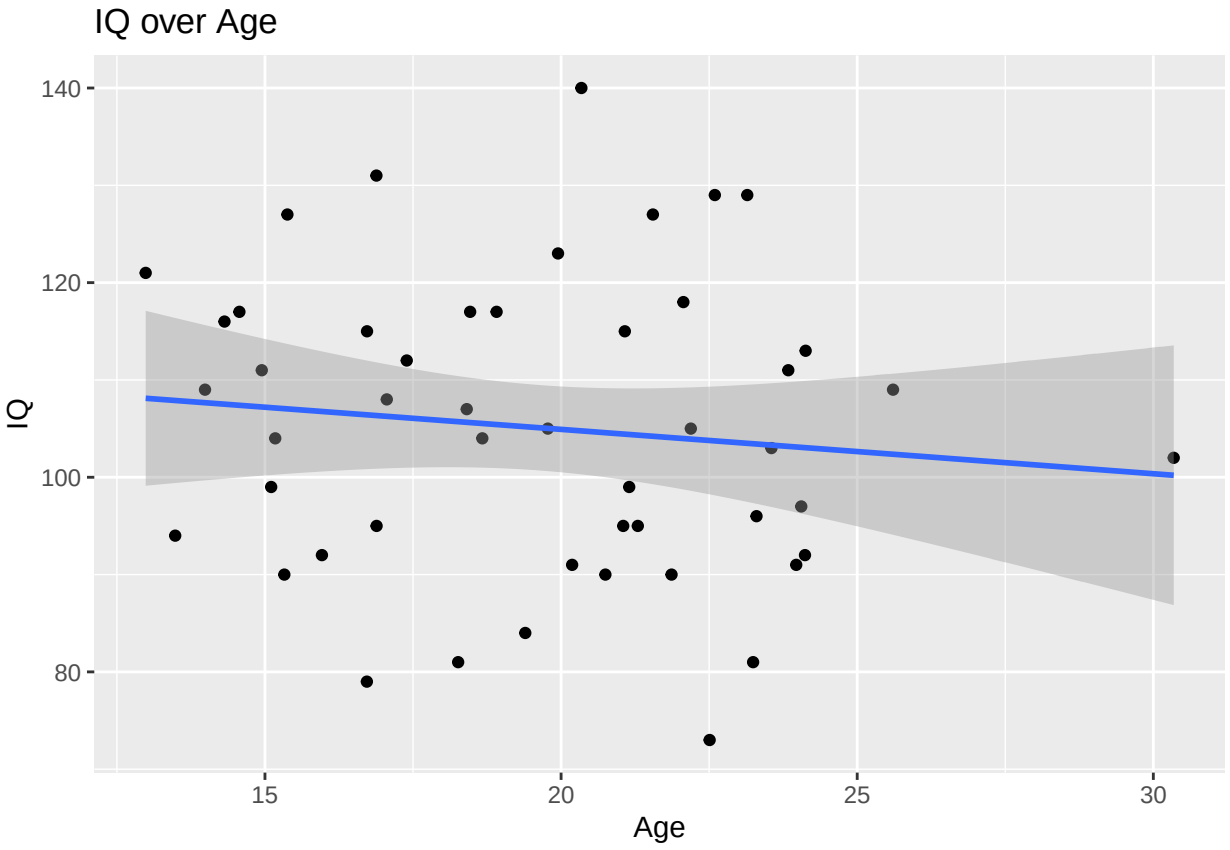
First, we run a simple linear model to see if there is an effect of age on WASI score (IQ). We regress WASI Score (IQ) on continuous age and see no significant correlation.

```
## # A tibble: 2 x 5
##   term        estimate std.error statistic  p.value
##   <chr>          <dbl>     <dbl>     <dbl>    <dbl>
## 1 (Intercept)  114.       11.7       9.74  7.40e-13
## 2 Age           -0.456     0.585    -0.778 4.40e- 1
```

```
## `geom_smooth()` using formula 'y ~ x'
```

```
## Warning: Removed 2 rows containing non-finite values (stat_smooth).
```

```
## Warning: Removed 2 rows containing missing values (geom_point).
```



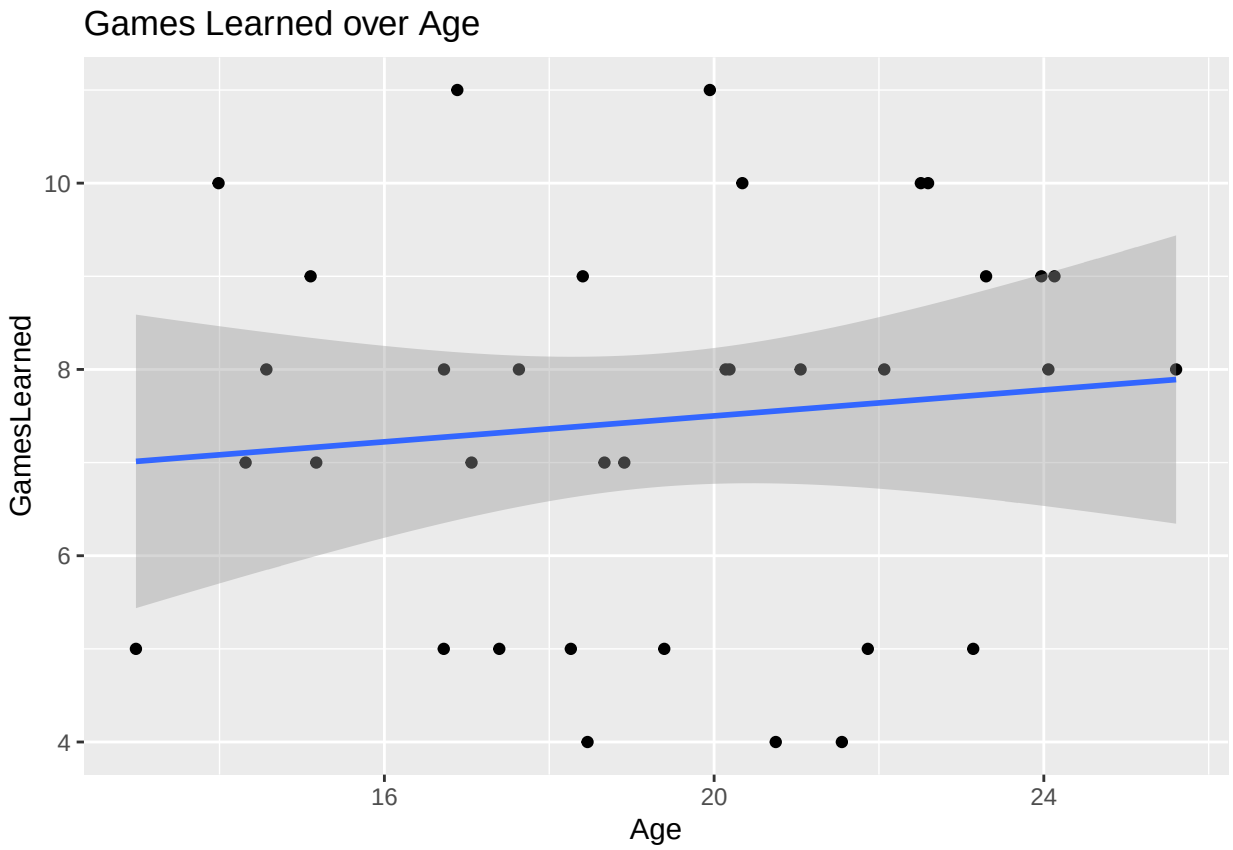
Look at Learning over Age

Next, we run a simple linear model to see if there is an effect of age on the number of games that a subject has learned. We compute number of games learned as the number of games that a subject's point of learning (100% accuracy in all subsequent trials) is before the 15th trial. We regress the sum stored in GamesLearned on continuous age and see no significant correlation.

```
## `summarise()` has grouped output by 'Subj'. You can override using the `.groups` argument.
```

```
## # A tibble: 2 x 5
##   term        estimate std.error statistic p.value
##   <chr>          <dbl>     <dbl>     <dbl>   <dbl>
## 1 (Intercept)   6.11       2.12      2.88  0.00699
## 2 Age           0.0696     0.108     0.644 0.524
```

```
## `geom_smooth()` using formula 'y ~ x'
```



Linear Models using Feedback data and Entropy as target variable

To get at the interactions we're interested in, we first run simple linear models with fixed effects to create plots with the interactions that we saw during visualizations

First, we'll look at `Entropy ~ WithinGameTrial + AgeGroup`.

```
data <- read.csv('https://raw.githubusercontent.com/angelaradulescu/ldm-analysis/main/ProcessedData/Feed

model_data <- data %>%
  select(Subj, Entropy, Age, AgeGroup, WithinGameTrial, Game, LearnedGame, Learned, IQ, PoL) %>%
  mutate(scaled_age = scale_this(Age),
         scaled_iq = scale_this(IQ),
         subject_id = as.factor(Subj),
         age_group = as.factor(AgeGroup))


# make new AlignedTrial value and LearnedYet value containing whether trial is pre- or post- PoL
model_data$AlignedTrial = model_data$WithinGameTrial - model_data$PoL
model_data$LearnedYet = model_data$AlignedTrial > 0
model_data %<>% mutate(learned_yet = as.factor(LearnedYet))
```

```
##
## Call:
## lm(formula = Entropy ~ WithinGameTrial + age_group, data = model_data)
##
```

```
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.35426 -0.29571 -0.01435  0.26387  0.70926
##
## Coefficients:
##                   Estimate Std. Error t value Pr(>|t|)
## (Intercept)      0.3422396  0.0061777  55.399  < 2e-16 ***
## WithinGameTrial -0.0038276  0.0004289  -8.924  < 2e-16 ***
## age_groupAdult   0.0158486  0.0052087   3.043  0.00235 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2917 on 13939 degrees of freedom
## Multiple R-squared:  0.006335,   Adjusted R-squared:  0.006193
## F-statistic: 44.43 on 2 and 13939 DF,  p-value: < 2.2e-16
```

```
## PhantomJS not found. You can install it with webshot::install_phantomjs(). If it is installed, pleas
```

Next, we'll look at the interaction: `Entropy ~ WithinGameTrial * AgeGroup`.

```
##
## Call:
## lm(formula = Entropy ~ WithinGameTrial * age_group, data = model_data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.35640 -0.29549 -0.01457  0.26389  0.70602
##
## Coefficients:
##                                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)                     0.3377000  0.0087885  38.425  < 2e-16 ***
## WithinGameTrial                -0.0033956  0.0007334  -4.630 3.69e-06 ***
## age_groupAdult                  0.0227492  0.0108361   2.099   0.0358 *
## WithinGameTrial:age_groupAdult -0.0006566  0.0009042  -0.726   0.4677
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2918 on 13938 degrees of freedom
## Multiple R-squared:  0.006373,   Adjusted R-squared:  0.006159
## F-statistic:  29.8 on 3 and 13938 DF,  p-value: < 2.2e-16
```

Next, we'll add the interaction of trial and whether or not the game was learned and add age group: `Entropy ~ WithinGameTrial*LearnedGame+AgeGroup`.

```
##
## Call:
## lm(formula = Entropy ~ WithinGameTrial * LearnedGame + age_group,
##     data = model_data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -0.3638 -0.2980 -0.0161  0.2636  0.7394
##
```

```
## Coefficients:
##                                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)                     0.3307041  0.0079977  41.350  < 2e-16 ***
## WithinGameTrial                -0.0017051  0.0006031  -2.827  0.00470 **
## LearnedGameTrue                 0.0231895  0.0102669   2.259  0.02392 *
## age_groupAdult                  0.0158940  0.0052007   3.056  0.00225 **
## WithinGameTrial:LearnedGameTrue -0.0042802  0.0008566  -4.997  5.9e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2913 on 13937 degrees of freedom
## Multiple R-squared:  0.009497,   Adjusted R-squared:  0.009213
## F-statistic: 33.41 on 4 and 13937 DF,  p-value: < 2.2e-16
```

Finally, we'll model the interaction of trial and whether or not the game was learned and age group: `Entropy ~ WithinGameTrial*LearnedGame*AgeGroup`.

```
##
## Call:
## lm(formula = Entropy ~ WithinGameTrial * LearnedGame * age_group,
##     data = model_data)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.36748 -0.29667 -0.01543  0.26357  0.72995
##
## Coefficients:
##                                                 Estimate Std. Error t value
## (Intercept)                                    3.296e-01  1.236e-02  26.655
## WithinGameTrial                               -1.709e-03  1.031e-03  -1.657
## LearnedGameTrue                                1.641e-02  1.755e-02   0.935
## age_groupAdult                                 1.764e-02  1.524e-02   1.157
## WithinGameTrial:LearnedGameTrue               -3.406e-03  1.465e-03  -2.326
## WithinGameTrial:age_groupAdult                 5.682e-06  1.271e-03   0.004
## LearnedGameTrue:age_groupAdult                 1.031e-02  2.164e-02   0.477
## WithinGameTrial:LearnedGameTrue:age_groupAdult -1.328e-03  1.806e-03  -0.735
##                                                Pr(>|t|)
## (Intercept)                                     <2e-16 ***
## WithinGameTrial                                 0.0976 .
## LearnedGameTrue                                 0.3499
## age_groupAdult                                  0.2472
## WithinGameTrial:LearnedGameTrue                 0.0201 *
## WithinGameTrial:age_groupAdult                  0.9964
## LearnedGameTrue:age_groupAdult                  0.6337
## WithinGameTrial:LearnedGameTrue:age_groupAdult  0.4621
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.2913 on 13934 degrees of freedom
## Multiple R-squared:  0.009581,   Adjusted R-squared:  0.009084
## F-statistic: 19.26 on 7 and 13934 DF,  p-value: < 2.2e-16
```

Linear Mixed Effects Models using Feedback data and Entropy as target variable

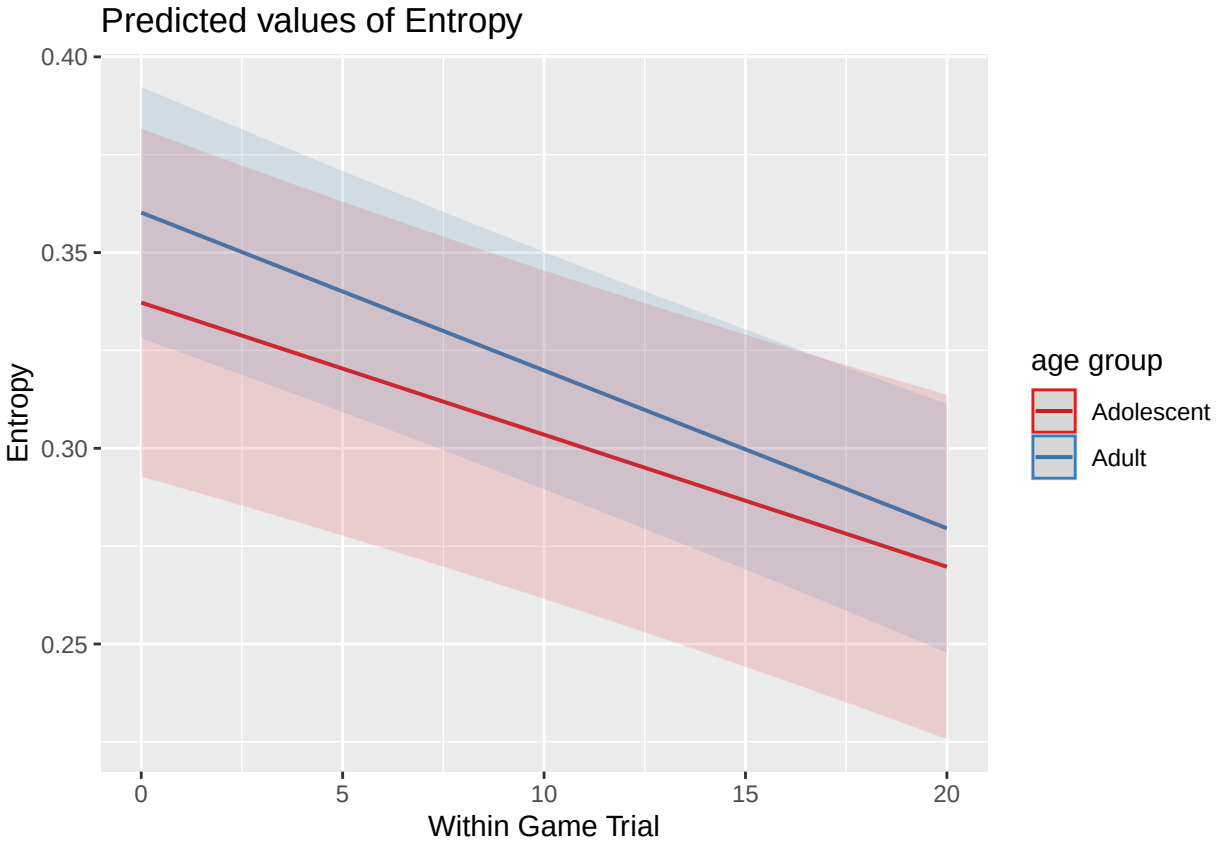
Now, using the **lme4** package and **lmer** function, we'll make linear mixed effects models using Entropy as the target variable.

Our most basic model is `Entropy ~ WithinGameTrial*AgeGroup + (1|Subject)`

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Entropy ~ WithinGameTrial * age_group + (1 | subject_id)
##    Data: model_data
##
## REML criterion at convergence: 4523.9
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.65263 -0.91381 -0.07975  0.84267  2.68096
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_id (Intercept) 0.005295 0.07276
##  Residual               0.080126 0.28306
## Number of obs: 13942, groups:  subject_id, 35
##
## Fixed effects:
##                                 Estimate Std. Error         df t value
## (Intercept)                    3.372e-01  2.267e-02  4.155e+01  14.875
## WithinGameTrial               -3.375e-03  7.116e-04  1.391e+04  -4.743
## age_groupAdult                 2.299e-02  2.796e-02  4.154e+01   0.822
## WithinGameTrial:age_groupAdult -6.582e-04  8.772e-04  1.391e+04  -0.750
##                                Pr(>|t|)
## (Intercept)                     < 2e-16 ***
## WithinGameTrial                2.12e-06 ***
## age_groupAdult                    0.416
## WithinGameTrial:age_groupAdult    0.453
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) WthnGT ag_grA
## WithinGmTrl -0.330
## age_grpAdlt -0.811  0.267
## WthnGmTr:_A  0.268 -0.811 -0.330
```

```
## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Entropy
##                              Chisq Df Pr(>Chisq)
## (Intercept)               221.2765  1  < 2.2e-16 ***
## WithinGameTrial            22.4988  1  2.103e-06 ***
## age_group                   0.6758  1      0.411
## WithinGameTrial:age_group   0.5630  1      0.453
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

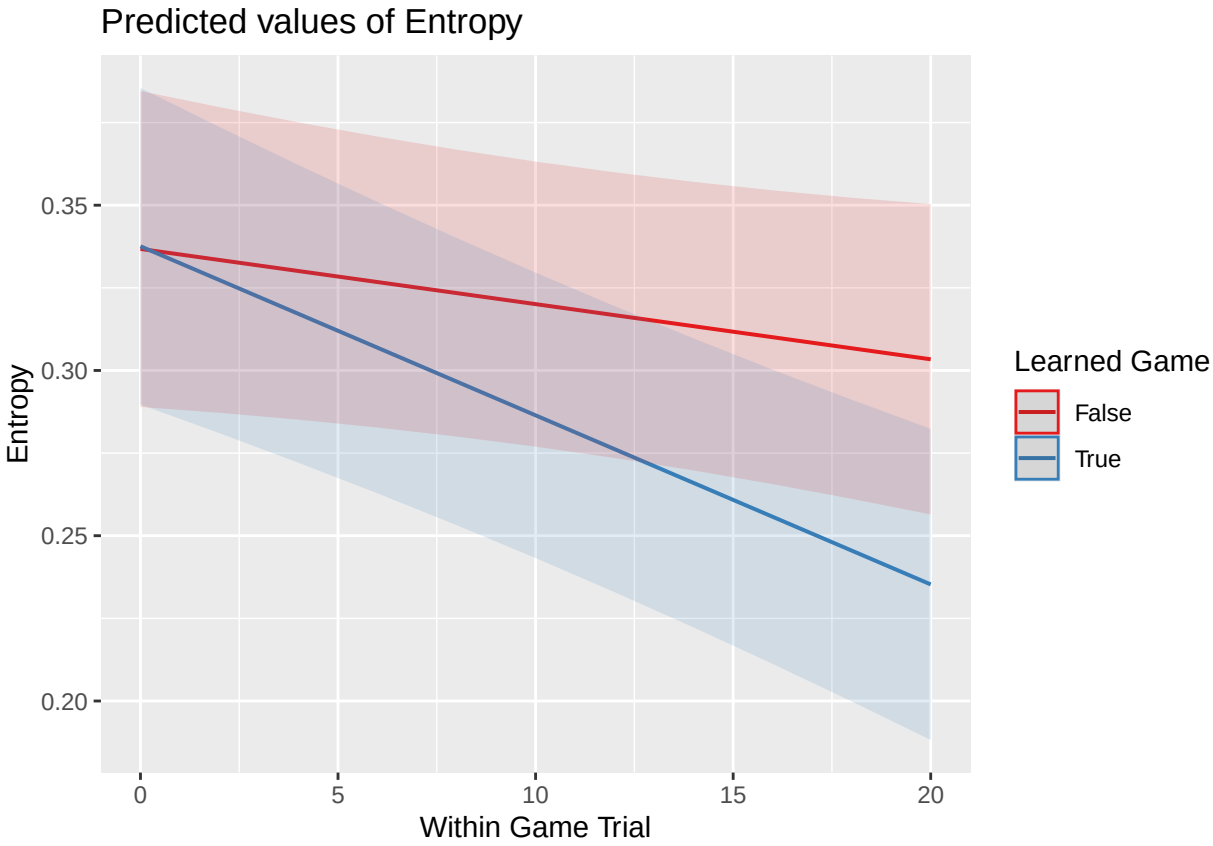
```
## Registered S3 method overwritten by 'parameters':
##   method                          from
##   format.parameters_distribution datawizard
```



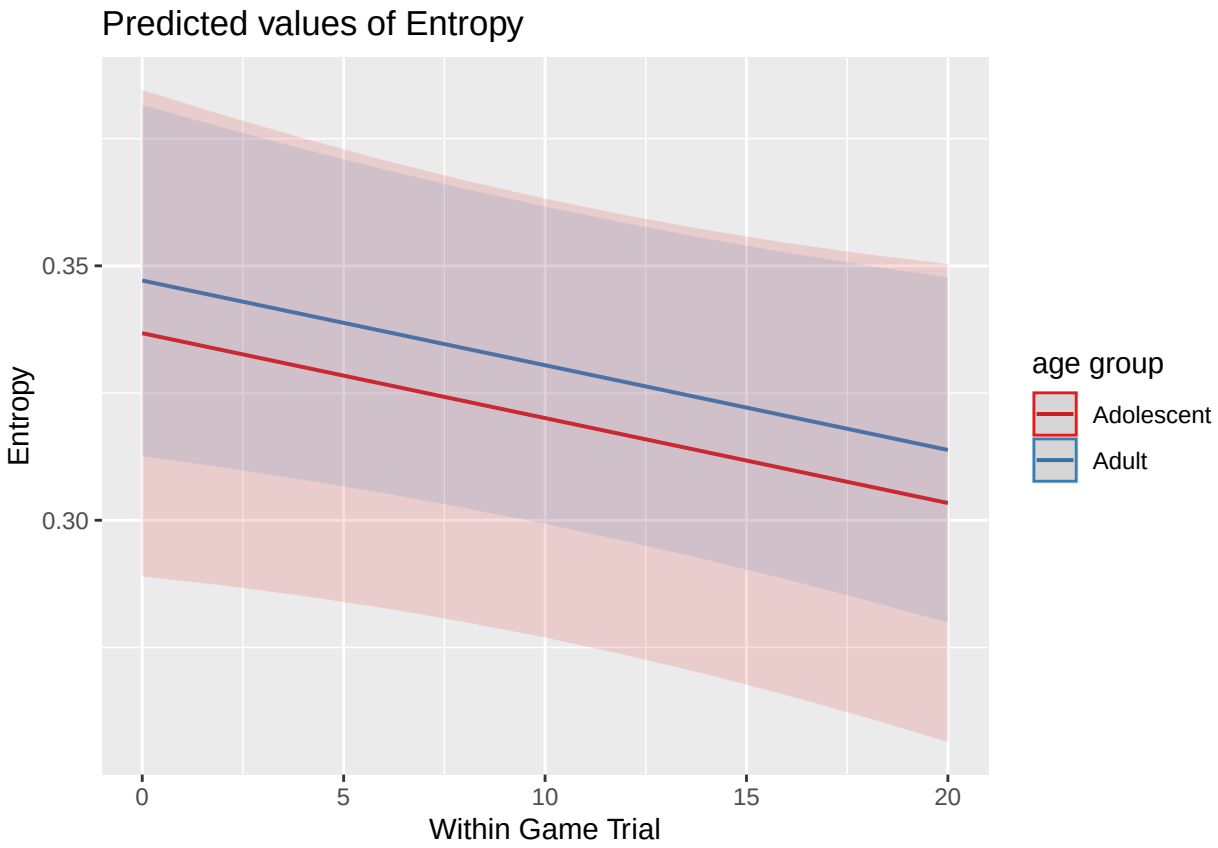
Next, we model `Entropy ~ WithinGameTrial*LearnedGame*AgeGroup + (1|Subject)`

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Entropy ~ WithinGameTrial * LearnedGame * age_group + (1 | subject_id)
##    Data: model_data
##
## REML criterion at convergence: 4503.6
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.66863 -0.90712 -0.08034  0.83528  2.72888
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_id (Intercept) 0.005397 0.07346
##  Residual               0.079802 0.28249
## Number of obs: 13942, groups:  subject_id, 35
##
## Fixed effects:
##                                              Estimate Std. Error         df
## (Intercept)                                 3.368e-01  2.438e-02  5.359e+01
## WithinGameTrial                            -1.669e-03  1.000e-03  1.390e+04
```

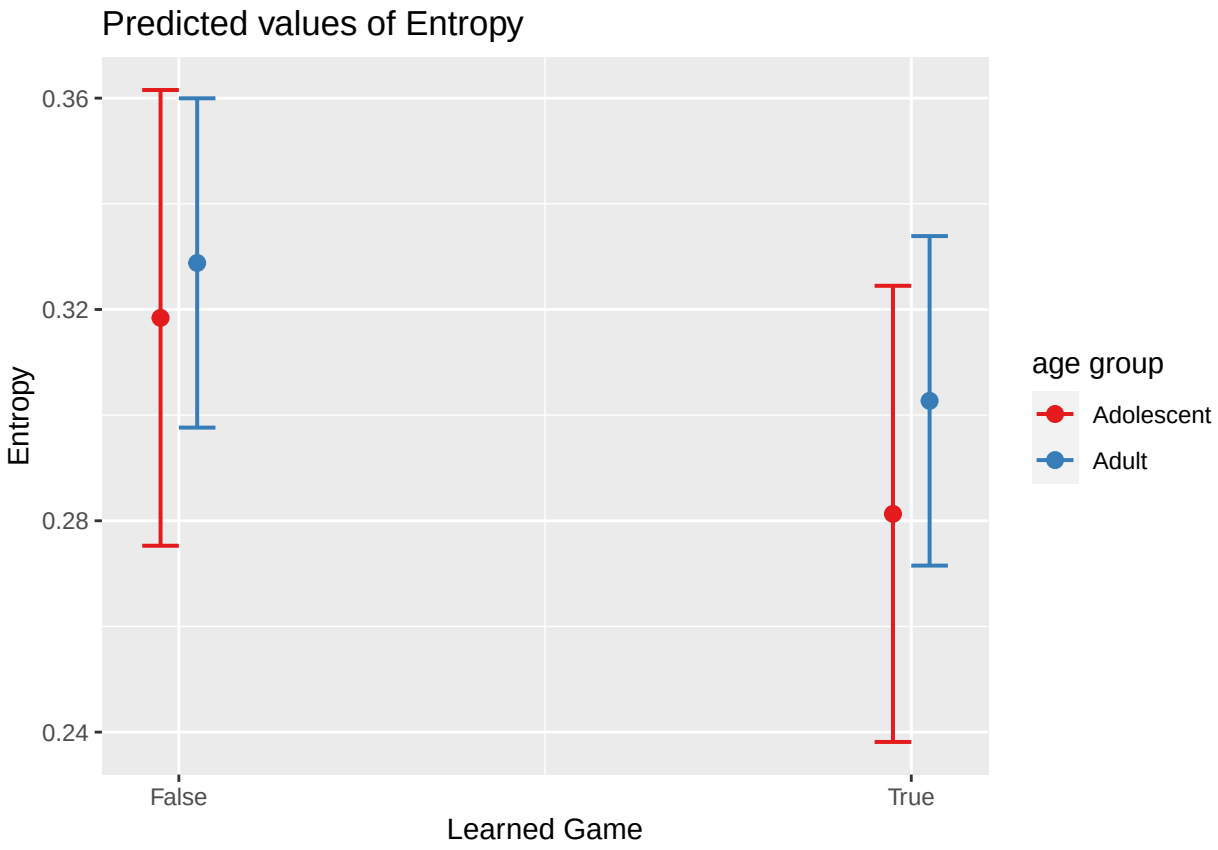
```
## LearnedGameTrue                                     8.049e-04  1.717e-02  1.392e+04
## age_groupAdult                                      1.035e-02  3.008e-02  5.358e+01
## WithinGameTrial:LearnedGameTrue                    -3.446e-03  1.420e-03  1.390e+04
## WithinGameTrial:age_groupAdult                      4.353e-06  1.233e-03  1.390e+04
## LearnedGameTrue:age_groupAdult                      2.561e-02  2.119e-02  1.392e+04
## WithinGameTrial:LearnedGameTrue:age_groupAdult -1.328e-03  1.751e-03  1.390e+04
##                                                    t value Pr(>|t|)
## (Intercept)                                         13.811   <2e-16 ***
## WithinGameTrial                                     -1.669   0.0951 .
## LearnedGameTrue                                      0.047   0.9626
## age_groupAdult                                       0.344   0.7322
## WithinGameTrial:LearnedGameTrue                     -2.426   0.0153 *
## WithinGameTrial:age_groupAdult                       0.004   0.9972
## LearnedGameTrue:age_groupAdult                       1.209   0.2269
## WithinGameTrial:LearnedGameTrue:age_groupAdult  -0.758   0.4483
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) WthnGT LrndGT ag_grA WtGT:LGT WGT:_A LGT:_A
## WithinGmTrl -0.431
## LearnedGmTr -0.349  0.612
## age_grpAdlt -0.811  0.350  0.283
## WthnGmT:LGT  0.304 -0.704 -0.869 -0.246
## WthnGmTr:_A  0.350 -0.811 -0.497 -0.431  0.571
## LrndGmTr:_A  0.283 -0.496 -0.810 -0.349  0.704    0.612
## WtGT:LGT:_A -0.246  0.571  0.705  0.303 -0.811   -0.704 -0.868

## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Entropy
##                                        Chisq Df Pr(>Chisq)
## (Intercept)                         190.7404  1    < 2e-16 ***
## WithinGameTrial                       2.7856  1    0.09511 .
## LearnedGame                           0.0022  1    0.96261
## age_group                             0.1183  1    0.73086
## WithinGameTrial:LearnedGame           5.8859  1    0.01526 *
## WithinGameTrial:age_group             0.0000  1    0.99718
## LearnedGame:age_group                 1.4606  1    0.22684
## WithinGameTrial:LearnedGame:age_group   0.5750  1    0.44826
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## [[1]]
```


Predicted values of Entropy
Entropy
0.35
0.30
0.25
0.20
0
5
10
15
20
Within Game Trial
Learned Game
False
True

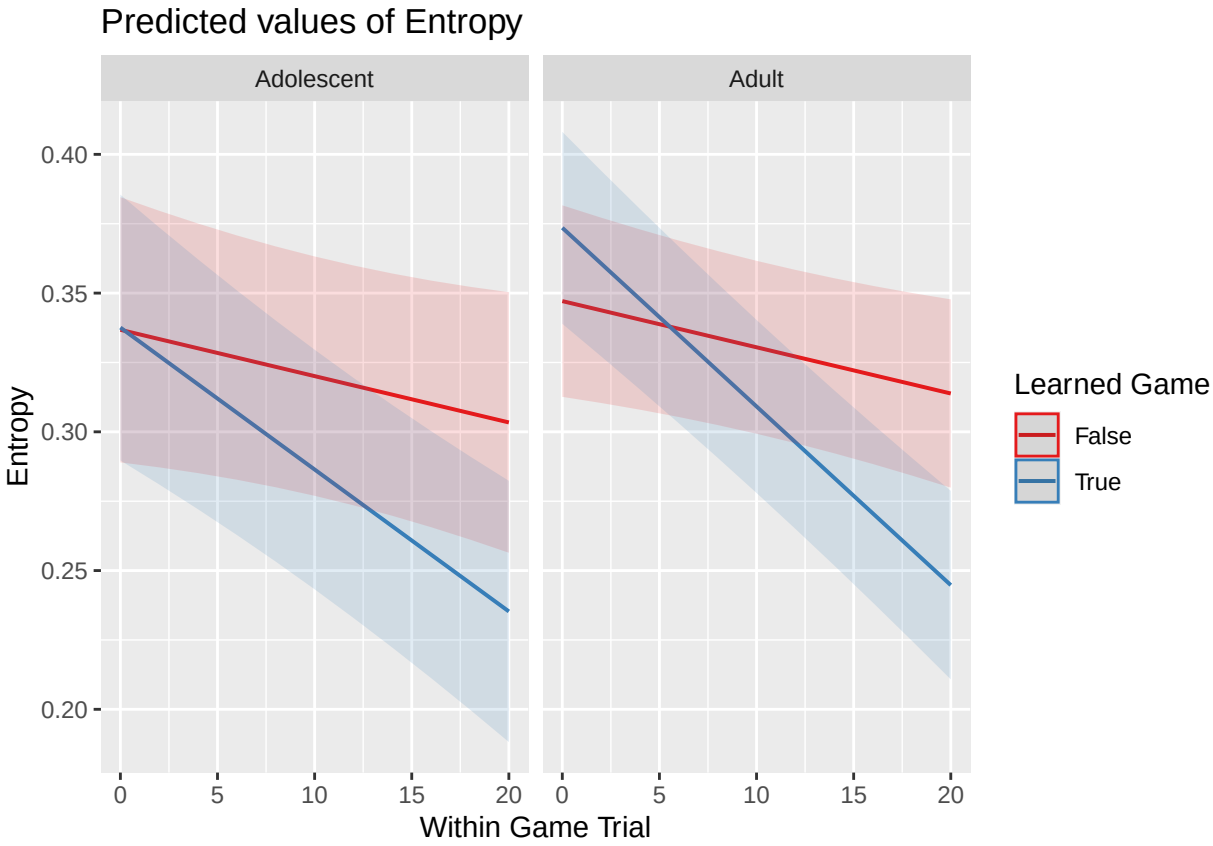
```
##
## [[2]]
```


Predicted values of Entropy
Entropy
0.35
0.30
0
5
10
15
20
Within Game Trial
age group
Adolescent
Adult

```
##
## [[3]]
```


Predicted values of Entropy
0.36
0.32
0.28
0.24
Entropy
False
True
Learned Game
age group
Adolescent
Adult

```
##
## [[4]]
```



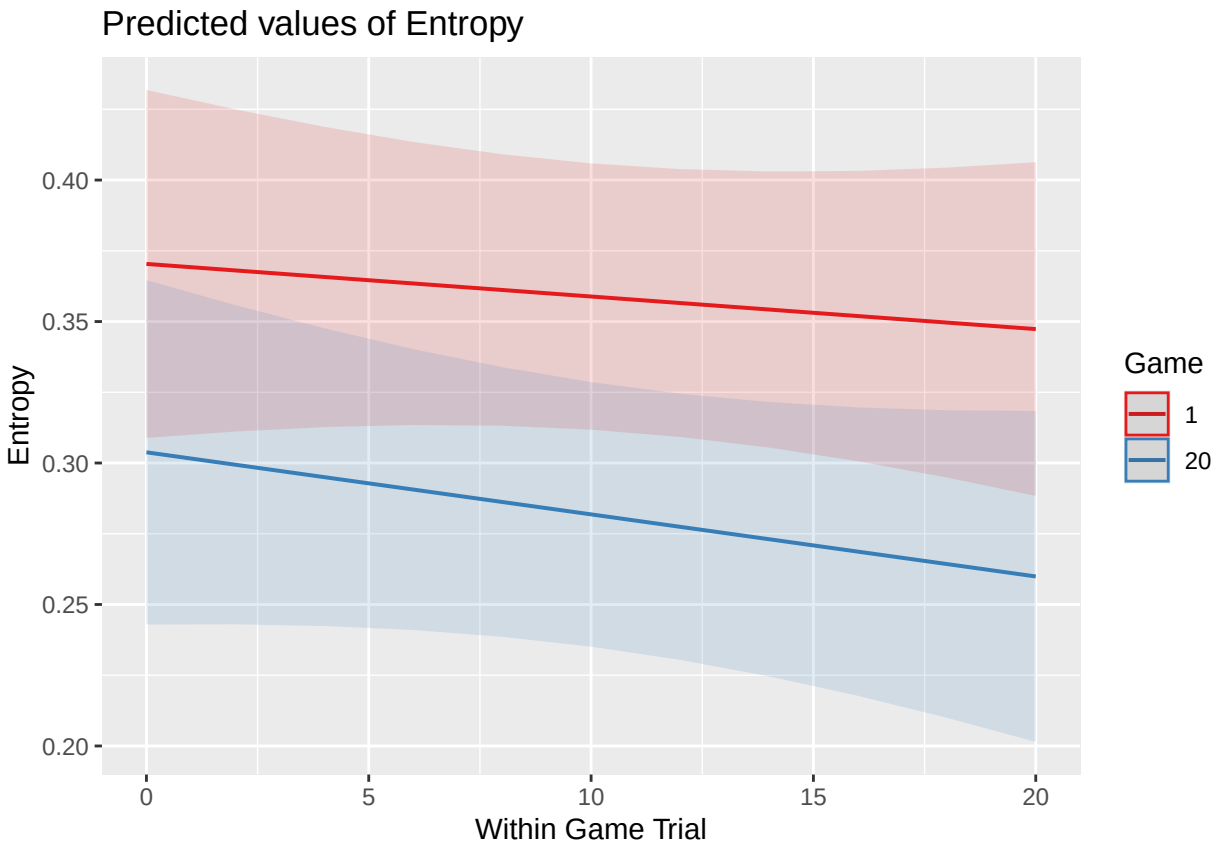
Next, we model `Entropy ~ WithinGameTrial*Game*LearnedGame*AgeGroup + (1|Subject)`

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Entropy ~ WithinGameTrial * Game * LearnedGame * age_group +
##     (1 | subject_id)
##    Data: model_data
##
## REML criterion at convergence: 4490.5
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.83911 -0.89868 -0.08175  0.83799  2.71200
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_id (Intercept) 0.005385 0.07338
##  Residual               0.079131 0.28130
## Number of obs: 13942, groups:  subject_id, 35
##
## Fixed effects:
##                                                Estimate Std. Error
## (Intercept)                                   3.739e-01  3.271e-02
## WithinGameTrial                              -1.097e-03  2.067e-03
## Game                                         -3.504e-03  2.056e-03
## LearnedGameTrue                               5.765e-02  3.562e-02
## age_groupAdult                                1.836e-02  4.010e-02
```

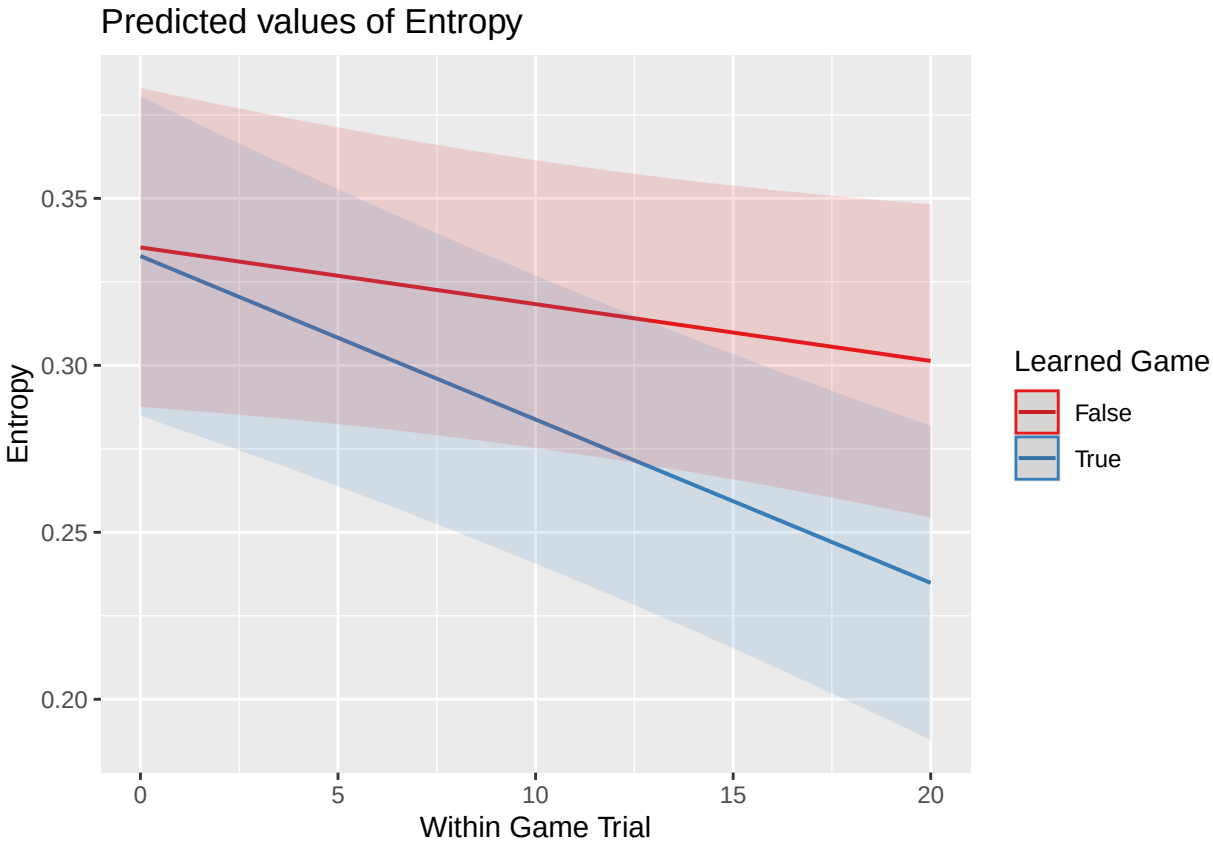
```
## WithinGameTrial:Game                                    -5.486e-05  1.710e-04
## WithinGameTrial:LearnedGameTrue                         -8.211e-03  2.942e-03
## Game:LearnedGameTrue                                    -5.478e-03  2.955e-03
## WithinGameTrial:age_groupAdult                          -4.982e-04  2.524e-03
## Game:age_groupAdult                                     -1.001e-03  2.548e-03
## LearnedGameTrue:age_groupAdult                          -1.095e-02  4.395e-02
## WithinGameTrial:Game:LearnedGameTrue                     4.561e-04  2.453e-04
## WithinGameTrial:Game:age_groupAdult                      4.748e-05  2.119e-04
## WithinGameTrial:LearnedGameTrue:age_groupAdult           1.948e-03  3.632e-03
## Game:LearnedGameTrue:age_groupAdult                      4.041e-03  3.649e-03
## WithinGameTrial:Game:LearnedGameTrue:age_groupAdult -3.194e-04  3.029e-04
##                                                             df t value Pr(>|t|)
## (Intercept)                                           1.734e+02  11.431  < 2e-16
## WithinGameTrial                                       1.389e+04  -0.531  0.59576
## Game                                                  1.390e+04  -1.704  0.08841
## LearnedGameTrue                                       1.391e+04   1.618  0.10558
## age_groupAdult                                        1.692e+02   0.458  0.64755
## WithinGameTrial:Game                                  1.389e+04  -0.321  0.74837
## WithinGameTrial:LearnedGameTrue                       1.389e+04  -2.790  0.00527
## Game:LearnedGameTrue                                  1.390e+04  -1.854  0.06379
## WithinGameTrial:age_groupAdult                        1.389e+04  -0.197  0.84353
## Game:age_groupAdult                                   1.390e+04  -0.393  0.69436
## LearnedGameTrue:age_groupAdult                        1.391e+04  -0.249  0.80321
## WithinGameTrial:Game:LearnedGameTrue                  1.389e+04   1.859  0.06301
## WithinGameTrial:Game:age_groupAdult                   1.389e+04   0.224  0.82270
## WithinGameTrial:LearnedGameTrue:age_groupAdult        1.389e+04   0.536  0.59166
## Game:LearnedGameTrue:age_groupAdult                   1.390e+04   1.108  0.26809
## WithinGameTrial:Game:LearnedGameTrue:age_groupAdult   1.389e+04  -1.055  0.29161
##
## (Intercept)                                          ***
## WithinGameTrial
## Game                                                 .
## LearnedGameTrue
## age_groupAdult
## WithinGameTrial:Game
## WithinGameTrial:LearnedGameTrue                      **
## Game:LearnedGameTrue                                 .
## WithinGameTrial:age_groupAdult
## Game:age_groupAdult
## LearnedGameTrue:age_groupAdult
## WithinGameTrial:Game:LearnedGameTrue                 .
## WithinGameTrial:Game:age_groupAdult
## WithinGameTrial:LearnedGameTrue:age_groupAdult
## Game:LearnedGameTrue:age_groupAdult
## WithinGameTrial:Game:LearnedGameTrue:age_groupAdult
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

##
## Correlation matrix not shown by default, as p = 16 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it

## Analysis of Deviance Table (Type III Wald chisquare tests)
```

```
##
## Response: Entropy
##                                            Chisq Df Pr(>Chisq)
## (Intercept)                             130.6599  1  < 2.2e-16 ***
## WithinGameTrial                           0.2815  1   0.595750
## Game                                      2.9034  1   0.088392 .
## LearnedGame                               2.6195  1   0.105558
## age_group                                 0.2098  1   0.646962
## WithinGameTrial:Game                      0.1029  1   0.748364
## WithinGameTrial:LearnedGame               7.7869  1   0.005263 **
## Game:LearnedGame                          3.4364  1   0.063774 .
## WithinGameTrial:age_group                 0.0390  1   0.843528
## Game:age_group                            0.1544  1   0.694355
## LearnedGame:age_group                     0.0621  1   0.803211
## WithinGameTrial:Game:LearnedGame          3.4568  1   0.062992 .
## WithinGameTrial:Game:age_group            0.0502  1   0.822696
## WithinGameTrial:LearnedGame:age_group     0.2878  1   0.591647
## Game:LearnedGame:age_group                1.2266  1   0.268069
## WithinGameTrial:Game:LearnedGame:age_group  1.1123  1   0.291589
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

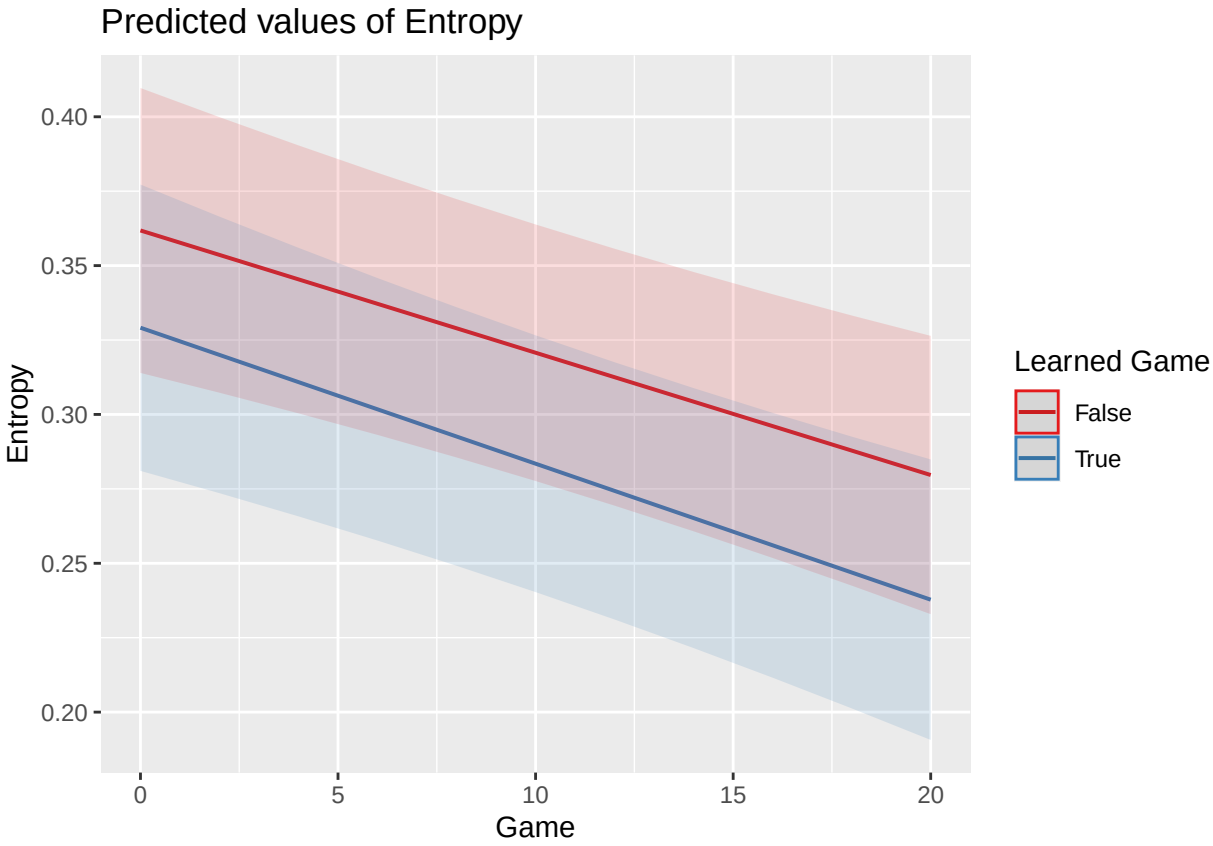
```
## [[1]]
```



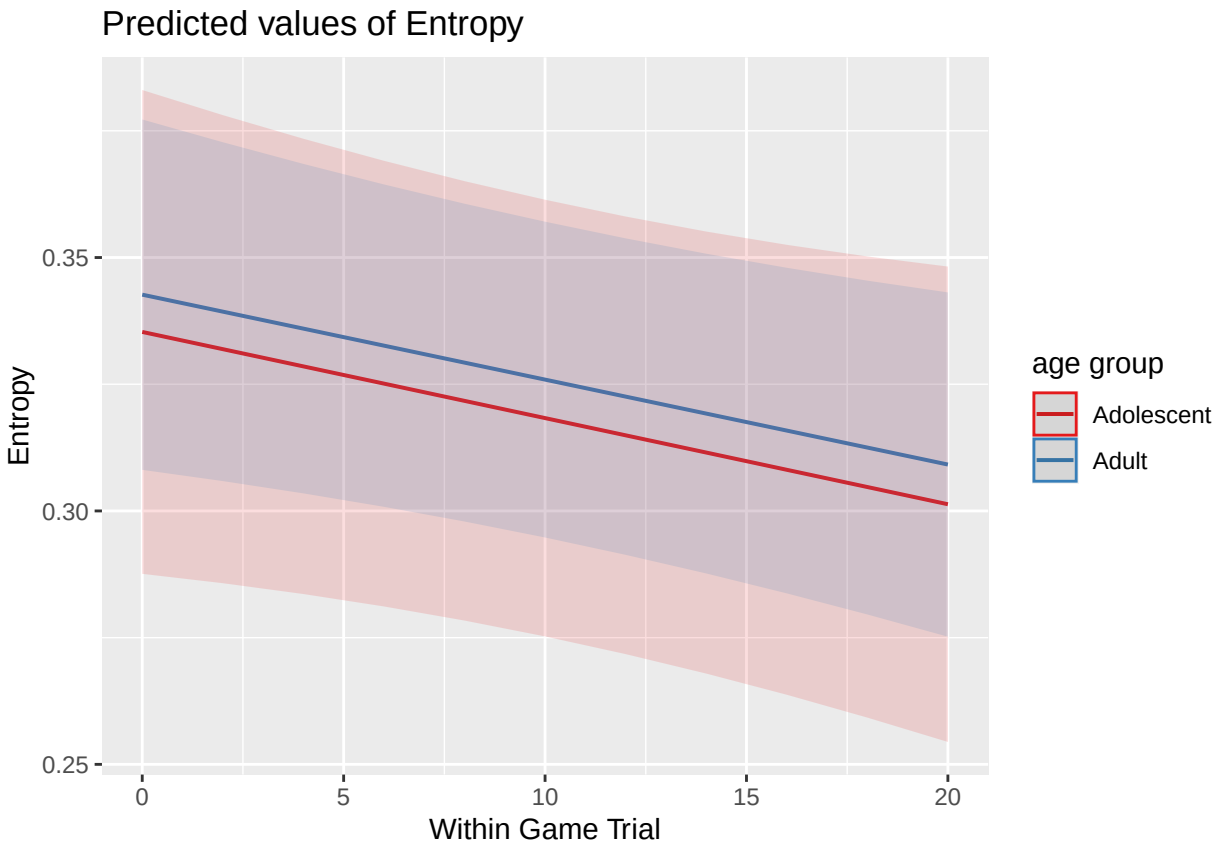

```
##
## [[2]]
```


Predicted values of Entropy
Entropy
0.35
0.30
0.25
0.20
0
5
10
15
20
Within Game Trial
Learned Game
False
True

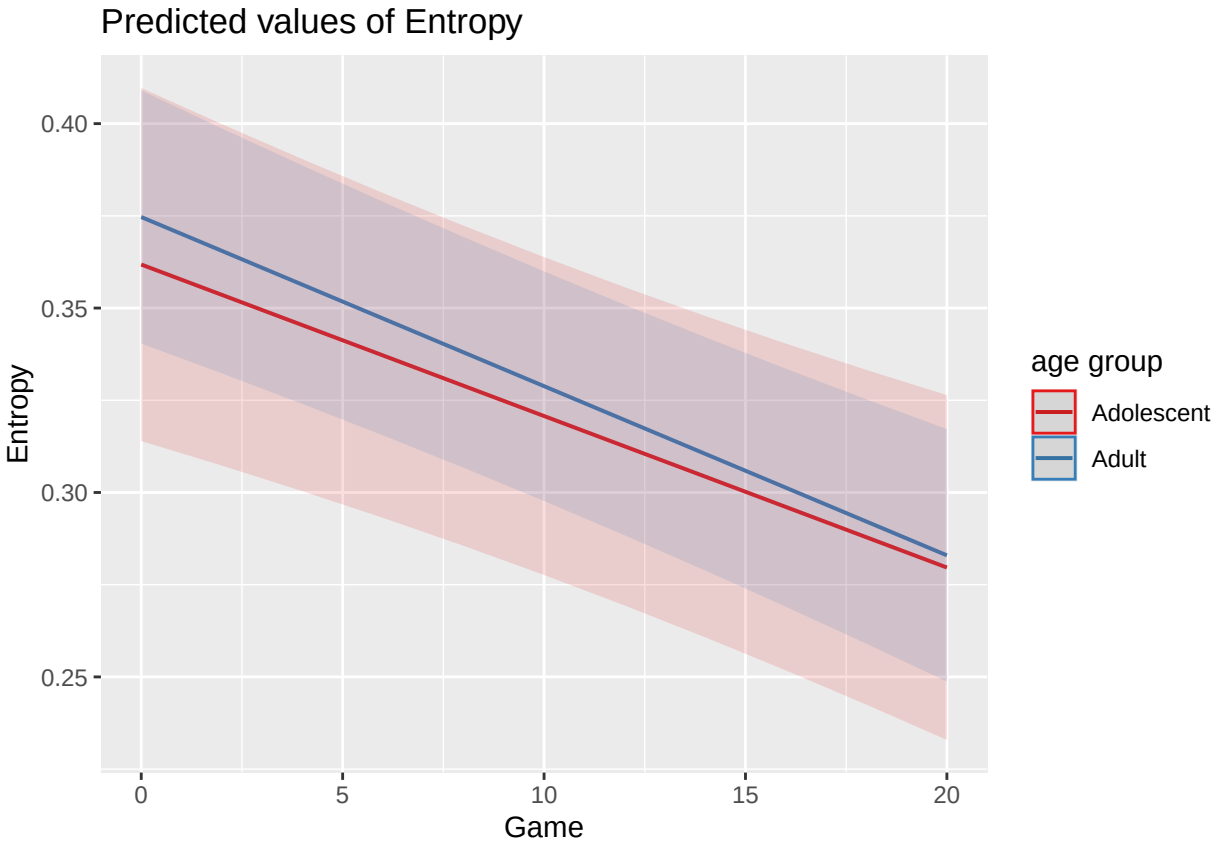
```
##
## [[3]]
```


Predicted values of Entropy
Entropy
0.40
0.35
0.30
0.25
0.20
0
5
10
15
20
Game
Learned Game
False
True

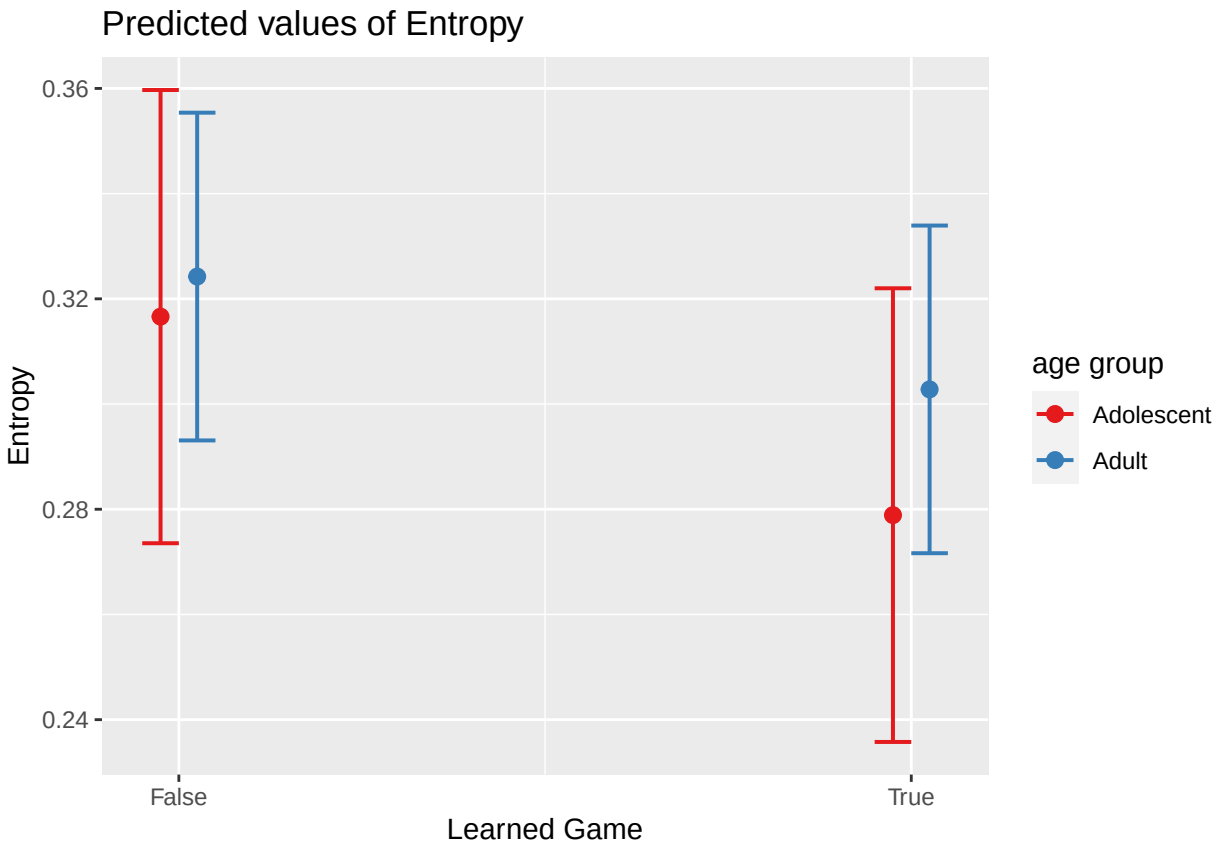
```
##
## [[4]]
```


Predicted values of Entropy
Entropy
0.35
0.30
0.25
0
5
10
15
20
Within Game Trial
age group
Adolescent
Adult

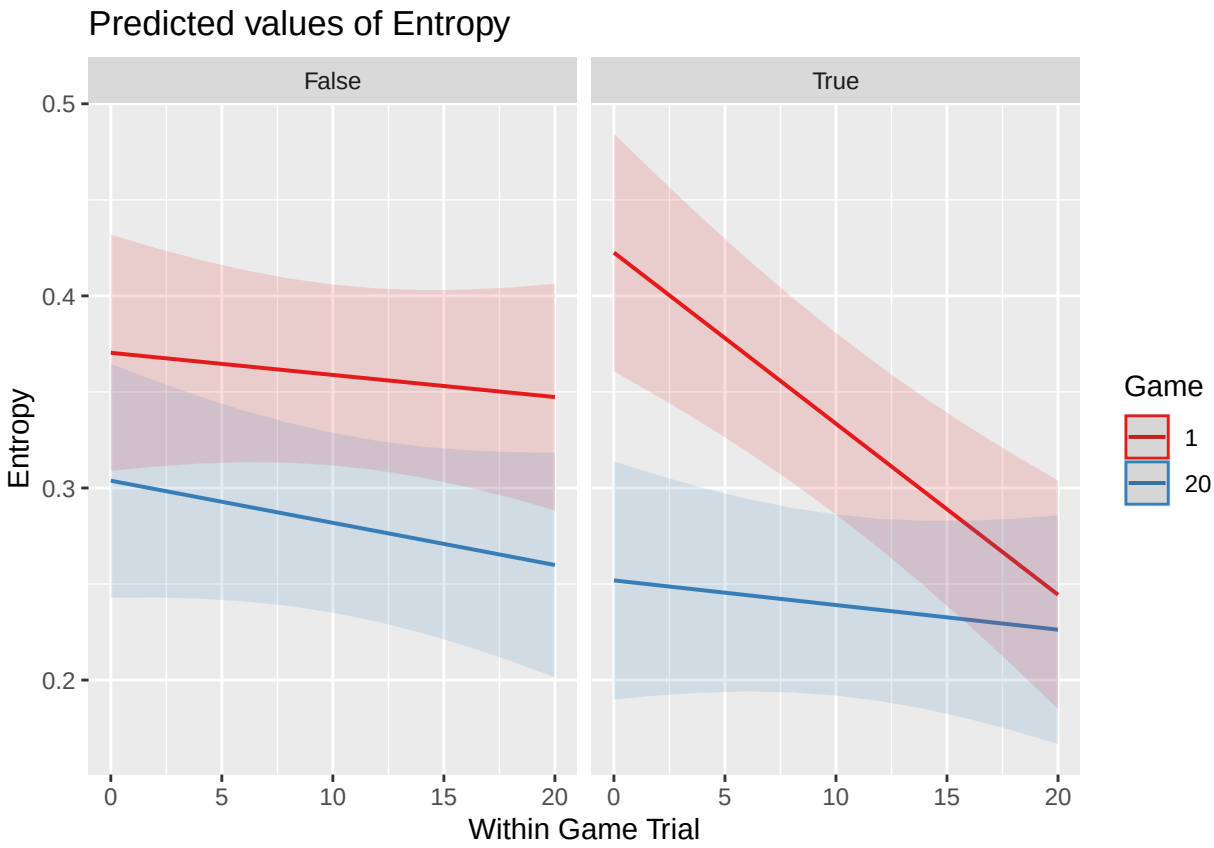
```
##
## [[5]]
```


Predicted values of Entropy
Entropy
0.40
0.35
0.30
0.25
0
5
10
15
20
Game
age group
Adolescent
Adult

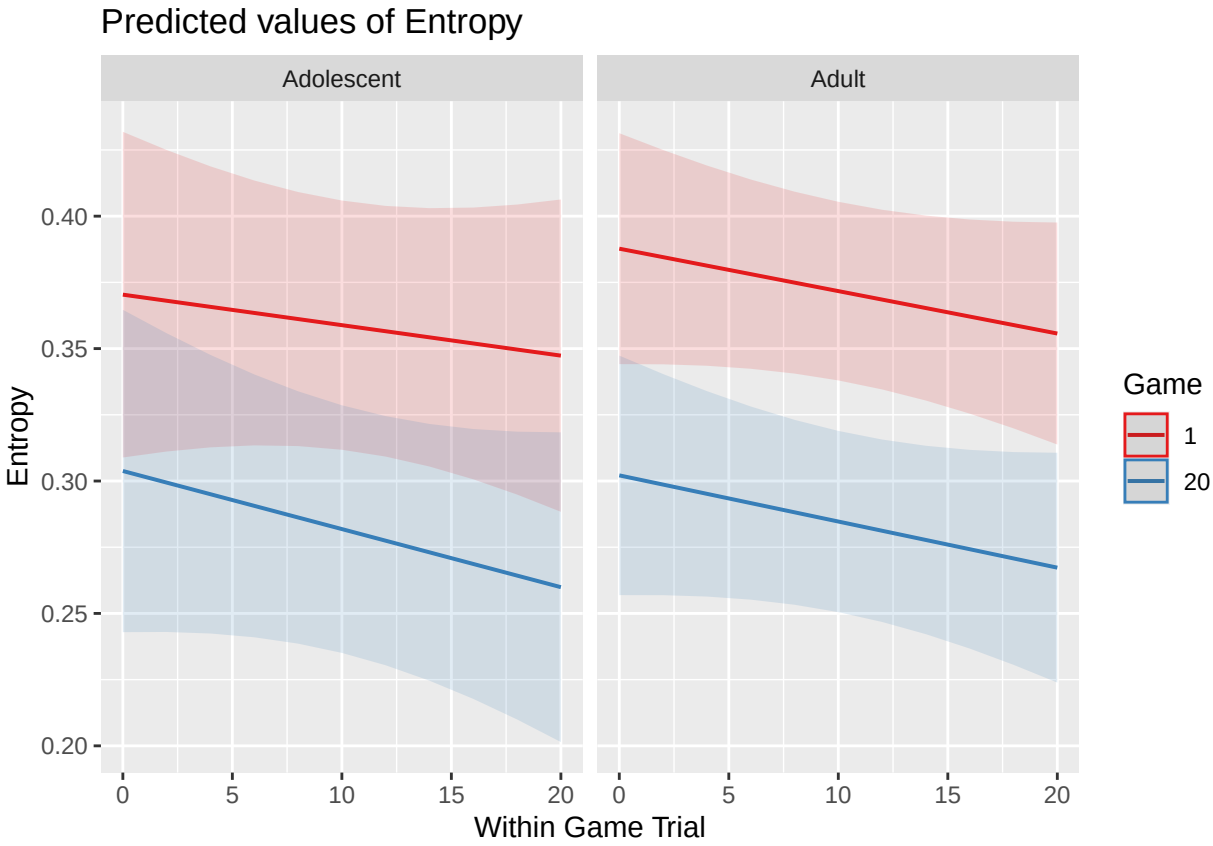
```
##
## [[6]]
```


Predicted values of Entropy
0.36
0.32
0.28
0.24
Entropy
False
True
Learned Game
age group
Adolescent
Adult

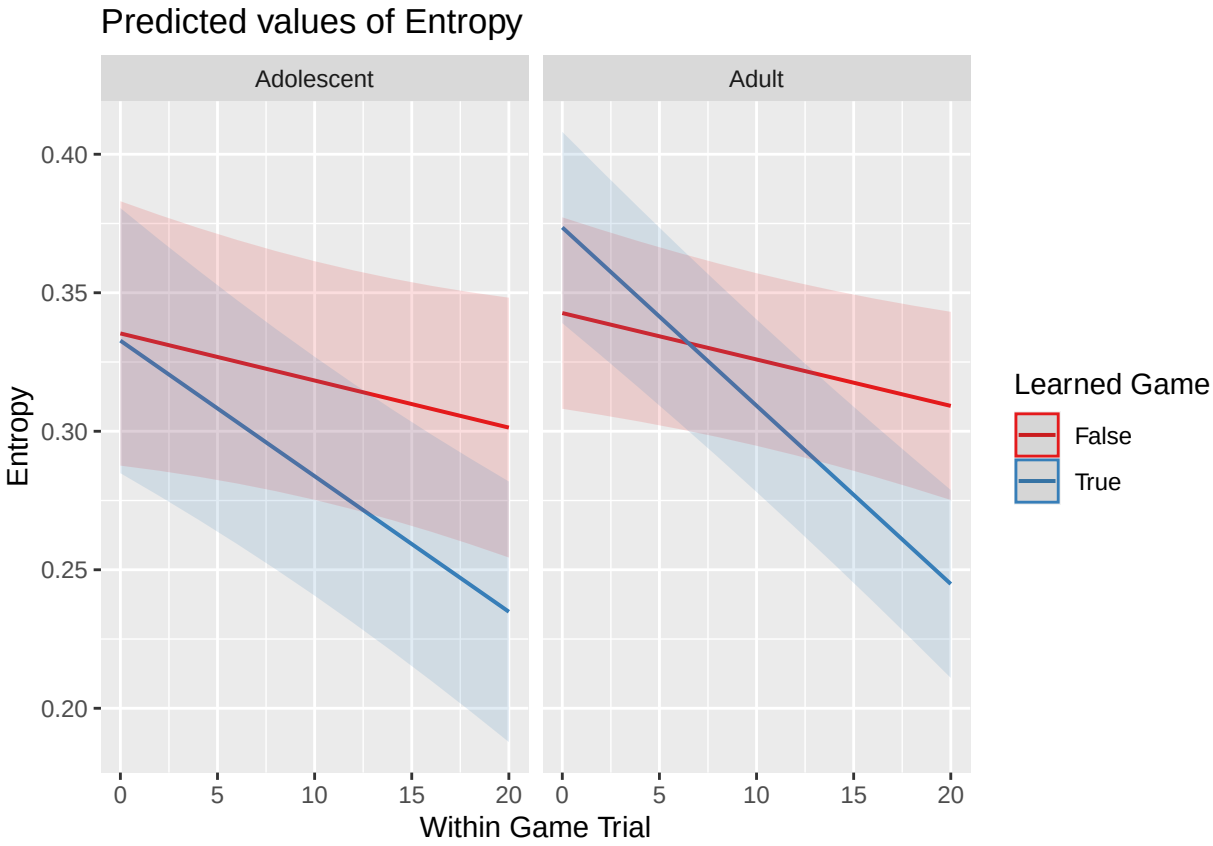
```
##
## [[7]]
```


Predicted values of Entropy
False
True
0.5
0.4
0.3
0.2
Entropy
0
5
10
15
20
Within Game Trial
Game
1
20

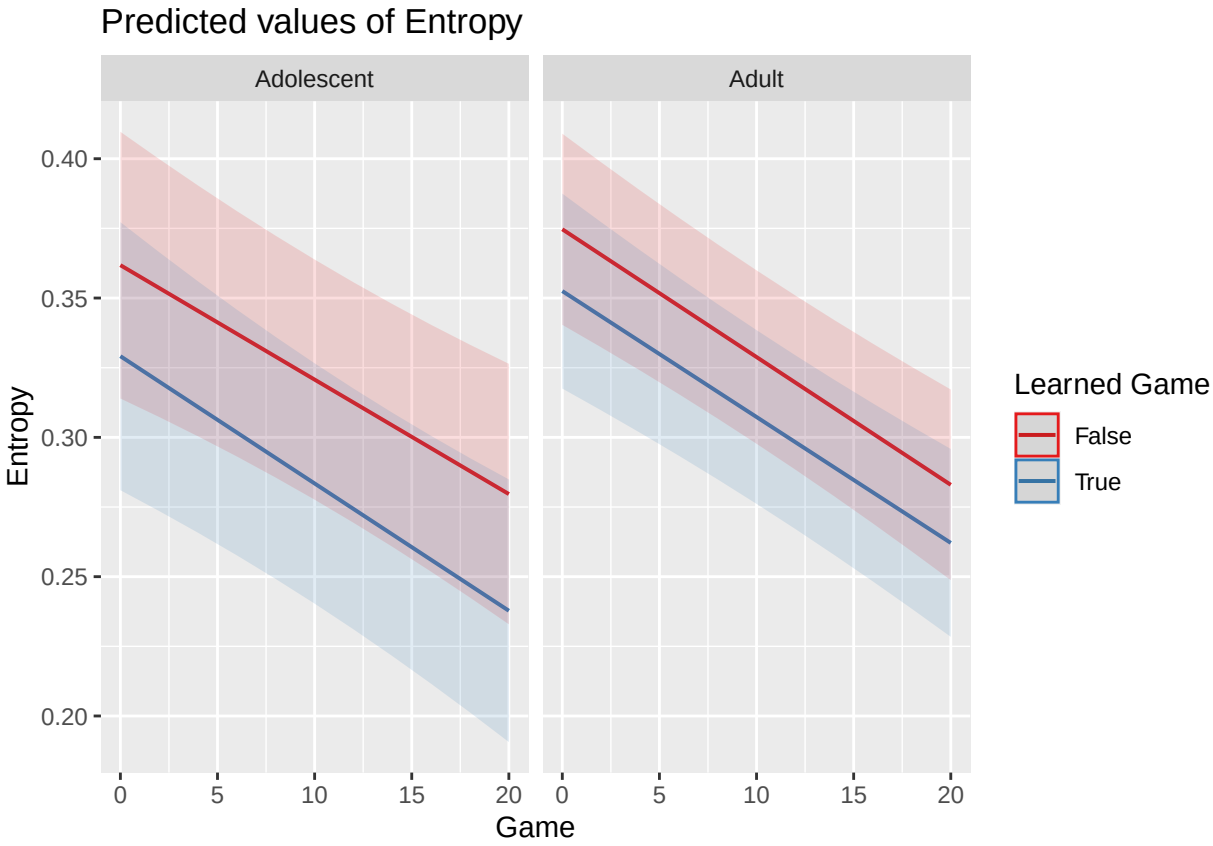
```
##
## [[8]]
```


Predicted values of Entropy
Adolescent
Adult
Entropy
0.40
0.35
0.30
0.25
0.20
0
5
10
15
20
Within Game Trial
Game
1
20

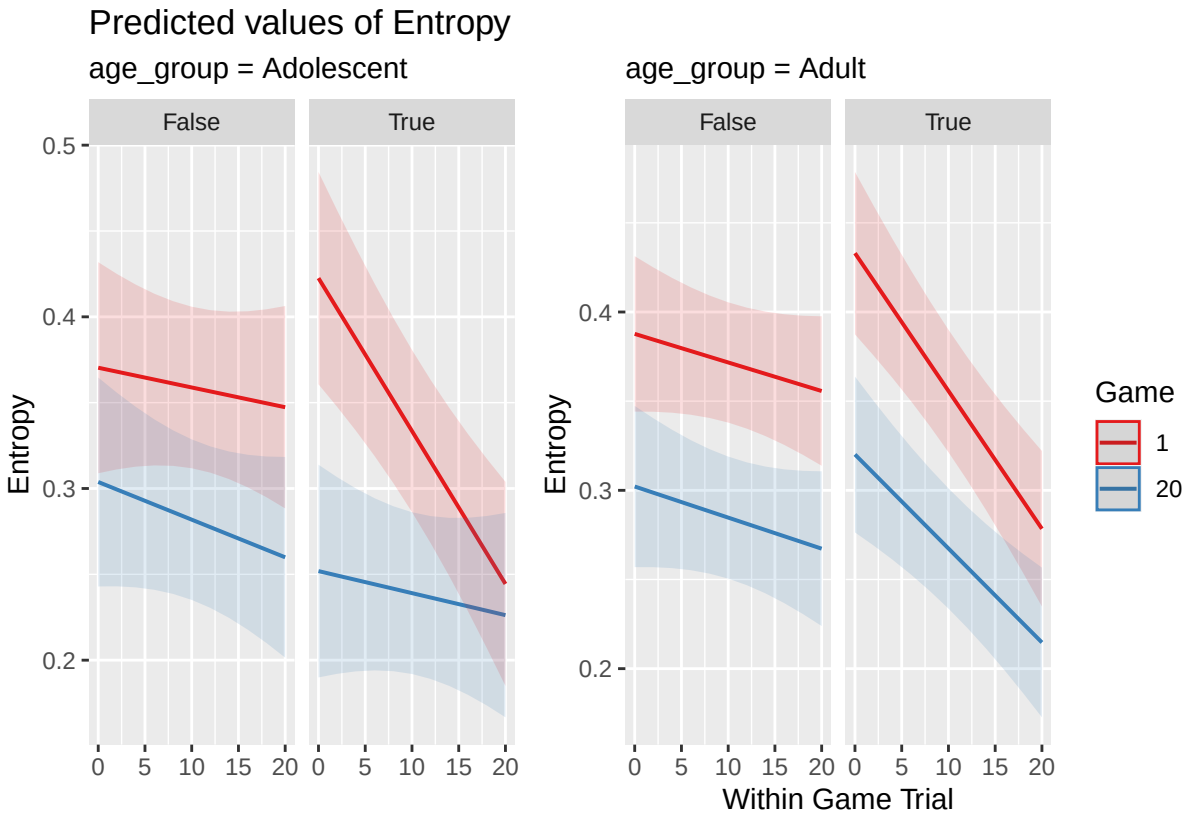
```
##
## [[9]]
```


Predicted values of Entropy
Adolescent
Adult
Entropy
0.40
0.35
0.30
0.25
0.20
0
5
10
15
20
Within Game Trial
Learned Game
False
True

```
##
## [[10]]
```


Predicted values of Entropy
Adolescent
Adult
Entropy
0.40
0.35
0.30
0.25
0.20
0
5
10
15
20
Game
Learned Game
False
True

```
##
## [[11]]
```

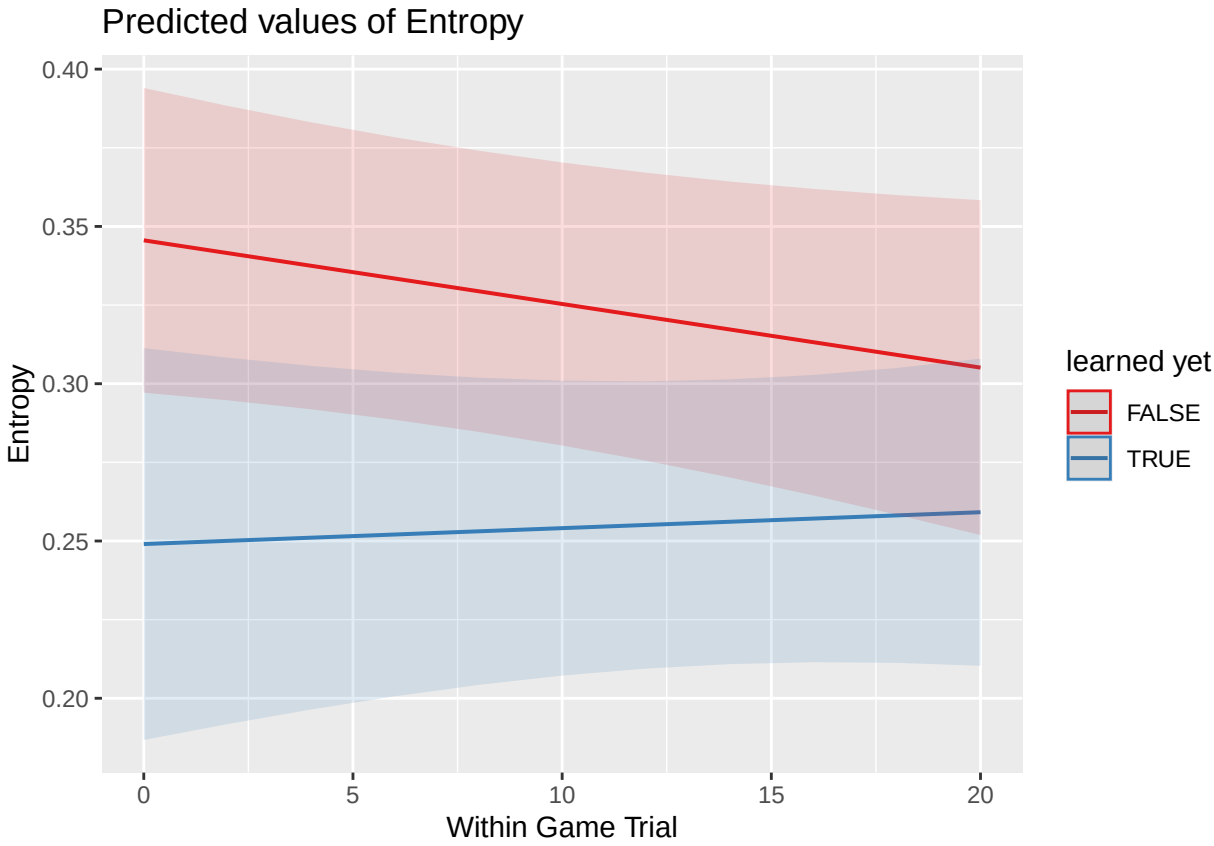


`LearnedGame` stores whether or not participants got 100% accuracy on the last 5 trials. We want to tease apart the "learning trials," or the trials before the point of learning (100% accuracy on all subsequent trials) from the "learned trials", after the point of learning. So, we'll replace `LearnedGame` with `LearnedYet`, a factorized boolean that stores whether or not the trial is after the point of learning for a given game.

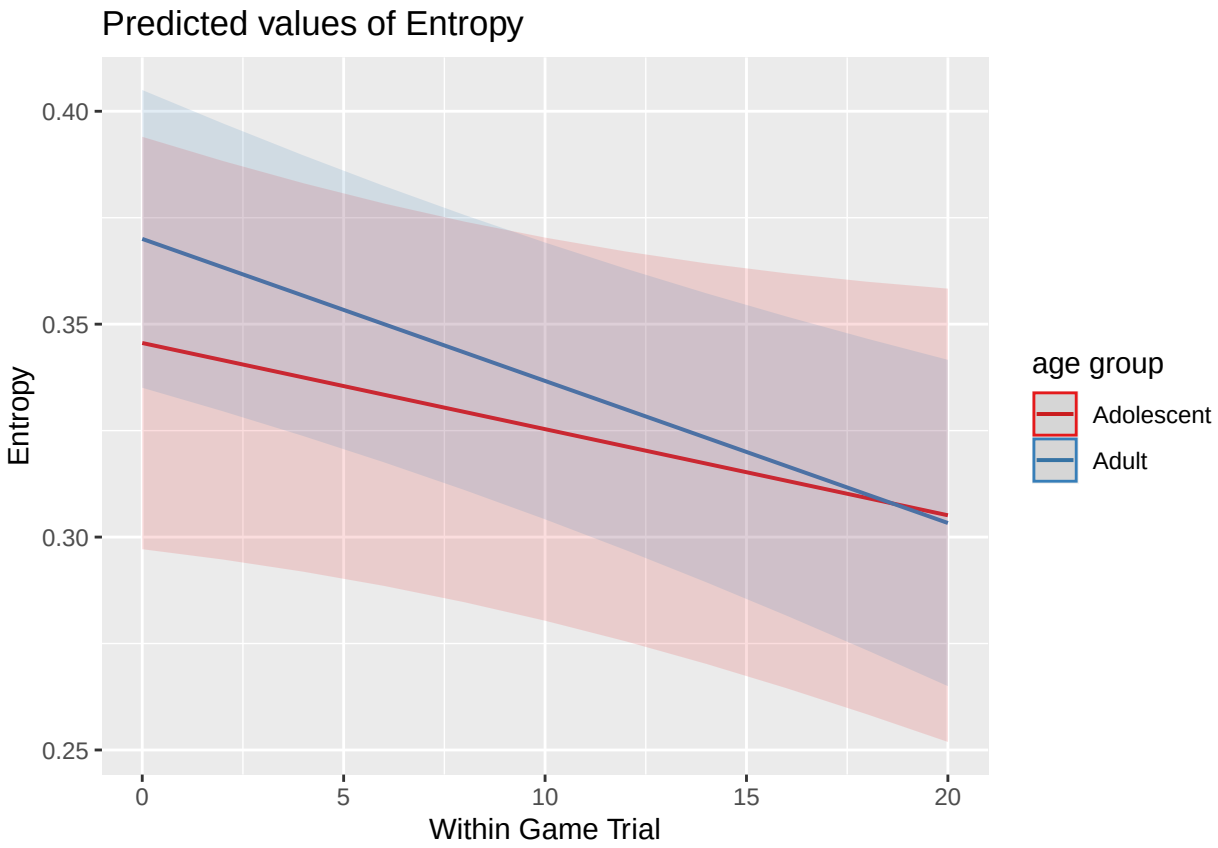
To just tease this effect apart, we model `Entropy ~ WithinGameTrial*LearnedYet*AgeGroup + (1|Subject)`

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Entropy ~ WithinGameTrial * learned_yet * age_group + (1 | subject_id)
##    Data: model_data
##
## REML criterion at convergence: 3370.2
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.72490 -0.88888 -0.08097  0.84401  2.72435
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_id (Intercept) 0.005766 0.07593
##  Residual               0.079304 0.28161
## Number of obs: 10529, groups:  subject_id, 35
##
## Fixed effects:
##                                              Estimate Std. Error         df
## (Intercept)                                 3.456e-01  2.471e-02  4.825e+01
## WithinGameTrial                            -2.023e-03  1.213e-03  1.050e+04
```

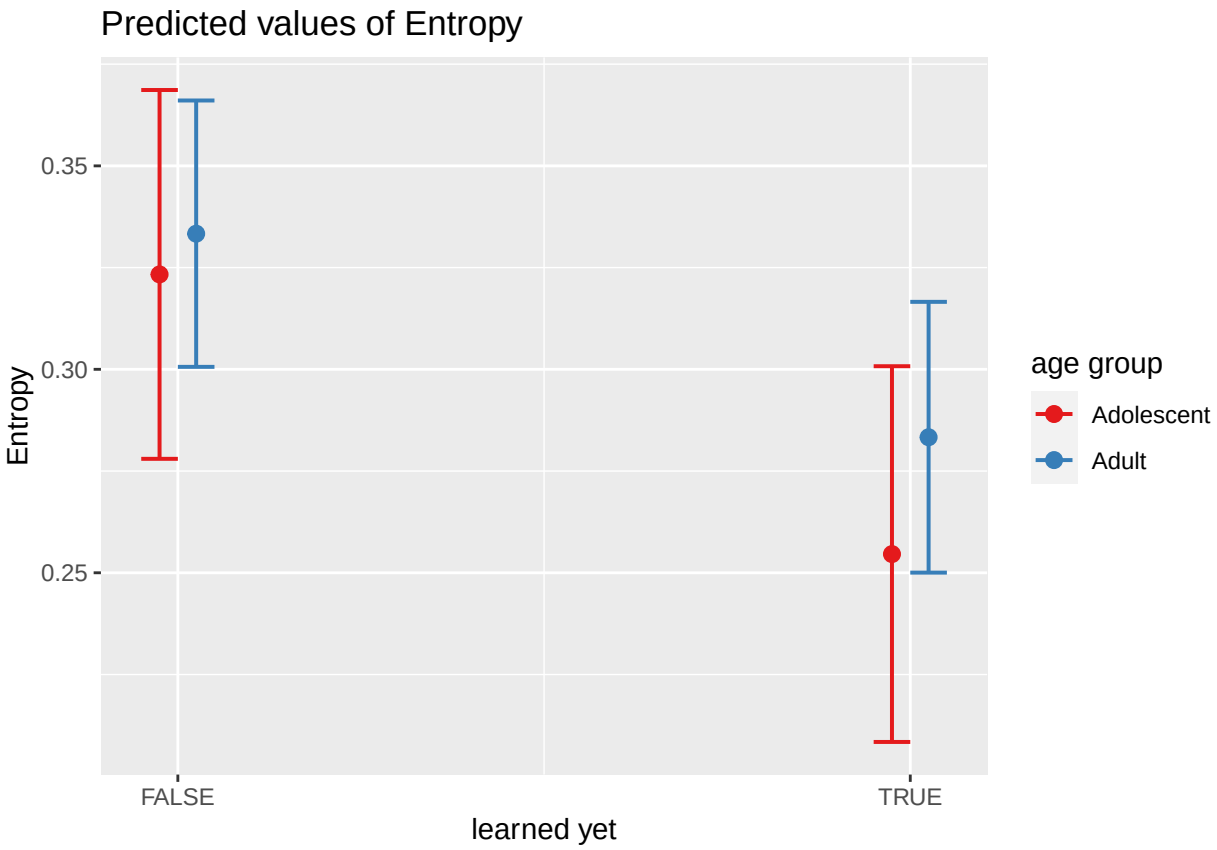
```
## learned_yetTRUE                                    -9.655e-02  2.564e-02  1.050e+04
## age_groupAdult                                      2.445e-02  3.047e-02  4.822e+01
## WithinGameTrial:learned_yetTRUE                     2.529e-03  1.971e-03  1.049e+04
## WithinGameTrial:age_groupAdult                     -1.313e-03  1.492e-03  1.050e+04
## learned_yetTRUE:age_groupAdult                      2.520e-02  3.149e-02  1.050e+04
## WithinGameTrial:learned_yetTRUE:age_groupAdult -5.902e-04  2.426e-03  1.049e+04
##                                                    t value Pr(>|t|)
## (Intercept)                                         13.987  < 2e-16 ***
## WithinGameTrial                                     -1.668 0.095433 .
## learned_yetTRUE                                     -3.766 0.000167 ***
## age_groupAdult                                       0.802 0.426263
## WithinGameTrial:learned_yetTRUE                      1.284 0.199345
## WithinGameTrial:age_groupAdult                      -0.880 0.378799
## learned_yetTRUE:age_groupAdult                       0.800 0.423523
## WithinGameTrial:learned_yetTRUE:age_groupAdult  -0.243 0.807773
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) WthnGT lr_TRUE ag_grA WtGT:_TRUE WGT:_A l_TRUE:
## WithinGmTrl -0.385
## lrnd_ytTRUE -0.204  0.362
## age_grpAdlt -0.811  0.312  0.165
## WthGT:_TRUE  0.237 -0.612 -0.897  -0.192
## WthnGmTr:_A  0.313 -0.813 -0.295  -0.384  0.497
## lrn_TRUE:_A  0.166 -0.295 -0.814  -0.204  0.730      0.364
## WGT:_TRUE:_ -0.192  0.497  0.728   0.236 -0.812     -0.612 -0.896

## Analysis of Deviance Table (Type III Wald chisquare tests)
##
## Response: Entropy
##                                        Chisq Df Pr(>Chisq)
## (Intercept)                          195.6285  1  < 2.2e-16 ***
## WithinGameTrial                        2.7808  1  0.0954031 .
## learned_yet                           14.1792  1  0.0001662 ***
## age_group                              0.6438  1  0.4223258
## WithinGameTrial:learned_yet            1.6474  1  0.1993165
## WithinGameTrial:age_group              0.7747  1  0.3787791
## learned_yet:age_group                  0.6406  1  0.4235045
## WithinGameTrial:learned_yet:age_group  0.0592  1  0.8077686
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## [[1]]
```


Predicted values of Entropy
0.40
0.35
0.30
0.25
0.20
Entropy
0
5
10
15
20
Within Game Trial
learned yet
FALSE
TRUE

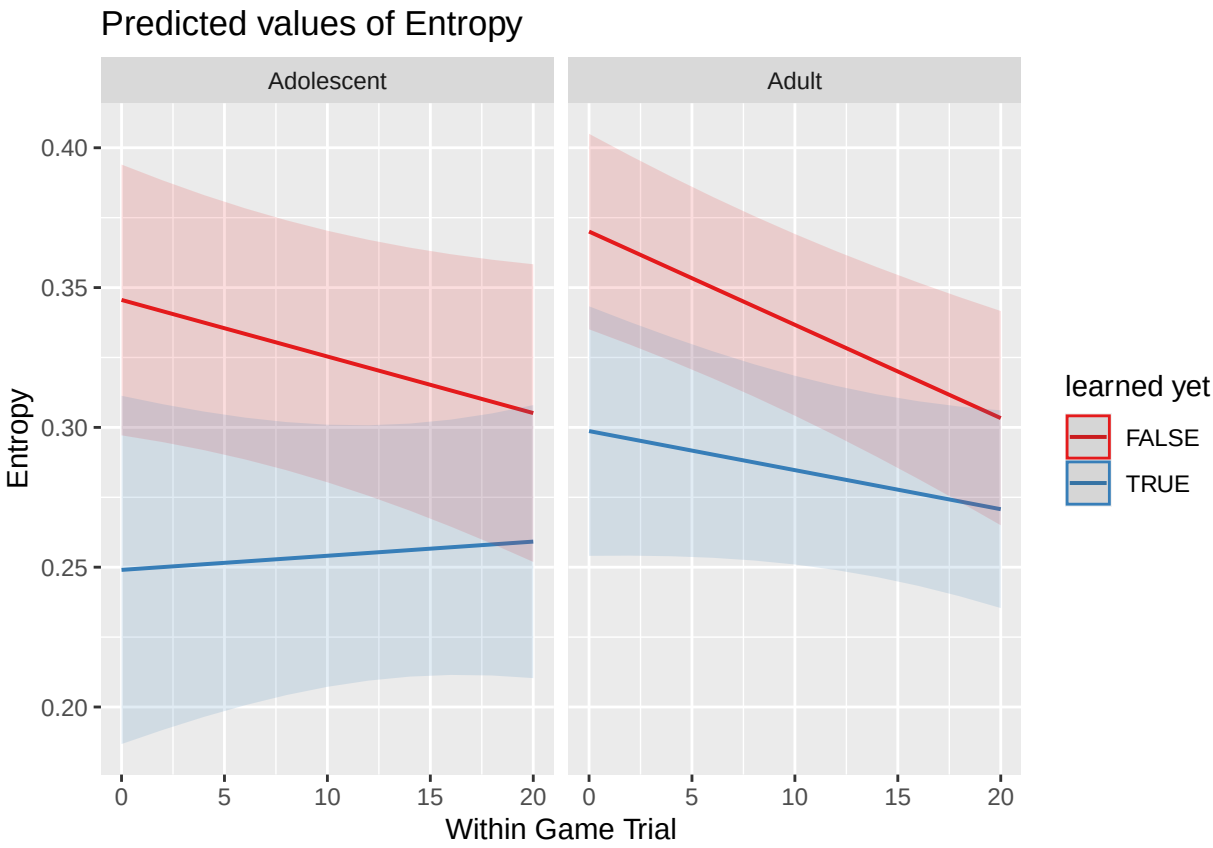
```
##
## [[2]]
```


Predicted values of Entropy
0.40
0.35
0.30
0.25
Entropy
0
5
10
15
20
Within Game Trial
age group
Adolescent
Adult

```
##
## [[3]]
```


Predicted values of Entropy
Entropy
0.35
0.30
0.25
FALSE
TRUE
learned yet
age group
Adolescent
Adult

```
##
## [[4]]
```

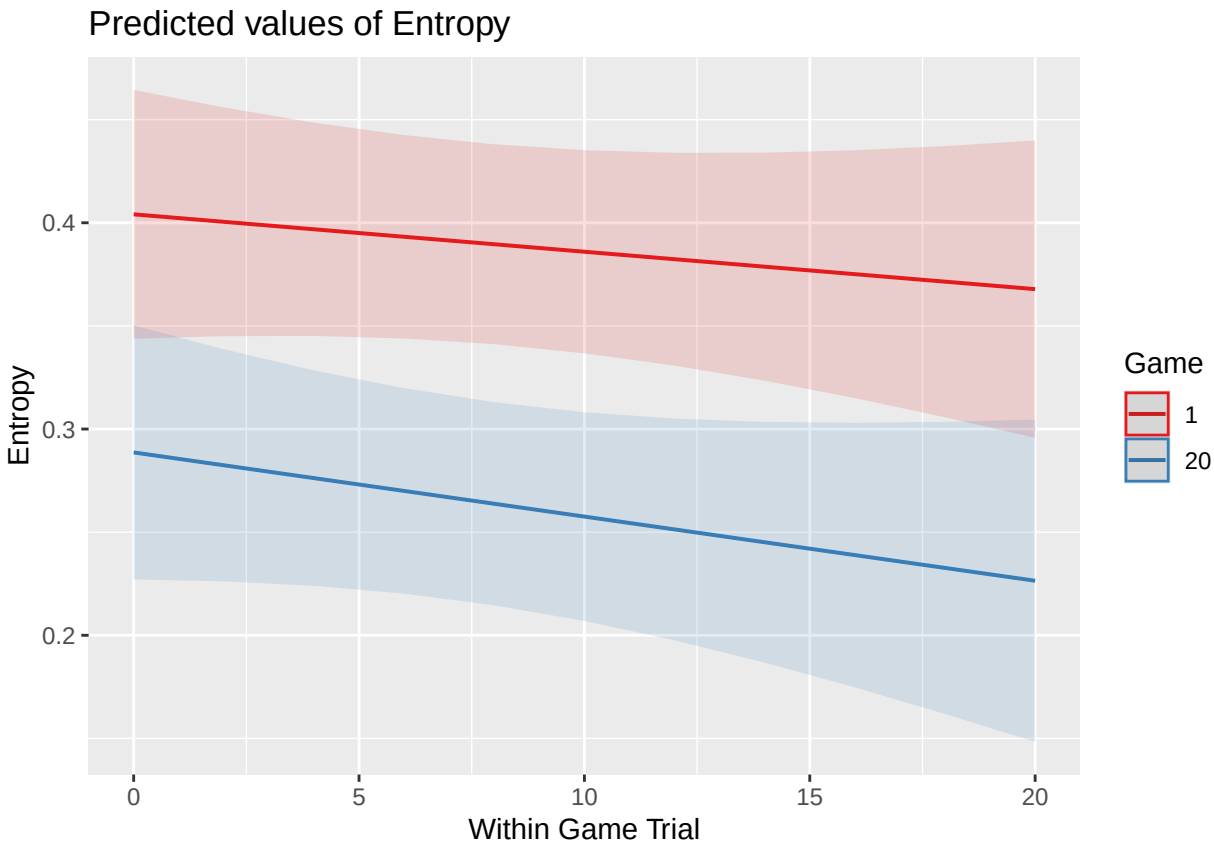


Next, we fully model `Entropy ~ WithinGameTrial*Game*LearnedYet*AgeGroup + (1|Subject)`

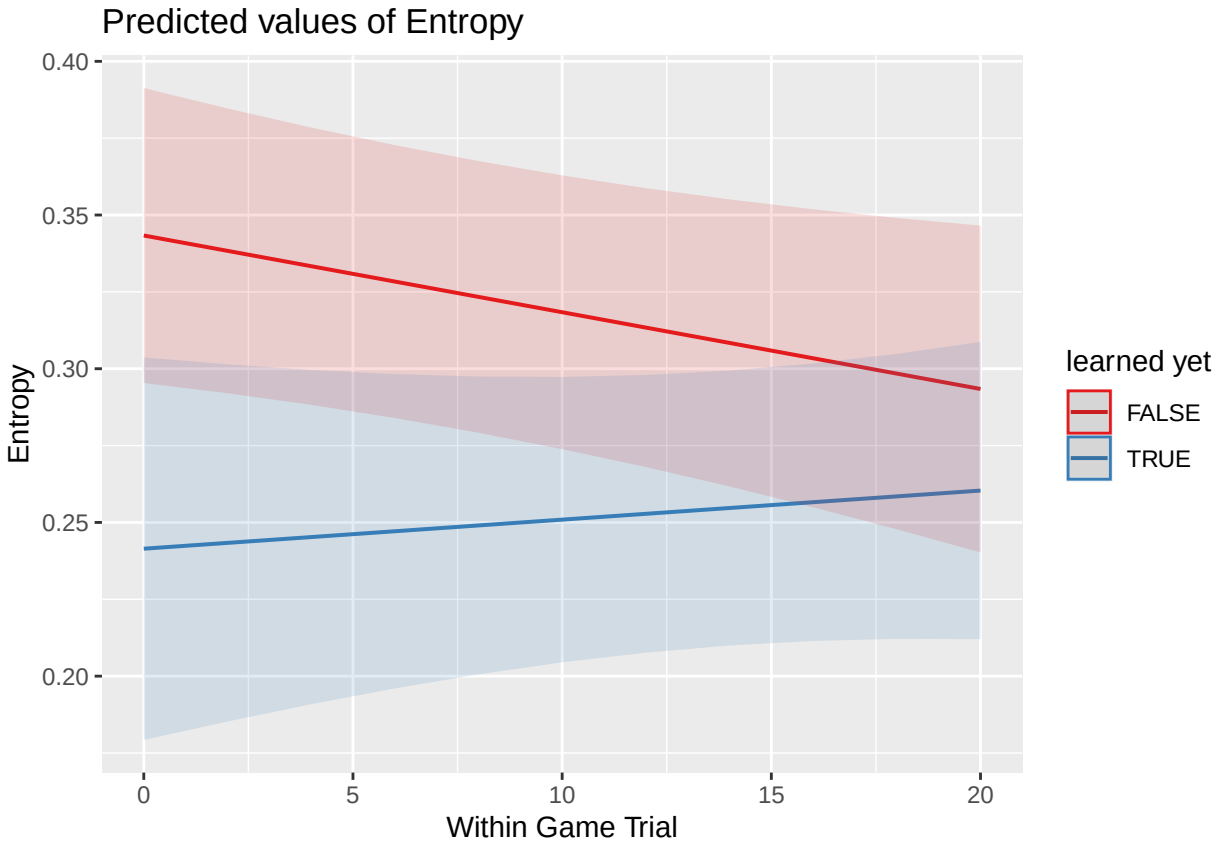
```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Entropy ~ WithinGameTrial * Game * learned_yet * age_group +
##     (1 | subject_id)
##    Data: model_data
##
## REML criterion at convergence: 3353.7
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -1.90489 -0.89168 -0.07879  0.83580  2.64796
##
## Random effects:
##  Groups     Name        Variance Std.Dev.
##  subject_id (Intercept) 0.005619 0.07496
##  Residual               0.078429 0.28005
## Number of obs: 10529, groups:  subject_id, 35
##
## Fixed effects:
##                                                 Estimate Std. Error
## (Intercept)                                    4.102e-01  3.204e-02
## WithinGameTrial                               -1.745e-03  2.463e-03
## Game                                          -6.076e-03  2.024e-03
## learned_yetTRUE                               -7.202e-02  5.240e-02
## age_groupAdult                                 2.778e-02  3.949e-02
```

```
## WithinGameTrial:Game                                       -6.826e-05  2.164e-04
## WithinGameTrial:learned_yetTRUE                            -1.640e-03  4.033e-03
## Game:learned_yetTRUE                                       -2.716e-03  4.555e-03
## WithinGameTrial:age_groupAdult                             -2.861e-03  3.027e-03
## Game:age_groupAdult                                        -2.547e-04  2.463e-03
## learned_yetTRUE:age_groupAdult                             -1.835e-02  6.461e-02
## WithinGameTrial:Game:learned_yetTRUE                        4.620e-04  3.518e-04
## WithinGameTrial:Game:age_groupAdult                         1.769e-04  2.614e-04
## WithinGameTrial:learned_yetTRUE:age_groupAdult              5.249e-03  4.974e-03
## Game:learned_yetTRUE:age_groupAdult                         4.661e-03  5.478e-03
## WithinGameTrial:Game:learned_yetTRUE:age_groupAdult -6.141e-04  4.243e-04
##                                                                    df t value Pr(>|t|)
## (Intercept)                                                 1.428e+02  12.802  < 2e-16
## WithinGameTrial                                             1.049e+04  -0.709  0.47852
## Game                                                        1.049e+04  -3.002  0.00269
## learned_yetTRUE                                             1.049e+04  -1.374  0.16934
## age_groupAdult                                              1.423e+02   0.703  0.48295
## WithinGameTrial:Game                                        1.049e+04  -0.316  0.75238
## WithinGameTrial:learned_yetTRUE                             1.049e+04  -0.407  0.68425
## Game:learned_yetTRUE                                        1.049e+04  -0.596  0.55106
## WithinGameTrial:age_groupAdult                              1.049e+04  -0.945  0.34458
## Game:age_groupAdult                                         1.049e+04  -0.103  0.91766
## learned_yetTRUE:age_groupAdult                              1.049e+04  -0.284  0.77637
## WithinGameTrial:Game:learned_yetTRUE                        1.049e+04   1.313  0.18911
## WithinGameTrial:Game:age_groupAdult                         1.049e+04   0.677  0.49848
## WithinGameTrial:learned_yetTRUE:age_groupAdult              1.049e+04   1.055  0.29132
## Game:learned_yetTRUE:age_groupAdult                         1.049e+04   0.851  0.39490
## WithinGameTrial:Game:learned_yetTRUE:age_groupAdult         1.049e+04  -1.447  0.14781
##
## (Intercept)                                                ***
## WithinGameTrial
## Game                                                       **
## learned_yetTRUE
## age_groupAdult
## WithinGameTrial:Game
## WithinGameTrial:learned_yetTRUE
## Game:learned_yetTRUE
## WithinGameTrial:age_groupAdult
## Game:age_groupAdult
## learned_yetTRUE:age_groupAdult
## WithinGameTrial:Game:learned_yetTRUE
## WithinGameTrial:Game:age_groupAdult
## WithinGameTrial:learned_yetTRUE:age_groupAdult
## Game:learned_yetTRUE:age_groupAdult
## WithinGameTrial:Game:learned_yetTRUE:age_groupAdult
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

##
## Correlation matrix not shown by default, as p = 16 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it

## Analysis of Deviance Table (Type III Wald chisquare tests)
```

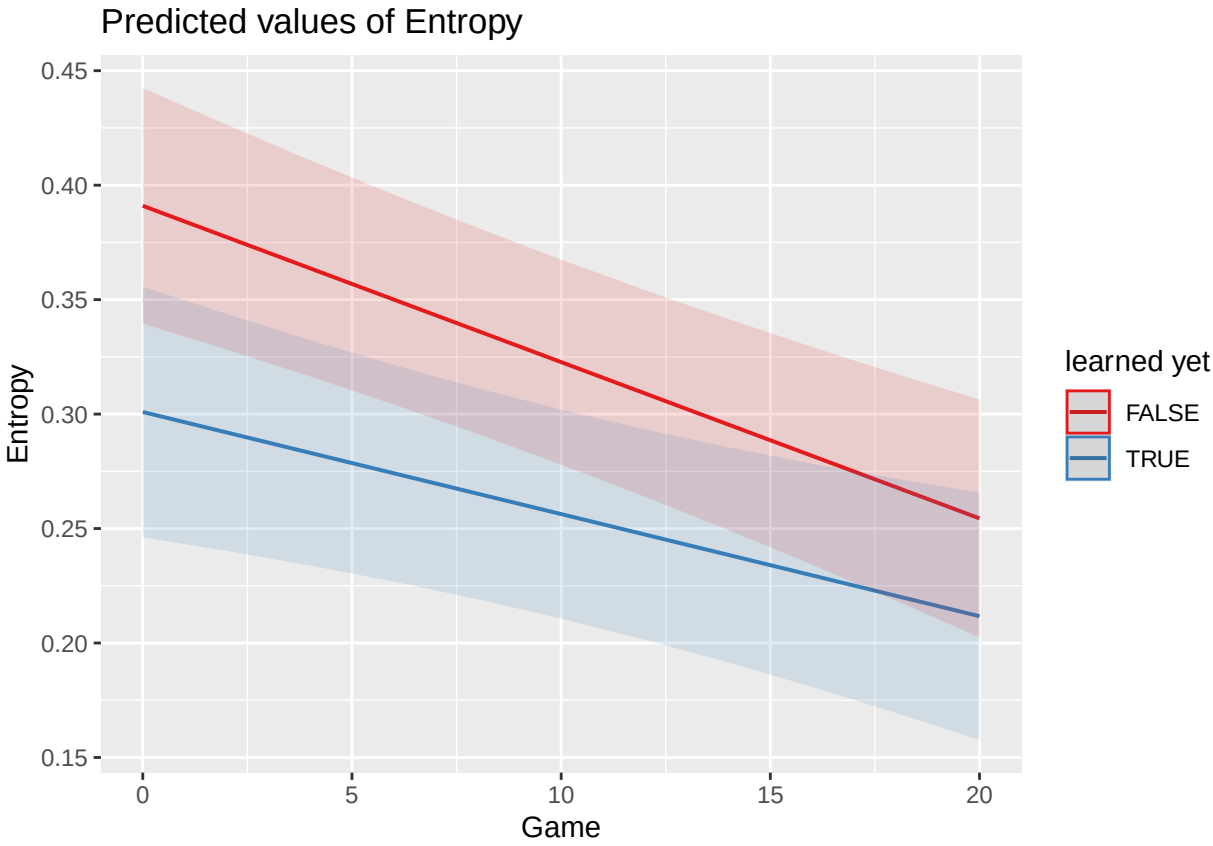
```
##
## Response: Entropy
##                                            Chisq Df Pr(>Chisq)
## (Intercept)                             163.8956  1  < 2.2e-16 ***
## WithinGameTrial                           0.5023  1   0.478508
## Game                                      9.0092  1   0.002686 **
## learned_yet                               1.8890  1   0.169314
## age_group                                 0.4948  1   0.481799
## WithinGameTrial:Game                      0.0995  1   0.752379
## WithinGameTrial:learned_yet               0.1654  1   0.684237
## Game:learned_yet                          0.3555  1   0.551044
## WithinGameTrial:age_group                 0.8934  1   0.344555
## Game:age_group                            0.0107  1   0.917657
## learned_yet:age_group                     0.0807  1   0.776367
## WithinGameTrial:Game:learned_yet          1.7247  1   0.189085
## WithinGameTrial:Game:age_group            0.4582  1   0.498462
## WithinGameTrial:learned_yet:age_group     1.1136  1   0.291300
## Game:learned_yet:age_group                0.7239  1   0.394879
## WithinGameTrial:Game:learned_yet:age_group  2.0951  1   0.147777
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

## [[1]]
```



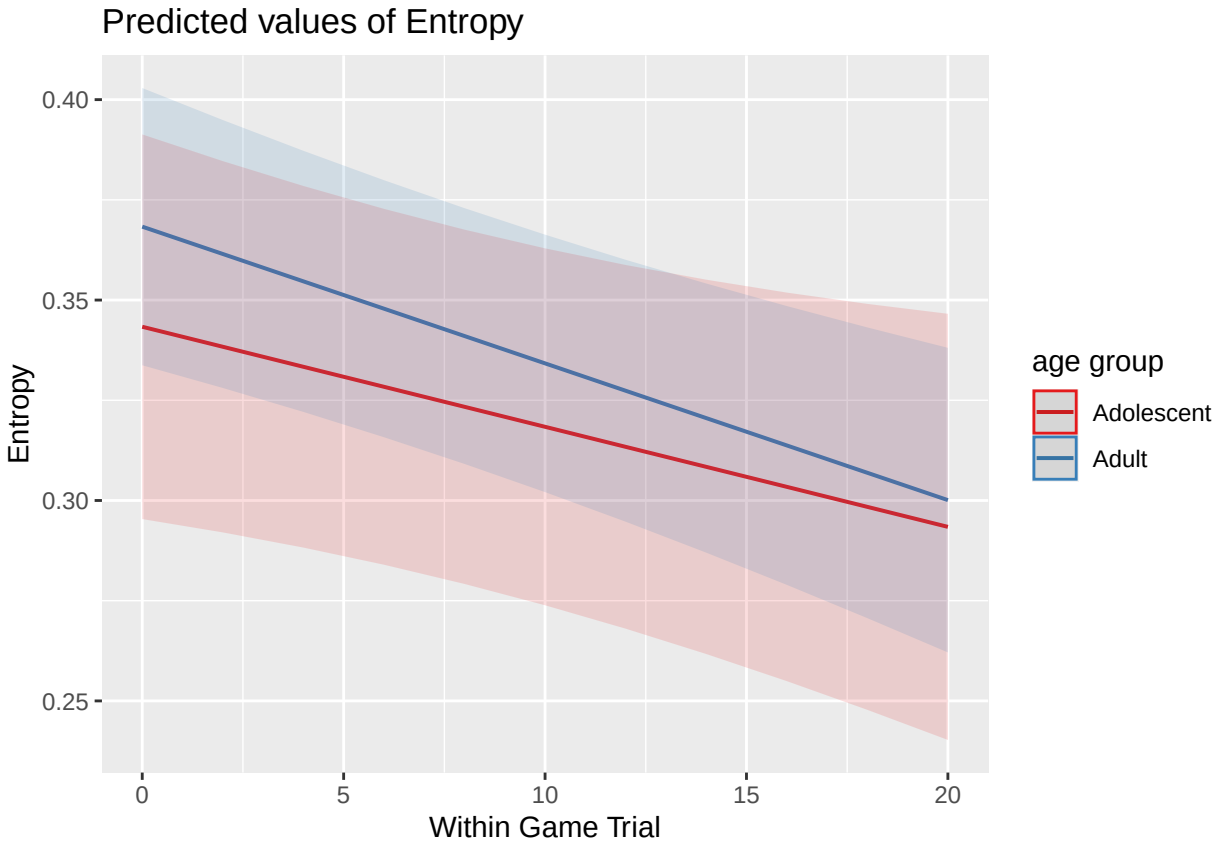

```
##
## [[2]]
```


Predicted values of Entropy
0.40
0.35
0.30
0.25
0.20
Entropy
0
5
10
15
20
Within Game Trial
learned yet
FALSE
TRUE

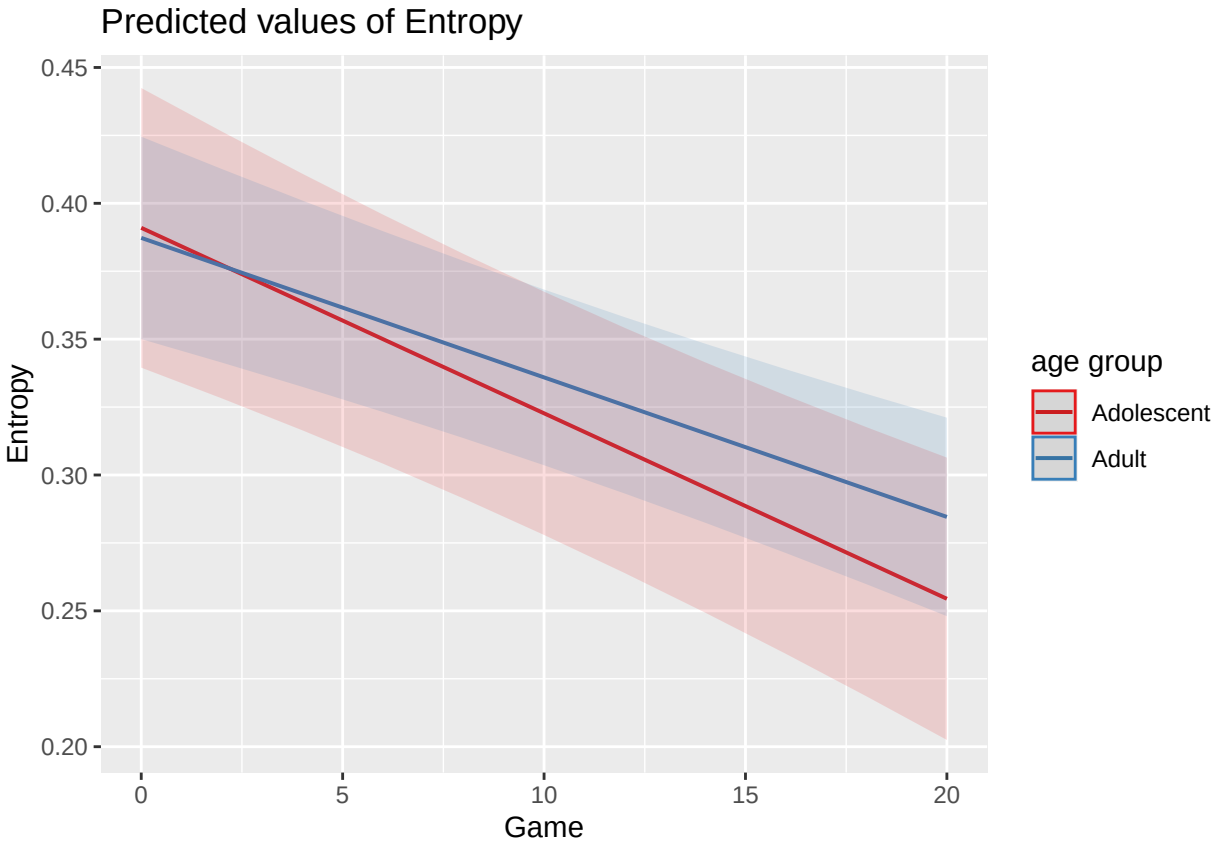
```
##
## [[3]]
```


Predicted values of Entropy
0.45
0.40
0.35
0.30
0.25
0.20
0.15
Entropy
0
5
10
15
20
Game
learned yet
FALSE
TRUE

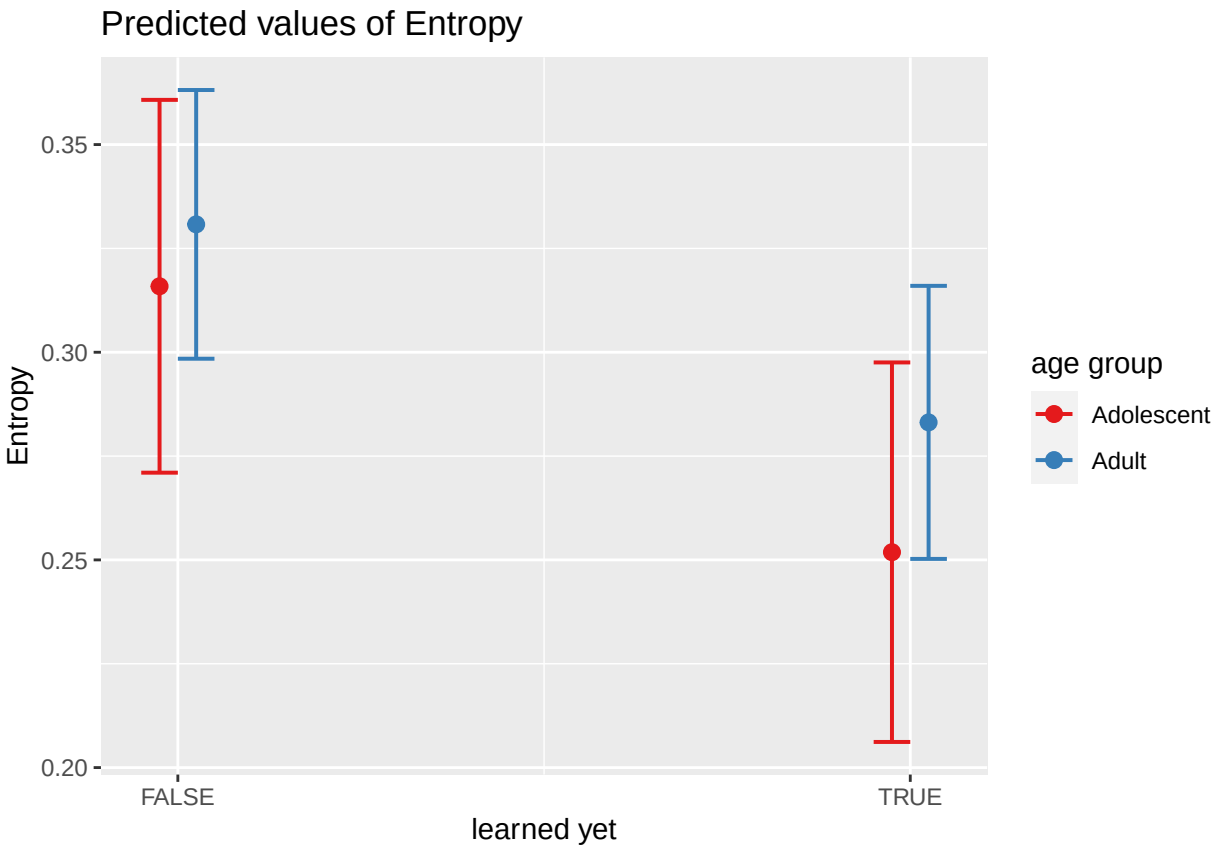
```
##
## [[4]]
```


Predicted values of Entropy
0.40
0.35
0.30
0.25
Entropy
0
5
10
15
20
Within Game Trial
age group
Adolescent
Adult

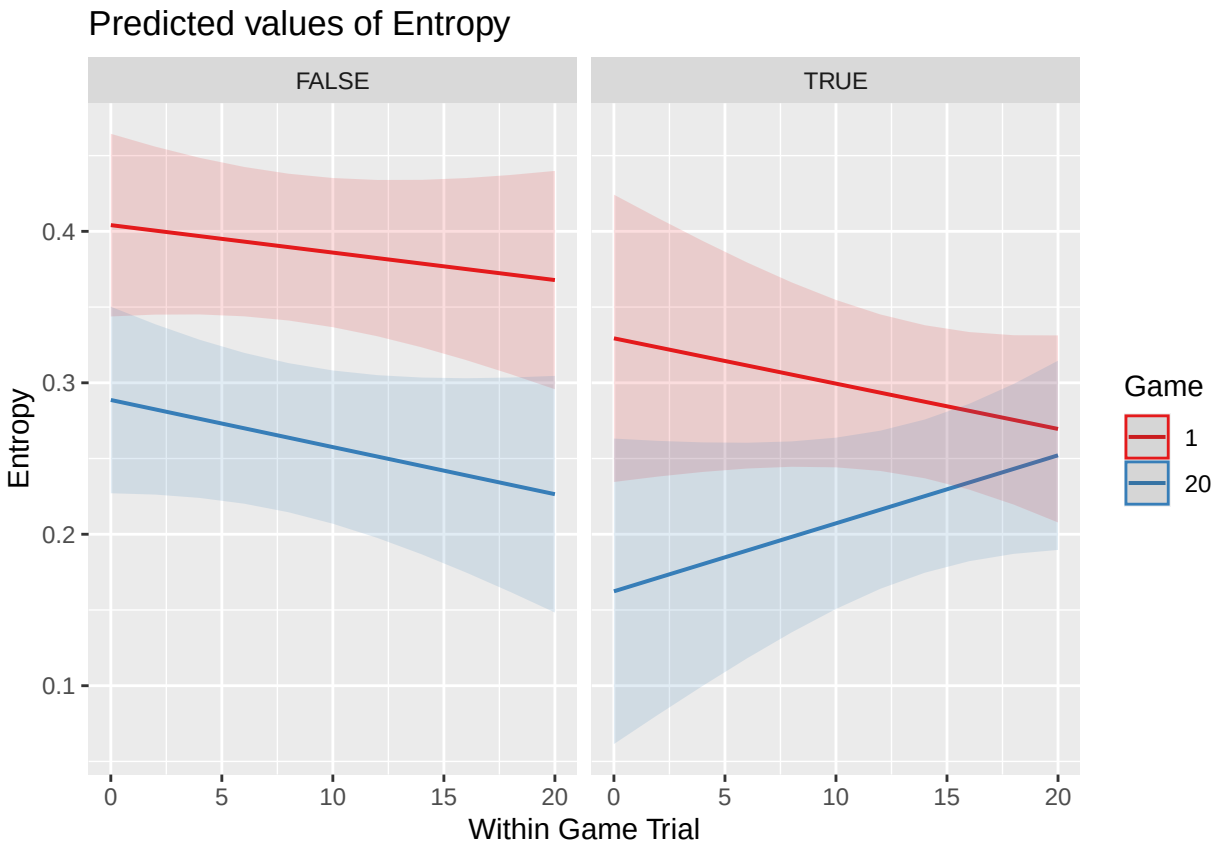
```
##
## [[5]]
```


Predicted values of Entropy
Entropy
0.45
0.40
0.35
0.30
0.25
0.20
0
5
10
15
20
Game
age group
Adolescent
Adult

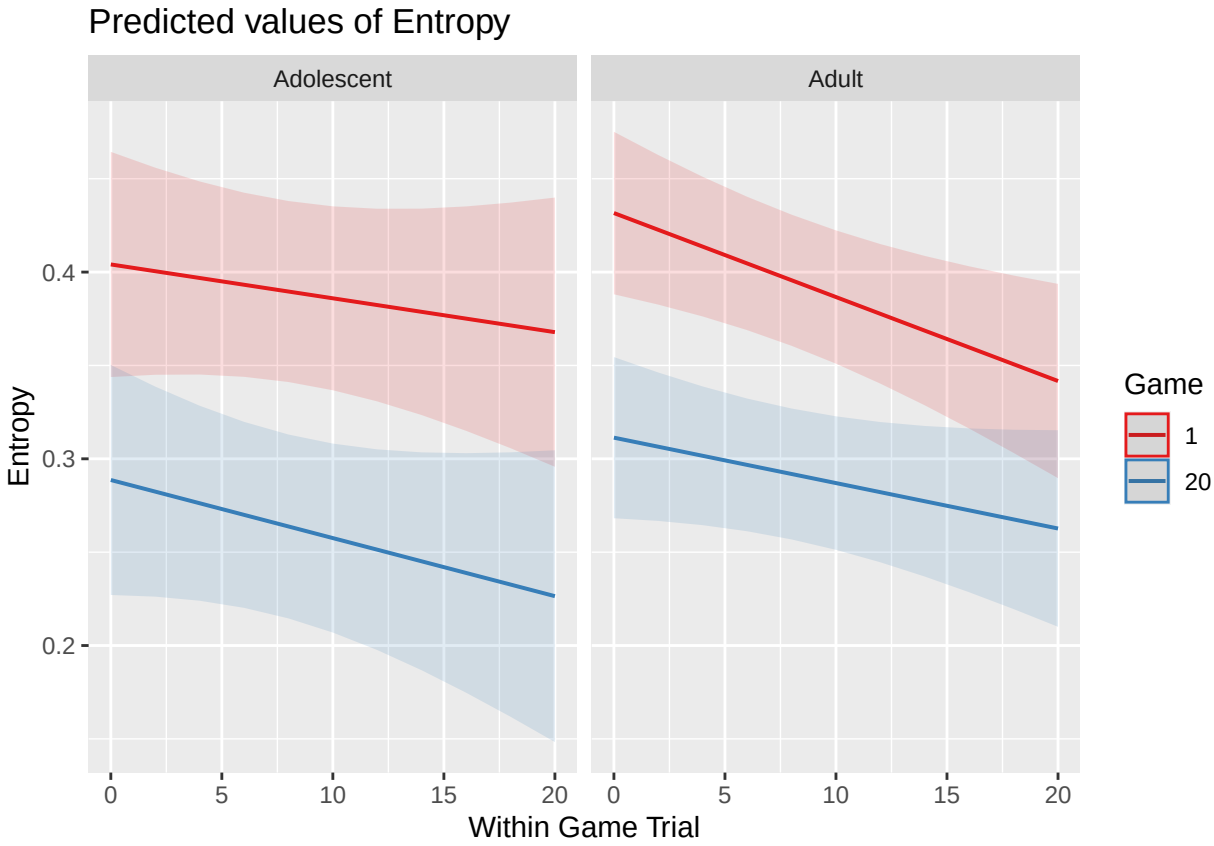
```
##
## [[6]]
```


Predicted values of Entropy
Entropy
0.35
0.30
0.25
0.20
FALSE
TRUE
learned yet
age group
Adolescent
Adult

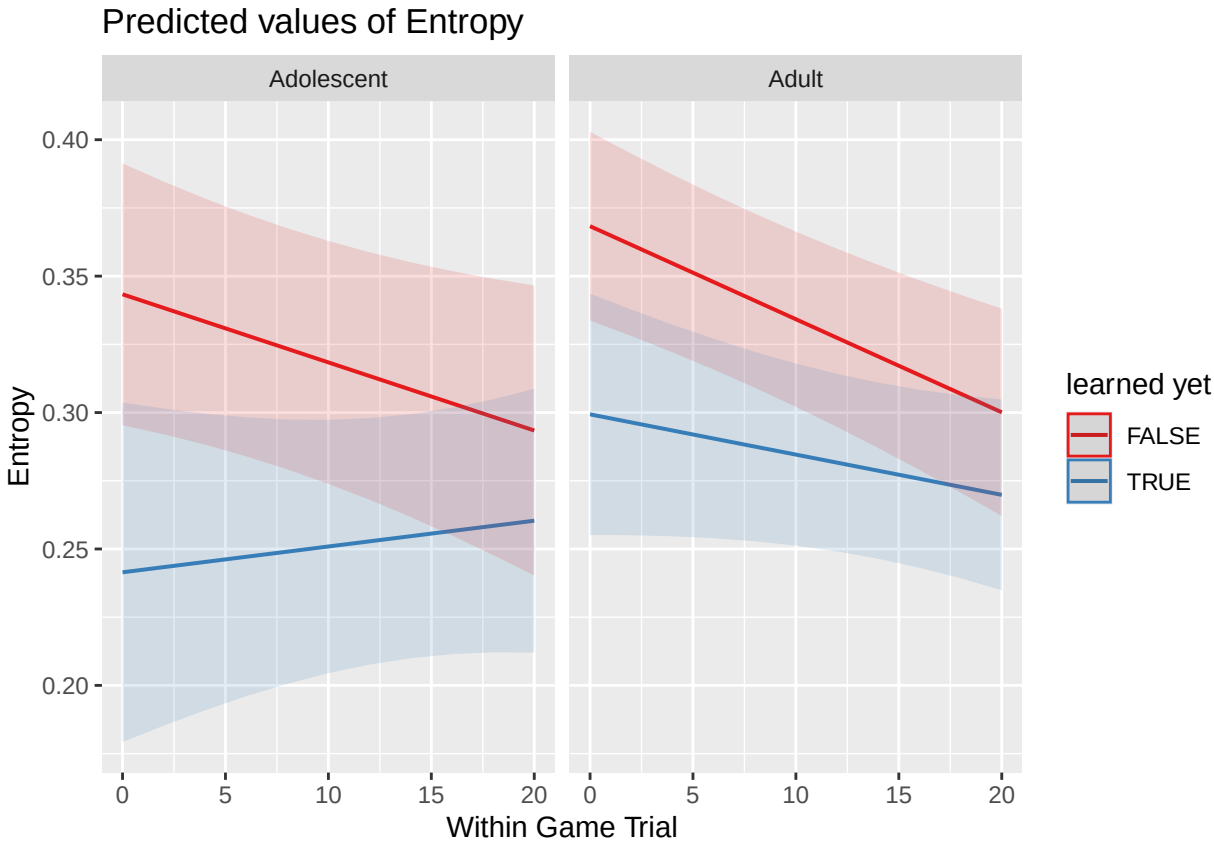
```
##
## [[7]]
```


Predicted values of Entropy
FALSE
TRUE
Entropy
0.4
0.3
0.2
0.1
0
5
10
15
20
Within Game Trial
Game
1
20

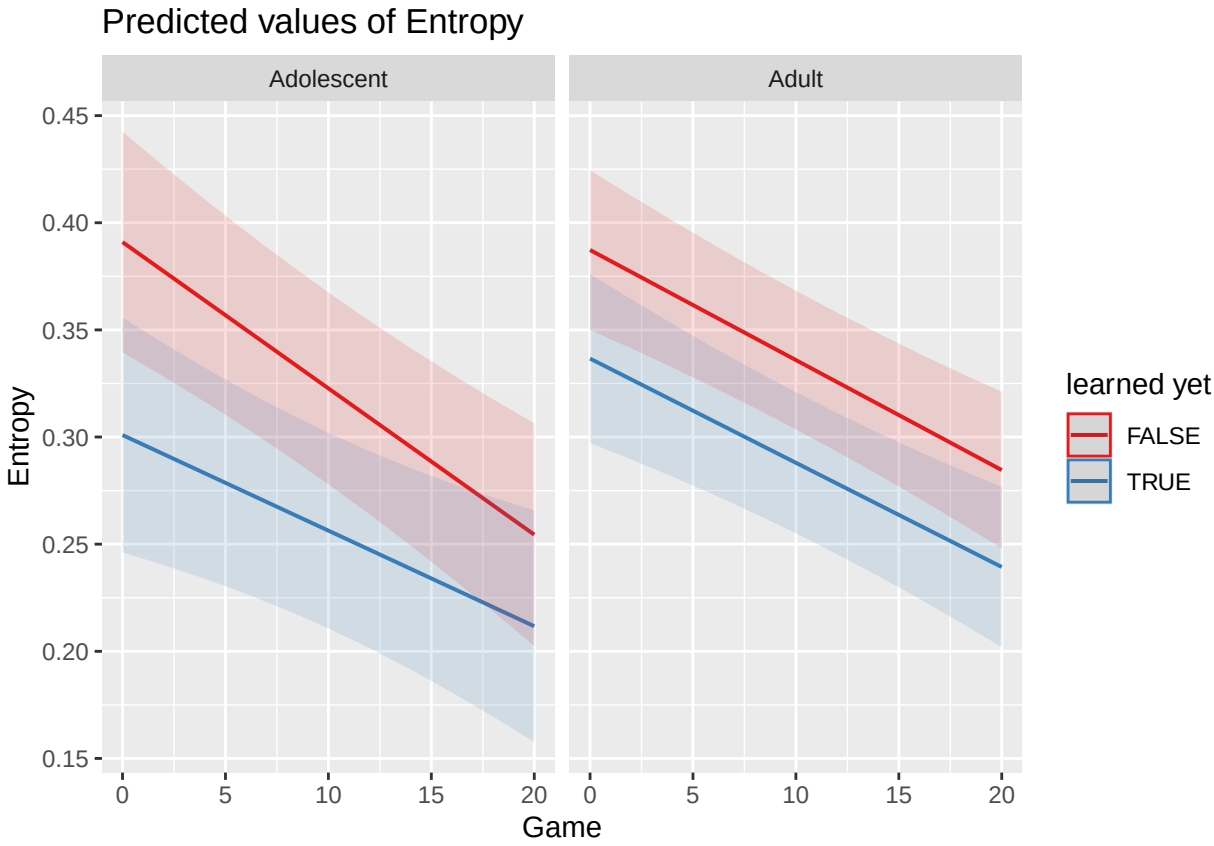
```
##
## [[8]]
```


Predicted values of Entropy
Adolescent
Adult
Entropy
0.4
0.3
0.2
0
5
10
15
20
Within Game Trial
Game
1
20

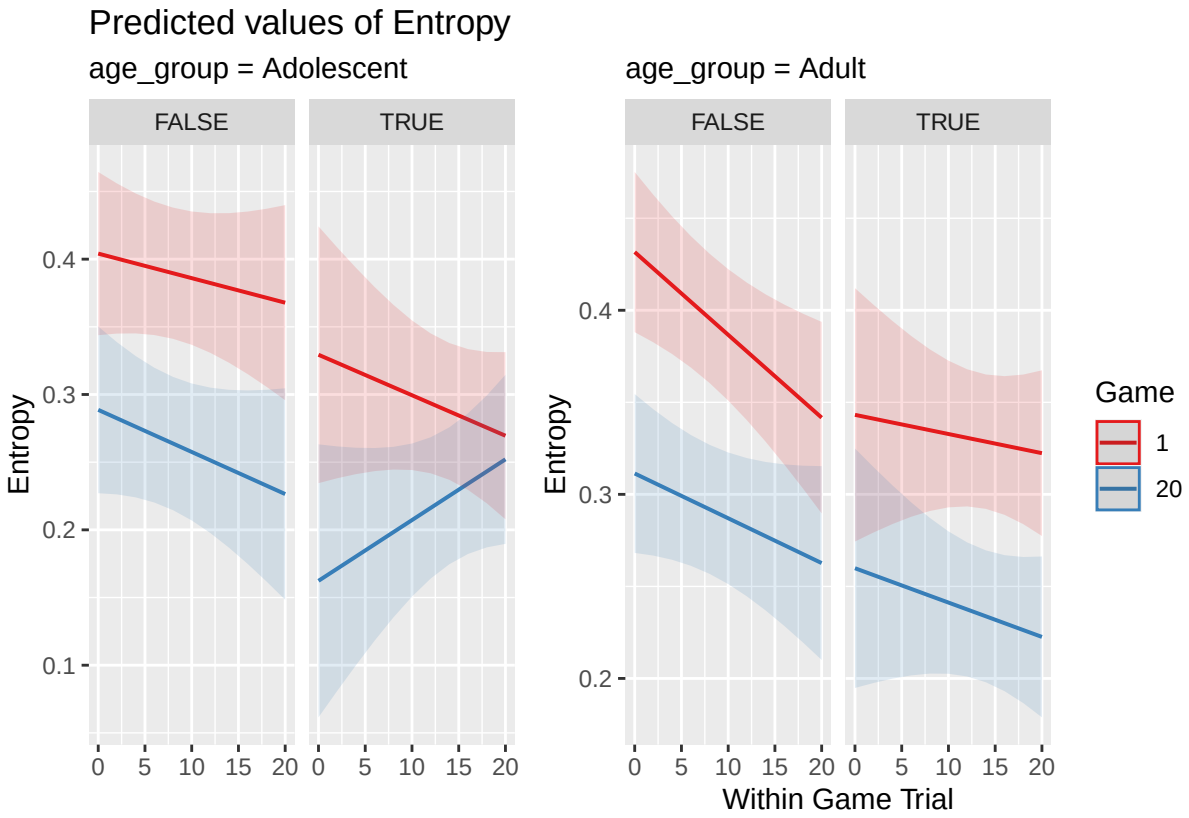
```
##
## [[9]]
```


Predicted values of Entropy
Adolescent
Adult
Entropy
0.40
0.35
0.30
0.25
0.20
0
5
10
15
20
Within Game Trial
learned yet
FALSE
TRUE

```
##
## [[10]]
```


Predicted values of Entropy
Adolescent
Adult
Entropy
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0
5
10
15
20
Game
learned yet
FALSE
TRUE

```
##
## [[11]]
```


Predicted values of Entropy
age_group = Adolescent
age_group = Adult
FALSE
TRUE
Entropy
0.4
0.3
0.2
0.1
0 5 10 15 20
Within Game Trial
Game
1
20