tACS LME

```
#install.packages("readxl")
#install.packages("lme4")
#install.packages("lmerTest")
```

Plots

```
library(ggplot2)
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --
```

```
## v tibble  3.1.6     v dplyr   1.0.8
## v tidyr   1.2.0     v stringr 1.4.0
## v readr   2.1.2     v forcats 0.5.1
## v purrr   0.3.4
```

```
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(hrbrthemes)
```

```
## NOTE: Either Arial Narrow or Roboto Condensed fonts are required to use these themes.
```

```
##        Please use hrbrthemes::import_roboto_condensed() to install Roboto Condensed and
```

```
##        if Arial Narrow is not on your system, please see https://bit.ly/arialnarrow
```

```
library(viridis)
```

```
## Loading required package: viridisLite
```

```
library("readxl")
library('lme4')
```

```
## Loading required package: Matrix
```

```
##
## Attaching package: 'Matrix'
```

```
## The following objects are masked from 'package:tidyr':
##
##      expand, pack, unpack
```

```
library('lmerTest')
```

```
##
## Attaching package: 'lmerTest'
```

```
## The following object is masked from 'package:lme4':
##
##      lmer
```

```
## The following object is masked from 'package:stats':
##
##     step
library('ggplot2')
data <- read_excel('tables/stats_LME_3.xlsx')
data <- data[complete.cases(data), ]
```
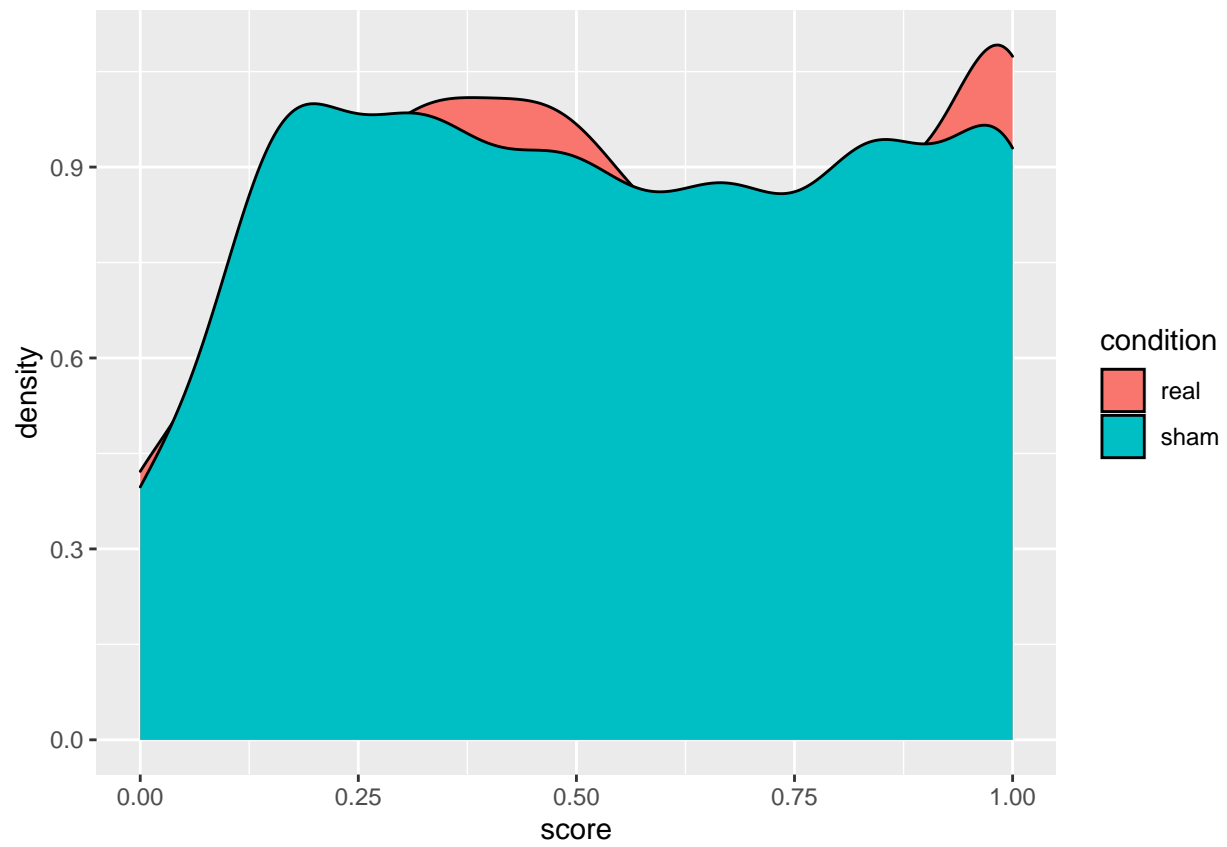
Recall

```
data_recall <- data[which(data$task == 'recall'), ]
p1 <- ggplot( data_recall, aes(x=session, y=score, fill=condition)) +
    geom_boxplot() +
    geom_jitter(color="black", size=0.4, alpha=0.9) +
    theme(
      plot.title = element_text(size=11)
    ) +
    ggtitle("Recall") +
    xlab("")
p1
```
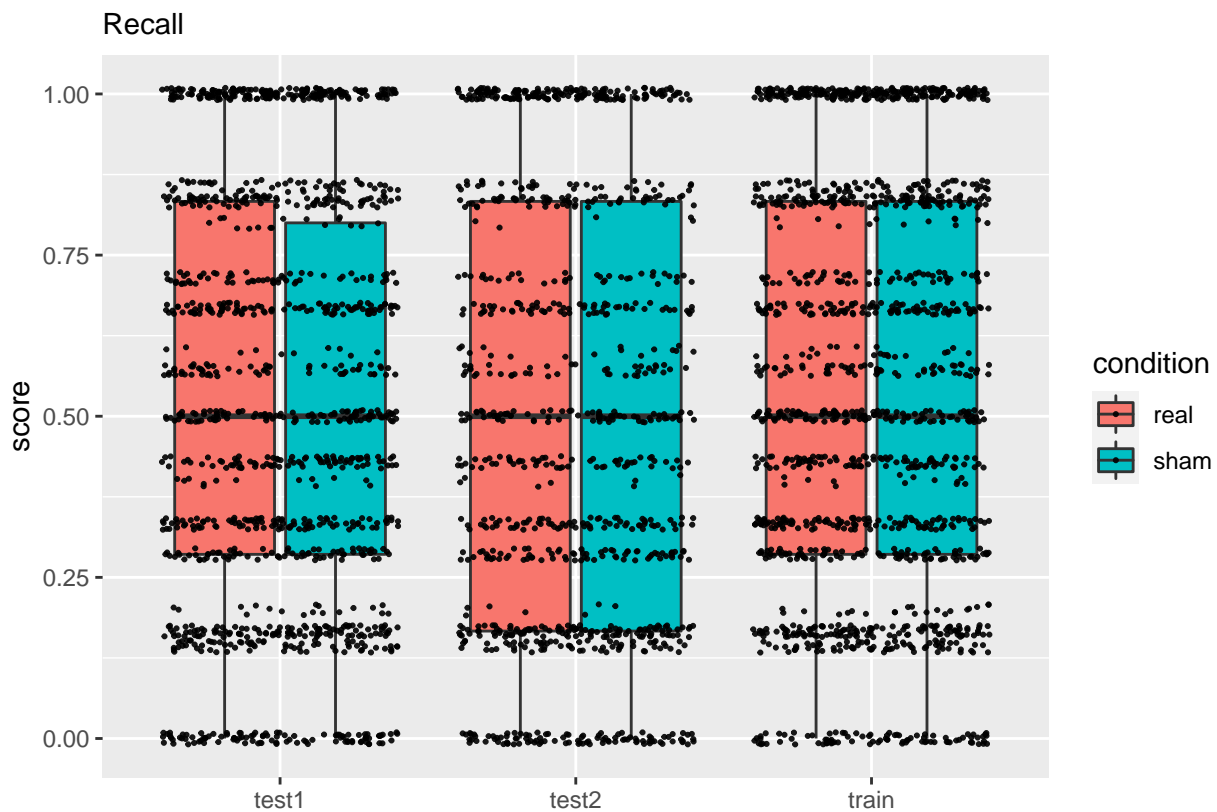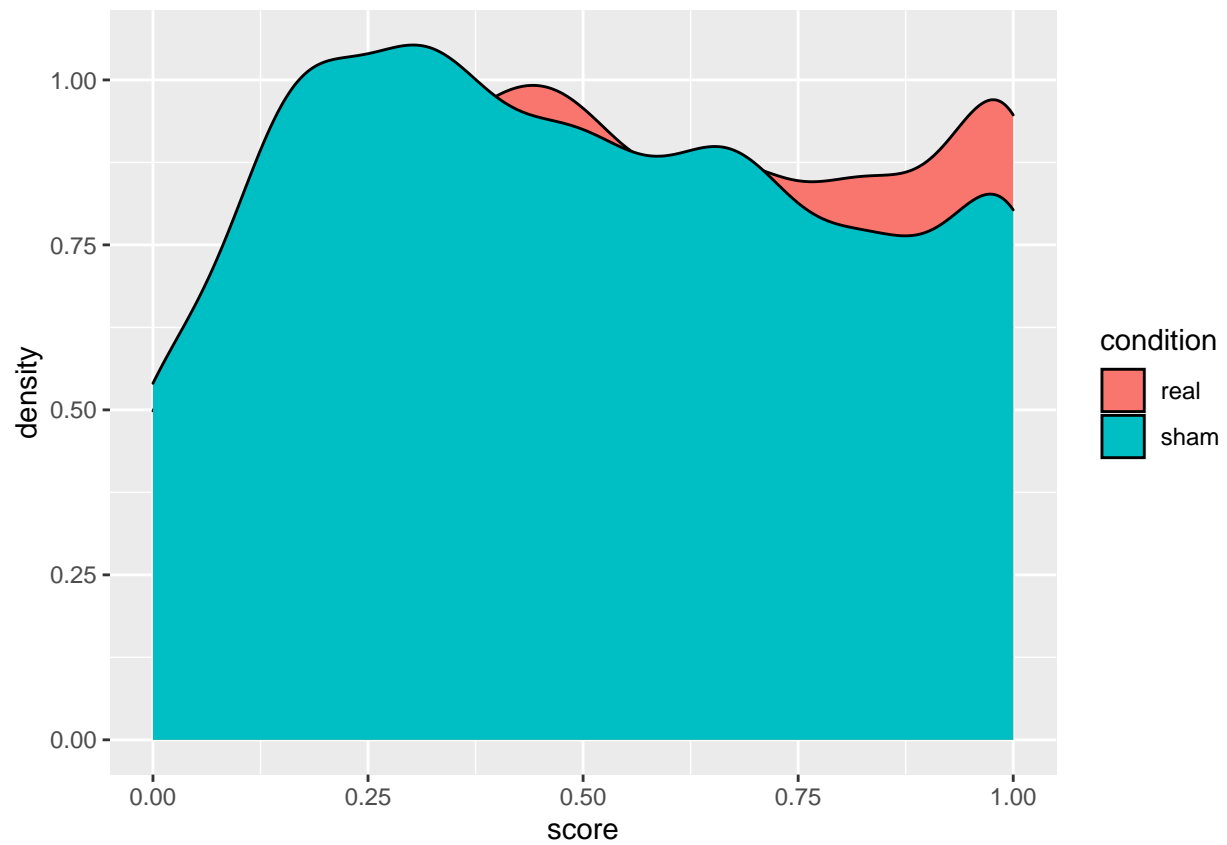


```
recall_train <- data_recall[which(data_recall$session == 'train'), ]
recall_test1 <- data_recall[which(data_recall$session == 'test1'), ]
recall_test2 <- data_recall[which(data_recall$session == 'test2'), ]
```
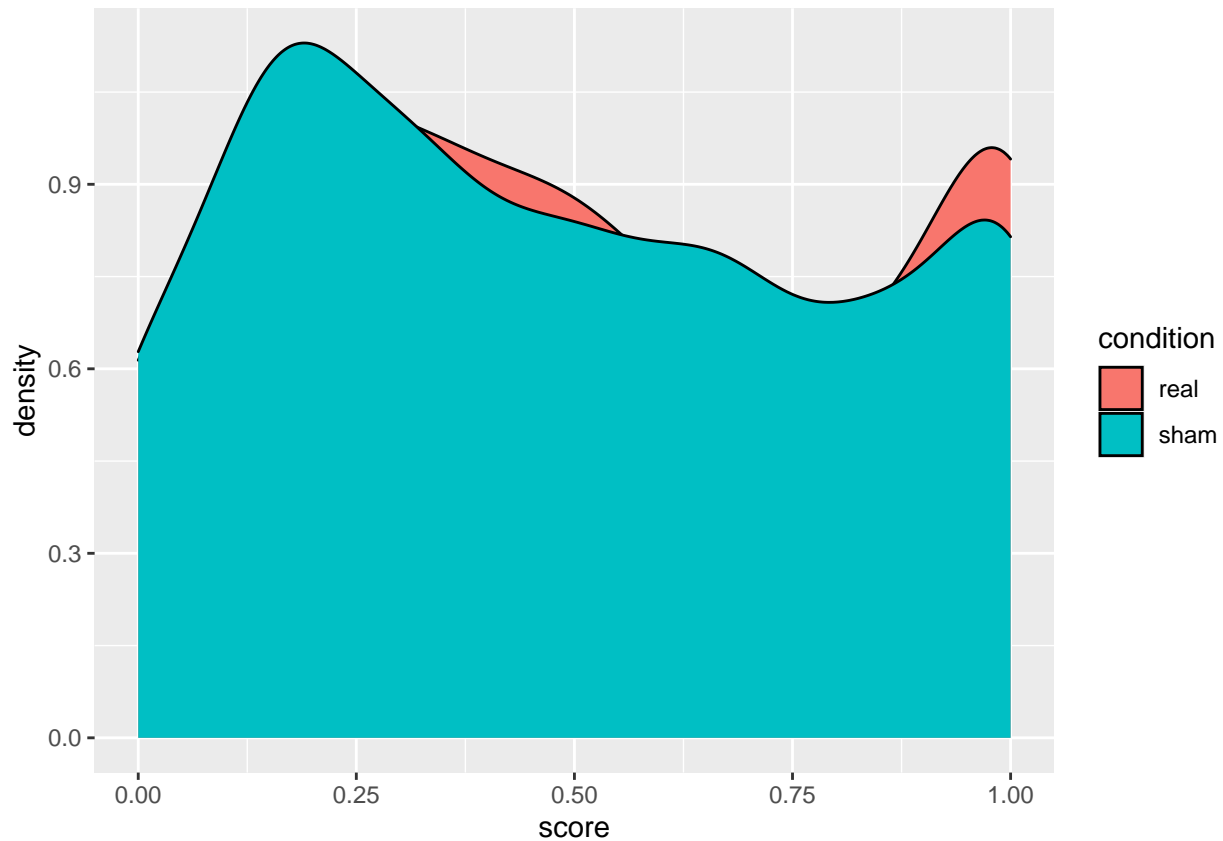
```
ggplot(recall_train) + geom_density(aes(x=score, fill=condition))
```

```
ggplot(recall_test1) + geom_density(aes(x=score, fill=condition))
```

```
ggplot(recall_test2) + geom_density(aes(x=score, fill=condition))
```

AFC

```r
AFC <- data[which(data$task == 'AFC'), ]
AFC_scores <- aggregate(AFC$score, by=list(AFC$participant, AFC$session, AFC$condition), FUN=sum)
AFC_scores <- setNames(AFC_scores, c('Participant', 'session', 'condition', 'score'))
p2 <- ggplot(AFC_scores,
            aes(x=session, y=score, fill=condition)) +
  geom_boxplot() +
  geom_jitter(color="black", size=0.4, alpha=0.9) +
  theme(
    plot.title = element_text(size=11)
    ) +
  ggtitle("AFC") +
  xlab("")
p2
```

AFC
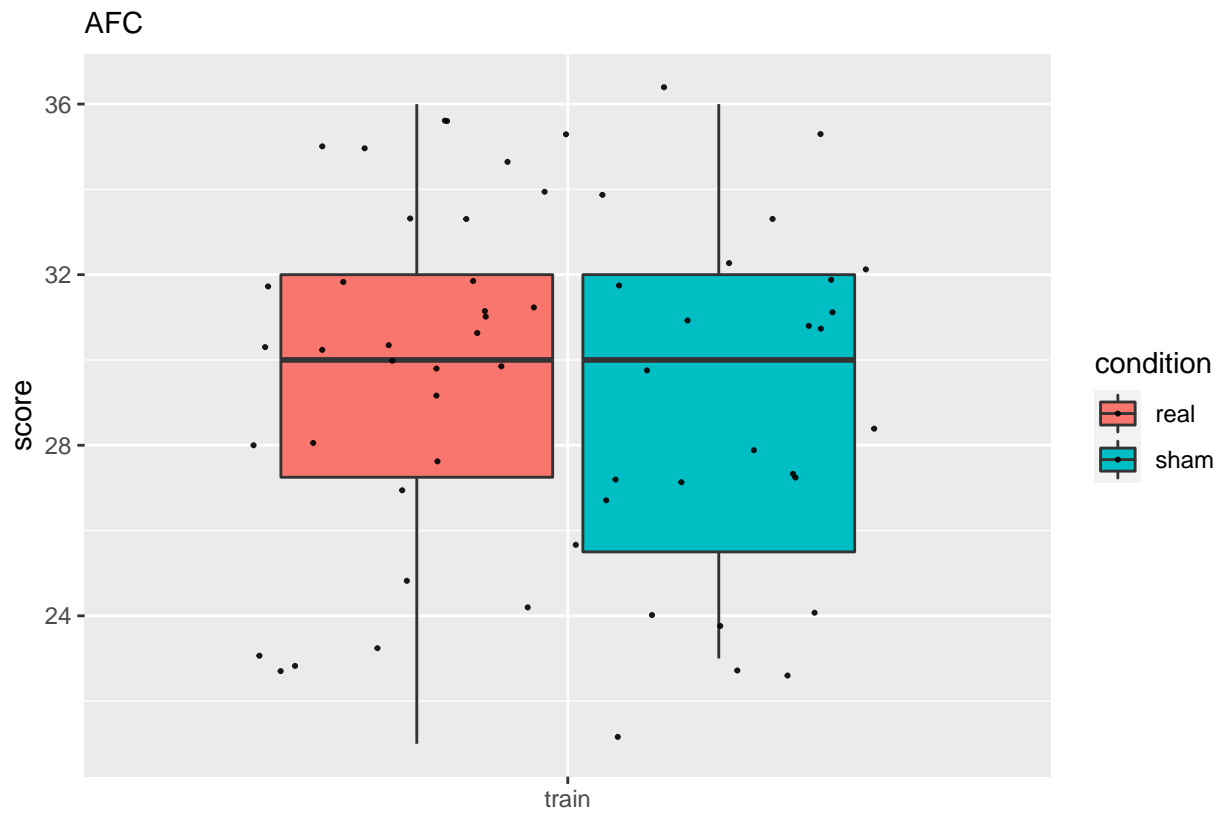
```
ggplot(AFC_scores) + geom_density(aes(x=score, fill=condition))
```

```
ggplot(AFC) + geom_density(aes(x=score, fill=condition))
```


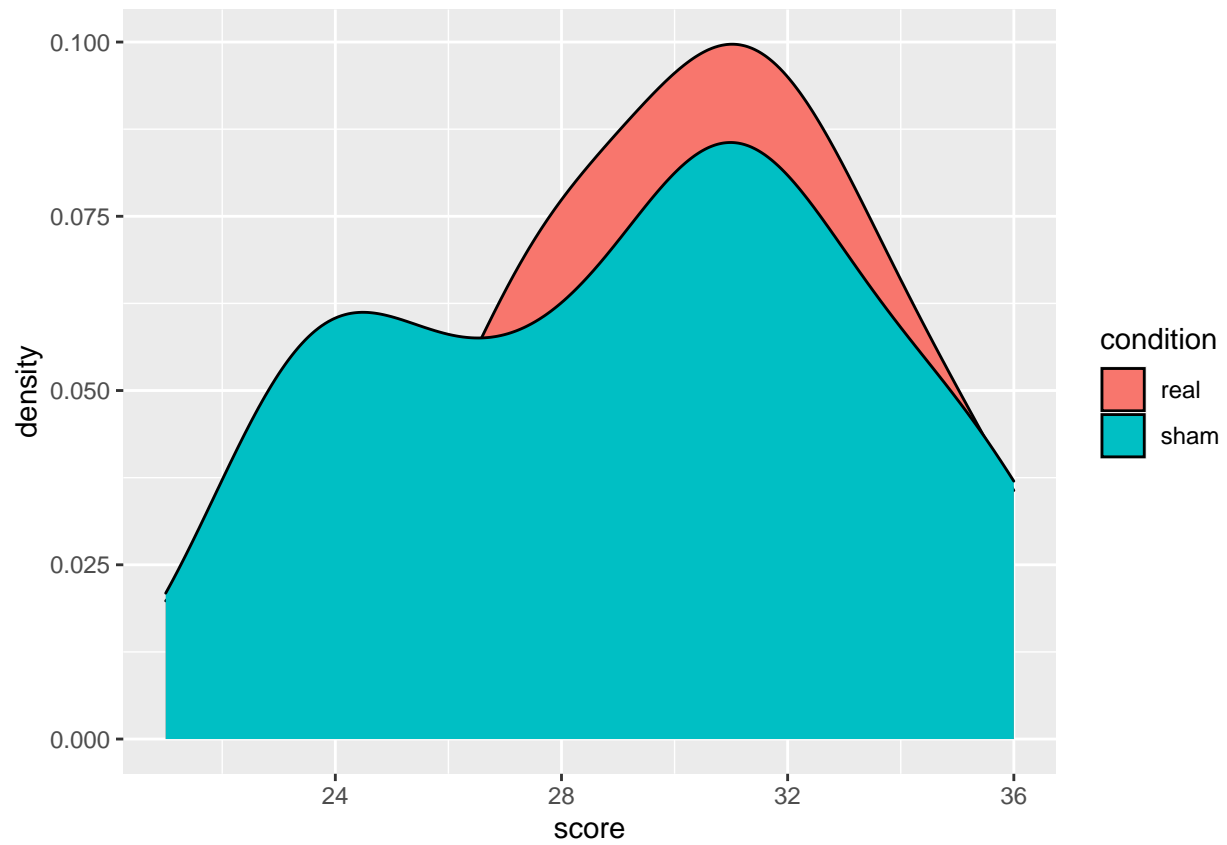## Recognition
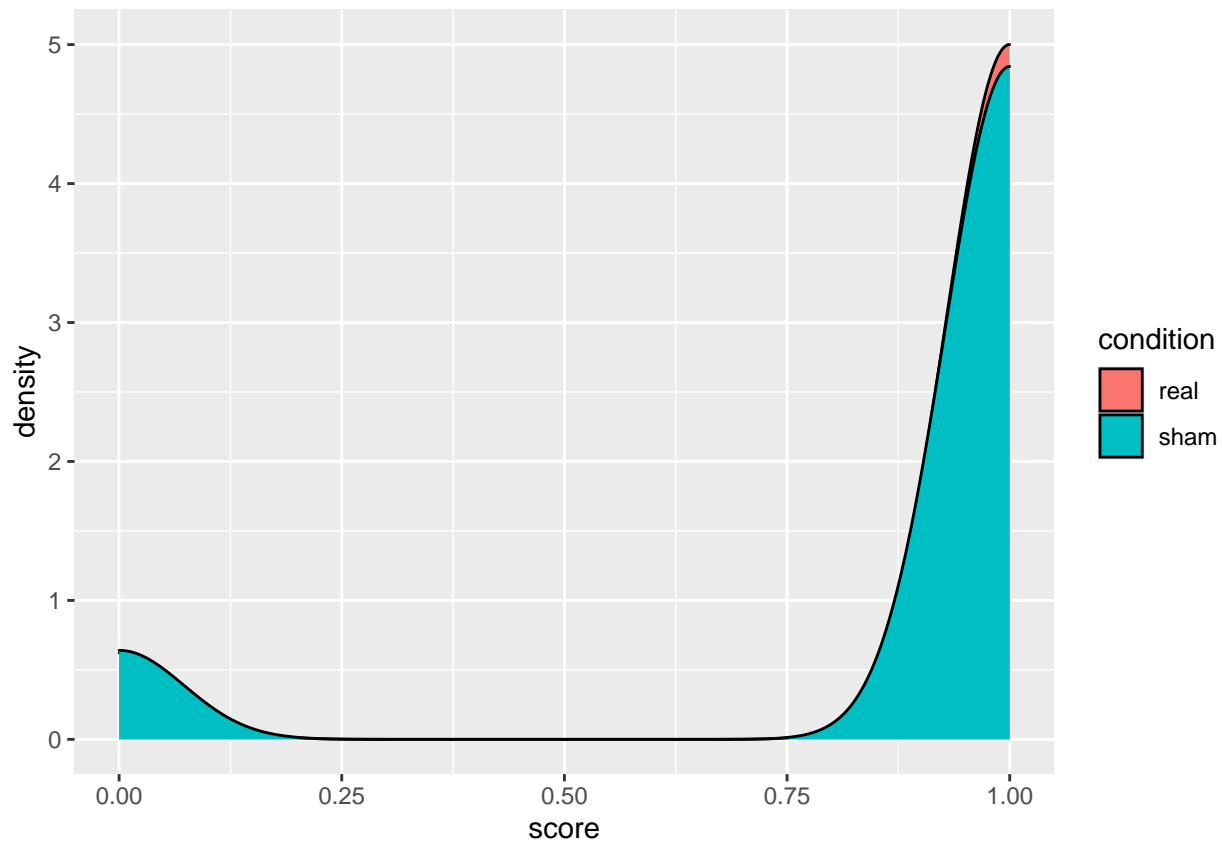
```r
recognition <- data[which(data$task == 'recognition'), ]
recognition1 <- recognition[which(recognition$session == 'test1'), ]
recognition2 <- recognition[which(recognition$session == 'test2'), ]
recognition_scores <- aggregate(recognition$score, by=list(recognition$participant, recognition$session
recognition_scores <- setNames(recognition_scores, c('Participant', 'session', 'condition', 'score'))

recognition_scores1 <- recognition_scores[
  which(recognition_scores$session == 'test1'), ]
recognition_scores2 <- recognition_scores[
  which(recognition_scores$session == 'test2'), ]
p3 <- ggplot( recognition_scores, aes(x=session, y=score, fill=condition)) + geom_boxplot() +
    geom_jitter(color="black", size=0.4, alpha=0.9) +
    theme(
      plot.title = element_text(size=11)
    ) +
    ggtitle("recognition") +
    xlab("")
p3
```

```
ggplot(recognition) + geom_density(aes(x=score, fill=condition))
```
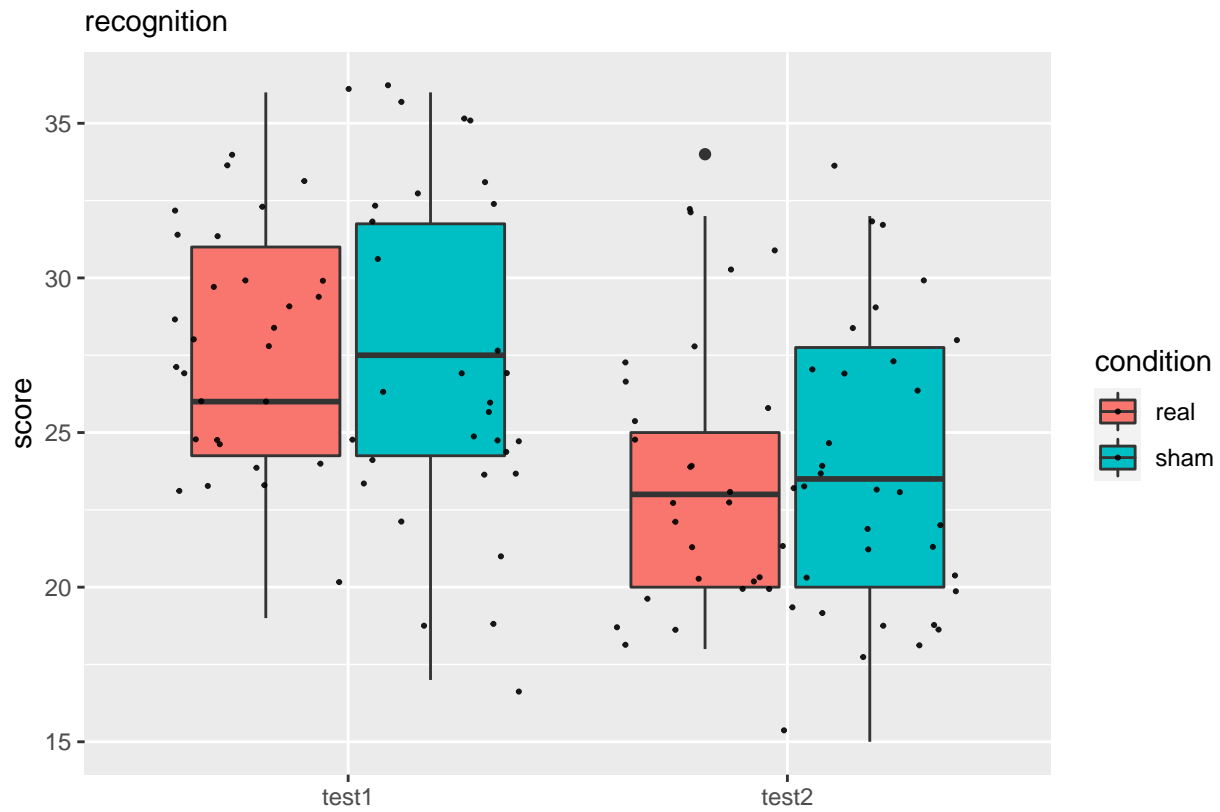
```
ggplot(recognition_scores) + geom_density(aes(x=score, fill=condition))
```
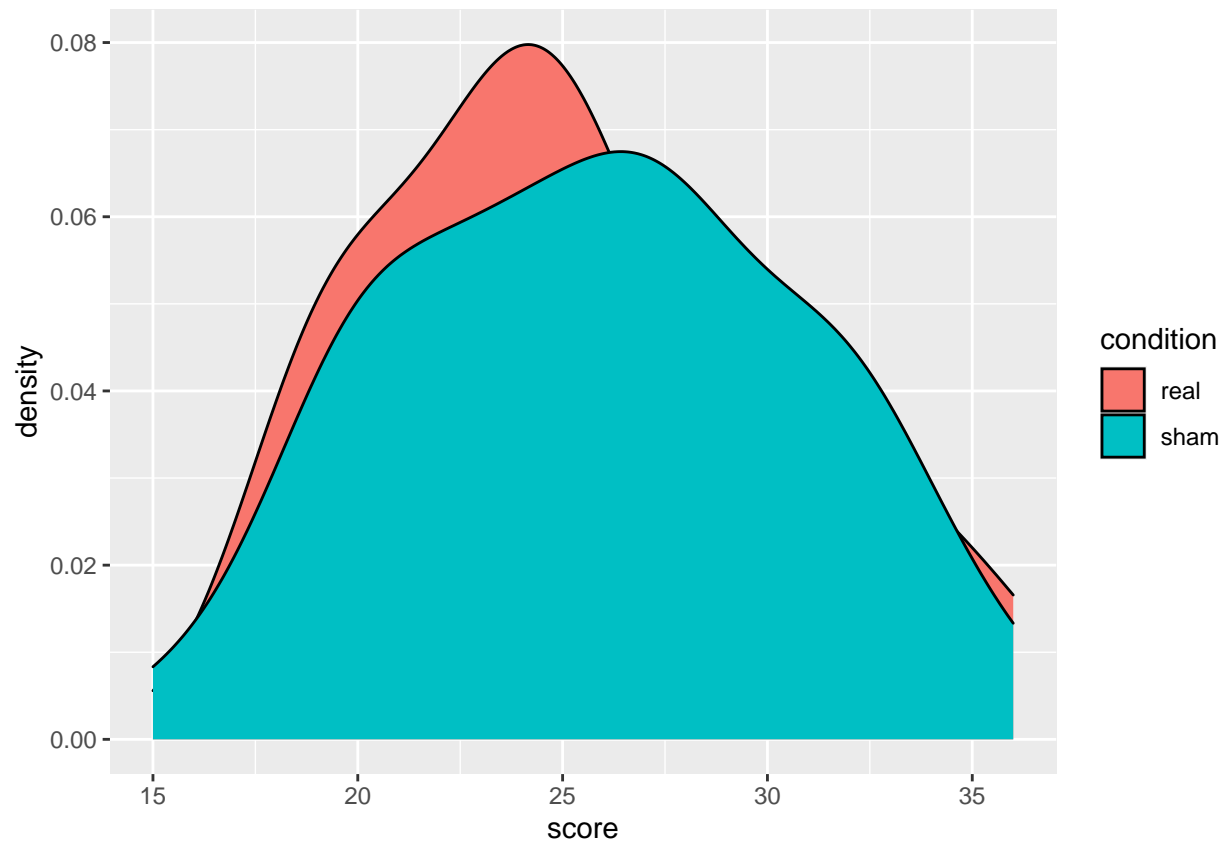


```
ggplot(recognition_scores1) + geom_density(aes(x=score, fill=condition))
```

```
ggplot(recognition_scores2) + geom_density(aes(x=score, fill=condition))
```
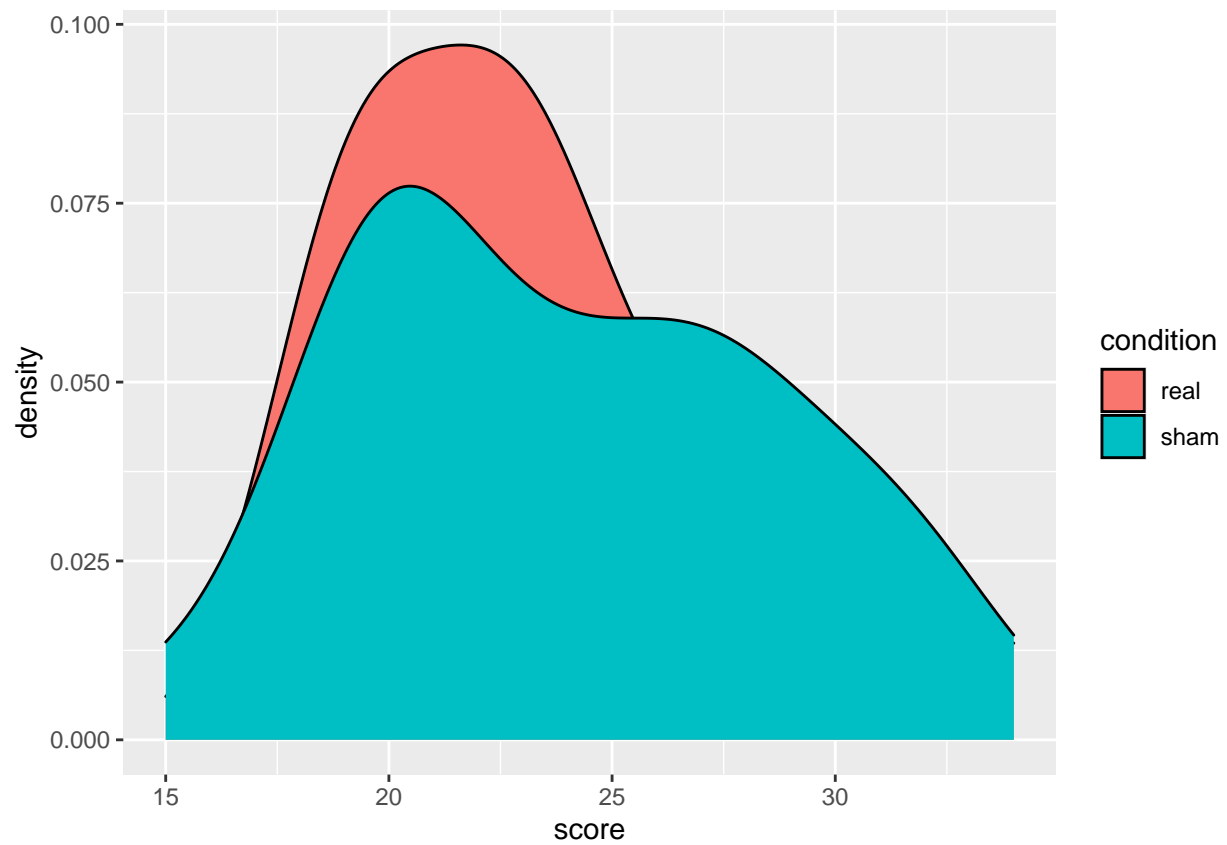
```
ggplot(recognition1) + geom_density(aes(x=score, fill=condition))
```
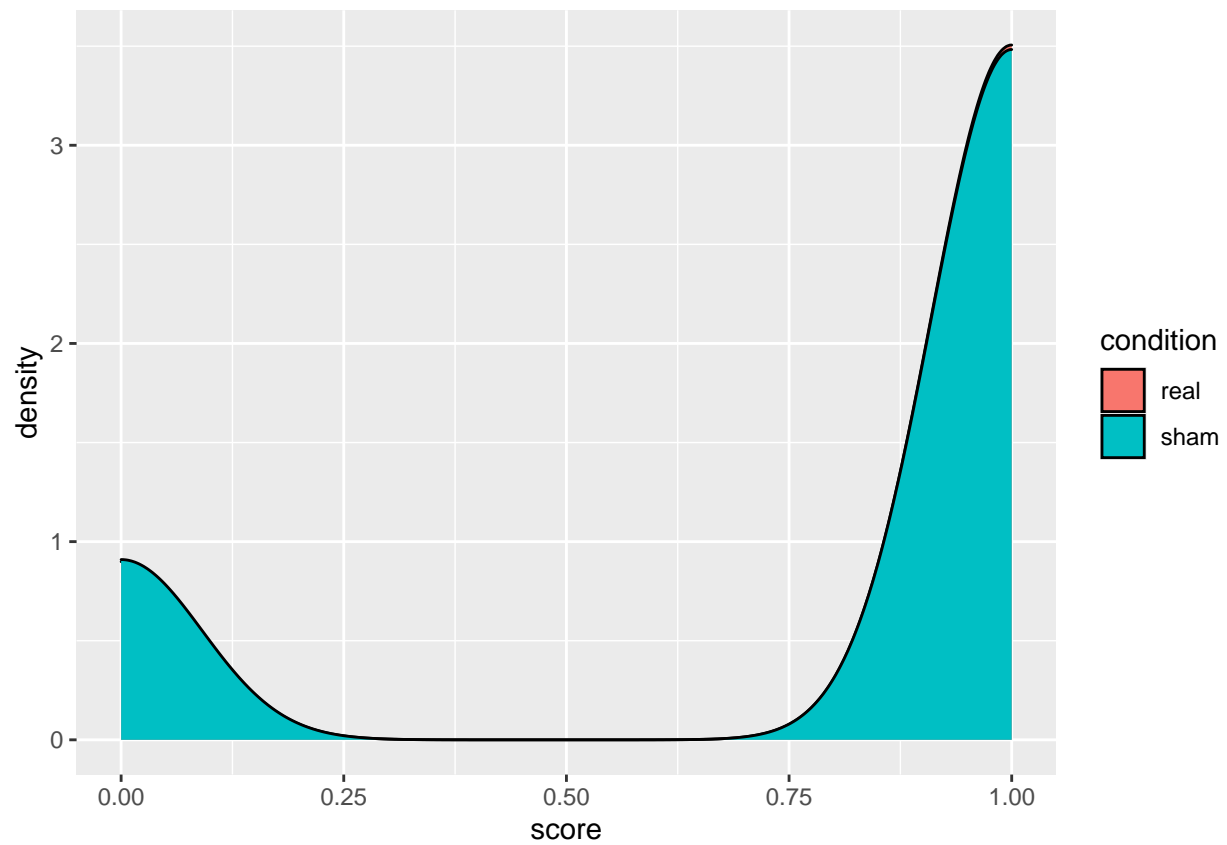
```
ggplot(recognition2) + geom_density(aes(x=score, fill=condition))
```
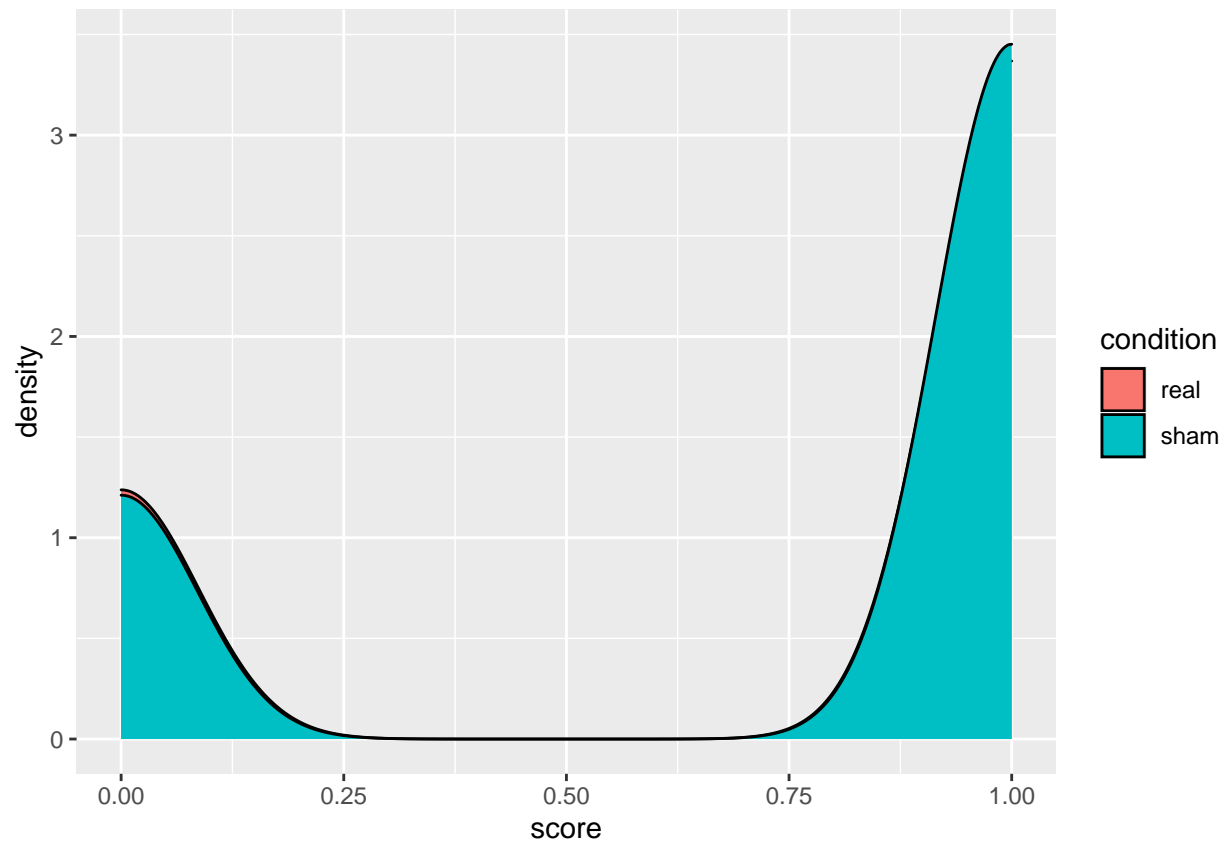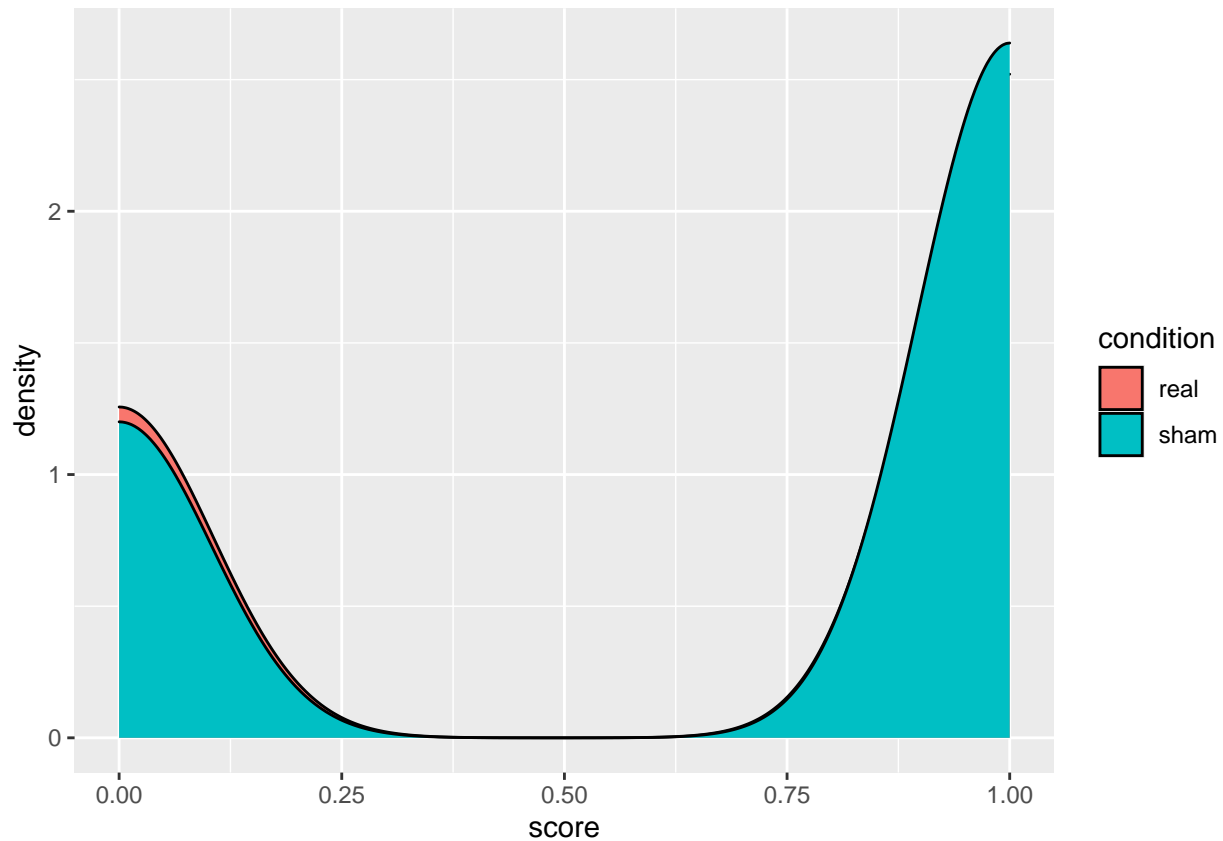
SEM

```
SEM <- data[which(data$task == 'SEM'), ]
SEM_scores <- aggregate(SEM$score, by=list(SEM$participant, SEM$session, SEM$condition), FUN=sum)
SEM_scores <- setNames(SEM_scores, c('Participant', 'session', 'condition', 'score'))
p4 <- ggplot(SEM_scores, aes(x=session, y=score, fill=condition)) + geom_boxplot() +
    geom_jitter(color="black", size=0.4, alpha=0.9) +
    theme(
      plot.title = element_text(size=11)
    ) +
    ggtitle("SEM") +
    xlab("")
p4
```
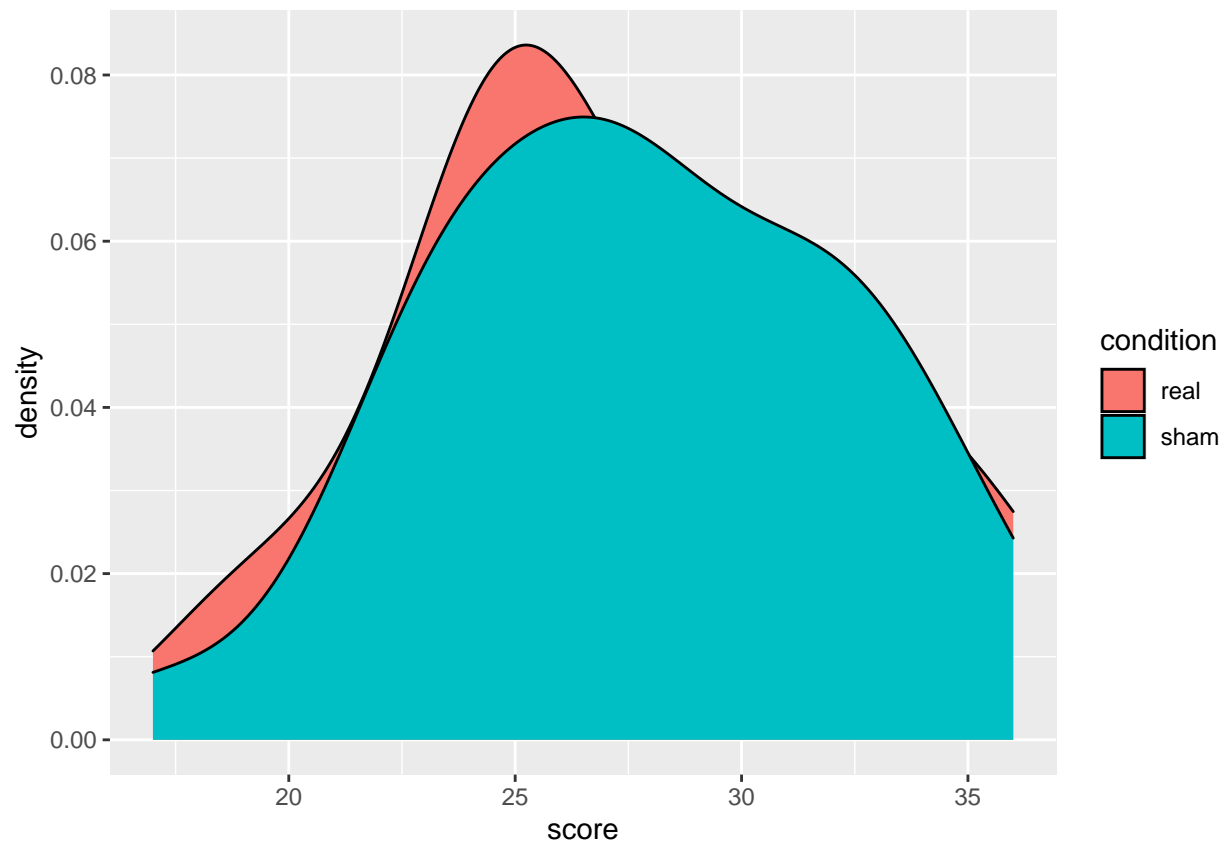
SEM
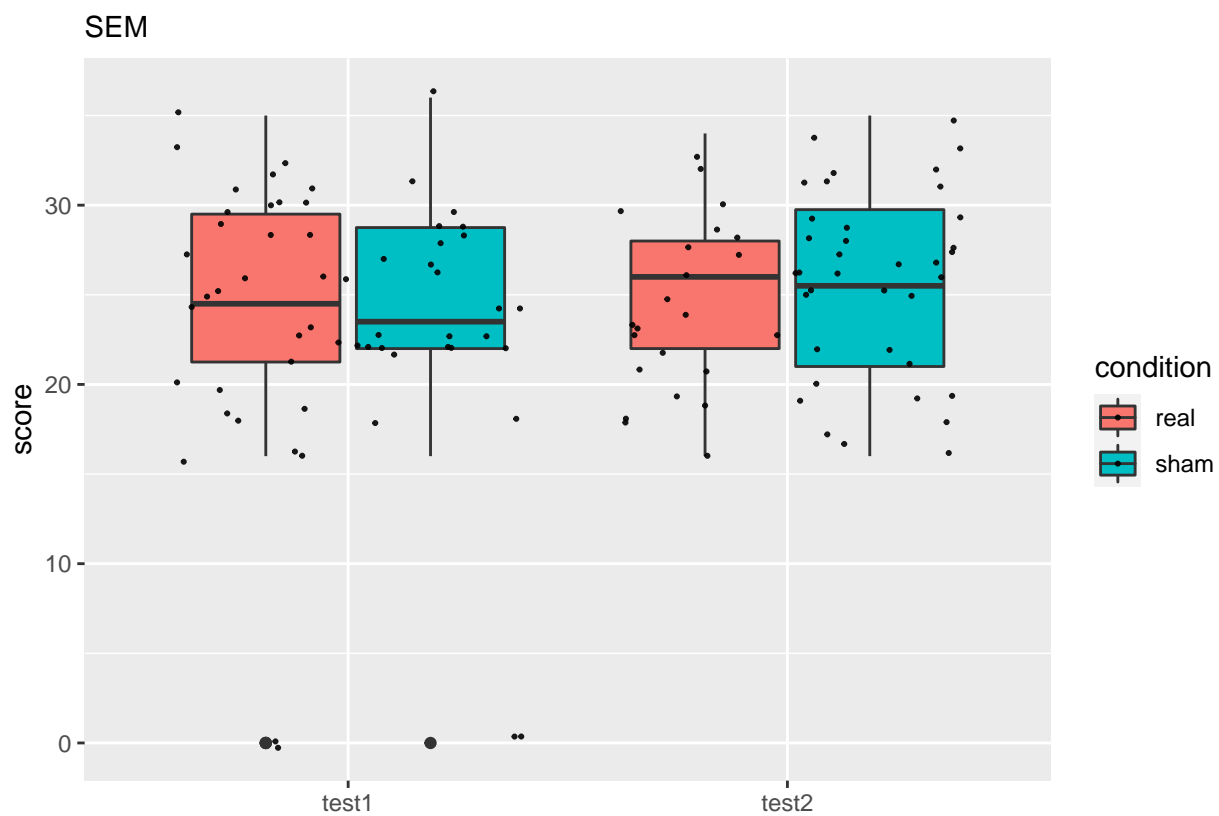
```
ggplot(SEM) + geom_density(aes(x=score, fill=condition))
```
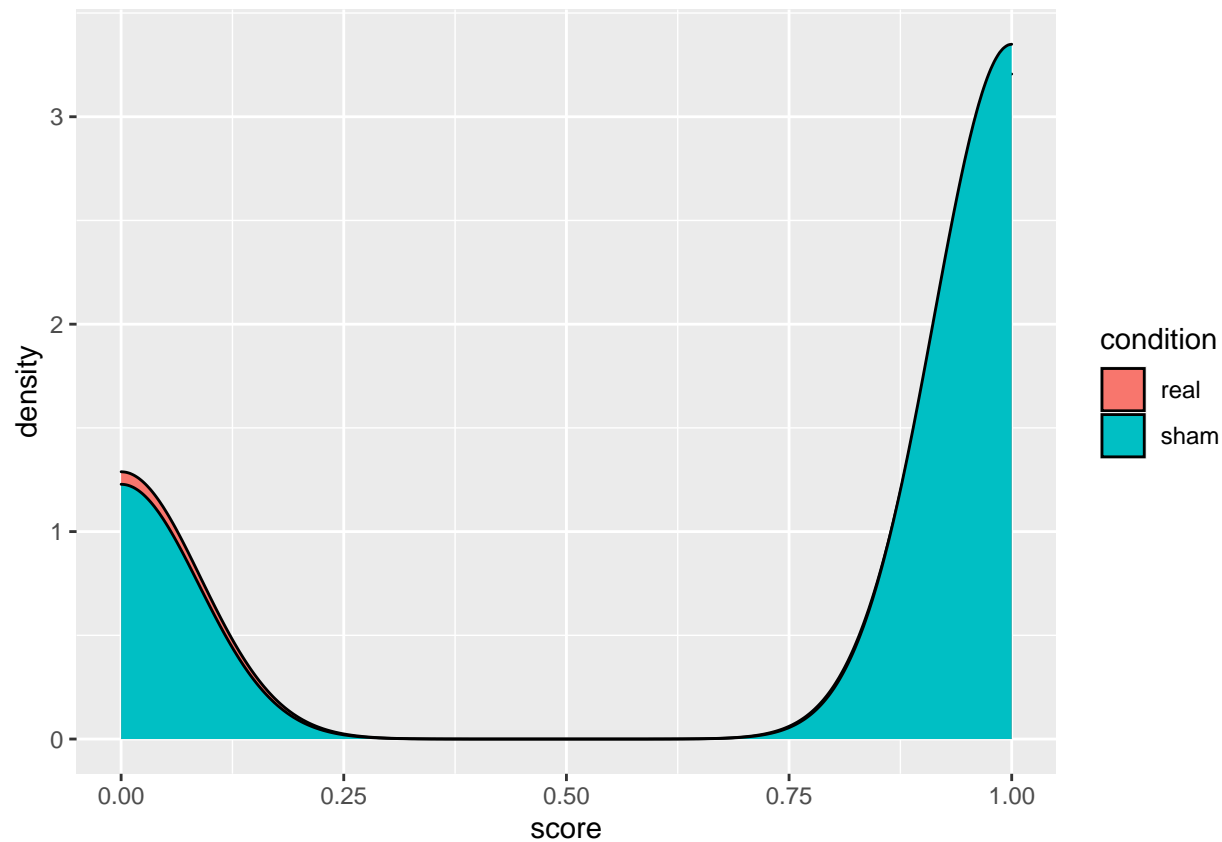
```
ggplot(SEM_scores) + geom_density(aes(x=score, fill=condition))
```
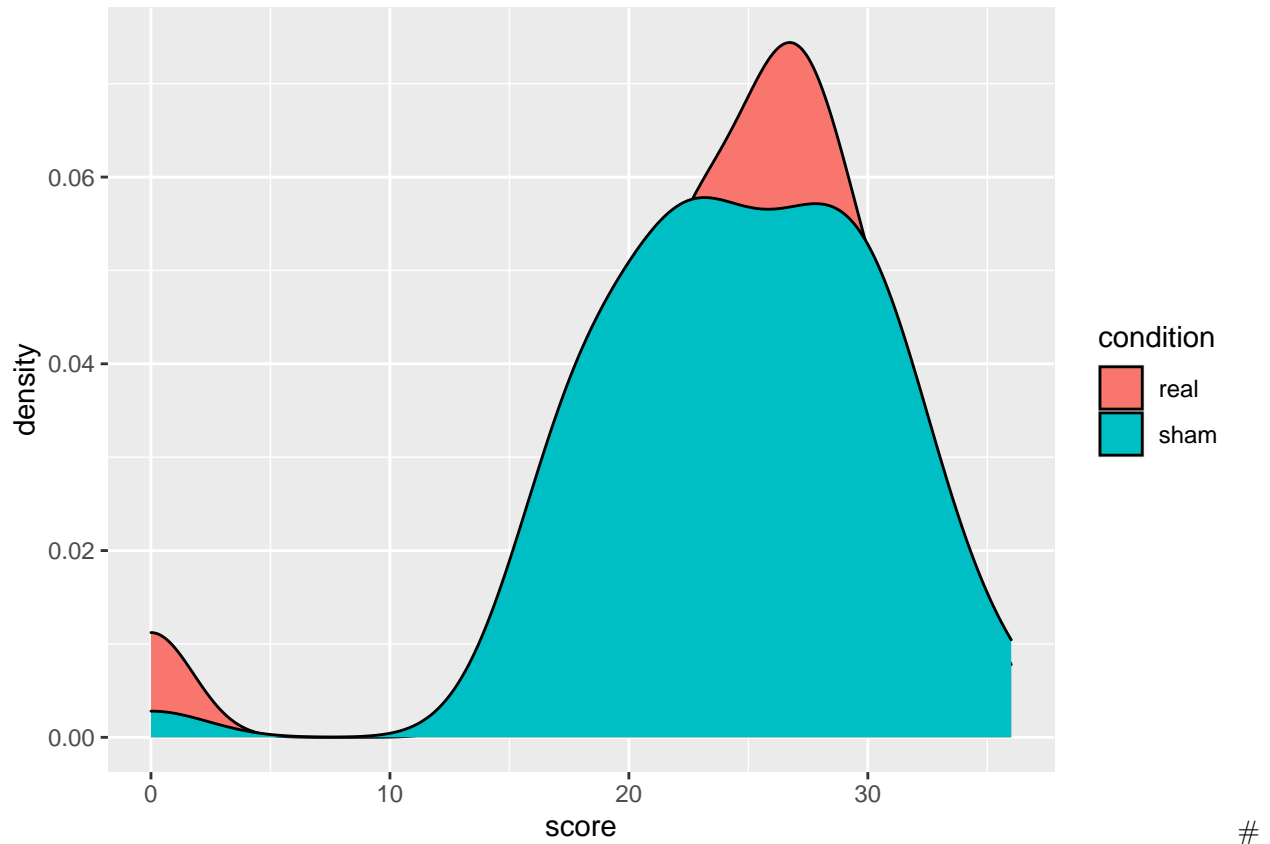
Statistical analysis

```
library("readxl")
library('lme4')
library('lmerTest')

data <- read_excel('tables/stats_LME_3.xlsx')
data <- data[complete.cases(data), ]
```

Recall

Random slope lme

```
data_recall <- data[which(data$task == 'recall'), ]

recall.model <- lmer(score ~ condition + session +
                        (1|participant) + (1|AL) + (1|L1) +
                        (1 + condition|participant),
                      data=data_recall, REML=FALSE)
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, : Model is nearly uniden
##  - Rescale variables?
```

```
recall.model_order <- lmer(score ~ condition +
                             session + stim_order +  (1|participant) +
                             (1|AL) + (1|L1) + (1 + condition|participant) +
```

```
                          (1 + stim_order|participant),
                    data=data_recall, REML=FALSE)
```

boundary (singular) fit: see help('isSingular')

Warning: Model failed to converge with 3 negative eigenvalues: -1.7e-02 -4.5e-02
-4.0e-01

```
recall.null <- lmer(score ~ session + (1|participant) + (1|AL) + (1|L1),
                    data=data_recall, REML=FALSE)
```

Random intercept

```
recall.model_intercept <- lmer(score ~ condition + session +
                               (1|participant) + (1|AL) + (1|L1),
                             data=data_recall, REML=FALSE)
recall.model_order_intercept <- lmer(score ~ condition +
                                   session + stim_order +
                                   (1|participant) + (1|AL) + (1|L1),
                                 data=data_recall, REML=FALSE)
recall.null <- lmer(score ~ session + (1|participant) + (1|AL) + (1|L1),
                    data=data_recall, REML=FALSE)
```

```
summary(recall.model)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: score ~ condition + session + (1 | participant) + (1 | AL) +
##     (1 | L1) + (1 + condition | participant)
##    Data: data_recall
##
##      AIC      BIC   logLik deviance df.resid
##   1210.1   1278.5   -594.1   1188.1     3700
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -3.05102 -0.73961  0.00113  0.73001  2.80842
##
## Random effects:
##  Groups       Name         Variance Std.Dev. Corr
##  L1           (Intercept)  0.001681 0.04100
##  AL           (Intercept)  0.003831 0.06190
##  participant  (Intercept)  0.020416 0.14289
##               conditionsham 0.006631 0.08143  -0.42
##  participant.1 (Intercept)  0.001345 0.03667
##  Residual                  0.074668 0.27325
## Number of obs: 3711, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     0.51119    0.03056   43.21425  16.728  < 2e-16 ***
## conditionsham  -0.01013    0.02266   56.93703  -0.447  0.65645
## sessiontest2   -0.02647    0.01164 3547.10143  -2.274  0.02302 *
## sessiontrain    0.02948    0.01058 3537.77177   2.788  0.00534 **
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2
## conditinshm -0.444
## sessiontst2 -0.157 -0.011
## sessiontran -0.184  0.003  0.476
## optimizer (nloptwrap) convergence code: 0 (OK)
## Model is nearly unidentifiable: large eigenvalue ratio
##  - Rescale variables?
```

summary(recall.model_order)

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: score ~ condition + session + stim_order + (1 | participant) +
##     (1 | AL) + (1 | L1) + (1 + condition | participant) + (1 +
##     stim_order | participant)
##    Data: data_recall
##
##      AIC       BIC    logLik deviance df.resid
##   1216.3    1309.6    -593.2   1186.3     3696
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -3.05415 -0.73775 -0.00138  0.73240  2.81384
##
## Random effects:
##  Groups       Name          Variance Std.Dev. Corr
##  L1           (Intercept)   0.001683 0.04103
##  AL           (Intercept)   0.003837 0.06194
##  participant  (Intercept)   0.010028 0.10014
##               stim_orderSR  0.007107 0.08430  -1.00
##  participant.1 (Intercept)  0.017726 0.13314
##               conditionsham 0.006609 0.08130  -0.55
##  participant.2 (Intercept)  0.000000 0.00000
##  Residual                   0.074663 0.27325
## Number of obs: 3711, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     0.48722    0.04380   17.48061  11.123 2.34e-09 ***
## conditionsham  -0.01011    0.02264   57.05927  -0.447  0.65677
## sessiontest2   -0.02652    0.01164 3547.60988  -2.279  0.02274 *
## sessiontrain    0.02950    0.01057 3538.17976   2.789  0.00531 **
## stim_orderSR    0.04806    0.05020   28.36234   0.957  0.34644
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2 sssntr
## conditinshm -0.344
## sessiontst2 -0.110 -0.012
## sessiontran -0.129  0.003  0.476
## stim_ordrSR -0.718 -0.003  0.001  0.001
```

```
## optimizer (nloptwrap) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
anova(recall.null, recall.model)
```

```
## Data: data_recall
## Models:
## recall.null: score ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recall.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition
##              npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## recall.null     7 1242.1 1285.7 -614.06   1228.1
## recall.model   11 1210.1 1278.5 -594.06   1188.1 39.992  4  4.344e-08 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(recall.model_order, recall.model)
```

```
## Data: data_recall
## Models:
## recall.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition
## recall.model_order: score ~ condition + session + stim_order + (1 | participant) + (1 | AL) + (1 | L
##                    npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## recall.model         11 1210.1 1278.5 -594.06   1188.1
## recall.model_order   15 1216.3 1309.6 -593.16   1186.3 1.7972  4      0.773
```

```
summary(recall.model_intercept)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: score ~ condition + session + (1 | participant) + (1 | AL) +
##     (1 | L1)
##    Data: data_recall
##
##      AIC      BIC   logLik deviance df.resid
##   1243.9   1293.7   -614.0   1227.9     3703
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.93178 -0.72882 -0.00949  0.74597  2.67349
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.001641 0.04051
##  AL          (Intercept) 0.003798 0.06163
##  participant (Intercept) 0.018859 0.13733
##  Residual                0.076270 0.27617
## Number of obs: 3711, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                  Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     5.107e-01  2.888e-02  4.784e+01  17.687  < 2e-16 ***
## conditionsham  -7.489e-03  1.662e-02  7.951e+01  -0.451  0.65341
## sessiontest2   -2.604e-02  1.175e-02  3.570e+03  -2.217  0.02669 *
## sessiontrain    2.858e-02  1.068e-02  3.558e+03   2.677  0.00747 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2
## conditinshm -0.286
## sessiontst2 -0.169 -0.013
## sessiontran -0.197  0.004  0.477
```

```
summary(recall.model_order_intercept)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: score ~ condition + session + stim_order + (1 | participant) +
##     (1 | AL) + (1 | L1)
##    Data: data_recall
##
##       AIC      BIC   logLik deviance df.resid
##    1245.2   1301.1   -613.6   1227.2     3702
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.93322 -0.72748 -0.00894  0.74646  2.67121
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.001642 0.04052
##  AL          (Intercept) 0.003796 0.06161
##  participant (Intercept) 0.018402 0.13566
##  Residual                0.076270 0.27617
## Number of obs: 3711, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                 Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)    4.889e-01  3.810e-02 3.876e+01  12.831 1.57e-15 ***
## conditionsham -7.543e-03  1.661e-02 7.951e+01  -0.454  0.65103
## sessiontest2  -2.599e-02  1.175e-02 3.570e+03  -2.213  0.02697 *
## sessiontrain   2.860e-02  1.068e-02 3.558e+03   2.679  0.00743 **
## stim_orderSR   4.399e-02  5.074e-02 3.052e+01   0.867  0.39270
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2 sssntr
## conditinshm -0.214
## sessiontst2 -0.131 -0.013
## sessiontran -0.151  0.004  0.477
## stim_ordrSR -0.660 -0.003  0.005  0.002
```

```
anova(recall.null, recall.model_intercept)
```

```
## Data: data_recall
## Models:
## recall.null: score ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recall.model_intercept: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
##                         npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## recall.null                7 1242.1 1285.7 -614.06   1228.1
```

```
## recall.model_intercept     8 1243.9 1293.7 -613.95    1227.9 0.2024  1      0.6528
anova(recall.model_order_intercept, recall.model)

## Data: data_recall
## Models:
## recall.model_order_intercept: score ~ condition + session + stim_order + (1 | participant) + (1 | AL
## recall.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition
##                                npar    AIC    BIC  logLik deviance  Chisq Df
## recall.model_order_intercept    9 1245.2 1301.1 -613.58    1227.2
## recall.model                   11 1210.1 1278.5 -594.06    1188.1 39.047  2
##                                Pr(>Chisq)
## recall.model_order_intercept
## recall.model                    3.32e-09 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Reaction time

```
data_recall_RT <- data_recall[which(data_recall$score >= 0.65), ]

recall_RT.model <- lmer(
  RT ~ condition + session +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
  data=data_recall_RT, REML=FALSE)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge with max|grad| = 0.00581334 (tol = 0.002, component 1)
recall_RT.model_order <- lmer(
  RT ~ condition + session + stim_order +  (1|participant) + (1|AL) +
    (1|L1) + (1 + condition|participant)  + (1 + stim_order|participant),
  data=data_recall_RT, REML=FALSE)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 2 negative eigenvalues

## Warning: Model failed to converge with 2 negative eigenvalues: -8.5e-03 -1.4e-02
recall_RT.model_intercept <- lmer(
  RT ~ condition + session +  (1|participant) + (1|AL) + (1|L1),
  data=data_recall_RT, REML=FALSE)

recall_RT.model_order_intercept <- lmer(
  RT ~ condition + session + stim_order +  (1|participant) + (1|AL) +(1|L1),
  data=data_recall_RT, REML=FALSE)

recall_RT.null <- lmer(RT ~ session + (1|participant) + (1|AL) + (1|L1),
                       data=data_recall_RT, REML=FALSE)

summary(recall_RT.model)

## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 |
```

```
##     L1) + (1 + condition | participant)
##    Data: data_recall_RT
##
##      AIC      BIC   logLik deviance df.resid
##   5926.7   5985.3  -2952.4   5904.7     1507
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.9403 -0.7047 -0.2067  0.5810  3.2631
##
## Random effects:
##  Groups       Name         Variance Std.Dev. Corr
##  L1           (Intercept)  0.04243  0.2060
##  AL           (Intercept)  0.21237  0.4608
##  participant  (Intercept)  0.40172  0.6338
##               conditionsham 0.21284  0.4613   -0.47
##  participant.1 (Intercept)  0.22524  0.4746
##  Residual                  2.54909  1.5966
## Number of obs: 1518, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     5.53927    0.18929   49.74726  29.264  < 2e-16 ***
## conditionsham   0.01889    0.16727   56.58230   0.113  0.91049
## sessiontest2   -0.51288    0.11025 1402.21154  -4.652  3.6e-06 ***
## sessiontrain   -0.27458    0.09631 1390.97952  -2.851  0.00442 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2
## conditinshm -0.475
## sessiontst2 -0.216 -0.023
## sessiontran -0.275 -0.001  0.468
## optimizer (nloptwrap) convergence code: 0 (OK)
## Model failed to converge with max|grad| = 0.00581334 (tol = 0.002, component 1)
```

```
summary(recall_RT.model_order)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + stim_order + (1 | participant) + (1 |
##     AL) + (1 | L1) + (1 + condition | participant) + (1 + stim_order |
##     participant)
##    Data: data_recall_RT
##
##      AIC      BIC   logLik deviance df.resid
##   5934.1   6014.0  -2952.0   5904.1     1503
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.9175 -0.7050 -0.2121  0.5892  3.2673
##
## Random effects:
##  Groups       Name            Variance Std.Dev. Corr
```

```
##  L1          (Intercept)    0.041924 0.20475
##  AL          (Intercept)    0.211441 0.45983
##  participant  (Intercept)    0.003922 0.06263
##               stim_orderSR  0.237458 0.48730  -0.54
##  participant.1 (Intercept)   0.363537 0.60294
##               conditionsham 0.214788 0.46345  -0.45
##  participant.2 (Intercept)   0.125732 0.35459
##  Residual                   2.550841 1.59714
## Number of obs: 1518, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)    5.45995    0.21932   13.58307  24.894 9.98e-13 ***
## conditionsham  0.02051    0.16736   55.91468   0.123  0.90291
## sessiontest2  -0.51339    0.11028 1399.72360  -4.655 3.54e-06 ***
## sessiontrain  -0.27446    0.09634 1388.92389  -2.849  0.00445 **
## stim_orderSR   0.15027    0.28669   28.78299   0.524  0.60418
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2 sssntr
## conditinshm -0.389
## sessiontst2 -0.188 -0.023
## sessiontran -0.236 -0.001  0.468
## stim_ordrSR -0.540 -0.015  0.003 -0.002
## optimizer (nloptwrap) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 2 negative eigenvalues
```

anova(recall_RT.model, recall_RT.null)

```
## Data: data_recall_RT
## Models:
## recall_RT.null: RT ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recall_RT.model: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition
##                 npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## recall_RT.null     7 5931.7 5969.0 -2958.9   5917.7
## recall_RT.model   11 5926.7 5985.3 -2952.4   5904.7 13.018  4    0.01119 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

anova(recall_RT.model_order, recall_RT.model)

```
## Data: data_recall_RT
## Models:
## recall_RT.model: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition
## recall_RT.model_order: RT ~ condition + session + stim_order + (1 | participant) + (1 | AL) + (1 | L1
##                        npar    AIC    BIC  logLik deviance Chisq Df Pr(>Chisq)
## recall_RT.model          11 5926.7 5985.3 -2952.4   5904.7
## recall_RT.model_order   15 5934.1 6014.0 -2952.1   5904.1 0.624  4     0.9604
```

summary(recall_RT.model_intercept)

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
```

```
## Formula: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 |
##     L1)
##    Data: data_recall_RT
##
##      AIC      BIC   logLik deviance df.resid
##   5933.7   5976.3  -2958.9   5917.7     1510
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.9522 -0.7129 -0.2189  0.6079  3.3110
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.0686   0.2619
##  AL          (Intercept) 0.2166   0.4654
##  participant (Intercept) 0.5508   0.7421
##  Residual                2.5836   1.6074
## Number of obs: 1518, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     5.53128    0.18175   63.58397  30.434  < 2e-16 ***
## conditionsham   0.01569    0.13710   80.20228   0.114  0.90916
## sessiontest2   -0.50232    0.11089 1408.38295  -4.530  6.4e-06 ***
## sessiontrain   -0.26265    0.09675 1391.19335  -2.715  0.00672 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2
## conditinshm -0.375
## sessiontst2 -0.227 -0.027
## sessiontran -0.285 -0.009  0.469
```

```
anova(recall_RT.null, recall_RT.model_intercept)
```

```
## Data: data_recall_RT
## Models:
## recall_RT.null: RT ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recall_RT.model_intercept: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
##                           npar    AIC    BIC  logLik deviance  Chisq Df
## recall_RT.null               7 5931.7 5969.0 -2958.9   5917.7
## recall_RT.model_intercept    8 5933.7 5976.3 -2958.9   5917.7 0.0131  1
##                           Pr(>Chisq)
## recall_RT.null
## recall_RT.model_intercept      0.909
```

```
anova(recall_RT.model_order_intercept, recall_RT.model_intercept)
```

```
## Data: data_recall_RT
## Models:
## recall_RT.model_intercept: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
## recall_RT.model_order_intercept: RT ~ condition + session + stim_order + (1 | participant) + (1 | AL
##                                 npar    AIC    BIC  logLik deviance  Chisq Df
## recall_RT.model_intercept          8 5933.7 5976.3 -2958.9   5917.7
```

```
## recall_RT.model_order_intercept    9 5935.6 5983.5 -2958.8   5917.6 0.1318  1
##                                  Pr(>Chisq)
## recall_RT.model_intercept
## recall_RT.model_order_intercept      0.7166
```

AFC

```
data_afc <- data[which(data$task == 'AFC'), ]

afc.model <- glmer(
  score ~ condition + (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
  data=data_afc, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

afc.model_order <- glmer(
  score ~ condition + stim_order +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant) + (1 + stim_order|participant),
  data=data_afc, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 1 negative eigenvalues
```

```
afc.model_intercept <- glmer(
  score ~ condition +  (1|participant) + (1|AL) + (1|L1),
  data=data_afc, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

afc.model_order_intercept <- glmer(
  score ~ condition + stim_order +  (1|participant) + (1|AL) + (1|L1),
  data=data_afc, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

afc.null <- glmer(
  score ~ (1|participant) + (1|AL) + (1|L1),
  data=data_afc,family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```
summary(afc.model)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + (1 | participant) + (1 | AL) + (1 | L1) +
##     (1 + condition | participant)
##    Data: data_afc
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   1379.4   1424.2   -681.7   1363.4     1988
##
```

```
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.7269  0.2105  0.3208  0.3939  0.7066
##
## Random effects:
##  Groups       Name          Variance Std.Dev. Corr
##  L1           (Intercept)   0.06315  0.2513
##  AL           (Intercept)   0.02066  0.1437
##  participant  (Intercept)   0.33147  0.5757
##               conditionsham 0.25830  0.5082  -0.59
##  participant.1 (Intercept)  0.36661  0.6055
## Number of obs: 1996, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)     2.3630     0.2055  11.501   <2e-16 ***
## conditionsham  -0.1049     0.2004  -0.523    0.601
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr)
## conditinshm -0.539
```

summary(afc.model_order)

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + stim_order + (1 | participant) + (1 | AL) +
##     (1 | L1) + (1 + condition | participant) + (1 + stim_order |
##     participant)
##    Data: data_afc
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   1383.4   1450.6   -679.7   1359.4     1984
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.9775  0.2135  0.3187  0.3796  0.7297
##
## Random effects:
##  Groups       Name          Variance Std.Dev. Corr
##  L1           (Intercept)   0.06621  0.2573
##  AL           (Intercept)   0.02154  0.1468
##  participant  (Intercept)   0.08595  0.2932
##               stim_orderSR  1.16078  1.0774  -0.30
##  participant.1 (Intercept)  0.04462  0.2112
##               conditionsham 0.26485  0.5146  -0.36
##  participant.2 (Intercept)  0.03094  0.1759
## Number of obs: 1996, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
```

```
## (Intercept)      2.27057     0.18224  12.459    <2e-16 ***
## conditionsham -0.03592     0.19304  -0.186     0.852
## stim_orderSR    0.14850     0.34909   0.425     0.671
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.415
## stim_ordrSR -0.376 -0.032
## optimizer (bobyqa) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 1 negative eigenvalues
```

```
anova(afc.null, afc.model)
```

```
## Data: data_afc
## Models:
## afc.null: score ~ (1 | participant) + (1 | AL) + (1 | L1)
## afc.model: score ~ condition + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | participan
##           npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## afc.null     4 1373.8 1396.2 -682.89   1365.8
## afc.model    8 1379.4 1424.2 -681.69   1363.4 2.3959  4     0.6634
```

```
anova(afc.model_order, afc.model)
```

```
## Data: data_afc
## Models:
## afc.model: score ~ condition + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | participan
## afc.model_order: score ~ condition + stim_order + (1 | participant) + (1 | AL) + (1 | L1) + (1 + con
##                 npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## afc.model          8 1379.4 1424.2 -681.69   1363.4
## afc.model_order   12 1383.4 1450.6 -679.70   1359.4 3.9792  4     0.4088
```

```
summary(afc.model_intercept)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + (1 | participant) + (1 | AL) + (1 | L1)
##    Data: data_afc
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   1375.5   1403.5   -682.8   1365.5     1991
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.6126  0.2146  0.3209  0.3969  0.7377
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.06554  0.2560
##  AL          (Intercept) 0.01474  0.1214
##  participant (Intercept) 0.58659  0.7659
## Number of obs: 1996, groups:  L1, 80; AL, 80; participant, 30
```

```
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    2.32107    0.18721  12.398   <2e-16 ***
## conditionsham -0.07191    0.14505  -0.496     0.62
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## conditinshm -0.398
```

```
summary(afc.model_order_intercept)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + stim_order + (1 | participant) + (1 | AL) +
##     (1 | L1)
##    Data: data_afc
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   1377.5   1411.1   -682.8   1365.5     1990
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.6260  0.2142  0.3214  0.3969  0.7373
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.06553  0.2560
##  AL          (Intercept) 0.01473  0.1214
##  participant (Intercept) 0.58808  0.7669
## Number of obs: 1996, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    2.30769    0.24420   9.450   <2e-16 ***
## conditionsham -0.07182    0.14505  -0.495    0.621
## stim_orderSR   0.02752    0.32223   0.085    0.932
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.310
## stim_ordrSR -0.641  0.007
```

```
anova(afc.null, afc.model_intercept)
```

```
## Data: data_afc
## Models:
## afc.null: score ~ (1 | participant) + (1 | AL) + (1 | L1)
## afc.model_intercept: score ~ condition + (1 | participant) + (1 | AL) + (1 | L1)
```

```
##                      npar     AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## afc.null                 4 1373.8 1396.2 -682.89   1365.8
## afc.model_intercept      5 1375.5 1403.5 -682.77   1365.5 0.2363  1     0.6269
```

```
anova(afc.model_order_intercept, afc.model_intercept)
```

```
## Data: data_afc
## Models:
## afc.model_intercept: score ~ condition + (1 | participant) + (1 | AL) + (1 | L1)
## afc.model_order_intercept: score ~ condition + stim_order + (1 | participant) + (1 | AL) + (1 | L1)
##                            npar    AIC    BIC  logLik deviance  Chisq Df
## afc.model_intercept           5 1375.5 1403.5 -682.77   1365.5
## afc.model_order_intercept     6 1377.5 1411.1 -682.77   1365.5 0.0073  1
##                            Pr(>Chisq)
## afc.model_intercept
## afc.model_order_intercept      0.9317
```

Reaction time

```
data_afc_RT <- data_afc[which(data_afc$score == 1), ]

afc_RT.model <- lmer(
  RT ~ condition + (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
  data=data_afc_RT, REML=FALSE)
```

```
## boundary (singular) fit: see help('isSingular')
```

```
## Warning: Model failed to converge with 1 negative eigenvalue: -1.7e+02
```

```
afc_RT.model_order <- lmer(
  RT ~ condition + stim_order +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant) + (1 + stim_order|participant),
  data=data_afc_RT, REML=FALSE)
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 2 negative eigenvalues
```

```
## Warning: Model failed to converge with 2 negative eigenvalues: -1.2e-02 -3.4e-02
```

```
afc_RT.model_intercept <- lmer(
  RT ~ condition + (1|participant) + (1|AL) + (1|L1),
  data=data_afc_RT, REML=FALSE)

afc_RT.model_order_intercept <- lmer(
  RT ~ condition + stim_order + (1|participant) + (1|AL) + (1|L1),
  data=data_afc_RT, REML=FALSE)

afc_RT.null <- lmer(
  RT ~  (1|participant) + (1|AL) + (1|L1),
  data=data_afc_RT, REML=FALSE)
```

```
summary(afc_RT.model)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
```

```
##    method [lmerModLmerTest]
## Formula: RT ~ condition + (1 | participant) + (1 | AL) + (1 | L1) + (1 +
##     condition | participant)
##    Data: data_afc_RT
##
##      AIC      BIC   logLik deviance df.resid
##   2772.2   2821.5  -1377.1   2754.2     1760
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.64990 -0.68335 -0.04343  0.66232  2.74212
##
## Random effects:
##  Groups       Name         Variance Std.Dev. Corr
##  L1           (Intercept)  0.005028 0.07091
##  AL           (Intercept)  0.008535 0.09239
##  participant  (Intercept)  0.001757 0.04191
##               conditionsham 0.018686 0.13670  -1.00
##  participant.1 (Intercept)  0.032245 0.17957
##  Residual                  0.254122 0.50410
## Number of obs: 1769, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)    2.24470    0.04124 40.53103  54.437   <2e-16 ***
## conditionsham -0.01261    0.04045 41.76192  -0.312    0.757
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## conditinshm -0.417
## optimizer (nloptwrap) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
summary(afc_RT.model_order)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##    method [lmerModLmerTest]
## Formula: RT ~ condition + stim_order + (1 | participant) + (1 | AL) +
##     (1 | L1) + (1 + condition | participant) + (1 + stim_order |
##     participant)
##    Data: data_afc_RT
##
##      AIC      BIC   logLik deviance df.resid
##   2778.8   2850.0  -1376.4   2752.8     1756
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.64948 -0.68217 -0.03765  0.65945  2.78979
##
## Random effects:
##  Groups       Name         Variance Std.Dev. Corr
##  L1           (Intercept)  0.005033 0.07094
##  AL           (Intercept)  0.008510 0.09225
```

```
##  participant   (Intercept)    0.040742 0.20185
##                stim_orderSR  0.084793 0.29119  -0.93
##  participant.1 (Intercept)    0.008863 0.09414
##                conditionsham 0.018547 0.13619  -0.75
##  participant.2 (Intercept)    0.000414 0.02035
##  Residual                     0.254144 0.50413
## Number of obs: 1769, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error       df t value Pr(>|t|)
## (Intercept)    2.23301    0.06226 15.95225  35.864   <2e-16 ***
## conditionsham -0.01331    0.04038 41.74356  -0.330    0.743
## stim_orderSR   0.02426    0.07049 26.54364   0.344    0.733
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.328
## stim_ordrSR -0.750  0.000
## optimizer (nloptwrap) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 2 negative eigenvalues
```

```
anova(afc_RT.null, afc_RT.model)
```

```
## Data: data_afc_RT
## Models:
## afc_RT.null: RT ~ (1 | participant) + (1 | AL) + (1 | L1)
## afc_RT.model: RT ~ condition + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | participan
##              npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## afc_RT.null     5 2774.4 2801.8 -1382.2   2764.4
## afc_RT.model    9 2772.2 2821.5 -1377.1   2754.2 10.161  4     0.0378 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(afc_RT.model_order, afc_RT.model)
```

```
## Data: data_afc_RT
## Models:
## afc_RT.model: RT ~ condition + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | participan
## afc_RT.model_order: RT ~ condition + stim_order + (1 | participant) + (1 | AL) + (1 | L1) + (1 + con
##                    npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## afc_RT.model          9 2772.2 2821.5 -1377.1   2754.2
## afc_RT.model_order   13 2778.8 2850.0 -1376.4   2752.8 1.4738  4     0.8313
```

```
summary(afc_RT.model_intercept)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + (1 | participant) + (1 | AL) + (1 | L1)
##    Data: data_afc_RT
##
##      AIC      BIC   logLik deviance df.resid
##   2776.1   2809.0  -1382.1   2764.1     1763
##
```

```
## Scaled residuals:
##     Min       1Q   Median       3Q      Max
## -2.77189 -0.69040 -0.05575  0.67086  2.79220
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.004747 0.06890
##  AL          (Intercept) 0.008113 0.09007
##  participant (Intercept) 0.032543 0.18040
##  Residual                0.259335 0.50925
## Number of obs: 1769, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error       df t value Pr(>|t|)
## (Intercept)     2.24627    0.04052 49.55833  55.430   <2e-16 ***
## conditionsham  -0.01594    0.03162 78.92858  -0.504    0.615
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr)
## conditinshm -0.388
```

```
summary(afc_RT.model_order_intercept)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + stim_order + (1 | participant) + (1 | AL) +
##     (1 | L1)
##    Data: data_afc_RT
##
##      AIC      BIC   logLik deviance df.resid
##   2778.0   2816.4  -1382.0   2764.0     1762
##
## Scaled residuals:
##     Min       1Q   Median       3Q      Max
## -2.77457 -0.68803 -0.05442  0.67040  2.79481
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.004752 0.06894
##  AL          (Intercept) 0.008109 0.09005
##  participant (Intercept) 0.032378 0.17994
##  Residual                0.259336 0.50925
## Number of obs: 1769, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error       df t value Pr(>|t|)
## (Intercept)     2.23428    0.05349 39.91328  41.773   <2e-16 ***
## conditionsham  -0.01595    0.03161 78.92786  -0.504    0.615
## stim_orderSR    0.02401    0.07011 30.03761   0.342    0.734
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
```

```
##              (Intr) cndtns
## conditinshm -0.294
## stim_ordrSR -0.654 -0.001
```

```
anova(afc_RT.null, afc_RT.model_intercept)
```

```
## Data: data_afc_RT
## Models:
## afc_RT.null: RT ~ (1 | participant) + (1 | AL) + (1 | L1)
## afc_RT.model_intercept: RT ~ condition + (1 | participant) + (1 | AL) + (1 | L1)
##                        npar    AIC    BIC  logLik deviance Chisq Df Pr(>Chisq)
## afc_RT.null              5 2774.4 2801.8 -1382.2   2764.4
## afc_RT.model_intercept   6 2776.2 2809.0 -1382.1   2764.2 0.254  1     0.6143
```

```
anova(afc_RT.model_order_intercept, afc_RT.model_intercept)
```

```
## Data: data_afc_RT
## Models:
## afc_RT.model_intercept: RT ~ condition + (1 | participant) + (1 | AL) + (1 | L1)
## afc_RT.model_order_intercept: RT ~ condition + stim_order + (1 | participant) + (1 | AL) + (1 | L1)
##                              npar    AIC    BIC  logLik deviance Chisq Df
## afc_RT.model_intercept          6 2776.2 2809.0 -1382.1   2764.2
## afc_RT.model_order_intercept    7 2778.0 2816.4 -1382.0   2764.0 0.117  1
##                              Pr(>Chisq)
## afc_RT.model_intercept
## afc_RT.model_order_intercept     0.7324
```

Recognition

```
data_recognition <- data[which(data$task == 'recognition'), ]

recognition.model <- glmer(
  score ~ condition + session +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
  data=data_recognition, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

recognition.model_order <- glmer(
  score ~ condition + session + stim_order +
    (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant) + (1 + stim_order|participant),
  data=data_recognition, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

recognition.model_intercept <- glmer(
  score ~ condition + session + (1|participant) + (1|AL) + (1|L1),
  data=data_recognition, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

recognition.model_order_intercept <- glmer(
  score ~ condition + session + stim_order +
    (1|participant) + (1|AL) + (1|L1),
  data=data_recognition, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```r
recognition.null <- glmer(
  score ~ session +  (1|participant) + (1|AL) + (1|L1),
  data=data_recognition,family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```r
summary(recognition.model)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + (1 | participant) + (1 | AL) +
##     (1 | L1) + (1 + condition | participant)
##    Data: data_recognition
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4582.9   4639.9  -2282.4   4564.9     4165
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.6106 -0.9515  0.4528  0.6198  1.2398
##
## Random effects:
##  Groups        Name         Variance Std.Dev. Corr
##  L1            (Intercept)  0.09977  0.3159
##  AL            (Intercept)  0.03858  0.1964
##  participant   (Intercept)  0.21227  0.4607
##                conditionsham 0.27373  0.5232   -0.48
##  participant.1 (Intercept)  0.16019  0.4002
## Number of obs: 4174, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.46853    0.13988  10.498   <2e-16 ***
## conditionsham  0.05844    0.13083   0.447    0.655
## sessiontest2  -0.65721    0.07447  -8.826   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.428
## sessiontst2 -0.310  0.000
```

```r
summary(recognition.model_order)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + stim_order + (1 | participant) +
##     (1 | AL) + (1 | L1) + (1 + condition | participant) + (1 +
##     stim_order | participant)
##    Data: data_recognition
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
```

```
##
##      AIC      BIC   logLik deviance df.resid
##   4588.6   4671.0  -2281.3   4562.6     4161
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.7576 -0.9539  0.4562  0.6181  1.2479
##
## Random effects:
##  Groups        Name         Variance Std.Dev. Corr
##  L1            (Intercept)  0.09952  0.3155
##  AL            (Intercept)  0.03837  0.1959
##  participant   (Intercept)  0.28947  0.5380
##                stim_orderSR 0.32703  0.5719   -1.00
##  participant.1 (Intercept)  0.07912  0.2813
##                conditionsham 0.27247 0.5220   -0.81
##  participant.2 (Intercept)  0.15860  0.3982
## Number of obs: 4174, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.47868    0.20652   7.160 8.07e-13 ***
## conditionsham  0.05728    0.13057   0.439    0.661
## sessiontest2  -0.65720    0.07447  -8.825  < 2e-16 ***
## stim_orderSR  -0.01803    0.23233  -0.078    0.938
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##            (Intr) cndtns sssnt2
## conditinshm -0.278
## sessiontst2 -0.210  0.000
## stim_ordrSR -0.755 -0.029  0.000
```

```
anova(recognition.null, recognition.model)
```

```
## Data: data_recognition
## Models:
## recognition.null: score ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recognition.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + cond
##                   npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## recognition.null     5 4593.2 4624.9 -2291.6   4583.2
## recognition.model    9 4582.9 4639.9 -2282.4   4564.9 18.324  4   0.001066 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(recognition.model_order, recognition.model)
```

```
## Data: data_recognition
## Models:
## recognition.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + cond
## recognition.model_order: score ~ condition + session + stim_order + (1 | participant) + (1 | AL) + (
##                         npar    AIC    BIC  logLik deviance Chisq Df Pr(>Chisq)
## recognition.model          9 4582.9 4639.9 -2282.4   4564.9
## recognition.model_order   13 4588.6 4671.0 -2281.3   4562.6 2.232  4     0.6932
```

```
summary(recognition.model_intercept)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + (1 | participant) + (1 | AL) +
##     (1 | L1)
##    Data: data_recognition
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4594.9   4632.9  -2291.4   4582.9     4168
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.5309 -0.9857  0.4620  0.6188  1.2148
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.10540  0.3247
##  AL          (Intercept) 0.03548  0.1884
##  participant (Intercept) 0.31628  0.5624
## Number of obs: 4174, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.45367    0.13212  11.003   <2e-16 ***
## conditionsham  0.04706    0.08462   0.556    0.578
## sessiontest2  -0.64952    0.07408  -8.768   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.318
## sessiontst2 -0.325  0.001
```

```
summary(recognition.model_order_intercept)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + stim_order + (1 | participant) +
##     (1 | AL) + (1 | L1)
##    Data: data_recognition
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4596.9   4641.2  -2291.4   4582.9     4167
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.5288 -0.9858  0.4621  0.6188  1.2150
##
```

```
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.10540  0.3246
##  AL          (Intercept) 0.03548  0.1884
##  participant (Intercept) 0.31617  0.5623
## Number of obs: 4174, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.448893   0.171905   8.428   <2e-16 ***
## conditionsham  0.047088   0.084620   0.556    0.578
## sessiontest2  -0.649523   0.074081  -8.768   <2e-16 ***
## stim_orderSR   0.009496   0.218889   0.043    0.965
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
## conditinshm -0.249
## sessiontst2 -0.250  0.001
## stim_ordrSR -0.640  0.008  0.000
```

```
anova(recognition.null, recognition.model_intercept)
```

```
## Data: data_recognition
## Models:
## recognition.null: score ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recognition.model_intercept: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
##                               npar    AIC    BIC  logLik deviance  Chisq Df
## recognition.null                 5 4593.2 4624.9 -2291.6   4583.2
## recognition.model_intercept      6 4594.9 4632.9 -2291.4   4582.9 0.3064  1
##                             Pr(>Chisq)
## recognition.null
## recognition.model_intercept     0.5799
```

```
anova(recognition.model_order_intercept, recognition.model_intercept)
```

```
## Data: data_recognition
## Models:
## recognition.model_intercept: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
## recognition.model_order_intercept: score ~ condition + session + stim_order + (1 | participant) + (1
##                                   npar    AIC    BIC  logLik deviance  Chisq Df
## recognition.model_intercept          6 4594.9 4632.9 -2291.4   4582.9
## recognition.model_order_intercept    7 4596.9 4641.2 -2291.4   4582.9 0.0019  1
##                                   Pr(>Chisq)
## recognition.model_intercept
## recognition.model_order_intercept     0.9654
```

Reaction time

```
data_recognition_RT <- data_recognition[which(data_recognition$score == 1),]

recognition_RT.model <- lmer(
  RT ~ condition + session +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
```

```
  data=data_recognition_RT, REML=FALSE)
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge with max|grad| = 0.0147191 (tol = 0.002, component 1)
```

```
recognition_RT.model_order <- lmer(
  RT ~ condition + session + stim_order +
    (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant) + (1 + stim_order|participant),
  data=data_recognition_RT, REML=FALSE)
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 3 negative eigenvalues
```

```
## Warning: Model failed to converge with 2 negative eigenvalues: -3.3e-03 -3.0e-02
```

```
recognition_RT.model_intercept <- lmer(
  RT ~ condition + session +  (1|participant) + (1|AL) + (1|L1),
  data=data_recognition_RT, REML=FALSE)
```

```
recognition_RT.model_order_intercept <- lmer(
  RT ~ condition + session + stim_order +
    (1|participant) + (1|AL) + (1|L1),
  data=data_recognition_RT, REML=FALSE)
```

```
recognition_RT.null <- lmer(
  RT ~ session + (1|participant) + (1|AL) + (1|L1),
  data=data_recognition_RT, REML=FALSE)
```

```
summary(recognition_RT.model)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 |
##     L1) + (1 + condition | participant)
##    Data: data_recognition_RT
##
##      AIC      BIC   logLik deviance df.resid
##   4667.5   4727.8  -2323.7   4647.5     3061
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.3263 -0.7178 -0.1595  0.5907  3.5181
##
## Random effects:
##  Groups       Name         Variance Std.Dev. Corr
##  L1           (Intercept)  0.001935 0.04399
##  AL           (Intercept)  0.005728 0.07568
##  participant  (Intercept)  0.026221 0.16193
##               conditionsham 0.017374 0.13181  -0.65
##  participant.1 (Intercept)  0.036941 0.19220
##  Residual                   0.249751 0.49975
## Number of obs: 3071, groups:  L1, 80; AL, 80; participant, 30
```

```
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     1.91552    0.05011   36.04380  38.224   <2e-16 ***
## conditionsham   0.01513    0.03464   42.97185   0.437    0.665
## sessiontest2   -0.01212    0.01816 2898.50355  -0.668    0.504
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.445
## sessiontst2 -0.166 -0.002
## optimizer (nloptwrap) convergence code: 0 (OK)
## Model failed to converge with max|grad| = 0.0147191 (tol = 0.002, component 1)
```

summary(recognition_RT.model_order)

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + stim_order + (1 | participant) + (1 |
##     AL) + (1 | L1) + (1 + condition | participant) + (1 + stim_order |
##     participant)
##    Data: data_recognition_RT
##
##      AIC      BIC   logLik deviance df.resid
##   4674.4   4758.8  -2323.2   4646.4     3057
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.3310 -0.7155 -0.1590  0.5876  3.5104
##
## Random effects:
##  Groups       Name         Variance  Std.Dev.  Corr
##  L1           (Intercept)  1.941e-03 0.0440513
##  AL           (Intercept)  5.723e-03 0.0756518
##  participant  (Intercept)  3.706e-02 0.1924982
##               stim_orderSR 1.956e-01 0.4422560 -0.98
##  participant.1 (Intercept) 9.978e-03 0.0998895
##               conditionsham 1.742e-02 0.1319840 -0.96
##  participant.2 (Intercept) 2.772e-08 0.0001665
##  Residual                  2.497e-01 0.4997472
## Number of obs: 3071, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     1.90673    0.05772   18.48093  33.033   <2e-16 ***
## conditionsham   0.01513    0.03466   42.94515   0.436    0.665
## sessiontest2   -0.01205    0.01816 2898.65422  -0.663    0.507
## stim_orderSR    0.01740    0.08577   28.07631   0.203    0.841
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
```

```
## conditinshm -0.363
## sessiontst2 -0.146 -0.002
## stim_ordrSR -0.549 -0.003  0.002
## optimizer (nloptwrap) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 3 negative eigenvalues
```

anova(recognition_RT.null, recognition_RT.model)

```
## Data: data_recognition_RT
## Models:
## recognition_RT.null: RT ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recognition_RT.model: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + cond
##                      npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## recognition_RT.null     6 4681.1 4717.3 -2334.5   4669.1
## recognition_RT.model   10 4667.5 4727.8 -2323.8   4647.5 21.583  4  0.0002426
##
## recognition_RT.null
## recognition_RT.model ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

anova(recognition_RT.model, recognition_RT.model_order)

```
## Data: data_recognition_RT
## Models:
## recognition_RT.model: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + cond
## recognition_RT.model_order: RT ~ condition + session + stim_order + (1 | participant) + (1 | AL) + (
##                            npar    AIC    BIC  logLik deviance Chisq Df
## recognition_RT.model         10 4667.5 4727.8 -2323.8   4647.5
## recognition_RT.model_order   14 4674.4 4758.8 -2323.2   4646.4 1.062  4
##                            Pr(>Chisq)
## recognition_RT.model
## recognition_RT.model_order     0.9002
```

summary(recognition_RT.model_intercept)

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 |
##     L1)
##    Data: data_recognition_RT
##
##      AIC      BIC   logLik deviance df.resid
##   4682.6   4724.8  -2334.3   4668.6     3064
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.2702 -0.7171 -0.1571  0.5941  3.5062
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.001627 0.04034
##  AL          (Intercept) 0.005613 0.07492
##  participant (Intercept) 0.052824 0.22983
##  Residual                0.254330 0.50431
```

```
## Number of obs: 3071, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     1.91379    0.04650   40.59900  41.154   <2e-16 ***
## conditionsham   0.01796    0.02484   81.40852   0.723    0.472
## sessiontest2   -0.01219    0.01831 2926.54262  -0.666    0.505
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.268
## sessiontst2 -0.180 -0.004
```

```
summary(recognition_RT.model_order_intercept)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + stim_order + (1 | participant) + (1 |
##     AL) + (1 | L1)
##    Data: data_recognition_RT
##
##      AIC      BIC   logLik deviance df.resid
##   4684.5   4732.8  -2334.3   4668.5     3063
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.2696 -0.7164 -0.1577  0.5941  3.5069
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.001627 0.04034
##  AL          (Intercept) 0.005611 0.07490
##  participant (Intercept) 0.052776 0.22973
##  Residual                0.254331 0.50431
## Number of obs: 3071, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     1.90678    0.06326   35.15144  30.140   <2e-16 ***
## conditionsham   0.01794    0.02484   81.41062   0.722    0.472
## sessiontest2   -0.01219    0.01831 2926.49633  -0.666    0.506
## stim_orderSR    0.01403    0.08589   29.97547   0.163    0.871
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
## conditinshm -0.194
## sessiontst2 -0.134 -0.004
## stim_ordrSR -0.678 -0.005  0.002
```

```
anova(recognition_RT.null, recognition_RT.model_intercept)
```

```
## Data: data_recognition_RT
## Models:
## recognition_RT.null: RT ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## recognition_RT.model_intercept: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
##                                npar   AIC    BIC  logLik deviance  Chisq Df
## recognition_RT.null               6 4681.1 4717.3 -2334.5   4669.1
## recognition_RT.model_intercept    7 4682.6 4724.8 -2334.3   4668.6 0.5197  1
##                                Pr(>Chisq)
## recognition_RT.null
## recognition_RT.model_intercept      0.471
```

```
anova(recognition_RT.model_intercept, recognition_RT.model_order_intercept)
```

```
## Data: data_recognition_RT
## Models:
## recognition_RT.model_intercept: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
## recognition_RT.model_order_intercept: RT ~ condition + session + stim_order + (1 | participant) + (1
##                                      npar   AIC    BIC  logLik deviance  Chisq
## recognition_RT.model_intercept          7 4682.6 4724.8 -2334.3   4668.6
## recognition_RT.model_order_intercept    8 4684.5 4732.8 -2334.3   4668.5 0.0267
##                                      Df Pr(>Chisq)
## recognition_RT.model_intercept
## recognition_RT.model_order_intercept  1     0.8703
```

Semantic decision

```
data_sem <- data[which(data$task == 'SEM'), ]

sem.model <- glmer(
  score ~ condition + session +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
  data=data_sem, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

sem.model_order <- glmer(
  score ~ condition + session + stim_order +
    (1|participant) + (1|AL) + (1|L1) + (1 + condition|participant) +
    (1 + stim_order|participant),
  data=data_sem, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 3 negative eigenvalues
```

```
sem.model_intercept <- glmer(
  score ~ condition + session + (1|participant) + (1|AL) + (1|L1),
  data=data_sem, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```r
sem.model_order_intercept <- glmer(
  score ~ condition + session + stim_order +
    (1|participant) + (1|AL) + (1|L1),
  data=data_sem, family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

sem.null <- glmer(
  score ~ session +  (1|participant) + (1|AL) + (1|L1),
  data=data_sem,family = binomial,
  control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))
```

```r
summary(sem.model)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + (1 | participant) + (1 | AL) +
##     (1 | L1) + (1 + condition | participant)
##    Data: data_sem
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4416.3   4473.0  -2199.1   4398.3     4030
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.4220 -0.7485  0.4365  0.6045  2.6055
##
## Random effects:
##  Groups       Name        Variance Std.Dev. Corr
##  L1           (Intercept) 0.27411  0.5236
##  AL           (Intercept) 0.02739  0.1655
##  participant  (Intercept) 0.51924  0.7206
##               conditionsham 0.19633  0.4431   -0.85
##  participant.1 (Intercept) 0.23475  0.4845
## Number of obs: 4039, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.05635    0.18458   5.723 1.05e-08 ***
## conditionsham  0.03387    0.11966   0.283   0.7772
## sessiontest2   0.12550    0.07546   1.663   0.0963 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.588
## sessiontst2 -0.203 -0.001
```

```r
summary(sem.model_order)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
```

```
## Formula: score ~ condition + session + stim_order + (1 | participant) +
##     (1 | AL) + (1 | L1) + (1 + condition | participant) + (1 +
##     stim_order | participant)
##    Data: data_sem
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4422.6   4504.5  -2198.3   4396.6     4026
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.3910 -0.7472  0.4376  0.6041  2.6096
##
## Random effects:
##  Groups       Name         Variance Std.Dev. Corr
##  L1           (Intercept)  0.27323  0.5227
##  AL           (Intercept)  0.02730  0.1652
##  participant  (Intercept)  0.09867  0.3141
##               stim_orderSR 0.67436  0.8212   -0.70
##  participant.1 (Intercept)  0.47709  0.6907
##               conditionsham 0.20288 0.4504   -0.93
##  participant.2 (Intercept)  0.05114  0.2262
## Number of obs: 4039, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    0.98742    0.20721   4.765 1.89e-06 ***
## conditionsham  0.03143    0.12088   0.260   0.7949
## sessiontest2   0.12557    0.07547   1.664   0.0961 .
## stim_orderSR   0.14276    0.27635   0.517   0.6054
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
## conditinshm -0.531
## sessiontst2 -0.182 -0.001
## stim_ordrSR -0.470 -0.025  0.002
## optimizer (bobyqa) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 3 negative eigenvalues
anova(sem.null, sem.model)

## Data: data_sem
## Models:
## sem.null: score ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## sem.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | p
##           npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## sem.null     5 4423.1 4454.6 -2206.5   4413.1
## sem.model    9 4416.3 4473.0 -2199.1   4398.3 14.783  4   0.005173 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(sem.model_order, sem.model)
```

```
## Data: data_sem
## Models:
## sem.model: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | p
## sem.model_order: score ~ condition + session + stim_order + (1 | participant) + (1 | AL) + (1 | L1) -
##                  npar    AIC    BIC  logLik deviance Chisq Df Pr(>Chisq)
## sem.model           9 4416.3 4473.0 -2199.1    4398.3
## sem.model_order    13 4422.6 4504.5 -2198.3    4396.6 1.706  4      0.7896
```

```
summary(sem.model_intercept)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##    Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + (1 | participant) + (1 | AL) +
##      (1 | L1)
##    Data: data_sem
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4423.9   4461.8  -2206.0   4411.9     4033
##
## Scaled residuals:
##     Min     1Q  Median     3Q     Max
## -4.0933 -0.7983  0.4362  0.6067  2.1005
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.27414  0.5236
##  AL          (Intercept) 0.02609  0.1615
##  participant (Intercept) 0.51939  0.7207
## Number of obs: 4039, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    1.02110    0.16073   6.353 2.11e-10 ***
## conditionsham  0.08961    0.08353   1.073   0.2834
## sessiontest2   0.12412    0.07519   1.651   0.0988 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.254
## sessiontst2 -0.232  0.000
```

```
summary(sem.model_order_intercept)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##    Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: score ~ condition + session + stim_order + (1 | participant) +
##      (1 | AL) + (1 | L1)
##    Data: data_sem
```

```
## Control: glmerControl(optimizer = "bobyqa", optCtrl = list(maxfun = 2e+05))
##
##      AIC      BIC   logLik deviance df.resid
##   4425.9   4470.1  -2206.0   4411.9     4032
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -4.0979 -0.7980  0.4362  0.6064  2.0997
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.27416  0.5236
##  AL          (Intercept) 0.02607  0.1615
##  participant (Intercept) 0.51944  0.7207
## Number of obs: 4039, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error z value Pr(>|z|)
## (Intercept)     1.00990    0.21128   4.780 1.75e-06 ***
## conditionsham   0.08966    0.08352   1.073   0.2831
## sessiontest2    0.12413    0.07519   1.651   0.0987 .
## stim_orderSR    0.02244    0.27499   0.082   0.9350
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
## conditinshm -0.198
## sessiontst2 -0.178  0.000
## stim_ordrSR -0.649  0.007  0.002
anova(sem.null, sem.model_intercept)


## Data: data_sem
## Models:
## sem.null: score ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## sem.model_intercept: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
##                     npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## sem.null               5 4423.1 4454.6 -2206.5   4413.1
## sem.model_intercept    6 4423.9 4461.8 -2206.0   4411.9 1.1304  1     0.2877
anova(sem.model_order_intercept, sem.model_intercept)


## Data: data_sem
## Models:
## sem.model_intercept: score ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
## sem.model_order_intercept: score ~ condition + session + stim_order + (1 | participant) + (1 | AL) +
##                           npar    AIC    BIC logLik deviance  Chisq Df
## sem.model_intercept          6 4423.9 4461.8  -2206   4411.9
## sem.model_order_intercept    7 4425.9 4470.1  -2206   4411.9 0.0067  1
##                           Pr(>Chisq)
## sem.model_intercept
## sem.model_order_intercept      0.935
```

Reaction time

```
data_sem_RT <- data_sem[which(data_sem$score == 1), ]

sem_RT.model <- lmer(
  RT ~ condition + session +  (1|participant) + (1|AL) + (1|L1) +
    (1 + condition|participant),
  data=data_sem_RT, REML=FALSE)
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 1 negative eigenvalues
```

```
## Warning: Model failed to converge with 1 negative eigenvalue: -9.1e-03
```

```
sem_RT.model_order <- lmer(
  RT ~ condition + session + stim_order + (1|participant) + (1|AL) +
    (1|L1) + (1 + condition|participant) + (1 + stim_order|participant),
  data=data_sem_RT, REML=FALSE)
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## unable to evaluate scaled gradient
```

```
## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge: degenerate Hessian with 1 negative eigenvalues
```

```
## Warning: Model failed to converge with 1 negative eigenvalue: -3.5e-01
```

```
sem_RT.model_intercept <- lmer(
  RT ~ condition + session + (1|participant) + (1|AL) + (1|L1),
  data=data_sem_RT, REML=FALSE)

sem_RT.model_order_intercept <- lmer(
  RT ~ condition + session + stim_order + (1|participant) + (1|AL) + (1|L1),
  data=data_sem_RT, REML=FALSE)

sem_RT.null <- lmer(
  RT ~ session +  (1|participant) + (1|AL) + (1|L1),
  data=data_sem_RT, REML=FALSE)
```

```
summary(sem_RT.model)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 |
##     L1) + (1 + condition | participant)
##    Data: data_sem_RT
##
##      AIC      BIC   logLik deviance df.resid
##   6060.8   6120.6  -3020.4   6040.8     2908
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.9191 -0.7224 -0.1886  0.6088  3.9081
##
## Random effects:
```

```
## Groups           Name          Variance Std.Dev. Corr
## L1              (Intercept)    0.001679 0.04097
## AL              (Intercept)    0.001173 0.03424
## participant     (Intercept)    0.144298 0.37987
##                 conditionsham 0.201171 0.44852  -0.60
## participant.1  (Intercept)    0.003634 0.06028
## Residual                      0.435704 0.66008
## Number of obs: 2918, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                Estimate Std. Error        df t value Pr(>|t|)
## (Intercept)     2.01725    0.07413   31.47500  27.213   <2e-16 ***
## conditionsham  -0.03577    0.08604   29.10577  -0.416    0.681
## sessiontest2   -0.32020    0.02489 2781.76610 -12.863   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.593
## sessiontst2 -0.183  0.008
## optimizer (nloptwrap) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 1 negative eigenvalues
```

```
summary(sem_RT.model_order)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + stim_order + (1 | participant) + (1 |
##     AL) + (1 | L1) + (1 + condition | participant) + (1 + stim_order |
##     participant)
##    Data: data_sem_RT
##
##      AIC      BIC   logLik deviance df.resid
##   6068.6   6152.3  -3020.3   6040.6     2904
##
## Scaled residuals:
##     Min     1Q  Median     3Q     Max
## -2.9186 -0.7221 -0.1870  0.6097  3.9091
##
## Random effects:
##  Groups          Name          Variance  Std.Dev. Corr
##  L1              (Intercept)    0.0016790 0.04098
##  AL              (Intercept)    0.0011695 0.03420
##  participant     (Intercept)    0.0497438 0.22303
##                  stim_orderSR   0.0041143 0.06414  -1.00
##  participant.1  (Intercept)    0.1177233 0.34311
##                  conditionsham 0.2013909 0.44877  -0.71
##  participant.2  (Intercept)    0.0003205 0.01790
##  Residual                      0.4356988 0.66007
## Number of obs: 2918, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                 Estimate Std. Error        df t value Pr(>|t|)
```

```
## (Intercept)       2.00870     0.09946    14.34699   20.197 6.11e-12 ***
## conditionsham    -0.03584     0.08608    29.10450   -0.416    0.680
## sessiontest2     -0.32028     0.02489  2781.55290  -12.866  < 2e-16 ***
## stim_orderSR      0.01737     0.11593    29.36691    0.150    0.882
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
## conditinshm -0.468
## sessiontst2 -0.132  0.008
## stim_ordrSR -0.651 -0.003 -0.008
## optimizer (nloptwrap) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 1 negative eigenvalues
```

```
anova(sem_RT.null, sem_RT.model)
```

```
## Data: data_sem_RT
## Models:
## sem_RT.null: RT ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## sem_RT.model: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | p
##               npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## sem_RT.null      6 6215.8 6251.6 -3101.9   6203.8
## sem_RT.model    10 6060.8 6120.6 -3020.4   6040.8 162.99  4  < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(sem_RT.model_order, sem_RT.model)
```

```
## Data: data_sem_RT
## Models:
## sem_RT.model: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1) + (1 + condition | p
## sem_RT.model_order: RT ~ condition + session + stim_order + (1 | participant) + (1 | AL) + (1 | L1) +
##                      npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## sem_RT.model           10 6060.8 6120.6 -3020.4   6040.8
## sem_RT.model_order     14 6068.6 6152.3 -3020.3   6040.6 0.1796  4     0.9962
```

```
summary(sem_RT.model_intercept)
```

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 |
##     L1)
##    Data: data_sem_RT
##
##      AIC      BIC   logLik deviance df.resid
##   6212.5   6254.4  -3099.3   6198.5     2911
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.6147 -0.7350 -0.1822  0.6210  3.6010
##
## Random effects:
##  Groups      Name        Variance Std.Dev.
##  L1          (Intercept) 0.023298 0.15264
```

```
##  AL         (Intercept) 0.000507 0.02252
##  participant (Intercept) 0.093845 0.30634
##  Residual                0.461321 0.67921
## Number of obs: 2918, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                  Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)       2.04351    0.06289   42.42060  32.493   <2e-16 ***
## conditionsham    -0.06024    0.02588   77.68035  -2.327   0.0225 *
## sessiontest2     -0.32861    0.02551 2785.30989 -12.879   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns
## conditinshm -0.212
## sessiontst2 -0.218  0.015
```

summary(sem_RT.model_order_intercept)

```
## Linear mixed model fit by maximum likelihood . t-tests use Satterthwaite's
##   method [lmerModLmerTest]
## Formula: RT ~ condition + session + stim_order + (1 | participant) + (1 |
##     AL) + (1 | L1)
##    Data: data_sem_RT
##
##      AIC      BIC   logLik deviance df.resid
##   6214.5   6262.4  -3099.3   6198.5     2910
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.6149 -0.7353 -0.1821  0.6212  3.6013
##
## Random effects:
##  Groups      Name        Variance  Std.Dev.
##  L1          (Intercept) 0.0232901 0.1526
##  AL          (Intercept) 0.0005061 0.0225
##  participant (Intercept) 0.0938496 0.3063
##  Residual                0.4613244 0.6792
## Number of obs: 2918, groups:  L1, 80; AL, 80; participant, 30
##
## Fixed effects:
##                  Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)     2.041e+00  8.500e-02  3.571e+01  24.009   <2e-16 ***
## conditionsham  -6.025e-02  2.588e-02  7.766e+01  -2.328   0.0225 *
## sessiontest2   -3.286e-01  2.551e-02  2.785e+03 -12.879   <2e-16 ***
## stim_orderSR    5.628e-03  1.148e-01  2.986e+01   0.049   0.9612
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) cndtns sssnt2
## conditinshm -0.152
## sessiontst2 -0.156  0.015
## stim_ordrSR -0.673 -0.007 -0.007
```

```
anova(sem_RT.null, sem_RT.model_intercept)
```

```
## Data: data_sem_RT
## Models:
## sem_RT.null: RT ~ session + (1 | participant) + (1 | AL) + (1 | L1)
## sem_RT.model_intercept: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
##                        npar    AIC    BIC  logLik deviance  Chisq Df Pr(>Chisq)
## sem_RT.null               6 6215.8 6251.6 -3101.9   6203.8
## sem_RT.model_intercept    7 6212.5 6254.4 -3099.3   6198.5 5.2392  1    0.02208
##
## sem_RT.null
## sem_RT.model_intercept *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
anova(sem_RT.model_order_intercept, sem_RT.model_intercept)
```

```
## Data: data_sem_RT
## Models:
## sem_RT.model_intercept: RT ~ condition + session + (1 | participant) + (1 | AL) + (1 | L1)
## sem_RT.model_order_intercept: RT ~ condition + session + stim_order + (1 | participant) + (1 | AL) +
##                              npar    AIC    BIC  logLik deviance  Chisq Df
## sem_RT.model_intercept          7 6212.5 6254.4 -3099.3   6198.5
## sem_RT.model_order_intercept    8 6214.5 6262.4 -3099.3   6198.5 0.0024  1
##                              Pr(>Chisq)
## sem_RT.model_intercept
## sem_RT.model_order_intercept     0.9609
```

Splitter samples analysis

```
t.test(score ~ condition,
       data = data_recall[which(data_recall$session == 'train'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = 0.63154, df = 1424.8, p-value = 0.5278
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.02226636  0.04341070
## sample estimates:
## mean in group real mean in group sham
##          0.5536832          0.5431110
```

```
t.test(score ~ condition,
       data = data_recall[which(data_recall$session == 'test1'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = 1.6874, df = 1276.7, p-value = 0.09178
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
```

```
##  -0.004878718  0.064865371
## sample estimates:
## mean in group real mean in group sham
##          0.5380659          0.5080726
```

```
t.test(score ~ condition,
       data = data_recall[which(data_recall$session == 'test2'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = 0.68408, df = 985.37, p-value = 0.4941
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.02685550  0.05559926
## sample estimates:
## mean in group real mean in group sham
##          0.5062125          0.4918406
```

```
recall_test2 <- data_recall[which(data_recall$session == 'test2'), ]
recall_test2[is.na(recall_test2)] <- 0
t.test(score ~ condition, data = recall_test2)
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = 0.68408, df = 985.37, p-value = 0.4941
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.02685550  0.05559926
## sample estimates:
## mean in group real mean in group sham
##          0.5062125          0.4918406
```

```
t.test(score ~ condition,
       data = data_afc[which(data_afc$session == 'train'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = 0.43245, df = 1991.8, p-value = 0.6655
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.02173922  0.03403868
## sample estimates:
## mean in group real mean in group sham
##          0.8893320          0.8831823
```

```
t.test(score ~ condition,
       data = data_sem[which(data_sem$session == 'test1'), ])
```

```
##
##  Welch Two Sample t-test
##
```

```
## data:  score by condition
## t = -1.6554, df = 1972, p-value = 0.098
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.073603445  0.006222606
## sample estimates:
## mean in group real mean in group sham
##          0.6961771          0.7298675
```

```
t.test(score ~ condition,
       data = data_sem[which(data_sem$session == 'test2'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = -0.19129, df = 2062, p-value = 0.8483
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.04200824  0.03454163
## sample estimates:
## mean in group real mean in group sham
##          0.7297297          0.7334630
```

```
t.test(score ~ condition,
       data = data_recognition[which(data_sem$session == 'test1'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = -0.98829, df = 1967.6, p-value = 0.3231
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.05996581  0.01977979
## sample estimates:
## mean in group real mean in group sham
##          0.7047325          0.7248255
```

```
t.test(score ~ condition,
       data = data_recognition[which(data_recognition$session == 'test2'), ])
```

```
##
##  Welch Two Sample t-test
##
## data:  score by condition
## t = -0.98187, df = 2089.4, p-value = 0.3263
## alternative hypothesis: true difference in means between group real and group sham is not equal to 0
## 95 percent confidence interval:
##  -0.06017530  0.02002234
## sample estimates:
## mean in group real mean in group sham
##          0.6673040          0.6873805
```

```
wilcox.test(score ~ condition,
            data = data_recall[which(data_recall$session == 'train'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 259622, p-value = 0.5553
## alternative hypothesis: true location shift is not equal to 0
```

```r
wilcox.test(score ~ condition,
            data = data_recall[which(data_recall$session == 'test1'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 215300, p-value = 0.0986
## alternative hypothesis: true location shift is not equal to 0
```

```r
wilcox.test(score ~ condition,
            data = data_recall[which(data_recall$session == 'test2'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 128402, p-value = 0.514
## alternative hypothesis: true location shift is not equal to 0
```

```r
wilcox.test(score ~ condition,
            data = data_afc[which(data_afc$session == 'train'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 501052, p-value = 0.6654
## alternative hypothesis: true location shift is not equal to 0
```

```r
wilcox.test(score ~ condition,
            data = data_sem[which(data_sem$session == 'test1'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 471131, p-value = 0.09808
## alternative hypothesis: true location shift is not equal to 0
```

```r
wilcox.test(score ~ condition,
            data = data_sem[which(data_sem$session == 'test2'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
```

```
## 
## data:  score by condition
## W = 530516, p-value = 0.8483
## alternative hypothesis: true location shift is not equal to 0
```

```
wilcox.test(score ~ condition,
            data = data_recognition[
              which(data_recognition$session == 'test1'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 543441, p-value = 0.8656
## alternative hypothesis: true location shift is not equal to 0
```

```
wilcox.test(score ~ condition,
            data = data_recognition[
              which(data_recognition$session == 'test2'), ],
            alternative = "two.sided")
```

```
## 
##  Wilcoxon rank sum test with continuity correction
## 
## data:  score by condition
## W = 536075, p-value = 0.3262
## alternative hypothesis: true location shift is not equal to 0
```

```
var.test(score ~ condition,
         data = data_recall[
           which(data_recall$session == 'train'), ],
         alternative = "two.sided")
```

```
## 
##  F test to compare two variances
## 
## data:  score by condition
## F = 1.0372, num df = 734, denom df = 693, p-value = 0.6261
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.8953686 1.2012210
## sample estimates:
## ratio of variances
##           1.037243
```

```
var.test(score ~ condition,
         data = data_recall[
           which(data_recall$session == 'test1'), ],
         alternative = "two.sided")
```

```
## 
##  F test to compare two variances
## 
## data:  score by condition
## F = 1.0285, num df = 648, denom df = 629, p-value = 0.7229
## alternative hypothesis: true ratio of variances is not equal to 1
```

```
## 95 percent confidence interval:
##  0.8804987 1.2011821
## sample estimates:
## ratio of variances
##          1.028509
```

```
var.test(score ~ condition,
         data = data_recall[
           which(data_recall$session == 'test2'), ],
         alternative = "two.sided")
```

```
##
##  F test to compare two variances
##
## data:  score by condition
## F = 1.0493, num df = 475, denom df = 526, p-value = 0.5899
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.8806237 1.2512793
## sample estimates:
## ratio of variances
##          1.049299
```

```
var.test(score ~ condition,
         data = data_recognition[
           which(data_recognition$session == 'test1'), ],
         alternative = "two.sided")
```

```
##
##  F test to compare two variances
##
## data:  score by condition
## F = 0.98926, num df = 1033, denom df = 1047, p-value = 0.8619
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.8759921 1.1172208
## sample estimates:
## ratio of variances
##          0.9892559
```

```
var.test(score ~ condition,
         data = data_recognition[
           which(data_recognition$session == 'test2'), ],
         alternative = "two.sided")
```

```
##
##  F test to compare two variances
##
## data:  score by condition
## F = 1.0331, num df = 1045, denom df = 1045, p-value = 0.5983
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.9150956 1.1664056
## sample estimates:
## ratio of variances
##          1.033137
```

```
var.test(score ~ condition,
         data = data_sem[
           which(data_sem$session == 'test1'), ],
         alternative = "two.sided")
```

```
##
##  F test to compare two variances
##
## data:  score by condition
## F = 1.0728, num df = 993, denom df = 980, p-value = 0.2701
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.9468211 1.2154487
## sample estimates:
## ratio of variances
##           1.072787
```

```
var.test(score ~ condition,
         data = data_sem[
           which(data_sem$session == 'test2'), ],
         alternative = "two.sided")
```

```
##
##  F test to compare two variances
##
## data:  score by condition
## F = 1.0088, num df = 1035, denom df = 1027, p-value = 0.8878
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.8928245 1.1398926
## sample estimates:
## ratio of variances
##           1.008838
```

```
var.test(score ~ condition,
         data = data_afc[
           which(data_afc$session == 'train'), ],
         alternative = "two.sided")
```

```
##
##  F test to compare two variances
##
## data:  score by condition
## F = 0.95394, num df = 1002, denom df = 992, p-value = 0.4567
## alternative hypothesis: true ratio of variances is not equal to 1
## 95 percent confidence interval:
##  0.842494 1.080093
## sample estimates:
## ratio of variances
##          0.9539432
```

```
lm_recall_train <- lm(score ~ condition,
  data = data_recall[which(data_recall$session == 'train'), ])
summary(lm_recall_train)
```

```
##
```

```
## Call:
## lm(formula = score ~ condition, data = data_recall[which(data_recall$session ==
##     "train"), ])
##
## Residuals:
##      Min      1Q  Median      3Q     Max
## -0.55368 -0.25740 -0.04311  0.29022  0.45689
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.55368    0.01167  47.435   <2e-16 ***
## conditionsham -0.01057    0.01675  -0.631    0.528
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.3164 on 1427 degrees of freedom
## Multiple R-squared:  0.0002791,  Adjusted R-squared:  -0.0004215
## F-statistic: 0.3984 on 1 and 1427 DF,  p-value: 0.528
```

```
anova(lm_recall_train)
```

```
## Analysis of Variance Table
##
## Response: score
##             Df Sum Sq  Mean Sq F value Pr(>F)
## condition    1   0.04 0.039897  0.3984  0.528
## Residuals 1427 142.90 0.100139
```

```
lm_recall_test1 <- lm(score ~ condition,
   data = data_recall[which(data_recall$session == 'test1'), ])
summary(lm_recall_test1)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_recall[which(data_recall$session ==
##     "test1"), ])
##
## Residuals:
##      Min      1Q  Median      3Q     Max
## -0.53807 -0.25235 -0.00807  0.29527  0.49193
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.53807    0.01248  43.121   <2e-16 ***
## conditionsham -0.02999    0.01778  -1.687   0.0918 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.3179 on 1277 degrees of freedom
## Multiple R-squared:  0.002224,   Adjusted R-squared:  0.001442
## F-statistic: 2.846 on 1 and 1277 DF,  p-value: 0.09185
```

```
anova(lm_recall_test1)
```

```
## Analysis of Variance Table
##
```

```
## Response: score
##             Df  Sum Sq Mean Sq F value  Pr(>F)
## condition    1   0.288 0.28758   2.846 0.09185 .
## Residuals 1277 129.039 0.10105
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
lm_recall_test2 <- lm(score ~ condition,
   data = data_recall[which(data_recall$session == 'test2'), ])
summary(lm_recall_test2)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_recall[which(data_recall$session ==
##     "test2"), ])
##
## Residuals:
##      Min      1Q  Median      3Q      Max
## -0.50621 -0.32517 -0.00621  0.32712  0.50816
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.50621    0.01521  33.282   <2e-16 ***
## conditionsham -0.01437    0.02098  -0.685    0.494
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.3318 on 1001 degrees of freedom
## Multiple R-squared:  0.0004684,  Adjusted R-squared:  -0.0005301
## F-statistic: 0.4691 on 1 and 1001 DF,  p-value: 0.4936
```

```
anova(lm_recall_test2)
```

```
## Analysis of Variance Table
##
## Response: score
##             Df  Sum Sq  Mean Sq F value Pr(>F)
## condition    1   0.052 0.051659  0.4691 0.4936
## Residuals 1001 110.229 0.110119
```

```
lm_afc <- lm(score ~ condition,
   data = data_afc[which(data_afc$session == 'train'), ])
summary(lm_afc)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_afc[which(data_afc$session ==
##     "train"), ])
##
## Residuals:
##     Min      1Q  Median      3Q      Max
## -0.8893  0.1107  0.1107  0.1168  0.1168
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.88933    0.01003  88.675   <2e-16 ***
```

```
## conditionsham -0.00615    0.01422  -0.433    0.665
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.3176 on 1994 degrees of freedom
## Multiple R-squared: 9.38e-05,   Adjusted R-squared:  -0.0004077
## F-statistic: 0.1871 on 1 and 1994 DF,  p-value: 0.6654
```

```
anova(lm_afc)
```

```
## Analysis of Variance Table
##
## Response: score
##             Df  Sum Sq  Mean Sq F value Pr(>F)
## condition    1   0.019 0.018871  0.1871 0.6654
## Residuals 1994 201.165 0.100885
```

```
lm_recognition1 <- lm(score ~ condition,
   data = data_recognition[which(data_recognition$session == 'test1'), ])
summary(lm_recognition1)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_recognition[which(data_recognition$session ==
##     "test1"), ])
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -0.7959  0.2041  0.2041  0.2071  0.2071
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.795938   0.012573  63.303   <2e-16 ***
## conditionsham -0.002999   0.017722  -0.169    0.866
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4043 on 2080 degrees of freedom
## Multiple R-squared: 1.377e-05,  Adjusted R-squared:  -0.000467
## F-statistic: 0.02864 on 1 and 2080 DF,  p-value: 0.8656
```

```
anova(lm_recognition1)
```

```
## Analysis of Variance Table
##
## Response: score
##             Df Sum Sq  Mean Sq F value Pr(>F)
## condition    1   0.00 0.004682  0.0286 0.8656
## Residuals 2080 340.01 0.163467
```

```
lm_recognition2 <- lm(score ~ condition,
   data = data_recognition[which(data_recognition$session == 'test2'), ])
summary(lm_recognition2)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_recognition[which(data_recognition$session ==
```

```
##      "test2"), ])
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -0.6874 -0.6673  0.3126  0.3327  0.3327
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.66730    0.01446  46.154   <2e-16 ***
## conditionsham  0.02008    0.02045   0.982    0.326
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4676 on 2090 degrees of freedom
## Multiple R-squared:  0.0004611,  Adjusted R-squared:  -1.718e-05
## F-statistic: 0.9641 on 1 and 2090 DF,  p-value: 0.3263
```

```
anova(lm_recognition2)
```

```
## Analysis of Variance Table
##
## Response: score
##             Df Sum Sq Mean Sq F value Pr(>F)
## condition    1   0.21 0.21080  0.9641 0.3263
## Residuals 2090 457.00 0.21866
```

```
lm_sem1 <- lm(score ~ condition,
   data = data_sem[which(data_sem$session == 'test1'), ])
summary(lm_sem1)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_sem[which(data_sem$session ==
##     "test1"), ])
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -0.7299 -0.6962  0.2701  0.3038  0.3038
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)    0.69618    0.01435  48.525   <2e-16 ***
## conditionsham  0.03369    0.02036   1.655   0.0981 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4523 on 1973 degrees of freedom
## Multiple R-squared:  0.001386,   Adjusted R-squared:  0.0008802
## F-statistic: 2.739 on 1 and 1973 DF,  p-value: 0.09808
```

```
anova(lm_sem1)
```

```
## Analysis of Variance Table
##
## Response: score
##             Df Sum Sq Mean Sq F value  Pr(>F)
```

```
## condition      1   0.56 0.56040  2.7391 0.09808 .
## Residuals 1973 403.66 0.20459
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
lm_sem2 <- lm(score ~ condition,
    data = data_sem[which(data_sem$session == 'test2'), ])
summary(lm_sem2)
```

```
##
## Call:
## lm(formula = score ~ condition, data = data_sem[which(data_sem$session ==
##     "test2"), ])
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -0.7335 -0.7297  0.2665  0.2703  0.2703
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.729730   0.013774  52.979   <2e-16 ***
## conditionsham 0.003733   0.019517   0.191    0.848
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4433 on 2062 degrees of freedom
## Multiple R-squared:  1.774e-05,  Adjusted R-squared:  -0.0004672
## F-statistic: 0.03659 on 1 and 2062 DF,  p-value: 0.8483
```

```r
anova(lm_sem2)
```

```
## Analysis of Variance Table
##
## Response: score
##              Df Sum Sq  Mean Sq F value Pr(>F)
## condition     1   0.01 0.007192  0.0366 0.8483
## Residuals 2062 405.29 0.196553
```