

# Nested Subject-Verb Dependencies

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## Preparing the data

Variables:

- nested: 1 if center embedding (objrel or objrel-nounpp), 0 mental embedding (SR or LR)
- long: 1 if LR (objrel-nounpp or mental embedding LR), 0 SR (objrel, mental embedding SR)
- violation\_position: “inner” or “outer” - verb on which the violation occurred (mental embedding has only “inner” - verb in embedded clause)
- congruent\_subjects: 1 if the two first subject nouns agree on number, else 0.
- number\_v2: “singular” or “plural”, based on the number of the second noun.
- congruent\_attractor: 1 if the two last nouns agree on number, else 0.

For example, the last three variables defines: ‘SSS’ = (1, ‘singular’, 1), ‘SSP’ = (1, ‘singular’, 0), ‘SPS’ = (0, ‘plural’, 0), etc

Note that when long=0 (i.e., no attractor noun), then there are only four conditions (SS, SP, PS, PP), and therefore congruent\_attractor=‘NA’: ‘SS’=(1, ‘singular’, ‘NA’), etc.

```
Data <- read.csv(file="../Paradigm/Results/dataframe_results_all_trials_LSTM_fixed.csv", header=TRUE)
Data <- subset(Data, trial_type == "Violation") # Take only trials in which there was a violation
Data <- subset(Data, violation_position != "other") # Take only trials in which the violation was on the
Data <- subset(Data, valid_answer != "REJECTED") # remove from it rejected trials (in which subject did not answer)

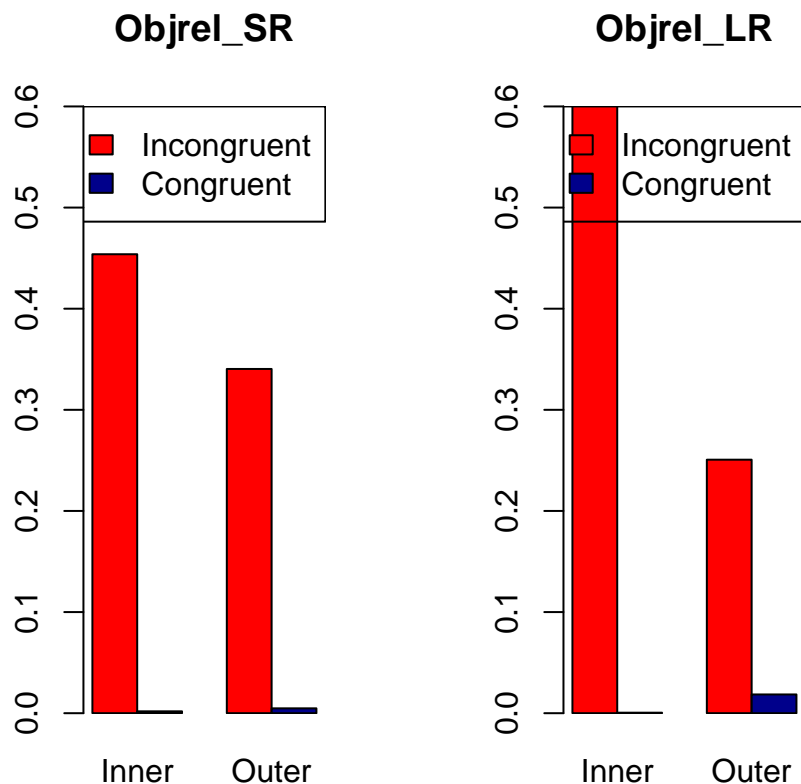
# Remove the following columns (which will not be analyzed):
Data$violation_type <- NULL
Data$correct_wrong <- NULL
```



```
## 5      : 9024
## (Other):126336
## congruent_subject_attractor  valid_answer  is_outlier      number_v2
##           :120000      Min.   :0.0000  NA's:180480  plural  :90080
## False_False: 10080      1st Qu.:1.0000      singular:90400
## False_True  : 20160      Median :1.0000
## True_True   : 30240      Mean   :0.8527
##           :1.0000
##           :1.0000
##
## nested      long
## 0: 60160    0:120000
## 1:120320    1: 60480
##
##
##
##
```

## PLOT - error rates

```
par(mfrow=c(1,2))
for (l in 0:1) {
  struct = ifelse(l=="0", "Objrel_SR", "Objrel_LR")
  curr_data = subset(Data, nested == 1 & long == l)
  curr_bysuj = with(curr_data, tapply(valid_answer, list(congruent_subjects=congruent_subjects, viola
  curr_bysuj <- 1 - curr_bysuj
  barplot(curr_bysuj, col=c("red", "darkblue"), main = struct, ylim=c(0,0.6), names.arg = c("Inner", "
  legend("topright", c("Incongruent", "Congruent"), fill=c("red", "darkblue"))
}
```



STATS - Short-Nested: violation\_position \* subjects-congruency

```
print('EMBEDDED')
```

```
## [1] "EMBEDDED"
```

```
print('ANOVA')
```

```
## [1] "ANOVA"
```

```
curr_Data = subset(Data, long == 0 & nested == 1 & violation_position=='inner')
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, congruent_subjects=congruent_subj
bysuj$error <- 1 - bysuj$x
anov = aov(error ~ congruent_subjects + Error(subject/congruent_subjects), data=bysuj)
summary(anov)
```

```
##
## Error: subject
##           Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.1184  0.00623
##
## Error: subject:congruent_subjects
##           Df Sum Sq Mean Sq F value  Pr(>F)
## congruent_subjects 1 2.0430   2.0430   336.7 1.51e-13 ***
## Residuals      19 0.1153   0.0061
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```

print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ congruent_subjects + (1 | subject), data=curr_Data, family="binomial")
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ congruent_subjects + (1 | subject)
## Data: curr_Data
##
##           AIC          BIC    logLik deviance df.resid
## 27233.3    27259.1 -13613.7  27227.3     39997
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -31.4972   0.0259   0.0415   0.7027   1.3866
##
## Random effects:
## Groups Name Variance Std.Dev.
## subject (Intercept) 0.2003  0.4476
## Number of obs: 40000, groups: subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      0.1945     0.1008   1.929   0.0537 .
## congruent_subjects1  6.1941     0.1645  37.643 <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## cngrnt_sb1 -0.012

print('MAIN')

## [1] "MAIN"

print('ANOVA')

## [1] "ANOVA"

curr_Data = subset(Data, long == 0 & nested == 1 & violation_position=='outer')
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, congruent_subjects=congruent_subj
bysuj$error <- 1 - bysuj$x
anov = aov(error ~ congruent_subjects + Error(subject/congruent_subjects), data=bysuj)
summary(anov)

##
## Error: subject
##           Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.06031 0.003174
##
## Error: subject:congruent_subjects
##           Df Sum Sq Mean Sq F value Pr(>F)

```

```

## congruent_subjects 1 1.1263 1.1263 350.4 1.06e-13 ***
## Residuals          19 0.0611 0.0032
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ congruent_subjects + (1 | subject), data=curr_Data, family="binomial")
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ congruent_subjects + (1 | subject)
## Data: curr_Data
##
##      AIC      BIC    logLik deviance df.resid
## 26419.2 26445.0 -13206.6 26413.2   39997
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -23.3275   0.0589   0.0716   0.6406   0.9321
##
## Random effects:
## Groups Name Variance Std.Dev.
## subject (Intercept) 0.1247 0.3532
## Number of obs: 40000, groups: subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      0.68225    0.08048   8.477  <2e-16 ***
## congruent_subjects1 4.70967    0.10345  45.528  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## cngrnt_sb1 -0.028

print('ANOVA-interaction')

## [1] "ANOVA-interaction"

curr_Data = subset(Data, long == 0 & nested == 1)
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, violation_position=violation_position), FUN=mean))
bysuj$error <- 1 - bysuj$valid_answer
anov = aov(error ~ violation_position * congruent_subjects + Error(subject/(violation_position*congruent_subjects)))
summary(anov)

##
## Error: subject
##      Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.0982 0.005168
##
## Error: subject:violation_position

```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## violation_position  1 0.06105 0.06105   14.41 0.00122 **
## Residuals          19 0.08048 0.00424
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:congruent_subjects
##              Df Sum Sq Mean Sq F value Pr(>F)
## congruent_subjects  1 3.1016  3.1016   596.4 8.2e-16 ***
## Residuals          19 0.0988  0.0052
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:violation_position:congruent_subjects
##              Df Sum Sq Mean Sq F value Pr(>F)
## violation_position:congruent_subjects  1 0.06774 0.06774   16.6 0.000646 ***
## Residuals          19 0.07753 0.00408
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
print('GLMM')
```

```
## [1] "GLMM"
```

```
glmm_with_random <- glmer(valid_answer ~ violation_position * congruent_subjects + (1 | subject), data=
summary(glmm_with_random)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ violation_position * congruent_subjects + (1 |
## subject)
## Data: curr_Data
##
##      AIC      BIC    logLik deviance df.resid
## 54239.5 54286.0 -27114.8 54229.5    79995
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -32.195   0.036   0.060   0.662   1.166
##
## Random effects:
## Groups Name Variance Std.Dev.
## subject (Intercept) 0.08709 0.2951
## Number of obs: 80000, groups: subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value
## (Intercept)      0.1895    0.0673   2.816
## violation_positionouter      0.4861    0.0208  23.371
## congruent_subjects1      6.1436    0.1580  38.894
## violation_positionouter:congruent_subjects1 -1.4427    0.1843  -7.829
##              Pr(>|z|)
## (Intercept)      0.00487 **
## violation_positionouter < 2e-16 ***
```

```
## congruent_subjects1 < 2e-16 ***
## violation_positionouter:congruent_subjects1 4.9e-15 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##      (Intr) vltn_p cngr_1
## vltn_pstntr -0.145
## cngrnt_sbj1 -0.015  0.054
## vltn_pst:_1  0.010 -0.102 -0.833

#glmm_wo_random <- glm(valid_answer ~ violation_position * congruent_subjects, data=curr_Data, family="binomial")
#summary(glmm_wo_random)
#anova(glmm_with_random, glmm_wo_random)
```

## STATS - Long-Nested: violation\_position \* subjects-congruency

```
print('EMBEDDED')

## [1] "EMBEDDED"

print('ANOVA')

## [1] "ANOVA"

curr_Data = subset(Data, long == 1 & nested == 1 & violation_position=='inner')
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, congruent_subjects=congruent_subjects), FUN=mean))
bysuj$error <- 1 - bysuj$x
anov = aov(error ~ congruent_subjects + Error(subject/congruent_subjects), data=bysuj)
summary(anov)

##
## Error: subject
##      Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.0508 0.002674
##
## Error: subject:congruent_subjects
##      Df Sum Sq Mean Sq F value Pr(>F)
## congruent_subjects  1  5.558    5.558    2087 <2e-16 ***
## Residuals      19  0.051    0.003
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ congruent_subjects + (1 | subject), data=curr_Data, family="binomial")
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ congruent_subjects + (1 | subject)
## Data: curr_Data
```



```

##
##      AIC      BIC   logLik deviance df.resid
## 11301.6 11325.4 -5647.8 11295.6   20157
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -51.371  -0.532   0.019   0.023   3.436
##
## Random effects:
##  Groups Name      Variance Std.Dev.
##  subject (Intercept) 0.1797  0.4239
## Number of obs: 20160, groups:  subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)    -1.12056    0.09777  -11.46  <2e-16 ***
## congruent_subjects1  8.84050    0.45063   19.62  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## cngrnt_sb1 -0.017
print('MAIN')

## [1] "MAIN"
print('ANOVA')

## [1] "ANOVA"
curr_Data = subset(Data, long == 1 & nested == 1 & violation_position=='outer')
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, congruent_subjects=congruent_subj
bysuj$error <- 1 - bysuj$x
anov = aov(error ~ congruent_subjects + Error(subject/congruent_subjects), data=bysuj)
summary(anov)

##
## Error: subject
##              Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.09464 0.004981
##
## Error: subject:congruent_subjects
##              Df Sum Sq Mean Sq F value Pr(>F)
## congruent_subjects 1 0.5389 0.5389 127.2 7.34e-10 ***
## Residuals      19 0.0805 0.0042
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print('GLMM')

## [1] "GLMM"
glmm_with_random <- glmer(valid_answer ~ congruent_subjects + (1 | subject), data=curr_Data, family="bin
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace

```

```

## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ congruent_subjects + (1 | subject)
## Data: curr_Data
##
##      AIC      BIC   logLik deviance df.resid
## 12819.3 12843.0 -6406.6 12813.3    20157
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -12.3980   0.1033   0.1608   0.4818   0.8080
##
## Random effects:
## Groups Name Variance Std.Dev.
## subject (Intercept) 0.2599 0.5099
## Number of obs: 20160, groups: subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      1.15937    0.11662   9.941  <2e-16 ***
## congruent_subjects1 2.92321    0.07765  37.647  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## cngrnt_sb1 -0.058
print('ANOVA-interaction')

## [1] "ANOVA-interaction"

curr_Data = subset(Data, long == 1 & nested == 1)
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, violation_position=violation_position), FUN=function(x) sum(x)))
bysuj$error <- 1 - bysuj$valid_answer
anov = aov(error ~ violation_position * congruent_subjects + Error(subject/(violation_position*congruent_subjects)))
summary(anov)

##
## Error: subject
##              Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.07205 0.003792
##
## Error: subject:violation_position
##              Df Sum Sq Mean Sq F value Pr(>F)
## violation_position 1 1.1390 1.1390 294.9 4.99e-13 ***
## Residuals 19 0.0734 0.0039
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:congruent_subjects
##              Df Sum Sq Mean Sq F value Pr(>F)
## congruent_subjects 1 4.779 4.779 1440 <2e-16 ***
## Residuals 19 0.063 0.003
## ---

```

```

## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:violation_position:congruent_subjects
##               Df Sum Sq Mean Sq F value    Pr(>F)
## violation_position:congruent_subjects  1 1.3179   1.3179   367.9 6.8e-14 ***
## Residuals                            19 0.0681   0.0036
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ violation_position * congruent_subjects + (1 | subject), data=
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ violation_position * congruent_subjects + (1 |
## subject)
## Data: curr_Data
##
##      AIC      BIC    logLik deviance df.resid
## 24441.9 24484.9 -12215.9 24431.9    40315
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -46.377  -0.451   0.028   0.413   2.217
##
## Random effects:
## Groups Name          Variance Std.Dev.
## subject (Intercept) 0.08999  0.3
## Number of obs: 40320, groups:  subject, 20
##
## Fixed effects:
##
##              Estimate Std. Error z value
## (Intercept)    -1.09930    0.07102  -15.48
## violation_positionouter    2.21656    0.03305   67.07
## congruent_subjects1      8.75117    0.45265   19.33
## violation_positionouter:congruent_subjects1 -5.85796    0.45960  -12.75
##
##              Pr(>|z|)
## (Intercept)    <2e-16 ***
## violation_positionouter    <2e-16 ***
## congruent_subjects1    <2e-16 ***
## violation_positionouter:congruent_subjects1    <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr) vltn_p cngr_1
## vltn_pstntr -0.232
## cngrnt_sb1 -0.011  0.036
## vltn_pst:_1  0.011 -0.071 -0.986

```

## STATS: objrel (SR vs. LR) - long \* subjects-congruency (inner verb only)

```
print('ANOVA')
```

```
## [1] "ANOVA"
```

```
curr_Data = subset(Data, violation_position == 'inner' & nested == 1)
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, long=long, congruent_subjects=congruent_subjects), FUN=function(x) {
  bysuj$error <- 1 - bysuj$x
  anov = aov(error ~ long * congruent_subjects + Error(subject/(long*congruent_subjects)), data=bysuj)
  summary(anov)
}))
```

```
##
## Error: subject
##           Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19 0.1134 0.005969
##
## Error: subject:long
##           Df Sum Sq Mean Sq F value Pr(>F)
## long       1 0.4229 0.4229 144.1 2.57e-10 ***
## Residuals 19 0.0558 0.0029
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:congruent_subjects
##           Df Sum Sq Mean Sq F value Pr(>F)
## congruent_subjects 1 7.17 7.170 1236 <2e-16 ***
## Residuals        19 0.11 0.006
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:long:congruent_subjects
##           Df Sum Sq Mean Sq F value Pr(>F)
## long:congruent_subjects 1 0.4308 0.4308 147.1 2.17e-10 ***
## Residuals        19 0.0557 0.0029
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
print('GLMM')
```

```
## [1] "GLMM"
```

```
glmm_with_random <- glmer(valid_answer ~ long * congruent_subjects + (1 | subject), data=curr_Data, family=binomial)
summary(glmm_with_random)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ long * congruent_subjects + (1 | subject)
## Data: curr_Data
##
##           AIC          BIC      logLik deviance df.resid
## 38766.2 38811.3 -19378.1 38756.2 60155
##
```

```
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -51.820  -0.491   0.036   0.052   2.798
##
## Random effects:
##   Groups Name            Variance Std.Dev.
##  subject (Intercept) 0.1418    0.3765
## Number of obs: 60160, groups:  subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      0.18991    0.08562   2.218  0.0265 *
## long1            -1.30183    0.02742 -47.481 < 2e-16 ***
## congruent_subjects1      6.17493    0.16398  37.657 < 2e-16 ***
## long1:congruent_subjects1 2.61985    0.45664   5.737 9.62e-09 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr) long1  cngr_1
## long1          -0.090
## cngrnt_sbj1 -0.015  0.043
## lng1:cngr_1  0.003 -0.057 -0.334
```

## STATS: objrel (SR vs. LR) - long \* violation-position \* subjects-congruency

```
print('ANOVA')
```

```
## [1] "ANOVA"
```

```
curr_Data = subset(Data, nested == 1)
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, long=long, violation_position=violation_position), FUN=function(x) {
  bysuj$error <- 1 - bysuj$x
  anov = aov(error ~ long * congruent_subjects*violation_position + Error(subject/(long*congruent_subjects))
  summary(anov)
```

```
##
## Error: subject
##              Df Sum Sq Mean Sq F value Pr(>F)
## Residuals 19  0.125  0.006577
##
## Error: subject:long
##              Df Sum Sq Mean Sq F value Pr(>F)
## long          1 0.1154  0.11543   48.41 1.25e-06 ***
## Residuals 19 0.0453  0.00238
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:congruent_subjects
##              Df Sum Sq Mean Sq F value Pr(>F)
## congruent_subjects 1  7.791   7.791  1224 <2e-16 ***
```

```

## Residuals          19  0.121   0.006
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:violation_position
##              Df Sum Sq Mean Sq F value    Pr(>F)
## violation_position  1 0.8637   0.8637   142.8 2.78e-10 ***
## Residuals          19 0.1149   0.0060
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:long:congruent_subjects
##              Df Sum Sq Mean Sq F value    Pr(>F)
## long:congruent_subjects  1 0.09032 0.09032   41.95 3.31e-06 ***
## Residuals          19 0.04091 0.00215
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:long:violation_position
##              Df Sum Sq Mean Sq F value    Pr(>F)
## long:violation_position  1 0.3363   0.3363   164 8.57e-11 ***
## Residuals          19 0.0390   0.0021
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:congruent_subjects:violation_position
##              Df Sum Sq Mean Sq F value    Pr(>F)
## congruent_subjects:violation_position  1 0.9916   0.9916   173.2 5.36e-11 ***
## Residuals          19 0.1088   0.0057
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Error: subject:long:congruent_subjects:violation_position
##              Df Sum Sq Mean Sq F value    Pr(>F)
## long:congruent_subjects:violation_position  1 0.3940   0.3940   203.2 1.34e-11
## Residuals          19 0.0368   0.0019
##
## long:congruent_subjects:violation_position ***
## Residuals
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ long * congruent_subjects * violation_position + (1 | subject)

## Warning in checkConv(attr(opt, "derivs"), opt$par, ctrl = control$checkConv, :
## Model failed to converge with max|grad| = 0.00103696 (tol = 0.001, component 1)

summary(glmm_with_random)

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

```

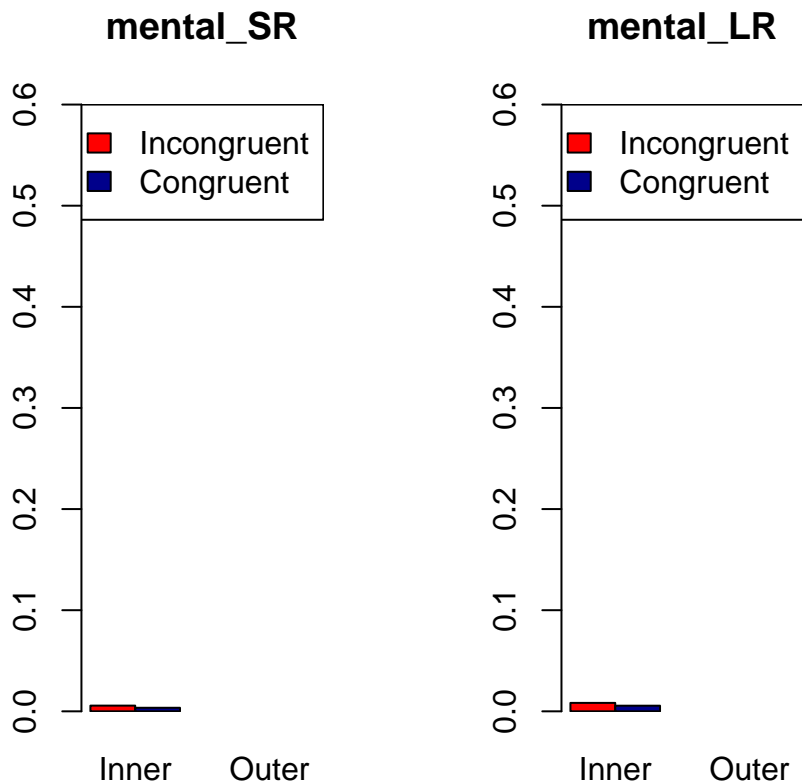
```

## Formula: valid_answer ~ long * congruent_subjects * violation_position +
## (1 | subject)
## Data: curr_Data
##
##      AIC      BIC   logLik deviance df.resid
## 78871.0 78958.3 -39426.5 78853.0 120311
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -48.148   0.021   0.061   0.555   2.129
##
## Random effects:
## Groups Name Variance Std.Dev.
## subject (Intercept) 0.06871 0.2621
## Number of obs: 120320, groups: subject, 20
##
## Fixed effects:
##
##                                     Estimate Std. Error z value
## (Intercept)                      0.18854    0.05978   3.154
## long1                          -1.28282    0.02710 -47.329
## congruent_subjects1             6.13549    0.14891  41.203
## violation_positionouter         0.48404    0.02075  23.333
## long1:congruent_subjects1       2.60063    0.34964   7.438
## long1:violation_positionouter   1.72222    0.03863  44.578
## congruent_subjects1:violation_positionouter -1.44040    0.17373  -8.291
## long1:congruent_subjects1:violation_positionouter -4.40681    0.35505 -12.412
##
##                                     Pr(>|z|)
## (Intercept)                      0.00161 **
## long1                            < 2e-16 ***
## congruent_subjects1              < 2e-16 ***
## violation_positionouter          < 2e-16 ***
## long1:congruent_subjects1        1.02e-13 ***
## long1:violation_positionouter    < 2e-16 ***
## congruent_subjects1:violation_positionouter < 2e-16 ***
## long1:congruent_subjects1:violation_positionouter < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##      (Intr) long1  cngr_1 vltn_p ln1:_1 lng1:_ cn1:_
## long1      -0.126
## cngrnt_sb1 -0.024  0.039
## vltn_pstntr -0.164  0.362  0.050
## lng1:cngr_1  0.021 -0.041 -0.203 -0.002
## lng1:vltn_p  0.090 -0.701 -0.020 -0.535  0.010
## cngrnt_s1:_  0.023 -0.034 -0.814 -0.103  0.104  0.049
## lng1:cn1:_ -0.022  0.040  0.174  0.031 -0.936 -0.063 -0.245
## convergence code: 0
## Model failed to converge with max|grad| = 0.00103696 (tol = 0.001, component 1)

```

## PLOT - error rates (mental)

```
par(mfrow=c(1,2))
for (l in 0:1) {
  struct = ifelse(l=="0", "mental_SR", "mental_LR")
  curr_data = subset(Data, nested == 0 & long == 1)
  curr_bysuj = with(curr_data, tapply(valid_answer, list(congruent_subjects=congruent_subjects, viola
  curr_bysuj <- 1 - curr_bysuj
  barplot(curr_bysuj, col=c("red", "darkblue"), main = struct, ylim=c(0,0.6), names.arg = c("Inner", "
  legend("topright", c("Incongruent", "Congruent"), fill=c("red", "darkblue"))
}
```



## STATS - mental-SR

```
print('ANOVA-embedded')

## [1] "ANOVA-embedded"

curr_Data = subset(Data, long == 0 & nested == 0 & violation_position=='inner')
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, congruent_subjects=congruent_subj
bysuj$error <- 1 - bysuj$x
anov = aov(error ~ congruent_subjects + Error(subject/congruent_subjects), data=bysuj)
summary(anov)

##
## Error: subject
##           Df    Sum Sq   Mean Sq F value Pr(>F)
```



```

## Residuals 19 0.0008123 4.275e-05
##
## Error: subject:congruent_subjects
##           Df      Sum Sq   Mean Sq F value    Pr(>F)
## congruent_subjects  1 4.623e-05 4.623e-05   10.55 0.00424 **
## Residuals          19 8.328e-05 4.380e-06
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ congruent_subjects + (1 | subject), data=curr_Data, family="binomial")
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##   Family: binomial ( logit )
##   Formula: valid_answer ~ congruent_subjects + (1 | subject)
##   Data: curr_Data
##
##           AIC      BIC    logLik deviance df.resid
##    2222.5    2248.3  -1108.3   2216.5     39997
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -32.014    0.033    0.056    0.077    0.130
##
## Random effects:
##   Groups Name            Variance Std.Dev.
##   subject (Intercept) 1.333      1.154
## Number of obs: 40000, groups:  subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      5.7112     0.2934  19.466 < 2e-16 ***
## congruent_subjects1  0.4830     0.1499   3.223  0.00127 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## cngrnt_sbj1 -0.195

#glmm_wo_random <- glm(valid_answer ~ violation_position * congruent_subjects, data=curr_Data, family="binomial")
#summary(glmm_wo_random)
#anova(glmm_with_random, glmm_wo_random)

```

## STATS - mental-LR

```

print('ANOVA-embedded')

## [1] "ANOVA-embedded"

```

```

curr_Data = subset(Data, long == 1 & nested == 0 & violation_position=='inner')
bysuj = with(curr_Data, aggregate(valid_answer, list(subject=subject, congruent_subjects=congruent_subj
bysuj$error <- 1 - bysuj$x
anov = aov(error ~ congruent_subjects + Error(subject/congruent_subjects), data=bysuj)
summary(anov)

##
## Error: subject
##           Df    Sum Sq   Mean Sq F value Pr(>F)
## Residuals 19 0.001295 6.817e-05
##
## Error: subject:congruent_subjects
##           Df    Sum Sq   Mean Sq F value Pr(>F)
## congruent_subjects 1 7.716e-05 7.716e-05 6.269 0.0216 *
## Residuals      19 2.338e-04 1.231e-05
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

print('GLMM')

## [1] "GLMM"

glmm_with_random <- glmer(valid_answer ~ congruent_subjects + (1 | subject), data=curr_Data, family="bin
summary(glmm_with_random)

## Generalized linear mixed model fit by maximum likelihood (Laplace
## Approximation) [glmerMod]
## Family: binomial ( logit )
## Formula: valid_answer ~ congruent_subjects + (1 | subject)
## Data: curr_Data
##
##      AIC      BIC    logLik deviance df.resid
## 1630.0   1653.7   -812.0   1624.0    20157
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -23.0438   0.0588   0.0722   0.0945   0.1551
##
## Random effects:
## Groups Name          Variance Std.Dev.
## subject (Intercept) 0.5916    0.7691
## Number of obs: 20160, groups: subject, 20
##
## Fixed effects:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)      5.0526     0.2157  23.42  <2e-16 ***
## congruent_subjects1 0.4098     0.1700   2.41  0.0159 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr)
## cngrnt_sb1 -0.315

```

```
#glmm_wo_random <- glm(valid_answer ~ violation_position * congruent_subjects, data=curr_Data, family="")  
#summary(glmm_wo_random)  
#anova(glmm_with_random, glmm_wo_random)
```