# M21 LDT ERP HC ORTHOGRAPIC SENSITIVITY N400

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2025-10-17

## Contents



## Set parameters

Set chunk parameters

Load libraries

Set ggplot parameters

Define standard error of the mean function

## 1 Load data files

```
dir_path <- "CSV files"

erp_2 <- read_csv(file.path(dir_path, "m21_ldt_mea_200300_050050_1.csv"))
erp_4 <- read_csv(file.path(dir_path, "m21_ldt_mea_300500_050050_1.csv"))
dmg_lng_vsl <- read_csv(file.path(dir_path, "demo_lang_vsl_pca_hc.csv"))
```

Now we extract `SubjID` from the `ERPset` column

We then join the ERP data and language into a single data frame

## 2 Format data files

Divide into word, non-word and difference wave dataframes

Then we do some more formatting and cleanup of the dataframes.We create separate columns, one for each independent variable (anteriority, laterality, morphological family size). To do this we have to use `seperate` function from the `stringr` package. Run `vignette("programming", package = "dplyr")` to see more about `tidy-selection` and `tidy-evaluation`.

Now we need to extract just the bins and channels that we intend to analyse. For this analysis we will use 9 channels: F3, Fz, F4, C3, Cz, C4, P3, Pz, P4 . We will use the`mutate` function from the `dplyr` package along with the `case_when` function. The `case_when` function is a sequence of two-sided formulas. The left hand side determines which values match this case. The right hand side provides the replacement value.

# 3 N400 Word Data

## 3.1 Nested ANOVA Model

```
#Fit ANOVA model
anova_model_n400_words_b <- mixed(
    value ~ Orthographic_Sensitivity * family_size * base_freq +
    (1 + family_size + base_freq | SubjID) +     # by-subject intercept + slopes
    (1 | SubjID:chlabel),                        # electrode nested within subject
  data   = n400_words_b,
  method = "KR"
)
anova_model_n400_words_b
```

```
|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: value ~ Orthographic_Sensitivity * family_size * base_freq +
|| Model:     (1 + family_size + base_freq | SubjID) + (1 | SubjID:chlabel)
|| Data: n400_words_b
||                                       Effect      df         F p.value
|| 1                       Orthographic_Sensitivity   1, 59      0.45    .507
|| 2                                  family_size   1, 59      1.90    .173
|| 3                                    base_freq   1, 59      0.77    .385
|| 4           Orthographic_Sensitivity:family_size   1, 59      0.05    .827
|| 5             Orthographic_Sensitivity:base_freq   1, 59      1.45    .233
|| 6                        family_size:base_freq 1, 1523 61.18 ***   <.001
|| 7 Orthographic_Sensitivity:family_size:base_freq 1, 1523      2.67    .102
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```
m1 <- anova_model_n400_words_b$full_model    # Extract the lmer model
ranova(m1) # Run random effects comparison
```

```
|| ANOVA-like table for random-effects: Single term deletions
||
|| Model:
|| value ~ Orthographic_Sensitivity + family_size + base_freq + (1 + family_size + base_freq | SubjID) + (1 | SubjID:chlabel) + Orthographic_Sensi
||                                                    npar  logLik     AIC    LRT Df Pr(>Chisq)
|| <none>                                               16 -4776.2  9584.5
|| family_size in (1 + family_size + base_freq | SubjID)   13 -5066.2 10158.4 579.98  3  < 2.2e-16 ***
|| base_freq in (1 + family_size + base_freq | SubjID)     13 -4906.4  9838.9 260.41  3  < 2.2e-16 ***
|| (1 | SubjID:chlabel)                                    15 -5216.8 10463.5 881.05  1  < 2.2e-16 ***
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# Extract effect sizes from your ANOVA model
eta_squared(anova_model_n400_words_b, partial = TRUE)
```

```
|| # Effect Size for ANOVA (Type III)
||
|| Parameter                                 | Eta2 (partial) |       95% CI
|| ------------------------------------------------------------------------------
|| Orthographic_Sensitivity                  |       7.51e-03 | [0.00, 1.00]
|| family_size                               |           0.03 | [0.00, 1.00]
|| base_freq                                 |           0.01 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size      |       8.20e-04 | [0.00, 1.00]
|| Orthographic_Sensitivity:base_freq        |           0.02 | [0.00, 1.00]
|| family_size:base_freq                     |           0.04 | [0.02, 1.00]
|| Orthographic_Sensitivity:family_size:base_freq |       1.75e-03 | [0.00, 1.00]
||
|| - One-sided CIs: upper bound fixed at [1.00].
```

```
# Compute Marginal(fixed effects only) and Conditional(fixed + random effects) R²
r2(anova_model_n400_words_b)
```

```
|| # R2 for Mixed Models
||
||   Conditional R2: 0.846
||      Marginal R2: 0.012
```

## 3.2 Main Effects

No significant main effects

## 3.3 Interactions

A two-way interaction betweeen Family Size and Base Frequency

| Effect | df | F | p.value | |
|---|---|---|---|---|
| family_size:base_freq | 1, 1523 | 61.18 *** | <.001 | 0.04 |

### 3.3.1 Simple Contrasts

```
# Estimated marginal means for the family_size × base frequency interaction
(emm1 <- emmeans(anova_model_n400_words_b, ~ family_size * base_freq))
```

```
||  family_size  base_freq           emmean    SE   df lower.CL upper.CL
||  Large Family High Base Frequency  0.649 0.366 59.9  -0.0831    1.381
||  Small Family High Base Frequency  0.785 0.432 59.6  -0.0792    1.650
||  Large Family Low Base Frequency   0.988 0.350 60.0   0.2879    1.688
||  Small Family Low Base Frequency   0.122 0.409 59.7  -0.6955    0.939
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
# Get all pairswise contrasts
(emm1_contrasts <- contrast(emm1,  method = "pairwise", by = NULL, adjust = "none"))
```

```
||  contrast                                                      estimate    SE   df t.ratio p.value
||  Large Family High Base Frequency - Small Family High Base Frequency   -0.136 0.272 66.1  -0.501  0.6184
||  Large Family High Base Frequency - Large Family Low Base Frequency    -0.339 0.196 73.9  -1.726  0.0886
||  Large Family High Base Frequency - Small Family Low Base Frequency     0.527 0.310 59.0   1.699  0.0946
||  Small Family High Base Frequency - Large Family Low Base Frequency    -0.202 0.336 59.0  -0.603  0.5490
||  Small Family High Base Frequency - Small Family Low Base Frequency     0.663 0.196 73.9   3.381  0.0012
||  Large Family Low Base Frequency - Small Family Low Base Frequency      0.866 0.272 66.1   3.179  0.0023
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
```

```
# Keep only the contrasts you want
# Simple effects of family_size at each level of base_freq
# Simple effects of base_freq at each level of family_size
keep <- c("Large Family High Base Frequency - Small Family High Base Frequency",
          "Large Family Low Base Frequency - Small Family Low Base Frequency",
          "Large Family High Base Frequency - Large Family Low Base Frequency",
          "Small Family High Base Frequency - Small Family Low Base Frequency")
(emm1_contrasts_filtered <- subset(emm1_contrasts, contrast %in% keep))
```

```
||  contrast                                                      estimate    SE   df t.ratio p.value
||  Large Family High Base Frequency - Small Family High Base Frequency   -0.136 0.272 66.1  -0.501  0.6184
||  Large Family High Base Frequency - Large Family Low Base Frequency    -0.339 0.196 73.9  -1.726  0.0886
||  Small Family High Base Frequency - Small Family Low Base Frequency     0.663 0.196 73.9   3.381  0.0012
||  Large Family Low Base Frequency - Small Family Low Base Frequency      0.866 0.272 66.1   3.179  0.0023
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
```

```
# Get Confidence Intervals
(emm1_contrasts_filtered_ci <- confint(emm1_contrasts_filtered))
```

```
||  contrast                                                      estimate    SE   df lower.CL upper.CL
||  Large Family High Base Frequency - Small Family High Base Frequency   -0.136 0.272 66.1   -0.680   0.4074
||  Large Family High Base Frequency - Large Family Low Base Frequency    -0.339 0.196 73.9   -0.730   0.0524
||  Small Family High Base Frequency - Small Family Low Base Frequency     0.663 0.196 73.9    0.272   1.0544
||  Large Family Low Base Frequency - Small Family Low Base Frequency      0.866 0.272 66.1    0.322   1.4095
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
# Get effect sizes
# Get all pairwise effect sizes
effs1 <- eff_size(emm1, sigma = sigma(m1), edf = df.residual(m1))

# Remove the two redundant rows (rows 3 and 4)
(effs1_filtered <- subset(effs1, contrast %in% keep))
```

```
||  contrast                                                    effect.size    SE   df lower.CL upper.CL
||  Large Family High Base Frequency - Small Family High Base Frequency     -0.0914 0.183 59.6   -0.457   0.2740
||  Large Family High Base Frequency - Large Family Low Base Frequency      -0.2271 0.132 59.9   -0.490   0.0362
||  Small Family High Base Frequency - Small Family Low Base Frequency       0.4449 0.132 59.6    0.181   0.7086
||  Large Family Low Base Frequency - Small Family Low Base Frequency        0.5806 0.183 59.7    0.215   0.9465
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| sigma used for effect sizes: 1.491
|| Degrees-of-freedom method: inherited from kenward-roger when re-gridding
|| Confidence level used: 0.95
```

For large-family words, n400 amplitude is more negative when base frequency is high than when it is low. For small-family words, base frequency has little effect. For low-frequency bases, small-family words elicit more negative amplitudes than large-family words.

- At High base frequency: Large - Small $= -0.136; SE = 0.272; t = -0.501; p = 0.6184$. This difference is not statistically significant ($p > .05$).
- At Low base frequency: Large - Small $= 0.866$ $SE = 0.272; t = 3.179; p = 0.0023$. This difference is statistically significant ($p = 0.0023$ after adjustment.

Thus: when base frequency is low, large vs small family_size differ significantly in predicted N400; but when base frequency is high, they do not differ significantly.

Next, contrasting High vs Low base_freq within each family_size:

- Large family_size: High - Low $= -0.339; SE = 0.196; t = -1.726; p = 0.0886$. This is a trend ($p \sim .09$), but not conventionally significant.
- Small family_size: High - Low $= 0.663; SE = 0.196; t = 3.381; p = 0.0012$. Significant difference: base_freq level matters when family_size is small.

So: when family_size is small, high vs low base frequency yields a significant difference; when family_size is large, the difference is marginal / not strong.

### 3.3.2 Interaction Contrasts

```
#  Interaction contrasts (difference-of-differences)
#    Compare base frequency effect in large vs small family)
contrast(emm1, interaction = "pairwise", by = NULL, adjust = "holm")
```

```
||  family_size_pairwise        base_freq_pairwise                      estimate    SE   df t.ratio p.value
||  Large Family - Small Family High Base Frequency - Low Base Frequency       -1 0.128 1523  -7.821  <.0001
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
```

```
# Get confidence intervals, for the frequency effect for each family size and then for interaction effect
confint(contrast(emmeans(m1, ~ family_size | base_freq), "pairwise"))
```

```
|| base_freq = High Base Frequency:
||  contrast                    estimate    SE   df lower.CL upper.CL
||  Large Family - Small Family   -0.136 0.272 66.1   -0.680    0.407
||
|| base_freq = Low Base Frequency:
||  contrast                    estimate    SE   df lower.CL upper.CL
||  Large Family - Small Family    0.866 0.272 66.1    0.322    1.409
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
confint(contrast(emm1, interaction = c("pairwise", "pairwise")))
```

```
||  family_size_pairwise        base_freq_pairwise                      estimate    SE   df lower.CL upper.CL
||  Large Family - Small Family High Base Frequency - Low Base Frequency       -1 0.128 1523    -1.25   -0.751
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

The final contrast tests whether the difference between Large vs Small family_size is itself different between High vs Low base_freq: Estimate $= -1.000$; $SE = 0.128$; $t = -7.821$; $p < .0001$

That is, the slope or effect of `family_size` depends strongly on the level of `base_freq` (consistent with your ANOVA). Put differently: the family size difference (Large - Small) is much more positive in the low base frequency condition than it is in the high base frequency condition. That difference of differences is highly significant.

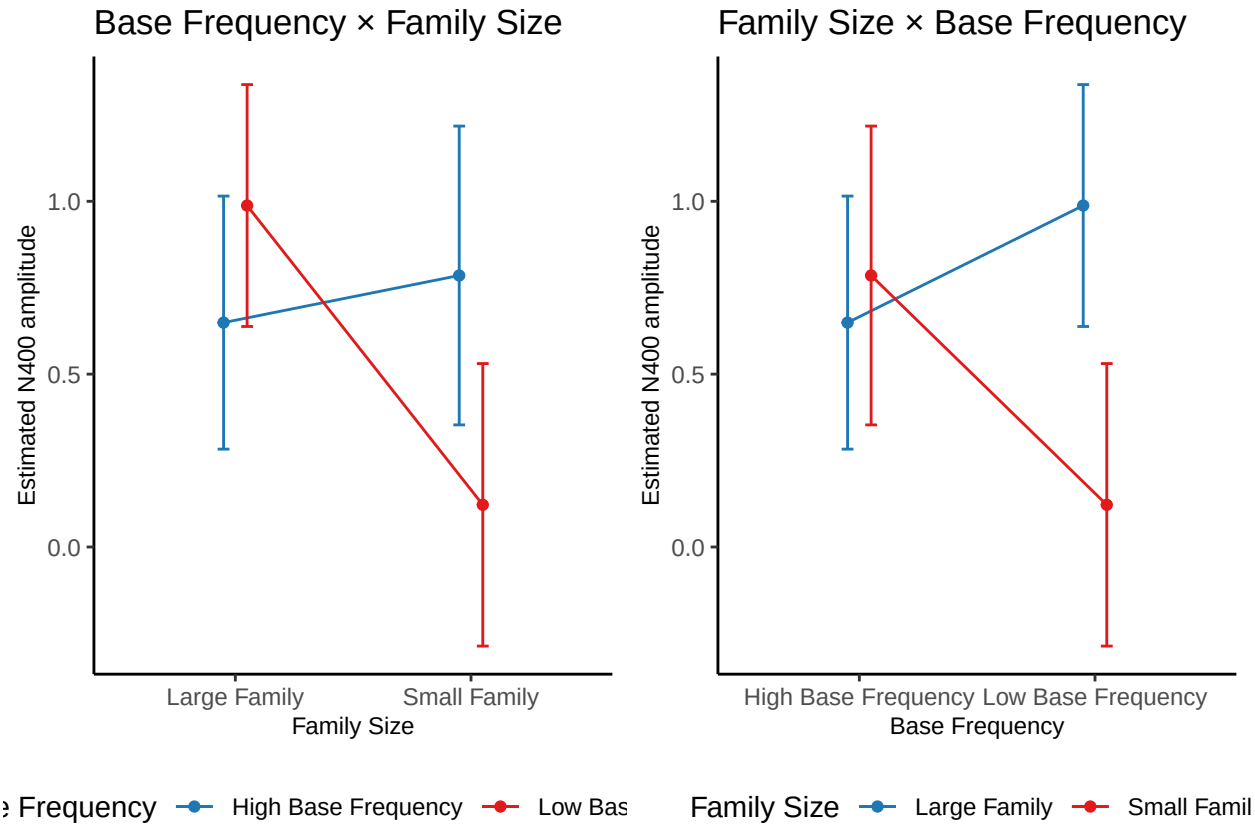
## 3.4 Plots

```
emm_df <- as.data.frame(emm1)
p1<- ggplot(emm_df,
       aes(x = family_size, y = emmean,
```

```
          color = base_freq, group = base_freq)) +
  geom_line(position = position_dodge(0.2)) +
  geom_point(position = position_dodge(0.2)) +
  geom_errorbar(aes(ymin = emmean - SE, ymax = emmean + SE),
                width = 0.1, position = position_dodge(0.2)) +
  labs(x = "Family Size", y = "Estimated N400 amplitude",
       color = "Base Frequency",
       title = "Base Frequency × Family Size") +
  scale_color_custom() +
  scale_fill_custom()

p2 <- ggplot(emm_df,
       aes(x = base_freq, y = emmean,
           color = family_size, group = family_size)) +
  geom_line(position = position_dodge(0.2)) +
  geom_point(position = position_dodge(0.2)) +
  geom_errorbar(aes(ymin = emmean - SE, ymax = emmean + SE),
                width = 0.1, position = position_dodge(0.2)) +
  labs(x = "Base Frequency", y = "Estimated N400 amplitude",
       color = "Family Size",
       title = "Family Size × Base Frequency") +
  scale_color_custom() +
  scale_fill_custom()

plot_grid(p1, p2, ncol = 2)
```



# 4 N400 Nonword Data

## 4.1 Compute the ANOVA

```
anova_model_n400_nonwords <- mixed(
    value ~ Orthographic_Sensitivity * family_size * complexity +
    (1 + family_size + complexity | SubjID) +     # by-subject intercept + slopes
    (1 | SubjID:chlabel),                        # electrode nested within subject
  data   = n400_nonwords,
  method = "KR"
)
anova_model_n400_nonwords
```

```
|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: value ~ Orthographic_Sensitivity * family_size * complexity +
|| Model:     (1 + family_size + complexity | SubjID) + (1 | SubjID:chlabel)
|| Data: n400_nonwords
||                                         Effect      df      F p.value
|| 1                       Orthographic_Sensitivity   1, 59   0.01    .932
|| 2                                  family_size   1, 59   0.01    .942
|| 3                                   complexity   1, 59   0.02    .884
|| 4            Orthographic_Sensitivity:family_size   1, 59   0.18    .675
|| 5             Orthographic_Sensitivity:complexity   1, 59   0.45    .506
|| 6                      family_size:complexity 1, 1523 5.87 *    .016
|| 7 Orthographic_Sensitivity:family_size:complexity 1, 1523   1.08    .299
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```
m2 <- anova_model_n400_nonwords$full_model    # Extract the lmer model
ranova(m2)    # Run random effects comparison
```

```
|| ANOVA-like table for random-effects: Single term deletions
||
|| Model:
|| value ~ Orthographic_Sensitivity + family_size + complexity + (1 + family_size + complexity | SubjID) + (1 | SubjID:chlabel) + Orthographic_Sen
||                                                    npar  logLik   AIC     LRT Df Pr(>Chisq)
|| <none>                                               16 -5055.9 10144
|| family_size in (1 + family_size + complexity | SubjID)   13 -5322.0 10670  532.05  3  < 2.2e-16 ***
|| complexity in (1 + family_size + complexity | SubjID)    13 -5420.1 10866  728.22  3  < 2.2e-16 ***
|| (1 | SubjID:chlabel)                                     15 -5561.8 11154 1011.64  1  < 2.2e-16 ***
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
# Extract effect sizes from your ANOVA model
eta_squared(anova_model_n400_nonwords, partial = TRUE)
```

```
|| # Effect Size for ANOVA (Type III)
||
|| Parameter                                 | Eta2 (partial) |       95% CI
|| ------------------------------------------------------------------------------
|| Orthographic_Sensitivity                  |       1.23e-04 | [0.00, 1.00]
|| family_size                               |       8.94e-05 | [0.00, 1.00]
|| complexity                                |       3.67e-04 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size      |       3.01e-03 | [0.00, 1.00]
|| Orthographic_Sensitivity:complexity       |       7.53e-03 | [0.00, 1.00]
|| family_size:complexity                    |       3.84e-03 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size:complexity |       7.08e-04 | [0.00, 1.00]
||
|| - One-sided CIs: upper bound fixed at [1.00].
```

```
# Compute Marginal(fixed effects only) and Conditional(fixed + random effects) R²
r2(anova_model_n400_nonwords)
```

```
|| # R2 for Mixed Models
||
||   Conditional R2: 0.852
||      Marginal R2: 0.001
```

All partial $\eta^2$ values are extremely small (all $< .01$),; the observed family_size × complexity interaction, although statistically significant, explains a very small proportion of variance.

## 4.2 Main Effects

No main effects. The N400 responses to nonwords were largely unaffected by orthographic sensitivity, family size, or complexity considered separately.

## 4.3 Interactions

A small but reliable `family_size` × `complexity` interaction ($t = 5.87$, $p = .016$) suggests the effect of family size (large vs. small) reversed or changed in magnitude depending on whether the nonwords were simple or complex, but this effect is weak and not influenced by

reader sensitivity. Overall, the nonword data show minimal systematic structure, consistent with the idea that participants did not engage lexical-semantic processing for these stimuli in a meaningful way.

### 4.3.1 Simple Contrasts

(a) Effect of family_size within each level of complexity. Tests whether "*large vs. small family*" differs for simple and complex items separately. This helps you see where the interaction is coming from — e.g., if the family size effect flips between complexity levels.

(b) Effect of complexity within each level of family_size. Tests whether "*complex vs. simple*" differs within large and small families.

```
# Estimated marginal means for the family_size × complexity interaction
(emm2 <- emmeans(anova_model_n400_nonwords, ~ family_size * complexity))
```

```
||  family_size  complexity emmean    SE   df lower.CL upper.CL
||  Large Family Complex    -0.267 0.418 59.9   -1.103    0.569
||  Small Family Complex    -0.075 0.401 59.9   -0.877    0.727
||  Large Family Simple     -0.144 0.472 59.7   -1.089    0.801
||  Small Family Simple     -0.295 0.457 59.7   -1.209    0.618
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
# Get all pairswise contrasts
emm2_contrasts <- contrast(emm2,  method = "pairwise", by = NULL, adjust = "none")

# Keep only the contrasts you want
# Simple effects of family_size at each level of complexity
# Simple effects of complexity at each level of family_size
keep2 <- c("Large Family Complex - Small Family Complex",
           "Large Family Simple - Small Family Simple",
           "Large Family Complex - Large Family Simple",
           "Small Family Complex - Small Family Simple")
(emm2_contrasts_filtered <- subset(emm2_contrasts, contrast %in% keep2))
```

```
||  contrast                                estimate    SE   df t.ratio p.value
||  Large Family Complex - Small Family Complex   -0.192 0.290 66.7  -0.662  0.5103
||  Large Family Complex - Large Family Simple    -0.123 0.338 64.5  -0.364  0.7171
||  Small Family Complex - Small Family Simple     0.220 0.338 64.5   0.652  0.5170
||  Large Family Simple - Small Family Simple      0.151 0.290 66.7   0.521  0.6040
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
```

```
# Get Confidence Intervals
(emm2_contrasts_filtered_ci <- confint(emm2_contrasts_filtered))
```

```
||  contrast                                estimate    SE   df lower.CL upper.CL
||  Large Family Complex - Small Family Complex   -0.192 0.290 66.7   -0.772    0.387
||  Large Family Complex - Large Family Simple    -0.123 0.338 64.5   -0.799    0.552
||  Small Family Complex - Small Family Simple     0.220 0.338 64.5   -0.455    0.896
||  Large Family Simple - Small Family Simple      0.151 0.290 66.7   -0.428    0.731
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
# Get effect sizes
# Get all pairwise effect sizes
effs2 <- eff_size(emm2, sigma = sigma(m2), edf = df.residual(m2))

# Remove the two redundant rows (rows 3 and 4)
(effs2_filtered <- subset(effs2, contrast %in% keep2))
```

```
||  contrast                                effect.size    SE   df lower.CL upper.CL
||  Large Family Complex - Small Family Complex     -0.1165 0.176 59.9   -0.469    0.236
||  Large Family Complex - Large Family Simple      -0.0746 0.205 59.7   -0.485    0.336
||  Small Family Complex - Small Family Simple       0.1336 0.205 59.7   -0.277    0.544
||  Large Family Simple - Small Family Simple        0.0917 0.176 59.7   -0.260    0.444
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| sigma used for effect sizes: 1.649
|| Degrees-of-freedom method: inherited from kenward-roger when re-gridding
|| Confidence level used: 0.95
```

### 4.3.2 Interaction Contrasts

If simple effects aren't significant, try looking at interaction contrasts, which test differences in the differences. You're now asking: Does the effect of Sensitivity change more in some complexity/family combinations than others?

The interaction contrast tests:

Is the difference in the effect of A across levels of B different at Complex vs. Simple levels?

Mathematically:

$$[[(A_1 - A_2) \text{ in } B_1] - [(A_1 - A_2) \text{ in } B_2]$$

```
#  Interaction contrasts (difference-of-differences)
#    Compare complexity effect in large vs small family)
contrast(emm2, interaction = "pairwise", by = NULL, adjust = "holm")
```

```
||  family_size_pairwise        complexity_pairwise estimate    SE   df t.ratio p.value
||  Large Family - Small Family Complex - Simple      -0.343 0.142 1523  -2.423  0.0155
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
```

```
# Get confidence intervals, for each complexity effect for each family size and then for interaction effect
confint(contrast(emmeans(m2, ~ family_size | complexity), "pairwise"))
```

```
|| complexity = Complex:
||  contrast                    estimate   SE   df lower.CL upper.CL
||  Large Family - Small Family   -0.192 0.29 66.7   -0.772    0.387
||
|| complexity = Simple:
||  contrast                    estimate   SE   df lower.CL upper.CL
||  Large Family - Small Family    0.151 0.29 66.7   -0.428    0.731
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
confint(contrast(emm2, interaction = c("pairwise", "pairwise")))
```

```
||  family_size_pairwise        complexity_pairwise estimate    SE   df lower.CL upper.CL
||  Large Family - Small Family Complex - Simple      -0.343 0.142 1523   -0.621  -0.0654
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

## 4.4 Plots

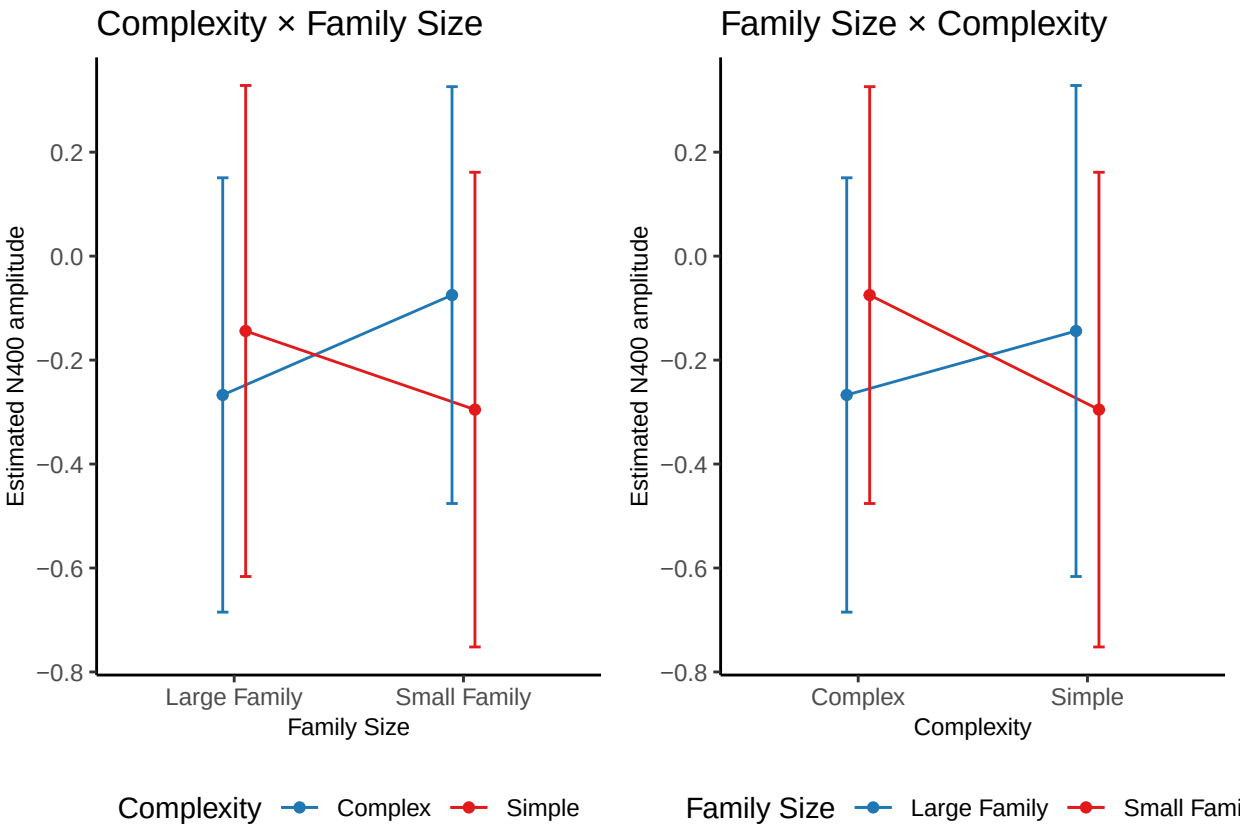
```
# Plot the interaction
library(ggplot2)

emm2_df <- as.data.frame(emm2)

p3<- ggplot(emm2_df,
       aes(x = family_size, y = emmean,
           color = complexity, group = complexity)) +
  geom_line(position = position_dodge(0.2)) +
  geom_point(position = position_dodge(0.2)) +
  geom_errorbar(aes(ymin = emmean - SE, ymax = emmean + SE),
                width = 0.1, position = position_dodge(0.2)) +
  labs(x = "Family Size", y = "Estimated N400 amplitude",
       color = "Complexity",
       title = "Complexity × Family Size") +
  scale_color_custom() +
  scale_fill_custom()

p4 <- ggplot(emm2_df,
       aes(x = complexity, y = emmean,
           color = family_size, group = family_size)) +
  geom_line(position = position_dodge(0.2)) +
  geom_point(position = position_dodge(0.2)) +
  geom_errorbar(aes(ymin = emmean - SE, ymax = emmean + SE),
                width = 0.1, position = position_dodge(0.2)) +
  labs(x = "Complexity", y = "Estimated N400 amplitude",
       color = "Family Size",
       title = "Family Size × Complexity") +
  scale_color_custom() +
  scale_fill_custom()

plot_grid(p3, p4, ncol = 2)
```


Complexity × Family Size
Estimated N400 amplitude
0.2
0.0
−0.2
−0.4
−0.6
−0.8
Large Family
Small Family
Family Size
Complexity
Complex
Simple
Family Size × Complexity
Estimated N400 amplitude
0.2
0.0
−0.2
−0.4
−0.6
−0.8
Complex
Simple
Complexity
Family Size
Large Family
Small Fami