M21 LDT ERP N250

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1.1 Load and format data files

```
erpdat_1 <- read_csv("m21_ldt_mea_200300_050050_1.csv")
dmg_lng_vsl <- read_csv("demo_lang_vsl_pca.csv")
```

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

```
# Remove '_LDT_diff_waves' from each string in the ERPset column
# This code first renames the column and then applies the `str_replace` function
# to the newly renamed column.
erpdat_1 <- erpdat_1 %>%
  rename(SubjID = ERPset) %>%
  mutate(SubjID = str_replace(SubjID, "_LDT_diff_waves", "")) |>
  mutate(binlabel = str_replace(binlabel, "Critical_", "")) |>
  mutate(binlabel = str_replace(binlabel, "_family", "")) |>
  select(-mlabel)
```

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

```
n250_1 <- erpdat_1 |>
  left_join(dmg_lng_vsl, by = "SubjID") |>
  select(SubjID, everything()) |>
  rename(orthographic_sensitivity = lang_type_ortho)
```

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`.

```
# Words
n250_1_words <- n250_1_words %>%
  separate(binlabel, into = c("trial_type","family_size"), sep = "_", remove = TRUE) |>
  select(-trial_type)

n250_1_words_b <- n250_1_words_b %>%
  separate(binlabel, into = c("trial_type", "family_size","tmp1", "base_freq", "tmp2"), sep = "_", remove = TRUE) |>
  select(-c(trial_type, tmp1, tmp2))

# Assuming your data frame is named 'df' and the column is named 'your_column'
n250_1_words_b$orthographic_sensitivity[n250_1_words_b$orthographic_sensitivity == "Low"] <- "Low Sensitivity"
n250_1_words_b$orthographic_sensitivity[n250_1_words_b$orthographic_sensitivity == "High"] <- "High Sensitivity"
n250_1_words_b$base_freq[n250_1_words_b$base_freq == "Low"] <- "Low Base Frequency"
n250_1_words_b$base_freq[n250_1_words_b$base_freq == "High"] <- "High Base Frequency"
n250_1_words_b$family_size[n250_1_words_b$family_size == "large"] <- "Large Family"
n250_1_words_b$family_size[n250_1_words_b$family_size == "small"] <- "Small Family"

# Nonwords
n250_1_nonwords <- n250_1_nonwords %>%
  separate(binlabel, into = c("trial_type", "family_size", "complexity"), sep = "_", remove = TRUE) |>
  select(-trial_type)

# Assuming your data frame is named 'df' and the column is named 'your_column'
n250_1_nonwords$orthographic_sensitivity[n250_1_nonwords$orthographic_sensitivity == "Low"] <- "Low Sensitivity"
n250_1_nonwords$orthographic_sensitivity[n250_1_nonwords$orthographic_sensitivity == "High"] <- "High Sensitivity"
n250_1_nonwords$complexity[n250_1_nonwords$complexity == "complex"] <- "Complex"
n250_1_nonwords$complexity[n250_1_nonwords$complexity == "simple"] <- "Simple"
n250_1_nonwords$family_size[n250_1_nonwords$family_size == "large"] <- "Large Family"
n250_1_nonwords$family_size[n250_1_nonwords$family_size == "small"] <- "Small Family"
```

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.

```
channels_1 <-  c(3, 2, 25, 7, 20, 21, 12, 11, 16)
channels_2 <-  c(3, 2, 29, 8, 23, 24, 14, 13, 19)

# Words
n250_1_words <- n250_1_words %>%
  filter(chindex %in% channels_1) %>%
  mutate(anteriority = case_when(grepl("F", chlabel) ~ "Frontal",
                                 grepl("C", chlabel) ~ "Central",
                                 grepl("P", chlabel) ~ "Parietal"),
         laterality = case_when(grepl("3", chlabel) ~ "Left",grepl("z", chlabel) ~ "Midline",
                                grepl("Z", chlabel) ~ "Midline",grepl("4", chlabel) ~ "Right"))
n250_1_words$anteriority <- factor(n250_1_words$anteriority, levels = c("Frontal",  "Central",  "Parietal"))
n250_1_words$laterality <- factor(n250_1_words$laterality, levels = c("Left", "Midline", "Right"))

n250_1_words_b <- n250_1_words_b %>%
  filter(chindex %in% channels_1) %>%
  mutate(anteriority = case_when(grepl("F", chlabel) ~ "Frontal",
                                 grepl("C", chlabel) ~ "Central",
                                 grepl("P", chlabel) ~ "Parietal"),
         laterality = case_when(grepl("3", chlabel) ~ "Left",grepl("z", chlabel) ~ "Midline",
                                grepl("Z", chlabel) ~ "Midline",grepl("4", chlabel) ~ "Right"))
n250_1_words_b$anteriority <- factor(n250_1_words_b$anteriority, levels = c("Frontal",  "Central",  "Parietal"))
n250_1_words_b$laterality <- factor(n250_1_words_b$laterality, levels = c("Left", "Midline", "Right"))

# Nonwords
n250_1_nonwords <- n250_1_nonwords %>%
  filter(chindex %in% channels_1) %>%
  mutate(anteriority = case_when(grepl("F", chlabel) ~ "Frontal",
                                 grepl("C", chlabel) ~ "Central",
                                 grepl("P", chlabel) ~ "Parietal"),
         laterality = case_when(grepl("3", chlabel) ~ "Left",grepl("z", chlabel) ~ "Midline",
                                grepl("Z", chlabel) ~ "Midline", grepl("4", chlabel) ~ "Right"))
n250_1_nonwords$anteriority <- factor(n250_1_nonwords$anteriority, levels = c("Frontal",  "Central","Parietal"))
n250_1_nonwords$laterality <- factor(n250_1_nonwords$laterality, levels = c("Left", "Midline", "Right"))
```

1.2 Real Word Data

1.2.1 Compute the ANOVA

```
anova_model_1a <- mixed(
  value ~ orthographic_sensitivity * family_size * base_freq  +
```

```
    laterality * anteriority  +  # Nuisance variables
    (1 | SubjID),
  data = n250_1_words_b,
  method = "KR")  # Kenward-Roger approximation for accurate F-tests
# Print ANOVA results
anova_model_1a
```

```
|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: value ~ orthographic_sensitivity * family_size * base_freq +
|| Model:     laterality * anteriority + (1 | SubjID)
|| Data: n250_1_words_b
||                                          Effect      df         F p.value
|| 1                         orthographic_sensitivity   1, 59      0.00    .970
|| 2                                     family_size 1, 2121   8.56 **    .003
|| 3                                       base_freq 1, 2121   6.67 **    .010
|| 4                                      laterality 2, 2121      0.29    .745
|| 5                                     anteriority 2, 2121 18.21 ***   <.001
|| 6            orthographic_sensitivity:family_size 1, 2121      0.12    .729
|| 7              orthographic_sensitivity:base_freq 1, 2121    4.12 *    .043
|| 8                          family_size:base_freq 1, 2121 14.76 ***   <.001
|| 9                        laterality:anteriority 4, 2121      0.76    .550
|| 10 orthographic_sensitivity:family_size:base_freq 1, 2121      0.23    .633
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```
# Partial Eta Squared
# Extract effect sizes from your ANOVA model
eta_squared(anova_model_1a , partial = TRUE)
```

```
|| # Effect Size for ANOVA (Type III)
||
|| Parameter                                     | Eta2 (partial) |       95% CI
|| ------------------------------------------------------------------------------
|| orthographic_sensitivity                      |       2.45e-05 | [0.00, 1.00]
|| family_size                                   |       4.02e-03 | [0.00, 1.00]
|| base_freq                                     |       3.13e-03 | [0.00, 1.00]
|| laterality                                    |       2.78e-04 | [0.00, 1.00]
|| anteriority                                   |           0.02 | [0.01, 1.00]
|| orthographic_sensitivity:family_size          |       5.67e-05 | [0.00, 1.00]
|| orthographic_sensitivity:base_freq            |       1.94e-03 | [0.00, 1.00]
|| family_size:base_freq                         |       6.91e-03 | [0.00, 1.00]
|| laterality:anteriority                        |       1.43e-03 | [0.00, 1.00]
|| orthographic_sensitivity:family_size:base_freq |       1.08e-04 | [0.00, 1.00]
||
|| - One-sided CIs: upper bound fixed at [1.00].
```

```
# Compute Marginal (fixed effects) and Conditional (fixed + random effects) R²
r2(anova_model_1a)
```

```
|| # R2 for Mixed Models
||
||   Conditional R2: 0.477
||      Marginal R2: 0.018
```

1.2.2 Significant Effects

Effect	df	F	p.value	
family_size	1, 2121	8.56 **	.003	4.02e-03
base_freq	1, 2121	6.67 **	.010	3.13e-03
orthographic_sensitivity:base_freq	1, 2121	4.12 *	.043	1.94e-03
family_size:base_freq	1, 2121	14.76 ***	<.001	6.91e-03

```
## `family_size` main effect
pairs <- emmeans(anova_model_1a, pairwise ~ family_size, adjust = "bonferroni", pbkrtest.limit = 6480)
(pairs_df <- as.data.frame(pairs$contrasts))
```

```
||  contrast                   estimate         SE   df t.ratio p.value
||  Large Family - Small Family 0.2739421 0.09363606 2121   2.926  0.0035
||
|| Results are averaged over the levels of: orthographic_sensitivity, base_freq, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
```

```
cohensd <- as.data.frame(cohens_d(value ~ family_size, data = n250_1_words_b))
(family_size_contrasts_df <- bind_cols(pairs_df,cohensd))
```

```
||  contrast                   estimate         SE   df t.ratio p.value
||  Large Family - Small Family 0.2739421 0.09363606 2121   2.926  0.0035
```

```
||    Cohens_d   CI      CI_low   CI_high
||  0.09242177 0.95 0.008717338 0.1761052
||
|| Results are averaged over the levels of: orthographic_sensitivity, base_freq, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
```

```
(family_size_means <- as.data.frame(pairs$emmeans))
```

```
||  family_size      emmean        SE    df  lower.CL   upper.CL
||  Large Family -0.6245618 0.2714427 62.67 -1.167052 -0.0820712
||  Small Family -0.8985039 0.2714427 62.67 -1.440994 -0.3560133
||
|| Results are averaged over the levels of: orthographic_sensitivity, base_freq, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
## `base_freq` main effect
pairs <- emmeans(anova_model_1a, pairwise ~ base_freq, adjust = "bonferroni", pbkrtest.limit = 6480)
(pairs_df <- as.data.frame(pairs$contrasts))
```

```
||  contrast                                  estimate         SE   df t.ratio
||  High Base Frequency - Low Base Frequency -0.2418075 0.09363606 2121  -2.582
||  p.value
||   0.0099
||
|| Results are averaged over the levels of: orthographic_sensitivity, family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
```

```
cohensd <- as.data.frame(cohens_d(value ~ base_freq, data = n250_1_words_b))
(base_freq_contrasts_df <- bind_cols(pairs_df,cohensd))
```

```
||  contrast                                  estimate         SE   df t.ratio
||  High Base Frequency - Low Base Frequency -0.2418075 0.09363606 2121  -2.582
||  p.value   Cohens_d   CI     CI_low     CI_high
||   0.0099 -0.0755643 0.95 -0.1592348 0.008123396
||
|| Results are averaged over the levels of: orthographic_sensitivity, family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
```

```
(base_freq_means <- as.data.frame(pairs$emmeans))
```

```
||  base_freq               emmean        SE    df  lower.CL   upper.CL
||  High Base Frequency -0.8824366 0.2714427 62.67 -1.424927 -0.3399460
||  Low Base Frequency  -0.6406291 0.2714427 62.67 -1.183120 -0.0981385
||
|| Results are averaged over the levels of: orthographic_sensitivity, family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
# Test whether the interaction between orthographic_sensitivity and base_freq improves model fit
reduced_model_int <- update(anova_model_1a,
  . ~ . - orthographic_sensitivity:base_freq - orthographic_sensitivity:family_size:base_freq)

anova(anova_model_1a, reduced_model_int)
```

```
|| Data: data
|| Models:
|| reduced_model_int: value ~ orthographic_sensitivity + family_size + base_freq + laterality + anteriority + orthographic_sensitivity:family_size
|| anova_model_1a: value ~ orthographic_sensitivity * family_size * base_freq + laterality * anteriority + (1 | SubjID)
||                   npar    AIC   BIC  logLik deviance Chisq Df Pr(>Chisq)
|| reduced_model_int   16 9947.4 10038 -4957.7   9915.4
|| anova_model_1a      18 9955.7 10058 -4959.8   9919.7     0  2          1
```

```
# Custom contrasts for orthographic_sensitivity × base_freq Interaction
pairs <- emmeans(anova_model_1a, pairwise ~ orthographic_sensitivity * base_freq, adjust = "bonferroni", pbkrtest.limit = 6480)
(pairs_df <- as.data.frame(pairs$contrasts))
```

```
||  contrast
||  High Sensitivity High Base Frequency - Low Sensitivity High Base Frequency
||  High Sensitivity High Base Frequency - High Sensitivity Low Base Frequency
||  High Sensitivity High Base Frequency - Low Sensitivity Low Base Frequency
||  Low Sensitivity High Base Frequency - High Sensitivity Low Base Frequency
||  Low Sensitivity High Base Frequency - Low Sensitivity Low Base Frequency
||  High Sensitivity Low Base Frequency - Low Sensitivity Low Base Frequency
||    estimate         SE      df t.ratio p.value
||  -0.1696982 0.5428854   62.67  -0.313  1.0000
||  -0.4318373 0.1377416 2121.00  -3.135  0.0104
||  -0.2214759 0.5428854   62.67  -0.408  1.0000
||  -0.2621391 0.5428854   62.67  -0.483  1.0000
||  -0.0517778 0.1268783 2121.00  -0.408  1.0000
||   0.2103614 0.5428854   62.67   0.387  1.0000
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
```

```
|| P value adjustment: bonferroni method for 6 tests
```

```
selected_contrasts_basefrq <- pairs$contrasts[pairs_df$contrast %in% c("High Sensitivity High Base Frequency - High Sensitivity Low Base Frequency
                                                                       "Low Sensitivity High Base Frequency - Low Sensitivity Low Base Frequency")
selected_contrasts_sensit <- pairs$contrasts[pairs_df$contrast %in% c("High Sensitivity High Base Frequency - Low Sensitivity High Base Frequency"
                                                                      "Low Sensitivity High Base Frequency - High Sensitivity Low Base Frequency")

selected_contrasts_basefrq_df <- as.data.frame(selected_contrasts_basefrq)  # Convert the emmGrid object to a dataframe
selected_contrasts_sensit_df <- as.data.frame(selected_contrasts_sensit)

cohensd_hi_basefrq <- as.data.frame(cohens_d(value ~ orthographic_sensitivity,
                                             data = subset(n250_1_words_b, base_freq == "High Base Frequency")))
cohensd_lo_basefrq <- as.data.frame(cohens_d(value ~ orthographic_sensitivity,
                                             data = subset(n250_1_words_b, base_freq == "Low Base Frequency")))
cohensd_hi_sensit <- as.data.frame(cohens_d(value ~ base_freq,
                                            data = subset(n250_1_words_b, orthographic_sensitivity == "High Sensitivity")))
cohensd_lo_sensit <- as.data.frame(cohens_d(value ~ base_freq,
                                            data = subset(n250_1_words_b, orthographic_sensitivity == "Low Sensitivity")))

cohensd_basefrq <- bind_rows(hi_basefrq = cohensd_hi_basefrq,
                             lo_basefrq = cohensd_lo_basefrq,
                             .id = "base_freq")

cohensd_sensit <- bind_rows(hi_sensit = cohensd_hi_sensit,
                            lo_sensi = cohensd_lo_sensit,
                            .id = "sensitivity")

(basefreq_contrasts_df <- bind_cols(selected_contrasts_basefrq_df,cohensd_basefrq))
```

```
||  contrast
||  High Sensitivity High Base Frequency - High Sensitivity Low Base Frequency
||  Low Sensitivity High Base Frequency - Low Sensitivity Low Base Frequency
||    estimate        SE   df t.ratio p.value base_freq     Cohens_d   CI
||  -0.4318373 0.1377416 2121  -3.135  0.0035 hi_basefrq -0.05609838 0.95
||  -0.0517778 0.1268783 2121  -0.408  1.0000 lo_basefrq  0.07101669 0.95
||      CI_low    CI_high
||  -0.1748061 0.06263491
||  -0.0477340 0.18973500
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
```

```
(sensitivity_contrasts_df <- bind_cols(selected_contrasts_sensit_df,cohensd_sensit))
```

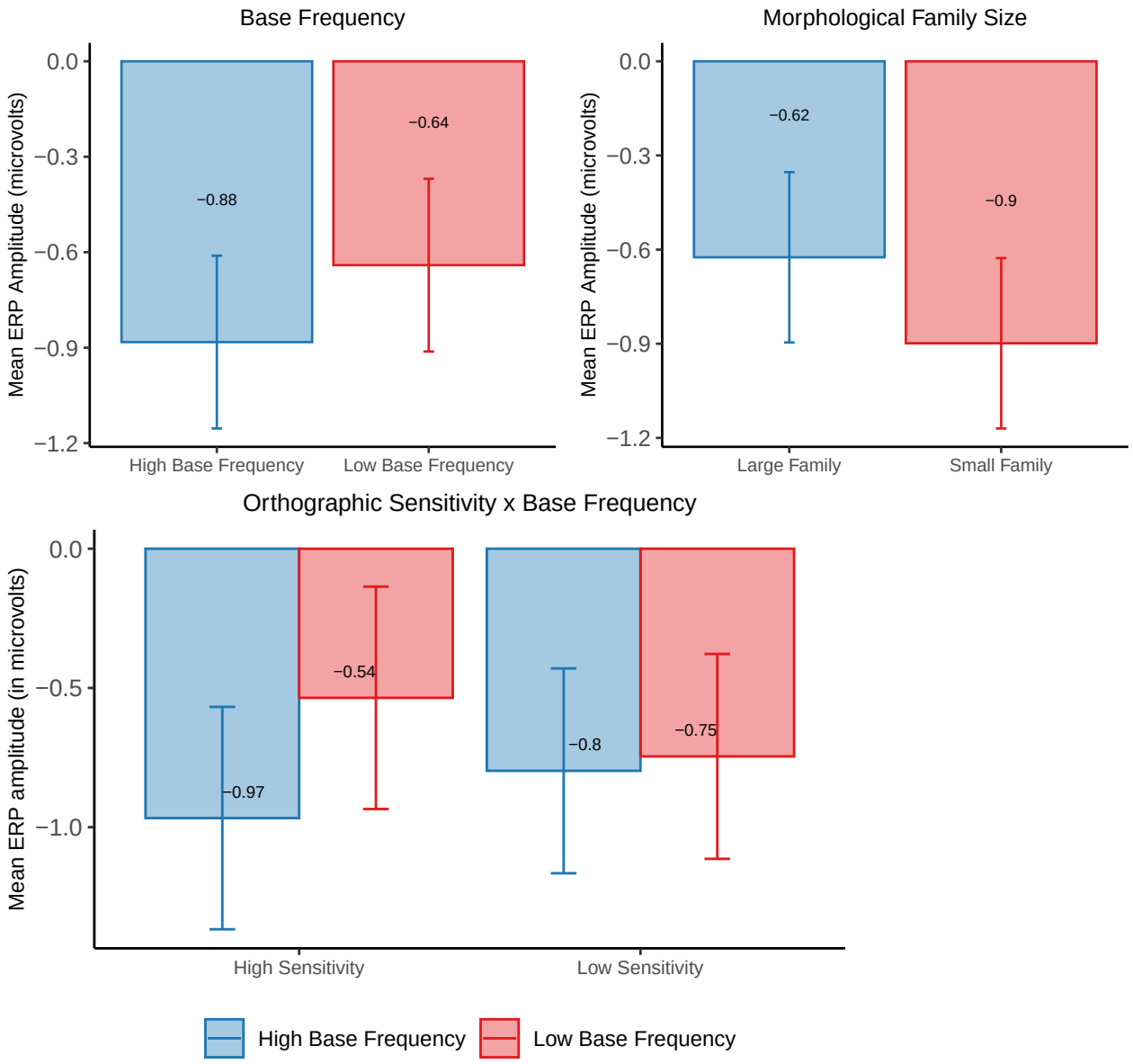
```
||  contrast
||  High Sensitivity High Base Frequency - Low Sensitivity High Base Frequency
||  Low Sensitivity High Base Frequency - High Sensitivity Low Base Frequency
||    estimate        SE    df t.ratio p.value sensitivity    Cohens_d   CI
||  -0.1696982 0.5428854 62.67  -0.313  1.0000 hi_sensit   -0.13529687 0.95
||  -0.2621391 0.5428854 62.67  -0.483  1.0000 lo_sensi    -0.01839444 0.95
||      CI_low     CI_high
||  -0.2588709 -0.01165578
||  -0.1321216  0.09534049
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
```

```
(sensitivity.basefreq_means <- as.data.frame(pairs$emmeans))
```

```
||  orthographic_sensitivity base_freq               emmean        SE    df
||  High Sensitivity         High Base Frequency -0.9672857 0.3993009 62.67
||  Low Sensitivity          High Base Frequency -0.7975875 0.3678090 62.67
||  High Sensitivity         Low Base Frequency  -0.5354484 0.3993009 62.67
||  Low Sensitivity          Low Base Frequency  -0.7458098 0.3678090 62.67
||   lower.CL    upper.CL
||  -1.765307 -0.16926482
||  -1.532670 -0.06250466
||  -1.333469  0.26257248
||  -1.480893 -0.01072688
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

1.2.3 Plots

N250 Amplitude by *Stem Base Frequency & Morphological Family Size*



1.3 Nonword Data

1.3.1 Compute the ANOVA

```
# Fit the ANOVA/mixed model
anova_model_1b <- mixed(
  value ~ orthographic_sensitivity * family_size * complexity +
    laterality * anteriority  +  # Nuisance variables
    (1 | SubjID),
  data = n250_1_nonwords,
  method = "KR"  # Kenward-Roger approximation for accurate F-tests
)

# Print ANOVA results
anova_model_1b
```

```
|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: value ~ orthographic_sensitivity * family_size * complexity +
|| Model:     laterality * anteriority + (1 | SubjID)
|| Data: n250_1_nonwords
||                                        Effect      df         F p.value
|| 1                        orthographic_sensitivity   1, 59      0.28    .597
|| 2                                  family_size 1, 2121      0.87    .352
```

```
|| 3                                       complexity 1, 2121      0.00    .948
|| 4                                       laterality 2, 2121      0.51    .598
|| 5                                     anteriority 2, 2121 35.66 ***   <.001
|| 6             orthographic_sensitivity:family_size 1, 2121    3.55 +    .060
|| 7              orthographic_sensitivity:complexity 1, 2121    5.15 *    .023
|| 8                          family_size:complexity 1, 2121      1.27    .259
|| 9                          laterality:anteriority 4, 2121      0.81    .519
|| 10 orthographic_sensitivity:family_size:complexity 1, 2121      1.02    .311
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
```

```r
# Partial Eta Squared
# Extract effect sizes from your ANOVA model
eta_squared(anova_model_1b , partial = TRUE)
```

```
|| # Effect Size for ANOVA (Type III)
||
|| Parameter                                        | Eta2 (partial) |       95% CI
|| -------------------------------------------------------------------------------
|| orthographic_sensitivity                         |       4.78e-03 | [0.00, 1.00]
|| family_size                                      |       4.08e-04 | [0.00, 1.00]
|| complexity                                       |       1.98e-06 | [0.00, 1.00]
|| laterality                                       |       4.84e-04 | [0.00, 1.00]
|| anteriority                                      |           0.03 | [0.02, 1.00]
|| orthographic_sensitivity:family_size             |       1.67e-03 | [0.00, 1.00]
|| orthographic_sensitivity:complexity              |       2.42e-03 | [0.00, 1.00]
|| family_size:complexity                           |       6.01e-04 | [0.00, 1.00]
|| laterality:anteriority                           |       1.53e-03 | [0.00, 1.00]
|| orthographic_sensitivity:family_size:complexity |       4.83e-04 | [0.00, 1.00]
||
|| - One-sided CIs: upper bound fixed at [1.00].
```

```r
# Compute Marginal (fixed effects) and Conditional (fixed + random effects) R²
r2(anova_model_1b)
```

```
|| # R2 for Mixed Models
||
||   Conditional R2: 0.407
||      Marginal R2: 0.025
```

1.3.2 Effects

Effect	df	F	p	eta-sqrd
orthographic_sensitivity x family_size	(1, 2121)	3.55 *	.060	1.67e-03
orthographic_sensitivity x complexity	(1, 2121)	5.15 *	.023	2.42e-03

```r
# Test whether the interaction between orthographic_sensitivity and complexity improves model fit
reduced_model_int <- update(anova_model_1b,
  . ~ . - orthographic_sensitivity:family_size - orthographic_sensitivity:family_size:complexity)

anova(anova_model_1b, reduced_model_int)
```

```
|| Data: data
|| Models:
|| reduced_model_int: value ~ orthographic_sensitivity + family_size + complexity + laterality + anteriority + orthographic_sensitivity:complexity
|| anova_model_1b: value ~ orthographic_sensitivity * family_size * complexity + laterality * anteriority + (1 | SubjID)
||                   npar    AIC   BIC  logLik deviance Chisq Df Pr(>Chisq)
|| reduced_model_int   16 9981.5 10073 -4974.8   9949.5
|| anova_model_1b      18 9989.5 10092 -4976.7   9953.5     0  2          1
```

```r
# Custom contrasts for orthographic_sensitivity × family_size (Interaction)

pairs <- emmeans(anova_model_1b, pairwise ~ orthographic_sensitivity * family_size, adjust = "bonferroni", pbkrtest.limit = 6480)
(pairs_df <- as.data.frame(pairs$contrasts))
```

```
||  contrast                                                  estimate
||  High Sensitivity Large Family - Low Sensitivity Large Family   0.4262769
||  High Sensitivity Large Family - High Sensitivity Small Family  0.2665933
||  High Sensitivity Large Family - Low Sensitivity Small Family   0.3359554
||  Low Sensitivity Large Family - High Sensitivity Small Family  -0.1596837
||  Low Sensitivity Large Family - Low Sensitivity Small Family   -0.0903215
||  High Sensitivity Small Family - Low Sensitivity Small Family   0.0693621
||         SE      df t.ratio p.value
||  0.4751615   63.98   0.897  1.0000
||  0.1393804 2121.00   1.913  0.3355
||  0.4751615   63.98   0.707  1.0000
||  0.4751615   63.98  -0.336  1.0000
||  0.1283878 2121.00  -0.704  1.0000
||  0.4751615   63.98   0.146  1.0000
```

```
||
|| Results are averaged over the levels of: complexity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 6 tests
```

```
selected_contrasts_famsize <- pairs$contrasts[pairs_df$contrast %in% c("High Sensitivity Large Family - High Sensitivity Small Family",
                                                                       "Low Sensitivity Large Family - Low Sensitivity Small Family"),]
selected_contrasts_sensit <- pairs$contrasts[pairs_df$contrast %in% c("High Sensitivity Large Family - Low Sensitivity Large Family ",
                                                                      "High Sensitivity Small Family - Low Sensitivity Small Family"), ]

selected_contrasts_df_famsize <- as.data.frame(selected_contrasts_famsize)  # Convert the emmGrid object to a dataframe
selected_contrasts_df_sensit <- as.data.frame(selected_contrasts_sensit)  # Convert the emmGrid object to a dataframe

cohensd_small <- as.data.frame(cohens_d(value ~ orthographic_sensitivity,
        data = subset(n250_1_nonwords, family_size == "Small Family")))
cohensd_large <- as.data.frame(cohens_d(value ~ orthographic_sensitivity,
        data = subset(n250_1_nonwords, family_size == "Large Family")))
cohensd_hi_sensit <- as.data.frame(cohens_d(value ~ family_size,
        data = subset(n250_1_nonwords, orthographic_sensitivity == "High Sensitivity")))
cohensd_lo_sensit <- as.data.frame(cohens_d(value ~ family_size,
        data = subset(n250_1_nonwords, orthographic_sensitivity == "Low Sensitivity")))

cohensd_sensit <- bind_rows(large = cohensd_large,
                            small = cohensd_small,
                            .id = "famsize")

cohensd_famsize <- bind_rows(hi_ortho = cohensd_hi_sensit,
                            lo_ortho = cohensd_lo_sensit,
                            .id = "sensit")

(sensit_contrasts_df <- bind_cols(selected_contrasts_df_sensit,cohensd_sensit))
```

```
||  contrast                                                 estimate
||  High Sensitivity Small Family - Low Sensitivity Small Family 0.06936213
||  High Sensitivity Small Family - Low Sensitivity Small Family 0.06936213
||         SE    df t.ratio p.value famsize   Cohens_d   CI      CI_low   CI_high
||  0.4751615 63.98   0.146  0.8844 large   0.14935752 0.95  0.03046174 0.2681853
||  0.4751615 63.98   0.146  0.8844 small   0.02442757 0.95 -0.09427969 0.1431237
||
|| Results are averaged over the levels of: complexity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
```

```
(famsize_contrasts_df <- bind_cols(selected_contrasts_df_famsize,cohensd_famsize))
```

```
||  contrast                                                   estimate
||  High Sensitivity Large Family - High Sensitivity Small Family  0.26659325
||  Low Sensitivity Large Family - Low Sensitivity Small Family   -0.09032155
||         SE   df t.ratio p.value sensit      Cohens_d   CI      CI_low
||  0.1393804 2121   1.913  0.1118 hi_ortho  0.08858633 0.95 -0.03496244
||  0.1283878 2121  -0.704  0.9636 lo_ortho -0.03343767 0.95 -0.14716722
||     CI_high
||  0.21209111
||  0.08030598
||
|| Results are averaged over the levels of: complexity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
```

```
(sensit.famsize_means <- as.data.frame(pairs$emmeans))
```

```
||  orthographic_sensitivity family_size      emmean        SE    df  lower.CL
||  High Sensitivity         Large Family -0.3691944 0.3494888 63.98 -1.067382
||  Low Sensitivity          Large Family -0.7954714 0.3219255 63.98 -1.438594
||  High Sensitivity         Small Family -0.6357877 0.3494888 63.98 -1.333975
||  Low Sensitivity          Small Family -0.7051498 0.3219255 63.98 -1.348273
||    upper.CL
||   0.3289931
||  -0.1523483
||   0.0623998
||  -0.0620267
||
|| Results are averaged over the levels of: complexity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
# Test whether the interaction between orthographic_sensitivity and complexity improves model fit
reduced_model_int <- update(anova_model_1b,
  . ~ . - orthographic_sensitivity:complexity - orthographic_sensitivity:family_size:complexity)

anova(anova_model_1b, reduced_model_int)
```

```
|| Data: data
|| Models:
```

```
|| reduced_model_int: value ~ orthographic_sensitivity + family_size + complexity + laterality + anteriority + orthographic_sensitivity:family_siz
|| anova_model_1b: value ~ orthographic_sensitivity * family_size * complexity + laterality * anteriority + (1 | SubjID)
||                  npar    AIC   BIC  logLik deviance Chisq Df Pr(>Chisq)
|| reduced_model_int   16 9983.2 10074 -4975.6   9951.2
|| anova_model_1b      18 9989.5 10092 -4976.7   9953.5     0  2          1
```

```
# Custom contrasts for lang_type_ortho × complexity (Interaction)
pairs <- emmeans(anova_model_1b, pairwise ~ orthographic_sensitivity * complexity, adjust = "bonferroni", pbkrtest.limit = 6480)
(pairs_df <- as.data.frame(pairs$contrasts))
```

```
||  contrast                                          estimate        SE
||  High Sensitivity Complex - Low Sensitivity Complex  0.0327318 0.4751615
||  High Sensitivity Complex - High Sensitivity Simple -0.2212242 0.1393804
||  High Sensitivity Complex - Low Sensitivity Simple   0.2416830 0.4751615
||  Low Sensitivity Complex - High Sensitivity Simple  -0.2539560 0.4751615
||  Low Sensitivity Complex - Low Sensitivity Simple    0.2089512 0.1283878
||  High Sensitivity Simple - Low Sensitivity Simple    0.4629072 0.4751615
||       df t.ratio p.value
||    63.98   0.069  1.0000
||  2121.00  -1.587  0.6757
||    63.98   0.509  1.0000
||    63.98  -0.534  1.0000
||  2121.00   1.628  0.6227
||    63.98   0.974  1.0000
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 6 tests
```

```
selected_contrasts_cmplxty <- pairs$contrasts[pairs_df$contrast %in% c("High Sensitivity Complex - High Sensitivity Simple",
                                                                       "Low Sensitivity Complex - Low Sensitivity Simple"),]
selected_contrasts_sensit <- pairs$contrasts[pairs_df$contrast %in% c("High Sensitivity Complex - Low Sensitivity Complex",
                                                                      "High Sensitivity Simple - Low Sensitivity Simple"), ]

selected_contrasts_df_cmplxty <- as.data.frame(selected_contrasts_cmplxty)  # Convert the emmGrid object to a dataframe
selected_contrasts_df_sensit  <- as.data.frame(selected_contrasts_sensit)

cohensd_complex <- as.data.frame(cohens_d(value ~ orthographic_sensitivity,
         data = subset(n250_1_nonwords, complexity == "Complex")))
cohensd_simple <- as.data.frame(cohens_d(value ~ orthographic_sensitivity,
         data = subset(n250_1_nonwords, complexity == "Simple")))
cohensd_hi_sensit <- as.data.frame(cohens_d(value ~ complexity,
         data = subset(n250_1_nonwords, orthographic_sensitivity == "High Sensitivity")))
cohensd_lo_sensit <- as.data.frame(cohens_d(value ~ complexity,
         data = subset(n250_1_nonwords, orthographic_sensitivity == "Low Sensitivity")))

cohensd_sensit <- bind_rows(complex = cohensd_complex,
                            simple = cohensd_simple,
                            .id = "sensitivity")

cohensd_cmplxty <- bind_rows(hi_sensit= cohensd_hi_sensit,
                            lo_sensit = cohensd_lo_sensit,
                            .id = "complexity")

(sensit_contrasts_df <- bind_cols(selected_contrasts_df_sensit,cohensd_sensit))
```

```
||  contrast                                        estimate        SE    df
||  High Sensitivity Complex - Low Sensitivity Complex 0.0327318 0.4751615 63.98
||  High Sensitivity Simple - Low Sensitivity Simple   0.4629072 0.4751615 63.98
||  t.ratio p.value sensitivity   Cohens_d   CI      CI_low   CI_high
||    0.069  1.0000 complex     0.01150673 0.95 -0.10719414 0.1302024
||    0.974  0.6672 simple      0.16252557 0.95  0.04359654 0.2813807
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
```

```
(cmplxty_contrasts_df <- bind_cols(selected_contrasts_df_cmplxty,cohensd_cmplxty))
```

```
||  contrast                                          estimate        SE   df
||  High Sensitivity Complex - High Sensitivity Simple -0.2212242 0.1393804 2121
||  Low Sensitivity Complex - Low Sensitivity Simple    0.2089512 0.1283878 2121
||  t.ratio p.value complexity    Cohens_d   CI      CI_low    CI_high
||   -1.587  0.2252 hi_sensit  -0.07348815 0.95 -0.19697776 0.05003796
||    1.628  0.2076 lo_sensit   0.07740237 0.95 -0.03638522 0.19115735
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
```

```
(sensit.cmplxty_means <- as.data.frame(pairs$emmeans))
```

```
||  orthographic_sensitivity complexity     emmean        SE    df  lower.CL
||  High Sensitivity         Complex    -0.6131032 0.3494888 63.98 -1.311291
||  Low Sensitivity          Complex    -0.6458350 0.3219255 63.98 -1.288958
||  High Sensitivity         Simple     -0.3918790 0.3494888 63.98 -1.090067
||  Low Sensitivity          Simple     -0.8547862 0.3219255 63.98 -1.497909
||     upper.CL
||   0.08508432
||  -0.00271191
||   0.30630853
||  -0.21166309
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

1.3.3 Plots

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