

M21 LDT ERP HC

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Set parameters

Set chunk parameters

Load libraries

Set ggplot parameters

Define standard error of the mean function

1 Load and format data files

```
erp_2 <- read_csv("m21_ldt_mea_200300_050050_1.csv")
erp_4 <- read_csv("m21_ldt_mea_300500_050050_1.csv")
dmg_lng_vsl <- read_csv("demo_lang_vsl_pca_hc.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.
erp_2 <- erp_2 |>
  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)

erp_4 <- erp_4 |>
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 <- erp_2 |>
left_join(dmg_lng_vsl, by = "SubjID") |>
select(SubjID, everything())

n400 <- erp_4 |>
left_join(dmg_lng_vsl, by = "SubjID") |>
select(SubjID, everything())
```

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 separate function from the `stringr` package. Run `vignette("programming", package = "dplyr")` to see more about tidy-selection and tidy-evaluation.

```
# Words
n250_words <- n250_words |>
separate(binlabel, into = c("trial_type", "family_size"), sep = "_", remove = TRUE) |>
select(-trial_type)

n250_words_b <- n250_words_b |>
separate(binlabel, into = c("trial_type", "family_size", "tmp1", "base_freq", "tmp2"), sep = "_", remove = TRUE) |>
select(-c(trial_type, tmp1, tmp2))

n400_words <- n400_words |>
separate(binlabel, into = c("trial_type", "family_size"), sep = "_", remove = TRUE) |>
select(-trial_type)

n400_words_b <- n400_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_words_b$Orthographic_Sensitivity[n250_words_b$Orthographic_Sensitivity == "Low"] <- "Low Sensitivity"
n250_words_b$Orthographic_Sensitivity[n250_words_b$Orthographic_Sensitivity == "High"] <- "High Sensitivity"
n250_words_b$base_freq[n250_words_b$base_freq == "Low"] <- "Low Base Frequency"
n250_words_b$base_freq[n250_words_b$base_freq == "High"] <- "High Base Frequency"
n250_words_b$family_size[n250_words_b$family_size == "large"] <- "Large Family"
n250_words_b$family_size[n250_words_b$family_size == "small"] <- "Small Family"

n400_words_b$Orthographic_Sensitivity[n400_words_b$Orthographic_Sensitivity == "Low"] <- "Low Sensitivity"
n400_words_b$Orthographic_Sensitivity[n400_words_b$Orthographic_Sensitivity == "High"] <- "High Sensitivity"
n400_words_b$base_freq[n400_words_b$base_freq == "Low"] <- "Low Base Frequency"
n400_words_b$base_freq[n400_words_b$base_freq == "High"] <- "High Base Frequency"
n400_words_b$family_size[n400_words_b$family_size == "large"] <- "Large Family"
n400_words_b$family_size[n400_words_b$family_size == "small"] <- "Small Family"

# Nonwords
n250_nonwords <- n250_nonwords |>
separate(binlabel, into = c("trial_type", "family_size", "complexity"), sep = "_", remove = TRUE) |>
select(-trial_type)

n400_nonwords <- n400_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_nonwords$Orthographic_Sensitivity[n250_nonwords$Orthographic_Sensitivity == "Low"] <- "Low Sensitivity"
n250_nonwords$Orthographic_Sensitivity[n250_nonwords$Orthographic_Sensitivity == "High"] <- "High Sensitivity"
n250_nonwords$complexity[n250_nonwords$complexity == "complex"] <- "Complex"
n250_nonwords$complexity[n250_nonwords$complexity == "simple"] <- "Simple"
n250_nonwords$family_size[n250_nonwords$family_size == "large"] <- "Large Family"
n250_nonwords$family_size[n250_nonwords$family_size == "small"] <- "Small Family"

n400_nonwords$Orthographic_Sensitivity[n400_nonwords$Orthographic_Sensitivity == "Low"] <- "Low Sensitivity"
n400_nonwords$Orthographic_Sensitivity[n400_nonwords$Orthographic_Sensitivity == "High"] <- "High Sensitivity"
n400_nonwords$complexity[n400_nonwords$complexity == "complex"] <- "Complex"
n400_nonwords$complexity[n400_nonwords$complexity == "simple"] <- "Simple"
n400_nonwords$family_size[n400_nonwords$family_size == "large"] <- "Large Family"
n400_nonwords$family_size[n400_nonwords$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_words <- n250_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_words$anteriority <- factor(n250_words$anteriority, levels = c("Frontal", "Central", "Parietal"))
n250_words$laterality <- factor(n250_words$laterality, levels = c("Left", "Midline", "Right"))

n250_words_b <- n250_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_words_b$anteriority <- factor(n250_words_b$anteriority, levels = c("Frontal", "Central", "Parietal"))
n250_words_b$laterality <- factor(n250_words_b$laterality, levels = c("Left", "Midline", "Right"))

n400_words <- n400_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"))
n400_words$anteriority <- factor(n400_words$anteriority, levels = c("Frontal", "Central", "Parietal"))
n400_words$laterality <- factor(n400_words$laterality, levels = c("Left", "Midline", "Right"))

n400_words_b <- n400_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"))
n400_words_b$anteriority <- factor(n400_words_b$anteriority, levels = c("Frontal", "Central", "Parietal"))
n400_words_b$laterality <- factor(n400_words_b$laterality, levels = c("Left", "Midline", "Right"))

# Nonwords
n250_nonwords <- n250_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_nonwords$anteriority <- factor(n250_nonwords$anteriority, levels = c("Frontal", "Central", "Parietal"))
n250_nonwords$laterality <- factor(n250_nonwords$laterality, levels = c("Left", "Midline", "Right"))

n400_nonwords <- n400_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"))
n400_nonwords$anteriority <- factor(n400_nonwords$anteriority, levels = c("Frontal", "Central", "Parietal"))
n400_nonwords$laterality <- factor(n400_nonwords$laterality, levels = c("Left", "Midline", "Right"))
```

2 N250 Word Data

2.1 Compute the ANOVA

```
anova_model_1a <- mixed(
  value ~ Orthographic_Sensitivity * family_size * base_freq +
    laterality * anteriority + # Nuisance variables
  (1 | SubjID),
  data = n250_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_words_b
||
||           Effect      df      F p.value
|| 1           Orthographic_Sensitivity  1, 59      0.03      .854
|| 2           family_size 1, 2121      8.10 **     .004
|| 3           base_freq 1, 2121      6.24 *      .013
|| 4           laterality 2, 2121      0.29      .745
|| 5           anteriority 2, 2121 18.18 ***     <.001
|| 6 Orthographic_Sensitivity:family_size 1, 2121      0.70      .403
|| 7 Orthographic_Sensitivity:base_freq 1, 2121      0.65      .421
|| 8 family_size:base_freq 1, 2121 14.43 ***     <.001
|| 9 laterality:anteriority 4, 2121      0.76      .551
|| 10 Orthographic_Sensitivity:family_size:base_freq 1, 2121      0.01      .925
|| ---
|| 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 | 5.82e-04 | [0.00, 1.00]
|| family_size | 3.81e-03 | [0.00, 1.00]
|| base_freq | 2.94e-03 | [0.00, 1.00]
|| laterality | 2.78e-04 | [0.00, 1.00]
|| anteriority | 0.02 | [0.01, 1.00]
|| Orthographic_Sensitivity:family_size | 3.30e-04 | [0.00, 1.00]
|| Orthographic_Sensitivity:base_freq | 3.05e-04 | [0.00, 1.00]
|| family_size:base_freq | 6.76e-03 | [0.00, 1.00]
|| laterality:anteriority | 1.43e-03 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size:base_freq | 4.14e-06 | [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: 0.476
|| Marginal R2: 0.017

```

2.2 Significant Effects

Effect	df	F	p.value	
family_size	1, 2121	8.10 **	.003	3.81e-03
base_freq	1, 2121	6.24 *	.010	2.94e-03
family_size:base_freq	1, 2121	14.43 ***	<.001	6.76e-03

Main Effects

```

## `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 0.2675816 0.09401042 2121  2.846  0.0045
||
|| 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_words_b))
(family_size_contrasts_df <- bind_cols(pairs_df,cohensd))

|| contrast      estimate      SE  df t.ratio p.value
|| Large Family - Small Family 0.2675816 0.09401042 2121  2.846  0.0045
|| 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 -0.6228727 0.2722607 62.68 -1.166997 -0.0787487
|| Small Family -0.8904543 0.2722607 62.68 -1.434578 -0.3463303
||
|| 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 -0.2349092 0.09401042 2121 -2.499
|| p.value
|| 0.0125
||
|| 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_words_b))
(base_freq_contrasts_df <- bind_cols(pairs_df, cohensd))

|| contrast                                     estimate      SE      df t.ratio
|| High Base Frequency - Low Base Frequency -0.2349092 0.09401042 2121 -2.499
|| p.value Cohens_d CI CI_low CI_high
|| 0.0125 -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 -0.8741181 0.2722607 62.68 -1.418242 -0.3299941
|| Low Base Frequency -0.6392089 0.2722607 62.68 -1.183333 -0.0950849
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

Interactions
# `base_freq` x `family_size` interaction

selected_contrasts_famsize <- c("Large Family High Base Frequency - Small Family High Base Frequency",
                                "Large Family Low Base Frequency - Small Family Low Base Frequency")
selected_contrasts_basefreq <- c("Large Family High Base Frequency - Large Family Low Base Frequency",
                                "Small Family High Base Frequency - Small Family Low Base Frequency")

emmeans_obj <- emmeans(anova_model_1a, pairwise ~ family_size * base_freq, adjust = "bonferroni", pbkrtest.limit = 6480)
# Get selected contrasts and convert the emmGrid object to a dataframe
(contrasts_df <- as.data.frame(emmeans_obj$contrasts))

|| contrast                                     estimate
|| Large Family High Base Frequency - Small Family High Base Frequency -0.0894763
|| Large Family High Base Frequency - Large Family Low Base Frequency -0.5919671
|| Large Family High Base Frequency - Small Family Low Base Frequency 0.0326724
|| Small Family High Base Frequency - Large Family Low Base Frequency -0.5024908
|| Small Family High Base Frequency - Small Family Low Base Frequency 0.1221487
|| Large Family Low Base Frequency - Small Family Low Base Frequency 0.6246395
|| SE      df t.ratio p.value
|| 0.1329508 2121 -0.673 1.0000
|| 0.1329508 2121 -4.453 0.0001
|| 0.1329508 2121 0.246 1.0000
|| 0.1329508 2121 -3.780 0.0010
|| 0.1329508 2121 0.919 1.0000
|| 0.1329508 2121 4.698 <.0001
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 6 tests
selected_contrasts_famsize_df <- as.data.frame(emmeans_obj$contrasts[contrasts_df$contrast %in% selected_contrasts_famsize, ])
selected_contrasts_basefreq_df <- as.data.frame(emmeans_obj$contrasts[contrasts_df$contrast %in% selected_contrasts_basefreq, ])

```

```

cohensd_hi_basefrq <- as.data.frame(cohens_d(value ~ family_size,
                                             data = subset(n250_words_b, base_freq == "High Base Frequency")))
cohensd_lo_basefrq <- as.data.frame(cohens_d(value ~ family_size,
                                             data = subset(n250_words_b, base_freq == "Low Base Frequency")))
cohensd_lrg_fam <- as.data.frame(cohens_d(value ~ base_freq,
                                           data = subset(n250_words_b, family_size == "Large Family")))
cohensd_sml_fam <- as.data.frame(cohens_d(value ~ base_freq,
                                           data = subset(n250_words_b, family_size == "Small Family")))

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

cohensd_famsize <- bind_rows(lrg_fam = cohensd_lrg_fam,
                             sml_fam = cohensd_sml_fam,
                             .id = "family_size")

(basefreq_contrasts_df <- bind_cols(selected_contrasts_basefrq_df, cohensd_basefrq))

```

```

|| contrast                                                                 estimate
|| Large Family High Base Frequency - Large Family Low Base Frequency -0.5919671
|| Small Family High Base Frequency - Small Family Low Base Frequency 0.1221487
||      SE df t.ratio p.value base_freq Cohens_d CI      CI_low
|| 0.1329508 2121 -4.453 <.0001 hi_basefrq -0.02625453 0.95 -0.14455152
|| 0.1329508 2121 0.919 0.7167 lo_basefrq 0.21467322 0.95 0.09598588
||      CI_high
|| 0.0920544
|| 0.3332632
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
(sensitivity_contrasts_df <- bind_cols(selected_contrasts_famsize_df, cohensd_famsize))

```

```

|| contrast                                                                 estimate
|| Large Family High Base Frequency - Small Family High Base Frequency -0.0894763
|| Large Family Low Base Frequency - Small Family Low Base Frequency 0.6246395
||      SE df t.ratio p.value family_size Cohens_d CI      CI_low
|| 0.1329508 2121 -0.673 1.0000 lrg_fam -0.20058496 0.95 -0.3191349
|| 0.1329508 2121 4.698 <.0001 sml_fam 0.04230879 0.95 -0.0760120
||      CI_high
|| -0.08194398
|| 0.16061027
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
(famsize_basefreq_means <- as.data.frame(emmeans_obj$emmeans))

```

```

|| family_size base_freq      emmean      SE df lower.CL
|| Large Family High Base Frequency -0.9188563 0.2802585 70.36 -1.4777640
|| Small Family High Base Frequency -0.8293799 0.2802585 70.36 -1.3882876
|| Large Family Low Base Frequency -0.3268891 0.2802585 70.36 -0.8857968
|| Small Family Low Base Frequency -0.9515286 0.2802585 70.36 -1.5104363
||      upper.CL
|| -0.3599486
|| -0.2704722
|| 0.2320186
|| -0.3926209
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

```

2.3 Model Comparisons

```

# Family Size
reduced_model <- update(anova_model_1a,
                        . ~ . - family_size - Orthographic_Sensitivity:family_size - family_size:base_freq - Orthographic_Sensitivity:family_size:base_freq)
anova(anova_model_1a, reduced_model)

|| Data: data
|| Models:
|| reduced_model: value ~ Orthographic_Sensitivity + base_freq + laterality + anteriority + Orthographic_Sensitivity:base_freq + laterality:anteriority
|| 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 14 9957.5 10037 -4964.7 9929.5
|| anova_model_1a 18 9958.7 10061 -4961.4 9922.7 6.787 4 0.1476

```

```

# Base Frequency
reduced_model <- update(anova_model_1a,
  . ~ . - base_freq - Orthographic_Sensitivity:base_freq - base_freq:family_size - Orthographic_Sensitivity:base_freq:family_size
anova(anova_model_1a, reduced_model)

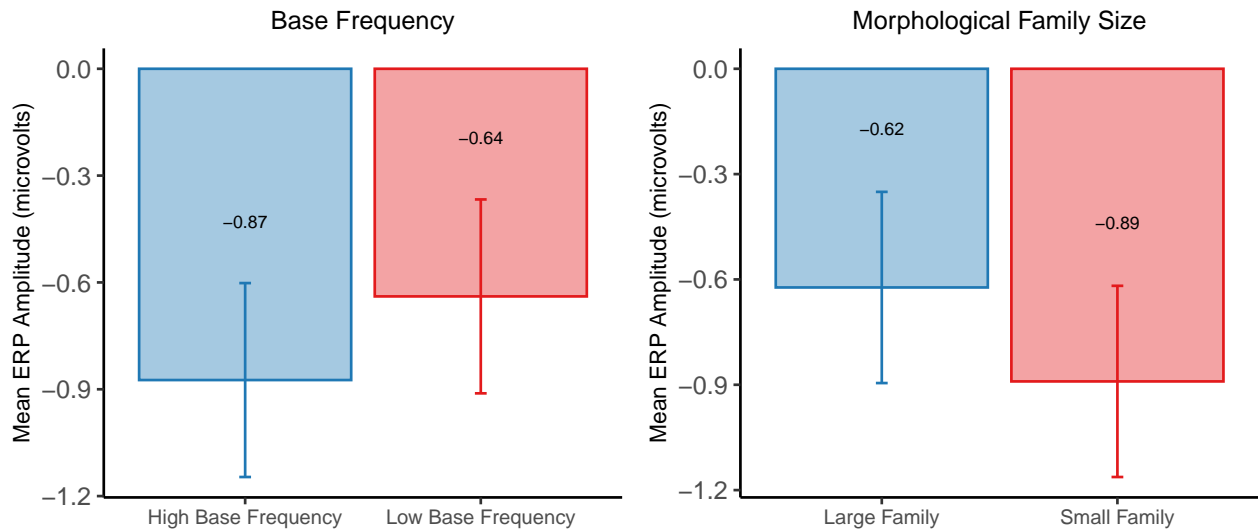
|| Data: data
|| Models:
|| reduced_model: value ~ Orthographic_Sensitivity + family_size + laterality + anteriority + Orthographic_Sensitivity:family_size + laterality:anteriority
|| anova_model_1a: value ~ Orthographic_Sensitivity * family_size * base_freq + laterality * anteriority + (1 | SubjID)
||      npar    AIC    BIC logLik deviance Chisq Df Pr(>Chisq)
|| reduced_model    14 9954.6 10034 -4963.3   9926.6
|| anova_model_1a   18 9958.7 10061 -4961.4   9922.7 3.8562  4    0.4258

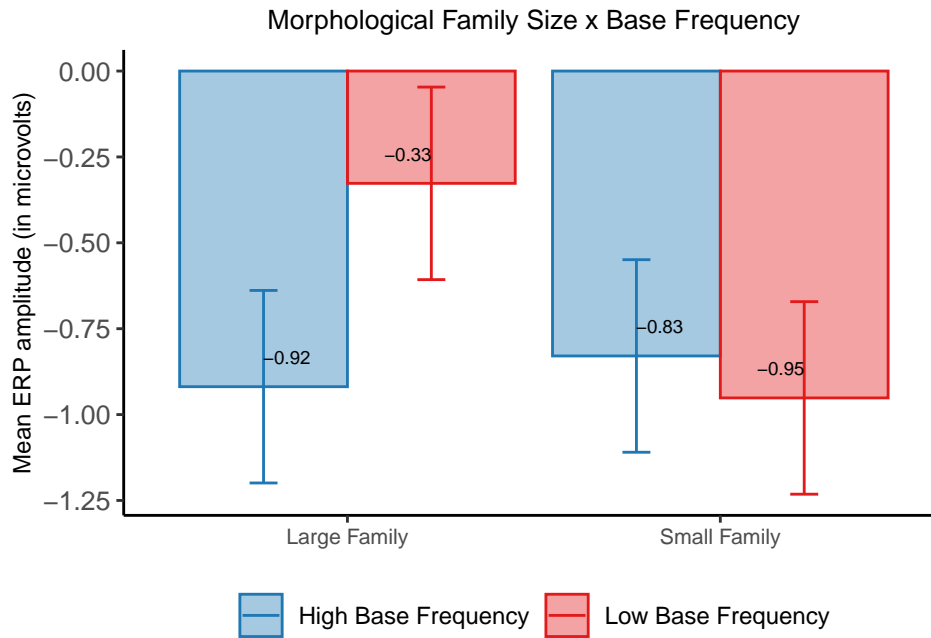
# Family Size x Base Frequency
reduced_model_int <- update(anova_model_1a,
  . ~ . - family_size:base_freq - Orthographic_Sensitivity:family_size:base_freq
anova(anova_model_1a, reduced_model_int)

|| 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 9960.7 10052 -4964.3   9928.7
|| anova_model_1a      18 9958.7 10061 -4961.4   9922.7 5.9396  2    0.05131
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

```

2.4 Plots





3 N250 Nonword Data

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_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_nonwords
||
||      Effect      df      F p.value
|| 1 Orthographic_Sensitivity 1, 59      0.05      .823
|| 2 family_size 1, 2121      0.59      .442
|| 3 complexity 1, 2121      0.07      .786
|| 4 laterality 2, 2121      0.51      .599
|| 5 anteriority 2, 2121 35.56 *** <.001
|| 6 Orthographic_Sensitivity:family_size 1, 2121      0.00      .976
|| 7 Orthographic_Sensitivity:complexity 1, 2121      1.73      .189
|| 8 family_size:complexity 1, 2121      0.78      .377
|| 9 laterality:anteriority 4, 2121      0.81      .520
|| 10 Orthographic_Sensitivity:family_size:complexity 1, 2121      1.86      .173
|| ---
|| 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_1b, partial = TRUE)
```

```
|| # Effect Size for ANOVA (Type III)
||
|| Parameter | Eta2 (partial) | 95% CI
|| -----|-----|-----
|| Orthographic_Sensitivity | 8.51e-04 | [0.00, 1.00]
|| family_size | 2.79e-04 | [0.00, 1.00]
|| complexity | 3.48e-05 | [0.00, 1.00]
|| laterality | 4.83e-04 | [0.00, 1.00]
|| anteriority | 0.03 | [0.02, 1.00]
```



```

|| Orthographic_Sensitivity:family_size | 4.33e-07 | [0.00, 1.00]
|| Orthographic_Sensitivity:complexity | 8.14e-04 | [0.00, 1.00]
|| family_size:complexity | 3.69e-04 | [0.00, 1.00]
|| laterality:anteriority | 1.52e-03 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size:complexity | 8.77e-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_1b)

|| # R2 for Mixed Models
||
|| Conditional R2: 0.405
|| Marginal R2: 0.022

```

3.2 Effects

No significant effects

4 N400 Word Data

4.1 Compute the ANOVA

```

anova_model_2a <- mixed(
  value ~ Orthographic_Sensitivity * family_size * base_freq +
    laterality * anteriority + # Nuisance variables
    (1 | SubjID),
  data = n400_words_b,
  method = "KR") # Kenward-Roger approximation for accurate F-tests
# Print ANOVA results
anova_model_2a

|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: value ~ Orthographic_Sensitivity * family_size * base_freq +
|| Model: laterality * anteriority + (1 | SubjID)
|| Data: n400_words_b
||
|| Effect df F p.value
|| 1 Orthographic_Sensitivity 1, 59 0.45 .507
|| 2 family_size 1, 2121 11.63 *** <.001
|| 3 base_freq 1, 2121 2.30 .129
|| 4 laterality 2, 2121 4.76 ** .009
|| 5 anteriority 2, 2121 104.58 *** <.001
|| 6 Orthographic_Sensitivity:family_size 1, 2121 0.30 .586
|| 7 Orthographic_Sensitivity:base_freq 1, 2121 4.36 * .037
|| 8 family_size:base_freq 1, 2121 21.94 *** <.001
|| 9 laterality:anteriority 4, 2121 0.78 .541
|| 10 Orthographic_Sensitivity:family_size:base_freq 1, 2121 0.96 .328
|| ---
|| 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_2a , partial = TRUE)

```

```

|| # Effect Size for ANOVA (Type III)
||
|| Parameter | Eta2 (partial) | 95% CI
|| -----|-----|-----
|| Orthographic_Sensitivity | 7.51e-03 | [0.00, 1.00]
|| family_size | 5.45e-03 | [0.00, 1.00]
|| base_freq | 1.09e-03 | [0.00, 1.00]
|| laterality | 4.47e-03 | [0.00, 1.00]
|| anteriority | 0.09 | [0.07, 1.00]
|| Orthographic_Sensitivity:family_size | 1.40e-04 | [0.00, 1.00]
|| Orthographic_Sensitivity:base_freq | 2.05e-03 | [0.00, 1.00]
|| family_size:base_freq | 0.01 | [0.00, 1.00]
|| laterality:anteriority | 1.46e-03 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size:base_freq | 4.52e-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_2a)

|| # R2 for Mixed Models
||
|| Conditional R2: 0.569

```

```
|| Marginal R2: 0.056
```

4.2 Effects

Effect	df	F	p.value	
family_size	1, 2121	11.63 **	.003	5.45e-03
Orthographic_Sensitivity:base_freq	1, 2121	4.36 *	.037	2.05e-03
family_size:base_freq	1, 2121	21.94 ***	<.001	0.01

Main Effects

```
## `family_size` main effect
pairs <- emmeans(anova_model_2a, 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 0.3647076 0.1069595 2121  3.410  0.0007
||
|| 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 = n400_words_b))
(family_size_contrasts_df <- bind_cols(pairs_df, cohensd))

|| contrast                estimate      SE  df t.ratio p.value
|| Large Family - Small Family 0.3647076 0.1069595 2121  3.410  0.0007
|| Cohens_d CI          CI_low CI_high
|| 0.09544102 0.95 0.01173328 0.179127
||
|| 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 0.8184090 0.358128 61.72  0.1024570 1.534361
|| Small Family 0.4537014 0.358128 61.72 -0.2622506 1.169653
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, base_freq, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

Interactions

```
# `Orthographic_Sensitivity` x `base_freq` interaction

selected_contrasts_orthosens <- c("High Orthographic High Base Frequency - Low Orthographic High Base Frequency",
  "High Orthographic Low Base Frequency - Low Orthographic Low Base Frequency")
selected_contrasts_basefreq <- c("High Orthographic High Base Frequency - High Orthographic Low Base Frequency",
  "Low Orthographic High Base Frequency - Low Orthographic Low Base Frequency")

emmeans_obj <- emmeans(anova_model_2a, pairwise ~ Orthographic_Sensitivity * base_freq, adjust = "bonferroni", pbkrtest.limit = 6480)

# Get selected contrasts and convert the emmGrid object to a dataframe
contrasts_df <- as.data.frame(emmeans_obj$contrasts)
selected_contrasts_orthosens_df <- as.data.frame(emmeans_obj$contrasts[contrasts_df$contrast %in% selected_contrasts_orthosens, ])
selected_contrasts_basefreq_df <- as.data.frame(emmeans_obj$contrasts[contrasts_df$contrast %in% selected_contrasts_basefreq, ])

cohensd_hi_basefreq <- as.data.frame(cohens_d(value ~ Orthographic_Sensitivity,
  data = subset(n400_words_b, base_freq == "High Base Frequency")))
cohensd_lo_basefreq <- as.data.frame(cohens_d(value ~ Orthographic_Sensitivity,
  data = subset(n400_words_b, base_freq == "Low Base Frequency")))
cohensd_hi_orthosens <- as.data.frame(cohens_d(value ~ base_freq,
  data = subset(n400_words_b, Orthographic_Sensitivity == "High Orthographic")))
cohensd_lo_orthosens <- as.data.frame(cohens_d(value ~ base_freq,
  data = subset(n400_words_b, Orthographic_Sensitivity == "Low Orthographic")))

cohensd_basefreq <- bind_rows(hi_basefreq = cohensd_hi_basefreq,
  lo_basefreq = cohensd_lo_basefreq,
  .id = "base_freq")

cohensd_orthosens <- bind_rows(hi_orthosens = cohensd_hi_orthosens,
  lo_orthosens = cohensd_lo_orthosens,
  .id = "Orthographic_Sensitivity")

(basefreq_contrasts_df <- bind_cols(selected_contrasts_basefreq_df, cohensd_basefreq))

|| contrast
```

```

|| High Orthographic High Base Frequency - High Orthographic Low Base Frequency
|| Low Orthographic High Base Frequency - Low Orthographic Low Base Frequency
|| estimate SE df t.ratio p.value base_freq Cohens_d CI
|| 0.3858252 0.1423201 2121 2.711 0.0135 hi_basefreq 0.18383138 0.95
|| -0.0610556 0.1597069 2121 -0.382 1.0000 lo_basefreq 0.06740484 0.95
|| CI_low CI_high
|| 0.06445672 0.3031225
|| -0.05172849 0.1865074
||
|| 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
(orthosens_contrasts_df <- bind_cols(selected_contrasts_orthosens_df, cohensd_orthosens))

|| contrast
|| High Orthographic High Base Frequency - Low Orthographic High Base Frequency
|| High Orthographic Low Base Frequency - Low Orthographic Low Base Frequency
|| estimate SE df t.ratio p.value Orthographic_Sensitivity Cohens_d
|| 0.6965734 0.716256 61.72 0.973 0.6692 hi_orthosens 0.09351089
|| 0.2496927 0.716256 61.72 0.349 1.0000 lo_orthosens -0.01904135
|| CI CI_low CI_high
|| 0.95 -0.01861321 0.2055967
|| 0.95 -0.14477104 0.1066982
||
|| 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
(orthosens.basefreq_means <- as.data.frame(emmeans_obj$emmeans))

|| Orthographic_Sensitivity base_freq emmean SE df
|| High Orthographic High Base Frequency 1.0655343 0.4765245 61.72
|| Low Orthographic High Base Frequency 0.3689609 0.5347402 61.72
|| High Orthographic Low Base Frequency 0.6797092 0.4765245 61.72
|| Low Orthographic Low Base Frequency 0.4300165 0.5347402 61.72
|| lower.CL upper.CL
|| 0.1128897 2.018179
|| -0.7000656 1.437987
|| -0.2729354 1.632354
|| -0.6390100 1.499043
||
|| Results are averaged over the levels of: family_size, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
# `base_freq` x `family_size` interaction

selected_contrasts_famsize <- c("Large Family High Base Frequency - Small Family High Base Frequency",
"Large Family Low Base Frequency - Small Family Low Base Frequency")
selected_contrasts_basefreq <- c("Large Family High Base Frequency - Large Family Low Base Frequency",
"Small Family High Base Frequency - Small Family Low Base Frequency")

emmeans_obj <- emmeans(anova_model_2a, pairwise ~ family_size * base_freq, adjust = "bonferroni", pbkrtest.limit = 6480)

# Get selected contrasts and convert the emmGrid object to a dataframe
contrasts_df <- as.data.frame(emmeans_obj$contrasts)
selected_contrasts_famsize_df <- as.data.frame(emmeans_obj$contrasts[contrasts_df$contrast %in% selected_contrasts_famsize,])
selected_contrasts_basefreq_df <- as.data.frame(emmeans_obj$contrasts[contrasts_df$contrast %in% selected_contrasts_basefreq,])

cohensd_hi_basefreq <- as.data.frame(cohens_d(value ~ family_size,
data = subset(n400_words_b, base_freq == "High Base Frequency")))
cohensd_lo_basefreq <- as.data.frame(cohens_d(value ~ family_size,
data = subset(n400_words_b, base_freq == "Low Base Frequency")))
cohensd_lrg_fam <- as.data.frame(cohens_d(value ~ base_freq,
data = subset(n400_words_b, family_size == "Large Family")))
cohensd_sml_fam <- as.data.frame(cohens_d(value ~ base_freq,
data = subset(n400_words_b, family_size == "Small Family")))

cohensd_basefreq <- bind_rows(hi_basefreq = cohensd_hi_basefreq,
lo_basefreq = cohensd_lo_basefreq,
.id = "base_freq")

cohensd_famsize <- bind_rows(lrg_fam = cohensd_lrg_fam,
sml_fam = cohensd_sml_fam,
.id = "family_size")

(basefreq_contrasts_df <- bind_cols(selected_contrasts_basefreq_df, cohensd_basefreq))

|| contrast estimate
|| Large Family High Base Frequency - Large Family Low Base Frequency -0.3386483

```

```

|| Small Family High Base Frequency - Small Family Low Base Frequency 0.6634179
||      SE df t.ratio p.value base_freq Cohens_d CI CI_low CI_high
|| 0.1512635 2121 -2.239 0.0505 hi_basefreq -0.0407526 0.95 -0.1590535 0.0775669
|| 0.1512635 2121 4.386 <.0001 lo_basefreq 0.2366583 0.95 0.1178928 0.3553166
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
(sensitivity_contrasts_df <- bind_cols(selected_contrasts_famsize_df,cohensd_famsize))

|| contrast estimate
|| Large Family High Base Frequency - Small Family High Base Frequency -0.1363255
|| Large Family Low Base Frequency - Small Family Low Base Frequency 0.8657407
||      SE df t.ratio p.value family_size Cohens_d CI CI_low
|| 0.1512635 2121 -0.901 0.7351 lrg_fam -0.0915178 0.95 -0.20985682
|| 0.1512635 2121 5.723 <.0001 sml_fam 0.1786143 0.95 0.06003985
||      CI_high
|| 0.02686293
|| 0.29710762
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| P value adjustment: bonferroni method for 2 tests
(famsize_basefreq_means <- as.data.frame(emmeans_obj$emmeans))

|| family_size base_freq emmean SE df lower.CL
|| Large Family High Base Frequency 0.6490848 0.3660271 67.34 -0.0814402
|| Small Family High Base Frequency 0.7854104 0.3660271 67.34 0.0548853
|| Large Family Low Base Frequency 0.9877332 0.3660271 67.34 0.2572081
|| Small Family Low Base Frequency 0.1219924 0.3660271 67.34 -0.6085326
|| upper.CL
|| 1.3796099
|| 1.5159354
|| 1.7182582
|| 0.8525175
||
|| Results are averaged over the levels of: Orthographic_Sensitivity, laterality, anteriority
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

```

4.3 Model Comparisons

```

# Family Size
reduced_model <- update(anova_model_1a,
  . ~ . - family_size - Orthographic_Sensitivity:family_size - family_size:base_freq - Orthographic_Sensitivity:family_size:
anova(anova_model_1a, reduced_model)

|| Data: data
|| Models:
|| reduced_model: value ~ Orthographic_Sensitivity + base_freq + laterality + anteriority + Orthographic_Sensitivity:base_freq + laterality:anteri
|| 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 14 9957.5 10037 -4964.7 9929.5
|| anova_model_1a 18 9958.7 10061 -4961.4 9922.7 6.787 4 0.1476

# Orthographic Sensitivity x Base Frequency
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 9946.8 10038 -4957.4 9914.8
|| anova_model_1a 18 9958.7 10061 -4961.4 9922.7 0 2 1

# Family Size x Base Frequency
reduced_model_int <- update(anova_model_1a,
  . ~ . - family_size:base_freq - Orthographic_Sensitivity:family_size:base_freq)
anova(anova_model_1a, reduced_model_int)

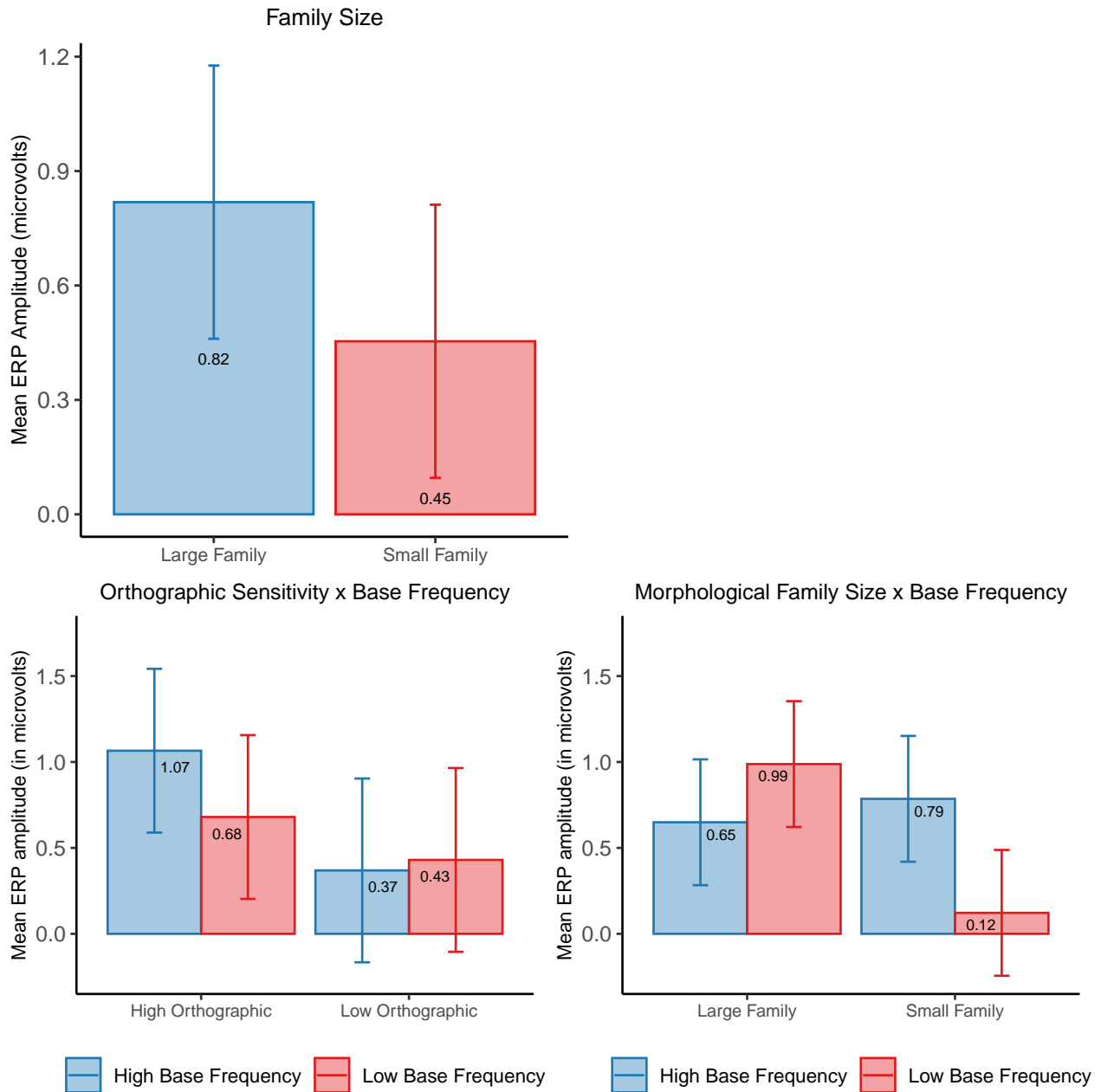
|| Data: data
|| Models:
|| reduced_model_int: value ~ Orthographic_Sensitivity + family_size + base_freq + laterality + anteriority + Orthographic_Sensitivity:family_size
|| anova_model_1a: value ~ Orthographic_Sensitivity * family_size * base_freq + laterality * anteriority + (1 | SubjID)
||      npar AIC BIC logLik deviance Chisq Df Pr(>Chisq)
|| reduced_model_int 16 9960.7 10052 -4964.3 9928.7
|| anova_model_1a 18 9958.7 10061 -4961.4 9922.7 5.9396 2 0.05131 .

```

```
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

4.4 Plots

...



5 N400 Nonword Data

5.1 Compute the ANOVA

```
# Fit the ANOVA/mixed model
anova_model_2b <- mixed(
  value ~ Orthographic_Sensitivity * family_size * complexity +
    laterality * anteriority + # Nuisance variables
  (1 | SubjID),
  data = n400_nonwords,
  method = "KR" # Kenward-Roger approximation for accurate F-tests
```

```

)

# Print ANOVA results
anova_model_2b

|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: value ~ Orthographic_Sensitivity * family_size * complexity +
|| Model:      laterality * anteriority + (1 | SubjID)
|| Data: n400_nonwords
||
||           Effect      df      F p.value
|| 1           Orthographic_Sensitivity  1, 59      0.01  .932
|| 2           family_size 1, 2121      0.03  .872
|| 3           complexity 1, 2121      0.15  .702
|| 4           laterality 2, 2121      4.22 *  .015
|| 5           anteriority 2, 2121 140.74 *** <.001
|| 6 Orthographic_Sensitivity:family_size 1, 2121      0.87  .350
|| 7 Orthographic_Sensitivity:complexity 1, 2121      3.03 +  .082
|| 8           family_size:complexity 1, 2121      1.82  .177
|| 9           laterality:anteriority 4, 2121      0.40  .812
|| 10 Orthographic_Sensitivity:family_size:complexity 1, 2121      0.34  .563
|| ---
|| 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_2b, partial = TRUE)

|| # Effect Size for ANOVA (Type III)
||
|| Parameter | Eta2 (partial) | 95% CI
|| -----|-----|-----
|| Orthographic_Sensitivity | 1.23e-04 | [0.00, 1.00]
|| family_size | 1.22e-05 | [0.00, 1.00]
|| complexity | 6.90e-05 | [0.00, 1.00]
|| laterality | 3.96e-03 | [0.00, 1.00]
|| anteriority | 0.12 | [0.10, 1.00]
|| Orthographic_Sensitivity:family_size | 4.11e-04 | [0.00, 1.00]
|| Orthographic_Sensitivity:complexity | 1.43e-03 | [0.00, 1.00]
|| family_size:complexity | 8.59e-04 | [0.00, 1.00]
|| laterality:anteriority | 7.45e-04 | [0.00, 1.00]
|| Orthographic_Sensitivity:family_size:complexity | 1.58e-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_2b)

|| # R2 for Mixed Models
||
|| Conditional R2: 0.522
|| Marginal R2: 0.065

```

5.2 Effects

No Significant Effects