# m21 LDT ERP analysis

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## Contents



# 1 Load libraries

Load libraries

```
library(ez)
library(pander)
library(kableExtra)
library(afex)
library(gridExtra)
library(ggplot2)
library(emmeans)
library(tidyverse)
library(dplyr)
library(RColorBrewer)
library(wesanderson)
library(ggsci)
```

## 2 Set ggplot2 parameters

Before we begin, let's set some general parameters for `ggplot2`. We will set a general theme using the `theme_set()` function. We will use the 'classic' theme which gives us clean white background rather than the default grey with white grid lines. And we will position the legend at the top of the graph rather than at the right side which is the default.

```
theme_set(theme_minimal() +  theme(legend.position = "bottom"))
```

#Define standard error of the mean function

```
sem <- function(x) sd(x)/sqrt(length(x))
```

## 3 Load and format data files

First we load the data files

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

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

Divide into word, non-word and difference wave dataframes

```
n400_1_words <- n400_1 |> filter(bini %in% c(1:2))
n400_1_nonwords <- n400_1 |> filter(bini %in% c(3:6))
n400_1_diff <- n400_1 |> filter(bini %in% c(9:11))

n400_2_words <- n400_2 |> filter(bini %in% c(1:2))
n400_2_nonwords <- n400_2 |> filter(bini %in% c(3:6))
n400_2_diff <- n400_2 |> filter(bini %in% c(9:11))
```

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.

## 4 Trim data to 2SD of each subject's mean

```
n400_1_nw_trm <- n400_1_nonwords %>%
  group_by(SubjID) %>%
  filter(abs(value - mean(value)) <= 3.5 * sd(value))
```

# 5 Now we can compute the ANOVA using `ezANOVA` and `aov_ez`

## 5.1 Group 1

```
anova_results.1a <- ezANOVA(n400_1_nonwords,
        dv = value,
        wid = SubjID,
        within = .(family_size, complexity, anteriority, laterality),
        between = .(lang_type_semantic, lang_type_ortho),
        type = 3)
anova_results.1a$ANOVA
```

```
||                                                                  Effect
|| 2                                                    lang_type_semantic
|| 3                                                       lang_type_ortho
|| 5                                                           family_size
|| 9                                                            complexity
|| 13                                                          anteriority
|| 17                                                           laterality
|| 4                                      lang_type_semantic:lang_type_ortho
|| 6                                          lang_type_semantic:family_size
|| 7                                             lang_type_ortho:family_size
|| 10                                         lang_type_semantic:complexity
|| 11                                            lang_type_ortho:complexity
|| 14                                         lang_type_semantic:anteriority
|| 15                                            lang_type_ortho:anteriority
|| 18                                         lang_type_semantic:laterality
|| 19                                            lang_type_ortho:laterality
|| 21                                                family_size:complexity
|| 25                                               family_size:anteriority
|| 29                                                complexity:anteriority
|| 33                                                family_size:laterality
|| 37                                                 complexity:laterality
|| 41                                                anteriority:laterality
|| 8                          lang_type_semantic:lang_type_ortho:family_size
|| 12                          lang_type_semantic:lang_type_ortho:complexity
|| 16                         lang_type_semantic:lang_type_ortho:anteriority
|| 20                          lang_type_semantic:lang_type_ortho:laterality
|| 22                              lang_type_semantic:family_size:complexity
|| 23                                 lang_type_ortho:family_size:complexity
|| 26                             lang_type_semantic:family_size:anteriority
|| 27                                lang_type_ortho:family_size:anteriority
|| 30                              lang_type_semantic:complexity:anteriority
|| 31                                 lang_type_ortho:complexity:anteriority
|| 34                              lang_type_semantic:family_size:laterality
|| 35                                 lang_type_ortho:family_size:laterality
|| 38                               lang_type_semantic:complexity:laterality
|| 39                                  lang_type_ortho:complexity:laterality
|| 42                              lang_type_semantic:anteriority:laterality
|| 43                                 lang_type_ortho:anteriority:laterality
|| 45                                     family_size:complexity:anteriority
|| 49                                      family_size:complexity:laterality
```

```
|| 53                                                family_size:anteriority:laterality
|| 57                                                 complexity:anteriority:laterality
|| 24                          lang_type_semantic:lang_type_ortho:family_size:complexity
|| 28                         lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 32                          lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 36                          lang_type_semantic:lang_type_ortho:family_size:laterality
|| 40                           lang_type_semantic:lang_type_ortho:complexity:laterality
|| 44                          lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 46                              lang_type_semantic:family_size:complexity:anteriority
|| 47                                 lang_type_ortho:family_size:complexity:anteriority
|| 50                               lang_type_semantic:family_size:complexity:laterality
|| 51                                  lang_type_ortho:family_size:complexity:laterality
|| 54                              lang_type_semantic:family_size:anteriority:laterality
|| 55                                 lang_type_ortho:family_size:anteriority:laterality
|| 58                               lang_type_semantic:complexity:anteriority:laterality
|| 59                                  lang_type_ortho:complexity:anteriority:laterality
|| 61                                      family_size:complexity:anteriority:laterality
|| 48            lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 52             lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 56            lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 60             lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 62                 lang_type_semantic:family_size:complexity:anteriority:laterality
|| 63                    lang_type_ortho:family_size:complexity:anteriority:laterality
|| 64 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||    DFn DFd            F            p p<.05          ges
|| 2    1  56 1.012796e-01 7.514833e-01       9.672072e-04
|| 3    1  56 1.069044e+00 3.056060e-01       1.011574e-02
|| 5    1  56 1.189231e+00 2.801549e-01       1.567831e-03
|| 9    1  56 1.038188e-02 9.192067e-01       1.242449e-05
|| 13   2 112 2.568706e+01 6.575766e-10     * 6.476117e-02
|| 17   2 112 5.130254e+00 7.382143e-03     * 3.076214e-03
|| 4    1  56 1.403661e-02 9.061143e-01       1.341596e-04
|| 6    1  56 2.363497e-01 6.287522e-01       3.119853e-04
|| 7    1  56 1.055863e+00 3.085788e-01       1.392249e-03
|| 10   1  56 1.806149e+00 1.843908e-01       2.156868e-03
|| 11   1  56 5.288218e-01 4.701319e-01       6.324734e-04
|| 14   2 112 7.639941e-01 4.682141e-01       2.055295e-03
|| 15   2 112 4.604372e+00 1.197590e-02     * 1.226001e-02
|| 18   2 112 1.096564e+00 3.375755e-01       6.591184e-04
|| 19   2 112 6.278264e-02 9.391806e-01       3.776060e-05
|| 21   1  56 2.734967e-02 8.692426e-01       3.297632e-05
|| 25   2 112 4.305109e-01 6.512482e-01       6.086088e-05
|| 29   2 112 7.586406e-01 4.706936e-01       1.004265e-04
|| 33   2 112 1.010474e-01 9.039725e-01       6.857270e-06
|| 37   2 112 2.352401e-02 9.767553e-01       2.474757e-06
|| 41   4 224 7.839296e-01 5.366662e-01       2.934025e-04
|| 8    1  56 2.215417e+00 1.422483e-01       2.916764e-03
|| 12   1  56 1.077120e+00 3.038033e-01       1.287397e-03
|| 16   2 112 7.186107e-01 4.896624e-01       1.933441e-03
|| 20   2 112 3.115665e-01 7.329315e-01       1.873636e-04
|| 22   1  56 6.538181e-02 7.991204e-01       7.882921e-05
|| 23   1  56 2.193267e-04 9.882367e-01       2.644575e-07
|| 26   2 112 8.522900e-01 4.291841e-01       1.204802e-04
|| 27   2 112 9.164566e-02 9.124968e-01       1.295647e-05
```

```
|| 30   2 112 3.812708e+00 2.500894e-02     * 5.045106e-04
|| 31   2 112 8.846276e-02 9.154011e-01       1.171147e-05
|| 34   2 112 6.176632e-01 5.410294e-01       4.191433e-05
|| 35   2 112 6.489225e-01 5.245621e-01       4.403548e-05
|| 38   2 112 6.539335e-01 5.219701e-01       6.879011e-05
|| 39   2 112 6.143275e-01 5.428174e-01       6.462405e-05
|| 42   4 224 2.564519e+00 3.918905e-02     * 9.591872e-04
|| 43   4 224 1.402300e+00 2.340966e-01       5.247194e-04
|| 45   2 112 1.002638e+00 3.701793e-01       1.414131e-04
|| 49   2 112 3.281261e-01 7.209622e-01       2.675197e-05
|| 53   4 224 9.718584e-01 4.237135e-01       7.597103e-05
|| 57   4 224 6.765466e-01 6.088752e-01       6.904026e-05
|| 24   1  56 1.903181e+00 1.732069e-01       2.289544e-03
|| 28   2 112 7.798169e-01 4.609632e-01       1.102365e-04
|| 32   2 112 4.665531e-01 6.283736e-01       6.176326e-05
|| 36   2 112 1.105094e+00 3.347633e-01       7.498868e-05
|| 40   2 112 1.215350e-01 8.856767e-01       1.278551e-05
|| 44   4 224 1.748748e+00 1.402529e-01       6.542704e-04
|| 46   2 112 8.177233e-01 4.440534e-01       1.153356e-04
|| 47   2 112 1.503948e-02 9.850750e-01       2.121480e-06
|| 50   2 112 2.961022e+00 5.583277e-02       2.413590e-04
|| 51   2 112 2.086973e+00 1.288604e-01       1.701256e-04
|| 54   4 224 2.340249e-01 9.190016e-01       1.829499e-05
|| 55   4 224 1.258241e+00 2.873608e-01       9.835559e-05
|| 58   4 224 1.244564e+00 2.929214e-01       1.269979e-04
|| 59   4 224 1.906320e+00 1.103208e-01       1.945118e-04
|| 61   4 224 1.864227e+00 1.176699e-01       1.003203e-04
|| 48   2 112 2.132169e-01 8.083081e-01       3.007568e-05
|| 52   2 112 4.693951e-01 6.266051e-01       3.826913e-05
|| 56   4 224 9.663091e-01 4.267831e-01       7.553727e-05
|| 60   4 224 4.313437e-01 7.859139e-01       4.401888e-05
|| 62   4 224 4.163821e+00 2.841620e-03     * 2.240413e-04
|| 63   4 224 1.816049e+00 1.266439e-01       9.772791e-05
|| 64   4 224 6.396776e-01 6.347208e-01       3.442545e-05
```

```
anova_results.1a$`Sphericity Corrections`
```

```
||                                                                                Effect
|| 13                                                                        anteriority
|| 14                                                       lang_type_semantic:anteriority
|| 15                                                          lang_type_ortho:anteriority
|| 16                                    lang_type_semantic:lang_type_ortho:anteriority
|| 17                                                                         laterality
|| 18                                                        lang_type_semantic:laterality
|| 19                                                           lang_type_ortho:laterality
|| 20                                     lang_type_semantic:lang_type_ortho:laterality
|| 25                                                          family_size:anteriority
|| 26                                       lang_type_semantic:family_size:anteriority
|| 27                                          lang_type_ortho:family_size:anteriority
|| 28                           lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 29                                                          complexity:anteriority
|| 30                                       lang_type_semantic:complexity:anteriority
|| 31                                          lang_type_ortho:complexity:anteriority
|| 32                           lang_type_semantic:lang_type_ortho:complexity:anteriority
```

```
|| 33                                                                 family_size:laterality
|| 34                                                lang_type_semantic:family_size:laterality
|| 35                                                   lang_type_ortho:family_size:laterality
|| 36                                 lang_type_semantic:lang_type_ortho:family_size:laterality
|| 37                                                                   complexity:laterality
|| 38                                                 lang_type_semantic:complexity:laterality
|| 39                                                    lang_type_ortho:complexity:laterality
|| 40                                  lang_type_semantic:lang_type_ortho:complexity:laterality
|| 41                                                                  anteriority:laterality
|| 42                                               lang_type_semantic:anteriority:laterality
|| 43                                                  lang_type_ortho:anteriority:laterality
|| 44                                 lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 45                                                 family_size:complexity:anteriority
|| 46                                    lang_type_semantic:family_size:complexity:anteriority
|| 47                                       lang_type_ortho:family_size:complexity:anteriority
|| 48                      lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 49                                                   family_size:complexity:laterality
|| 50                                     lang_type_semantic:family_size:complexity:laterality
|| 51                                        lang_type_ortho:family_size:complexity:laterality
|| 52                       lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 53                                                 family_size:anteriority:laterality
|| 54                                    lang_type_semantic:family_size:anteriority:laterality
|| 55                                       lang_type_ortho:family_size:anteriority:laterality
|| 56                      lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 57                                                   complexity:anteriority:laterality
|| 58                                     lang_type_semantic:complexity:anteriority:laterality
|| 59                                        lang_type_ortho:complexity:anteriority:laterality
|| 60                       lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 61                                          family_size:complexity:anteriority:laterality
|| 62                           lang_type_semantic:family_size:complexity:anteriority:laterality
|| 63                              lang_type_ortho:family_size:complexity:anteriority:laterality
|| 64 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||          GGe        p[GG] p[GG]<.05       HFe        p[HF] p[HF]<.05
|| 13 0.5665160 1.430722e-06         * 0.5703142 1.337065e-06         *
|| 14 0.5665160 4.008280e-01           0.5703142 4.016293e-01
|| 15 0.5665160 3.131379e-02         * 0.5703142 3.105250e-02         *
|| 16 0.5665160 4.163572e-01           0.5703142 4.172209e-01
|| 17 0.9247835 8.986180e-03         * 0.9549814 8.303575e-03         *
|| 18 0.9247835 3.340956e-01           0.9549814 3.355514e-01
|| 19 0.9247835 9.280039e-01           0.9549814 9.327354e-01
|| 20 0.9247835 7.159134e-01           0.9549814 7.229287e-01
|| 25 0.7890239 6.040884e-01           0.8080262 6.088174e-01
|| 26 0.7890239 4.061656e-01           0.8080262 4.085086e-01
|| 27 0.7890239 8.689941e-01           0.8080262 8.737684e-01
|| 28 0.7890239 4.339403e-01           0.8080262 4.366680e-01
|| 29 0.8466263 4.508798e-01           0.8701994 4.541541e-01
|| 30 0.8466263 3.206071e-02         * 0.8701994 3.085924e-02         *
|| 31 0.8466263 8.861892e-01           0.8701994 8.913268e-01
|| 32 0.8466263 5.965347e-01           0.8701994 6.017766e-01
|| 33 0.9553502 8.959829e-01           0.9882723 9.019418e-01
|| 34 0.9553502 5.339610e-01           0.9882723 5.392024e-01
|| 35 0.9553502 5.178595e-01           0.9882723 5.228299e-01
|| 36 0.9553502 3.328293e-01           0.9882723 3.342710e-01
|| 37 0.6555688 9.286399e-01           0.6649877 9.308549e-01
```

```
|| 38 0.6555688 4.609162e-01           0.6649877 4.629669e-01
|| 39 0.6555688 4.776495e-01           0.6649877 4.798322e-01
|| 40 0.6555688 7.958798e-01           0.6649877 7.992511e-01
|| 41 0.8128803 5.134378e-01           0.8689194 5.208944e-01
|| 42 0.8128803 5.145044e-02           0.8689194 4.740640e-02         *
|| 43 0.8128803 2.416327e-01           0.8689194 2.394555e-01
|| 44 0.8128803 1.541066e-01           0.8689194 1.498414e-01
|| 45 0.6606367 3.422384e-01           0.6703940 3.433036e-01
|| 46 0.6606367 4.001430e-01           0.6703940 4.017238e-01
|| 47 0.6606367 9.476738e-01           0.6703940 9.495715e-01
|| 48 0.6606367 7.136463e-01           0.6703940 7.171464e-01
|| 49 0.8337484 6.814995e-01           0.8562767 6.873260e-01
|| 50 0.8337484 6.593432e-02           0.8562767 6.447133e-02
|| 51 0.8337484 1.378875e-01           0.8562767 1.366629e-01
|| 52 0.8337484 5.919601e-01           0.8562767 5.970288e-01
|| 53 0.7890040 4.104261e-01           0.8415949 4.141519e-01
|| 54 0.7890040 8.814998e-01           0.8415949 8.924202e-01
|| 55 0.7890040 2.902079e-01           0.8415949 2.896998e-01
|| 56 0.7890040 4.131239e-01           0.8415949 4.169469e-01
|| 57 0.6502020 5.473162e-01           0.6846829 5.546211e-01
|| 58 0.6502020 2.950072e-01           0.6846829 2.952170e-01
|| 59 0.6502020 1.393956e-01           0.6846829 1.362647e-01
|| 60 0.6502020 7.028017e-01           0.6846829 7.129763e-01
|| 61 0.9111706 1.244055e-01           0.9824546 1.189706e-01
|| 62 0.9111706 3.927780e-03         * 0.9824546 3.028835e-03         *
|| 63 0.9111706 1.332843e-01           0.9824546 1.279292e-01
|| 64 0.9111706 6.203270e-01           0.9824546 6.319751e-01
```

```r
anova_results.1b <- aov_ez(id = "SubjID",
                           dv = "value",
                           data = n400_1_nonwords,
                           within = c("family_size",
                                      "complexity",
                                      "anteriority",
                                      "laterality"),
                           between = c("lang_type_semantic","lang_type_ortho"),
                           type = 3)
anova_results.1b
```

```
|| Anova Table (Type 3 tests)
||
|| Response: value
||                                                                                Effect
|| 1                                                                  lang_type_semantic
|| 2                                                                     lang_type_ortho
|| 3                                                  lang_type_semantic:lang_type_ortho
|| 4                                                                         family_size
|| 5                                                      lang_type_semantic:family_size
|| 6                                                         lang_type_ortho:family_size
|| 7                                       lang_type_semantic:lang_type_ortho:family_size
|| 8                                                                         complexity
|| 9                                                      lang_type_semantic:complexity
|| 10                                                        lang_type_ortho:complexity
|| 11                                      lang_type_semantic:lang_type_ortho:complexity
```

```
|| 12                                                                        anteriority
|| 13                                                      lang_type_semantic:anteriority
|| 14                                                         lang_type_ortho:anteriority
|| 15                                      lang_type_semantic:lang_type_ortho:anteriority
|| 16                                                                         laterality
|| 17                                                       lang_type_semantic:laterality
|| 18                                                          lang_type_ortho:laterality
|| 19                                       lang_type_semantic:lang_type_ortho:laterality
|| 20                                                              family_size:complexity
|| 21                                          lang_type_semantic:family_size:complexity
|| 22                                             lang_type_ortho:family_size:complexity
|| 23                              lang_type_semantic:lang_type_ortho:family_size:complexity
|| 24                                                          family_size:anteriority
|| 25                                       lang_type_semantic:family_size:anteriority
|| 26                                          lang_type_ortho:family_size:anteriority
|| 27                            lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 28                                                          complexity:anteriority
|| 29                                        lang_type_semantic:complexity:anteriority
|| 30                                           lang_type_ortho:complexity:anteriority
|| 31                            lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 32                                                          family_size:laterality
|| 33                                        lang_type_semantic:family_size:laterality
|| 34                                           lang_type_ortho:family_size:laterality
|| 35                            lang_type_semantic:lang_type_ortho:family_size:laterality
|| 36                                                           complexity:laterality
|| 37                                         lang_type_semantic:complexity:laterality
|| 38                                            lang_type_ortho:complexity:laterality
|| 39                             lang_type_semantic:lang_type_ortho:complexity:laterality
|| 40                                                          anteriority:laterality
|| 41                                        lang_type_semantic:anteriority:laterality
|| 42                                           lang_type_ortho:anteriority:laterality
|| 43                            lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 44                                              family_size:complexity:anteriority
|| 45                                  lang_type_semantic:family_size:complexity:anteriority
|| 46                                     lang_type_ortho:family_size:complexity:anteriority
|| 47                  lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 48                                               family_size:complexity:laterality
|| 49                                  lang_type_semantic:family_size:complexity:laterality
|| 50                                     lang_type_ortho:family_size:complexity:laterality
|| 51                   lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 52                                              family_size:anteriority:laterality
|| 53                                  lang_type_semantic:family_size:anteriority:laterality
|| 54                                     lang_type_ortho:family_size:anteriority:laterality
|| 55                  lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 56                                               complexity:anteriority:laterality
|| 57                                  lang_type_semantic:complexity:anteriority:laterality
|| 58                                     lang_type_ortho:complexity:anteriority:laterality
|| 59                   lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 60                                        family_size:complexity:anteriority:laterality
|| 61                      lang_type_semantic:family_size:complexity:anteriority:laterality
|| 62                         lang_type_ortho:family_size:complexity:anteriority:laterality
|| 63 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||              df    MSE         F   ges p.value
|| 1         1, 56 366.93      0.10 <.001    .751
```

```
|| 2         1, 56 366.93      1.07  .010    .306
|| 3         1, 56 366.93      0.01 <.001    .906
|| 4         1, 56  50.68      1.19  .002    .280
|| 5         1, 56  50.68      0.24 <.001    .629
|| 6         1, 56  50.68      1.06  .001    .309
|| 7         1, 56  50.68      2.22  .003    .142
|| 8         1, 56  45.94      0.01 <.001    .919
|| 9         1, 56  45.94      1.81  .002    .184
|| 10        1, 56  45.94      0.53 <.001    .470
|| 11        1, 56  45.94      1.08  .001    .304
|| 12  1.13, 63.45  91.33 25.69 ***  .065   <.001
|| 13  1.13, 63.45  91.33      0.76  .002    .401
|| 14  1.13, 63.45  91.33    4.60 *  .012    .031
|| 15  1.13, 63.45  91.33      0.72  .002    .416
|| 16 1.85, 103.58  12.48   5.13 **  .003    .009
|| 17 1.85, 103.58  12.48      1.10 <.001    .334
|| 18 1.85, 103.58  12.48      0.06 <.001    .928
|| 19 1.85, 103.58  12.48      0.31 <.001    .716
|| 20        1, 56  46.28      0.03 <.001    .869
|| 21        1, 56  46.28      0.07 <.001    .799
|| 22        1, 56  46.28      0.00 <.001    .988
|| 23        1, 56  46.28      1.90  .002    .173
|| 24  1.58, 88.37   3.44      0.43 <.001    .604
|| 25  1.58, 88.37   3.44      0.85 <.001    .406
|| 26  1.58, 88.37   3.44      0.09 <.001    .869
|| 27  1.58, 88.37   3.44      0.78 <.001    .434
|| 28  1.69, 94.82   3.00      0.76 <.001    .451
|| 29  1.69, 94.82   3.00    3.81 * <.001    .032
|| 30  1.69, 94.82   3.00      0.09 <.001    .886
|| 31  1.69, 94.82   3.00      0.47 <.001    .597
|| 32 1.91, 107.00   1.36      0.10 <.001    .896
|| 33 1.91, 107.00   1.36      0.62 <.001    .534
|| 34 1.91, 107.00   1.36      0.65 <.001    .518
|| 35 1.91, 107.00   1.36      1.11 <.001    .333
|| 36  1.31, 73.42   3.08      0.02 <.001    .929
|| 37  1.31, 73.42   3.08      0.65 <.001    .461
|| 38  1.31, 73.42   3.08      0.61 <.001    .478
|| 39  1.31, 73.42   3.08      0.12 <.001    .796
|| 40 3.25, 182.09   4.42      0.78 <.001    .513
|| 41 3.25, 182.09   4.42    2.56 + <.001    .051
|| 42 3.25, 182.09   4.42      1.40 <.001    .242
|| 43 3.25, 182.09   4.42      1.75 <.001    .154
|| 44  1.32, 73.99   4.10      1.00 <.001    .342
|| 45  1.32, 73.99   4.10      0.82 <.001    .400
|| 46  1.32, 73.99   4.10      0.02 <.001    .948
|| 47  1.32, 73.99   4.10      0.21 <.001    .714
|| 48  1.67, 93.38   1.88      0.33 <.001    .681
|| 49  1.67, 93.38   1.88    2.96 + <.001    .066
|| 50  1.67, 93.38   1.88      2.09 <.001    .138
|| 51  1.67, 93.38   1.88      0.47 <.001    .592
|| 52 3.16, 176.74   0.95      0.97 <.001    .410
|| 53 3.16, 176.74   0.95      0.23 <.001    .881
|| 54 3.16, 176.74   0.95      1.26 <.001    .290
|| 55 3.16, 176.74   0.95      0.97 <.001    .413
```

```
|| 56 2.60, 145.65   1.51      0.68 <.001    .547
|| 57 2.60, 145.65   1.51      1.24 <.001    .295
|| 58 2.60, 145.65   1.51      1.91 <.001    .139
|| 59 2.60, 145.65   1.51      0.43 <.001    .703
|| 60 3.64, 204.10   0.57      1.86 <.001    .124
|| 61 3.64, 204.10   0.57   4.16 ** <.001    .004
|| 62 3.64, 204.10   0.57      1.82 <.001    .133
|| 63 3.64, 204.10   0.57      0.64 <.001    .620
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
||
|| Sphericity correction method: GG
```

## 5.2 Group 2

```
anova_results.2a <- ezANOVA(n400_2_nonwords,
        dv = value,
        wid = SubjID,
        within = .(family_size, complexity,anteriority, laterality),
        between = .(lang_type_semantic, lang_type_ortho),
        type = 3)
anova_results.2a$ANOVA
```

```
||                                                                                  Effect
|| 2                                                                  lang_type_semantic
|| 3                                                                     lang_type_ortho
|| 5                                                                         family_size
|| 9                                                                          complexity
|| 13                                                                        anteriority
|| 17                                                                         laterality
|| 4                                                  lang_type_semantic:lang_type_ortho
|| 6                                                      lang_type_semantic:family_size
|| 7                                                         lang_type_ortho:family_size
|| 10                                                     lang_type_semantic:complexity
|| 11                                                        lang_type_ortho:complexity
|| 14                                                     lang_type_semantic:anteriority
|| 15                                                        lang_type_ortho:anteriority
|| 18                                                     lang_type_semantic:laterality
|| 19                                                        lang_type_ortho:laterality
|| 21                                                            family_size:complexity
|| 25                                                           family_size:anteriority
|| 29                                                            complexity:anteriority
|| 33                                                            family_size:laterality
|| 37                                                             complexity:laterality
|| 41                                                            anteriority:laterality
|| 8                                  lang_type_semantic:lang_type_ortho:family_size
|| 12                                  lang_type_semantic:lang_type_ortho:complexity
|| 16                                 lang_type_semantic:lang_type_ortho:anteriority
|| 20                                  lang_type_semantic:lang_type_ortho:laterality
|| 22                                      lang_type_semantic:family_size:complexity
|| 23                                         lang_type_ortho:family_size:complexity
|| 26                                     lang_type_semantic:family_size:anteriority
```

```
|| 27                                          lang_type_ortho:family_size:anteriority
|| 30                                       lang_type_semantic:complexity:anteriority
|| 31                                          lang_type_ortho:complexity:anteriority
|| 34                                       lang_type_semantic:family_size:laterality
|| 35                                          lang_type_ortho:family_size:laterality
|| 38                                        lang_type_semantic:complexity:laterality
|| 39                                           lang_type_ortho:complexity:laterality
|| 42                                       lang_type_semantic:anteriority:laterality
|| 43                                          lang_type_ortho:anteriority:laterality
|| 45                                              family_size:complexity:anteriority
|| 49                                               family_size:complexity:laterality
|| 53                                              family_size:anteriority:laterality
|| 57                                               complexity:anteriority:laterality
|| 24                          lang_type_semantic:lang_type_ortho:family_size:complexity
|| 28                        lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 32                         lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 36                         lang_type_semantic:lang_type_ortho:family_size:laterality
|| 40                          lang_type_semantic:lang_type_ortho:complexity:laterality
|| 44                         lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 46                             lang_type_semantic:family_size:complexity:anteriority
|| 47                                lang_type_ortho:family_size:complexity:anteriority
|| 50                              lang_type_semantic:family_size:complexity:laterality
|| 51                                 lang_type_ortho:family_size:complexity:laterality
|| 54                             lang_type_semantic:family_size:anteriority:laterality
|| 55                                lang_type_ortho:family_size:anteriority:laterality
|| 58                              lang_type_semantic:complexity:anteriority:laterality
|| 59                                 lang_type_ortho:complexity:anteriority:laterality
|| 61                                     family_size:complexity:anteriority:laterality
|| 48            lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 52             lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 56            lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 60             lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 62                 lang_type_semantic:family_size:complexity:anteriority:laterality
|| 63                    lang_type_ortho:family_size:complexity:anteriority:laterality
|| 64 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||    DFn DFd            F            p p<.05          ges
|| 2    1  35 6.985461e-01 4.089424e-01       1.103839e-02
|| 3    1  35 1.608032e+00 2.131394e-01       2.505003e-02
|| 5    1  35 8.590813e-06 9.976780e-01       1.364393e-08
|| 9    1  35 2.117362e+00 1.545482e-01       2.547424e-03
|| 13   2  70 4.750670e+01 9.231223e-14     * 1.795487e-01
|| 17   2  70 2.637710e+00 7.862668e-02       2.887182e-03
|| 4    1  35 7.612059e-02 7.842477e-01       1.214802e-03
|| 6    1  35 5.817963e-01 4.507196e-01       9.231556e-04
|| 7    1  35 2.693391e-01 6.070417e-01       4.275814e-04
|| 10   1  35 5.333730e-01 4.700528e-01       6.429327e-04
|| 11   1  35 1.523834e+00 2.252644e-01       1.834653e-03
|| 14   2  70 4.576340e-01 6.346586e-01       2.103673e-03
|| 15   2  70 6.421585e-01 5.292266e-01       2.949402e-03
|| 18   2  70 7.567219e-01 4.730011e-01       8.300008e-04
|| 19   2  70 1.081698e+00 3.446179e-01       1.186024e-03
|| 21   1  35 8.236043e+00 6.920894e-03     * 5.788081e-03
|| 25   2  70 8.824656e-02 9.156368e-01       2.484703e-05
|| 29   2  70 8.716391e-02 9.166262e-01       2.854520e-05
```

```
|| 33   2  70 1.217289e+00 3.022204e-01       2.262341e-04
|| 37   2  70 3.917181e-01 6.773668e-01       1.036081e-04
|| 41   4 140 5.983784e+00 1.786168e-04     * 4.643660e-03
|| 8    1  35 7.070515e-03 9.334669e-01       1.122926e-05
|| 12   1  35 1.756564e+00 1.936406e-01       2.114261e-03
|| 16   2  70 1.398208e+00 2.538526e-01       6.399676e-03
|| 20   2  70 4.749062e-01 6.239325e-01       5.210559e-04
|| 22   1  35 2.524968e+00 1.210509e-01       1.781634e-03
|| 23   1  35 1.695908e+00 2.013290e-01       1.197344e-03
|| 26   2  70 1.289683e-01 8.792102e-01       3.631238e-05
|| 27   2  70 7.383565e-02 9.288966e-01       2.078952e-05
|| 30   2  70 1.016749e+00 3.670486e-01       3.328727e-04
|| 31   2  70 1.336810e-01 8.750919e-01       4.377837e-05
|| 34   2  70 9.570160e-01 3.890040e-01       1.778708e-04
|| 35   2  70 1.536775e+00 2.222410e-01       2.855939e-04
|| 38   2  70 6.236392e-01 5.389415e-01       1.649404e-04
|| 39   2  70 1.211172e+00 3.040125e-01       3.202814e-04
|| 42   4 140 2.166914e+00 7.581763e-02       1.686610e-03
|| 43   4 140 9.783793e-01 4.214832e-01       7.622230e-04
|| 45   2  70 1.406225e+00 2.519034e-01       3.847017e-04
|| 49   2  70 8.099137e-01 4.490213e-01       1.226574e-04
|| 53   4 140 5.369208e-01 7.088300e-01       2.085877e-04
|| 57   4 140 6.461044e-01 6.305385e-01       2.420151e-04
|| 24   1  35 3.082204e-01 5.823055e-01       2.178231e-04
|| 28   2  70 2.690729e+00 7.484673e-02       7.570568e-04
|| 32   2  70 2.512027e+00 8.839201e-02       8.220078e-04
|| 36   2  70 7.861796e-01 4.595627e-01       1.461238e-04
|| 40   2  70 3.296992e-01 7.202507e-01       8.720576e-05
|| 44   4 140 1.036461e+00 3.907118e-01       8.074358e-04
|| 46   2  70 5.440184e-02 9.470915e-01       1.488825e-05
|| 47   2  70 2.477740e+00 9.126675e-02       6.776383e-04
|| 50   2  70 1.498835e+00 2.304712e-01       2.269673e-04
|| 51   2  70 5.332237e-01 5.890744e-01       8.075744e-05
|| 54   4 140 1.156170e+00 3.329078e-01       4.490511e-04
|| 55   4 140 7.659243e-01 5.491302e-01       2.975266e-04
|| 58   4 140 5.134807e-01 7.259198e-01       1.923470e-04
|| 59   4 140 6.434233e-01 6.324227e-01       2.410110e-04
|| 61   4 140 1.062570e+00 3.774637e-01       3.824285e-04
|| 48   2  70 1.919202e+00 1.543657e-01       5.249637e-04
|| 52   2  70 4.259145e-01 6.548534e-01       6.450636e-05
|| 56   4 140 1.040733e+00 3.885193e-01       4.042340e-04
|| 60   4 140 4.792059e-01 7.509562e-01       1.795102e-04
|| 62   4 140 1.522891e+00 1.987713e-01       5.480113e-04
|| 63   4 140 1.198644e+00 3.141711e-01       4.313814e-04
|| 64   4 140 1.105971e+00 3.562373e-01       3.980426e-04
```

```
anova_results.2a$`Sphericity Corrections`
```

```
||                                                                    Effect
|| 13                                                            anterioriity
|| 14                                                lang_type_semantic:anterioriity
|| 15                                                   lang_type_ortho:anterioriity
|| 16                                lang_type_semantic:lang_type_ortho:anterioriity
|| 17                                                             laterality
```

```
|| 18                                                    lang_type_semantic:laterality
|| 19                                                       lang_type_ortho:laterality
|| 20                                    lang_type_semantic:lang_type_ortho:laterality
|| 25                                                        family_size:anteriority
|| 26                                       lang_type_semantic:family_size:anteriority
|| 27                                          lang_type_ortho:family_size:anteriority
|| 28                          lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 29                                                      complexity:anteriority
|| 30                                       lang_type_semantic:complexity:anteriority
|| 31                                          lang_type_ortho:complexity:anteriority
|| 32                           lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 33                                                      family_size:laterality
|| 34                                       lang_type_semantic:family_size:laterality
|| 35                                          lang_type_ortho:family_size:laterality
|| 36                           lang_type_semantic:lang_type_ortho:family_size:laterality
|| 37                                                       complexity:laterality
|| 38                                        lang_type_semantic:complexity:laterality
|| 39                                           lang_type_ortho:complexity:laterality
|| 40                            lang_type_semantic:lang_type_ortho:complexity:laterality
|| 41                                                      anteriority:laterality
|| 42                                       lang_type_semantic:anteriority:laterality
|| 43                                          lang_type_ortho:anteriority:laterality
|| 44                           lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 45                                             family_size:complexity:anteriority
|| 46                                lang_type_semantic:family_size:complexity:anteriority
|| 47                                   lang_type_ortho:family_size:complexity:anteriority
|| 48                lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 49                                              family_size:complexity:laterality
|| 50                                 lang_type_semantic:family_size:complexity:laterality
|| 51                                    lang_type_ortho:family_size:complexity:laterality
|| 52                 lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 53                                             family_size:anteriority:laterality
|| 54                                lang_type_semantic:family_size:anteriority:laterality
|| 55                                   lang_type_ortho:family_size:anteriority:laterality
|| 56                lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 57                                              complexity:anteriority:laterality
|| 58                                 lang_type_semantic:complexity:anteriority:laterality
|| 59                                    lang_type_ortho:complexity:anteriority:laterality
|| 60                 lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 61                                    family_size:complexity:anteriority:laterality
|| 62                       lang_type_semantic:family_size:complexity:anteriority:laterality
|| 63                          lang_type_ortho:family_size:complexity:anteriority:laterality
|| 64 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||          GGe        p[GG] p[GG]<.05       HFe        p[HF] p[HF]<.05
|| 13 0.5673693 8.749078e-09         * 0.5736053 7.411747e-09         *
|| 14 0.5673693 5.267595e-01           0.5736053 5.288098e-01
|| 15 0.5673693 4.465544e-01           0.5736053 4.481339e-01
|| 16 0.5673693 2.483636e-01           0.5736053 2.486201e-01
|| 17 0.9659122 8.071280e-02           1.0213094 7.862668e-02
|| 18 0.9659122 4.689022e-01           1.0213094 4.730011e-01
|| 19 0.9659122 3.430290e-01           1.0213094 3.446179e-01
|| 20 0.9659122 6.173996e-01           1.0213094 6.239325e-01
|| 25 0.6610669 8.353027e-01           0.6769553 8.405974e-01
|| 26 0.6610669 7.906257e-01           0.6769553 7.962163e-01
```

```
|| 27 0.6610669 8.530501e-01           0.6769553 8.581556e-01
|| 28 0.6610669 9.778628e-02           0.6769553 9.661057e-02
|| 29 0.5882717 8.096206e-01           0.5965618 8.129412e-01
|| 30 0.5882717 3.323350e-01           0.5965618 3.333475e-01
|| 31 0.5882717 7.576542e-01           0.5965618 7.610916e-01
|| 32 0.5882717 1.159249e-01           0.5965618 1.153450e-01
|| 33 0.6736463 2.904944e-01           0.6909181 2.914427e-01
|| 34 0.6736463 3.593046e-01           0.6909181 3.613113e-01
|| 35 0.6736463 2.260405e-01           0.6909181 2.260537e-01
|| 36 0.6736463 4.153478e-01           0.6909181 4.182112e-01
|| 37 0.7214981 6.102446e-01           0.7442241 6.166210e-01
|| 38 0.7214981 4.896299e-01           0.7442241 4.942863e-01
|| 39 0.7214981 2.944905e-01           0.7442241 2.955880e-01
|| 40 0.7214981 6.495379e-01           0.7442241 6.563118e-01
|| 41 0.5918948 2.237230e-03         * 0.6376546 1.679736e-03         *
|| 42 0.5918948 1.120363e-01           0.6376546 1.072561e-01
|| 43 0.5918948 3.918347e-01           0.6376546 3.964063e-01
|| 44 0.5918948 3.688032e-01           0.6376546 3.723867e-01
|| 45 0.7422897 2.513287e-01           0.7674804 2.516219e-01
|| 46 0.7422897 9.014586e-01           0.7674804 9.073963e-01
|| 47 0.7422897 1.079421e-01           0.7674804 1.062306e-01
|| 48 0.7422897 1.663703e-01           0.7674804 1.652656e-01
|| 49 0.7287837 4.154271e-01           0.7523668 4.188466e-01
|| 50 0.7287837 2.329813e-01           0.7523668 2.329752e-01
|| 51 0.7287837 5.341844e-01           0.7523668 5.396692e-01
|| 52 0.7287837 5.920452e-01           0.7523668 5.983488e-01
|| 53 0.3319166 5.163948e-01           0.3400120 5.205000e-01
|| 54 0.3319166 3.044437e-01           0.3400120 3.055720e-01
|| 55 0.3319166 4.209716e-01           0.3400120 4.238037e-01
|| 56 0.3319166 3.342785e-01           0.3400120 3.358447e-01
|| 57 0.3330719 4.681510e-01           0.3412940 4.716722e-01
|| 58 0.3330719 5.283807e-01           0.3412940 5.326745e-01
|| 59 0.3330719 4.692738e-01           0.3412940 4.728102e-01
|| 60 0.3330719 5.456947e-01           0.3412940 5.501912e-01
|| 61 0.3140015 3.249027e-01           0.3201771 3.261320e-01
|| 62 0.3140015 2.281671e-01           0.3201771 2.282787e-01
|| 63 0.3140015 2.919270e-01           0.3201771 2.927636e-01
|| 64 0.3140015 3.139148e-01           0.3201771 3.150126e-01
```

```
anova_results.2b <- aov_ez(id = "SubjID",
                           dv = "value",
                           data = n400_2_nonwords,
                           within = c("family_size",
                                      "complexity",
                                      "anteriority",
                                      "laterality"),
                           between = c("lang_type_semantic","lang_type_ortho"),
                           type = 3)
anova_results.2b
```

```
|| Anova Table (Type 3 tests)
||
|| Response: value
||                                                                        Effect
```

```
|| 1                                                                                                  lang_type_semantic
|| 2                                                                                                     lang_type_ortho
|| 3                                                                                  lang_type_semantic:lang_type_ortho
|| 4                                                                                                         family_size
|| 5                                                                                     lang_type_semantic:family_size
|| 6                                                                                        lang_type_ortho:family_size
|| 7                                                                   lang_type_semantic:lang_type_ortho:family_size
|| 8                                                                                                         complexity
|| 9                                                                                      lang_type_semantic:complexity
|| 10                                                                                        lang_type_ortho:complexity
|| 11                                                                  lang_type_semantic:lang_type_ortho:complexity
|| 12                                                                                                       anteriority
|| 13                                                                                     lang_type_semantic:anteriority
|| 14                                                                                        lang_type_ortho:anteriority
|| 15                                                                  lang_type_semantic:lang_type_ortho:anteriority
|| 16                                                                                                       laterality
|| 17                                                                                     lang_type_semantic:laterality
|| 18                                                                                        lang_type_ortho:laterality
|| 19                                                                  lang_type_semantic:lang_type_ortho:laterality
|| 20                                                                                          family_size:complexity
|| 21                                                                      lang_type_semantic:family_size:complexity
|| 22                                                                         lang_type_ortho:family_size:complexity
|| 23                                                   lang_type_semantic:lang_type_ortho:family_size:complexity
|| 24                                                                                         family_size:anteriority
|| 25                                                                      lang_type_semantic:family_size:anteriority
|| 26                                                                         lang_type_ortho:family_size:anteriority
|| 27                                                   lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 28                                                                                         complexity:anteriority
|| 29                                                                      lang_type_semantic:complexity:anteriority
|| 30                                                                         lang_type_ortho:complexity:anteriority
|| 31                                                   lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 32                                                                                          family_size:laterality
|| 33                                                                      lang_type_semantic:family_size:laterality
|| 34                                                                         lang_type_ortho:family_size:laterality
|| 35                                                   lang_type_semantic:lang_type_ortho:family_size:laterality
|| 36                                                                                          complexity:laterality
|| 37                                                                       lang_type_semantic:complexity:laterality
|| 38                                                                          lang_type_ortho:complexity:laterality
|| 39                                                    lang_type_semantic:lang_type_ortho:complexity:laterality
|| 40                                                                                         anteriority:laterality
|| 41                                                                      lang_type_semantic:anteriority:laterality
|| 42                                                                         lang_type_ortho:anteriority:laterality
|| 43                                                   lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 44                                                                        family_size:complexity:anteriority
|| 45                                                           lang_type_semantic:family_size:complexity:anteriority
|| 46                                                              lang_type_ortho:family_size:complexity:anteriority
|| 47                                      lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 48                                                                         family_size:complexity:laterality
|| 49                                                           lang_type_semantic:family_size:complexity:laterality
|| 50                                                              lang_type_ortho:family_size:complexity:laterality
|| 51                                       lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 52                                                                        family_size:anteriority:laterality
|| 53                                                           lang_type_semantic:family_size:anteriority:laterality
|| 54                                                              lang_type_ortho:family_size:anteriority:laterality
```

```
|| 55            lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 56                                                 complexity:anteriority:laterality
|| 57                              lang_type_semantic:complexity:anteriority:laterality
|| 58                                 lang_type_ortho:complexity:anteriority:laterality
|| 59              lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 60                                    family_size:complexity:anteriority:laterality
|| 61                  lang_type_semantic:family_size:complexity:anteriority:laterality
|| 62                     lang_type_ortho:family_size:complexity:anteriority:laterality
|| 63 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||              df    MSE         F   ges p.value
|| 1        1, 35 548.70      0.70  .011    .409
|| 2        1, 35 548.70      1.61  .025    .213
|| 3        1, 35 548.70      0.08  .001    .784
|| 4        1, 35  54.54      0.00 <.001    .998
|| 5        1, 35  54.54      0.58 <.001    .451
|| 6        1, 35  54.54      0.27 <.001    .607
|| 7        1, 35  54.54      0.01 <.001    .933
|| 8        1, 35  41.42      2.12  .003    .155
|| 9        1, 35  41.42      0.53 <.001    .470
|| 10       1, 35  41.42      1.52  .002    .225
|| 11       1, 35  41.42      1.76  .002    .194
|| 12 1.13, 39.72 139.41 47.51 ***  .180   <.001
|| 13 1.13, 39.72 139.41      0.46  .002    .527
|| 14 1.13, 39.72 139.41      0.64  .003    .447
|| 15 1.13, 39.72 139.41      1.40  .006    .248
|| 16 1.93, 67.61  19.51    2.64 +  .003    .081
|| 17 1.93, 67.61  19.51      0.76 <.001    .469
|| 18 1.93, 67.61  19.51      1.08  .001    .343
|| 19 1.93, 67.61  19.51      0.47 <.001    .617
|| 20       1, 35  24.27   8.24 **  .006    .007
|| 21       1, 35  24.27      2.52  .002    .121
|| 22       1, 35  24.27      1.70  .001    .201
|| 23       1, 35  24.27      0.31 <.001    .582
|| 24 1.32, 46.27   7.31      0.09 <.001    .835
|| 25 1.32, 46.27   7.31      0.13 <.001    .791
|| 26 1.32, 46.27   7.31      0.07 <.001    .853
|| 27 1.32, 46.27   7.31    2.69 + <.001    .098
|| 28 1.18, 41.18   9.56      0.09 <.001    .810
|| 29 1.18, 41.18   9.56      1.02 <.001    .332
|| 30 1.18, 41.18   9.56      0.13 <.001    .758
|| 31 1.18, 41.18   9.56      2.51 <.001    .116
|| 32 1.35, 47.16   4.74      1.22 <.001    .290
|| 33 1.35, 47.16   4.74      0.96 <.001    .359
|| 34 1.35, 47.16   4.74      1.54 <.001    .226
|| 35 1.35, 47.16   4.74      0.79 <.001    .415
|| 36 1.44, 50.50   6.30      0.39 <.001    .610
|| 37 1.44, 50.50   6.30      0.62 <.001    .490
|| 38 1.44, 50.50   6.30      1.21 <.001    .294
|| 39 1.44, 50.50   6.30      0.33 <.001    .650
|| 40 2.37, 82.87  11.31   5.98 **  .005    .002
|| 41 2.37, 82.87  11.31      2.17  .002    .112
|| 42 2.37, 82.87  11.31      0.98 <.001    .392
|| 43 2.37, 82.87  11.31      1.04 <.001    .369
|| 44 1.48, 51.96   6.33      1.41 <.001    .251
```

```
|| 45 1.48, 51.96   6.33      0.05 <.001    .901
|| 46 1.48, 51.96   6.33      2.48 <.001    .108
|| 47 1.48, 51.96   6.33      1.92 <.001    .166
|| 48 1.46, 51.01   3.57      0.81 <.001    .415
|| 49 1.46, 51.01   3.57      1.50 <.001    .233
|| 50 1.46, 51.01   3.57      0.53 <.001    .534
|| 51 1.46, 51.01   3.57      0.43 <.001    .592
|| 52 1.33, 46.47  10.05      0.54 <.001    .516
|| 53 1.33, 46.47  10.05      1.16 <.001    .304
|| 54 1.33, 46.47  10.05      0.77 <.001    .421
|| 55 1.33, 46.47  10.05      1.04 <.001    .334
|| 56 1.33, 46.63   9.66      0.65 <.001    .468
|| 57 1.33, 46.63   9.66      0.51 <.001    .528
|| 58 1.33, 46.63   9.66      0.64 <.001    .469
|| 59 1.33, 46.63   9.66      0.48 <.001    .546
|| 60 1.26, 43.96   9.84      1.06 <.001    .325
|| 61 1.26, 43.96   9.84      1.52 <.001    .228
|| 62 1.26, 43.96   9.84      1.20 <.001    .292
|| 63 1.26, 43.96   9.84      1.11 <.001    .314
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
||
|| Sphericity correction method: GG
```

# 6 Examine and plot interactions

## 6.1 Group 1

### 6.1.1 Language Type Orthographic by Anteriority Interaction

Pairwise Comparisons `lang_type_ortho | anteriority`

```
emms <- emmeans(anova_results.1b, ~ lang_type_ortho | anteriority )
pairwise_results <- pairs(emms, by = c("anteriority"))
summary(pairwise_results)
```

```
|| anteriority = Frontal:
||  contrast                            estimate    SE df t.ratio p.value
||  High Orthographic - Low Orthographic   -0.412 1.080 56  -0.382  0.7040
||
|| anteriority = Central:
||  contrast                            estimate    SE df t.ratio p.value
||  High Orthographic - Low Orthographic    1.130 0.908 56   1.245  0.2183
||
|| anteriority = Parietal:
||  contrast                            estimate    SE df t.ratio p.value
||  High Orthographic - Low Orthographic    1.853 0.809 56   2.290  0.0258
||
|| Results are averaged over the levels of: lang_type_semantic, laterality, complexity, family_size
```

Condition Means `lang_type_ortho | anteriority`

```
(nw_ltortho_ant_1 <- n400_1_nonwords |>
    na.omit()|>
   group_by(anteriority, lang_type_ortho) |>
   summarise(mean = mean(value),
             se = sem(value),
             num_stim = n()))
```

```
|| # A tibble: 6 x 5
|| # Groups:   anteriority [3]
||   anteriority lang_type_ortho     mean    se num_stim
||   <fct>       <chr>              <dbl> <dbl>    <int>
|| 1 Frontal     High Orthographic -1.37  0.260      372
|| 2 Frontal     Low Orthographic  -0.979 0.227      348
|| 3 Central     High Orthographic -0.128 0.211      372
|| 4 Central     Low Orthographic  -1.22  0.237      348
|| 5 Parietal    High Orthographic  2.26  0.215      372
|| 6 Parietal    Low Orthographic   0.472 0.195      348
```

Diff Scores `lang_type_ortho | anteriority`

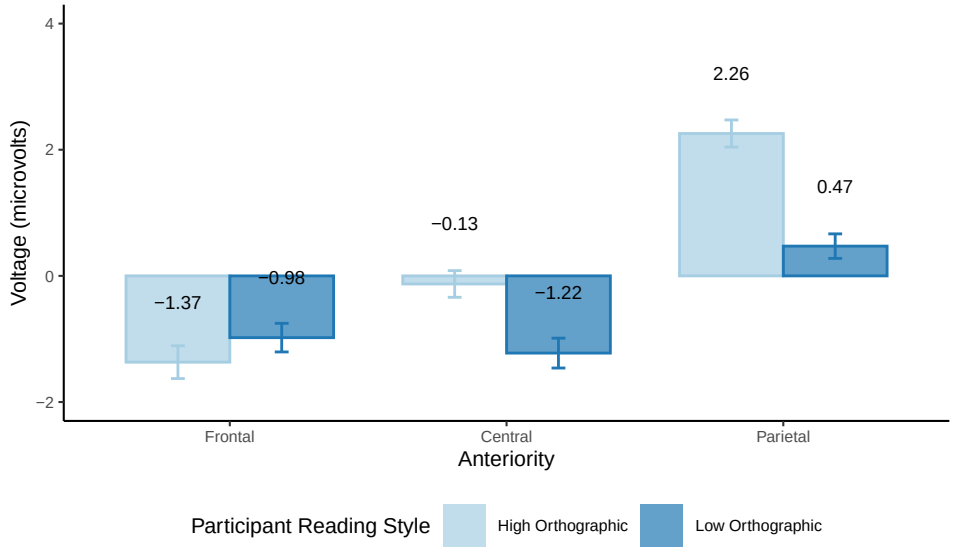
```
(difference_scores_1.1 <- nw_ltortho_ant_1 %>%
  pivot_wider(names_from = lang_type_ortho, values_from = c(mean, se, num_stim)) %>%
  mutate(mean_diff = `mean_Low Orthographic` - `mean_High Orthographic`,
         avg_se = mean(`se_Low Orthographic`,`se_High Orthographic`),
         total_num_stim = sum(`num_stim_Low Orthographic`, `num_stim_High Orthographic`)))
```

```
|| # A tibble: 3 x 10
|| # Groups:   anteriority [3]
||   anteriority `mean_High Orthographic` `mean_Low Orthographic`
||   <fct>                           <dbl>                   <dbl>
|| 1 Frontal                        -1.37                   -0.979
|| 2 Central                        -0.128                  -1.22
|| 3 Parietal                        2.26                    0.472
|| # i 7 more variables: `se_High Orthographic` <dbl>,
||   `se_Low Orthographic` <dbl>, `num_stim_High Orthographic` <int>,
||   `num_stim_Low Orthographic` <int>, mean_diff <dbl>, avg_se <dbl>,
||   total_num_stim <int>
```

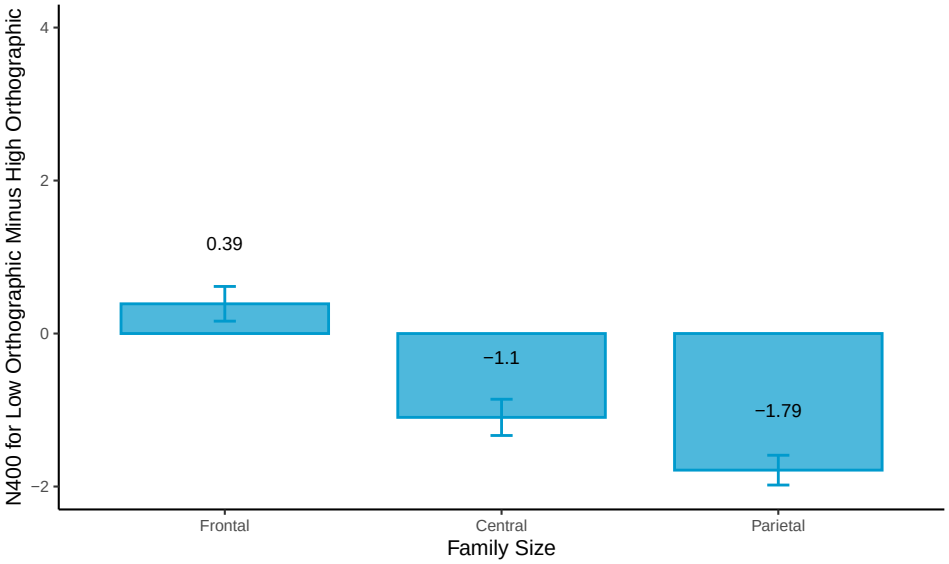
Plot interaction `lang_type_ortho | anteriority`

```
# plot raw scores
p1.a <-  nw_ltortho_ant_1 |> ggplot(aes(x=anteriority,
                                        y=mean,
                                        fill = lang_type_ortho,
                                        colour = lang_type_ortho,
                                        ymin = mean - se,
                                        ymax = mean + se)) +
  coord_cartesian(xlim = NULL,ylim = c(-2, 4), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = .75,  alpha = .7)  +
  labs(y = "Voltage (microvolts)", x = "Anteriority")  +
  geom_errorbar(width = .1, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
```

```
   geom_text(aes(label = round(mean, digits = 2)),colour = "black",size = 2.5, vjust = -4,
             position = position_dodge(.75))+
  guides(fill=guide_legend(title="Participant Reading Style"),
         colour= "none") +
  theme(legend.position = "bottom")
p1.a + scale_fill_brewer(palette = "Paired")+
      scale_colour_brewer(palette = "Paired")
```




```
# plot diff scores
p1.b <- difference_scores_1.1 |> ggplot(aes(x = anteriority,
                                      y = mean_diff,
                                      ymin = mean_diff - avg_se,
                                      ymax = mean_diff + avg_se)) +
  coord_cartesian(xlim = NULL,ylim = c(-2, 4), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.7,
           colour = "deepskyblue3", fill= "deepskyblue3") +
  labs(y = "N400 for Low Orthographic Minus High Orthographic", x = "Family Size") +
  geom_errorbar(width = .08, position = position_dodge(0.75), colour = "deepskyblue3") +
  theme_classic(base_size = 8) +
  geom_text(aes(label = round(mean_diff, digits = 2)),colour = "black",size = 2.5, vjust = -4,
             position = position_dodge(.75))+
    guides(fill=guide_legend(title="Anteriority"),
           colour= "none") +
  theme(legend.position = "bottom")
p1.b
```




```
# grid.arrange(p1.a, p1.b, nrow = 1)
```

### 6.1.2 Language Type Semantic by Complexity by Anteriority Interaction

Simple Effects `complexity | lang_type_semantic * anteriority`

```
# Examine the 2-way interaction between ` lang_type_semantics` and `complexity`
# at each level of `Anteriority`
(se_frontal_1.1 <-n400_1_nonwords |> filter(anteriority == "Frontal")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity,
          between = lang_type_semantic))
```

```
|| $ANOVA
||                          Effect DFn DFd          F          p p<.05
|| 2           lang_type_semantic   1  58 0.04094368 0.84035477
|| 3                   complexity   1  58 0.30137823 0.58512703
|| 4 lang_type_semantic:complexity   1  58 4.01792501 0.04969536     *
||            ges
|| 2 0.0006525972
|| 3 0.0003892505
|| 4 0.0051646322
```

```
(se_central_1.1 <-n400_1_nonwords |> filter(anteriority == "Central")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity,
          between = lang_type_semantic))
```

```
|| $ANOVA
||                          Effect DFn DFd           F         p p<.05
|| 2           lang_type_semantic   1  58 0.068996897 0.7937337
```

```
|| 3                    complexity   1  58 0.004955495 0.9441212
|| 4 lang_type_semantic:complexity   1  58 2.313923826 0.1336535
||            ges
|| 2 1.063029e-03
|| 3 9.009375e-06
|| 4 4.189261e-03
```

```
(se_parietal_1.1 <-n400_1_nonwords |> filter(anteriority == "Parietal")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity,
          between = lang_type_semantic))
```

```
|| $ANOVA
||                          Effect DFn DFd           F         p p<.05
|| 2           lang_type_semantic   1  58 0.395056322 0.5321210
|| 3                    complexity   1  58 0.007765497 0.9300832
|| 4 lang_type_semantic:complexity   1  58 0.216326500 0.6435949
||            ges
|| 2 5.948399e-03
|| 3 1.626214e-05
|| 4 4.528230e-04
```

```
# Examine `complexity` at each level of ` lang_type_semantic` at Frontal sites.
(se_frontal_hisem_1.1 <-n400_1_nonwords |> filter(anteriority == "Frontal" &
                                                   lang_type_semantic == "High Semantic")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity))
```

```
|| $ANOVA
||       Effect DFn DFd         F         p p<.05         ges
|| 2 complexity   1  29 0.9781744 0.3308307       0.002331362
```

```
(se_frontal_losem_1.1 <-n400_1_nonwords |> filter(anteriority == "Frontal" &
                                                   lang_type_semantic == "Low Semantic")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity))
```

```
|| $ANOVA
||       Effect DFn DFd        F        p p<.05        ges
|| 2 complexity   1  29 3.554641 0.069434       0.01006415
```

We found a marginally significant effect of complexity for low semantic readers at frontal sites $F(1, 29) = 3.554641, p = 0.069434$.

Pairwise Comparisons `complexity | lang_type_semantic * anteriority`

```
emms <- emmeans(anova_results.1b, ~ complexity| lang_type_semantic * anteriority )
pairwise_results <- pairs(emms, by = c("lang_type_semantic", "anteriority"))
summary(pairwise_results)
```

```
|| lang_type_semantic = High Semantic, anteriority = Frontal:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.4384 0.432 56  -1.016  0.3141
||
|| lang_type_semantic = Low Semantic, anteriority = Frontal:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.7347 0.429 56   1.714  0.0921
||
|| lang_type_semantic = High Semantic, anteriority = Central:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.4723 0.440 56  -1.073  0.2878
||
|| lang_type_semantic = Low Semantic, anteriority = Central:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.4505 0.437 56   1.031  0.3072
||
|| lang_type_semantic = High Semantic, anteriority = Parietal:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.1823 0.444 56  -0.410  0.6831
||
|| lang_type_semantic = Low Semantic, anteriority = Parietal:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.0871 0.441 56   0.197  0.8443
||
|| Results are averaged over the levels of: lang_type_ortho, laterality, family_size
```

Condition Means `complexity | lang_type_semantic * anteriority`

```
(nw_ltseman_cmplx_ant_1 <- n400_1_nonwords |>
    na.omit()|>
   group_by(anteriority, lang_type_semantic, complexity) |>
   summarise(mean = mean(value),
             se = sem(value),
             num_stim = n()))
```

```
|| # A tibble: 12 x 6
|| # Groups:   anteriority, lang_type_semantic [6]
||    anteriority lang_type_semantic complexity   mean    se num_stim
||    <fct>       <chr>              <chr>       <dbl> <dbl>    <int>
||  1 Frontal     High Semantic      complex    -1.29  0.315      180
||  2 Frontal     High Semantic      simple     -0.854 0.405      180
||  3 Frontal     Low Semantic       complex    -0.903 0.337      180
||  4 Frontal     Low Semantic       simple     -1.67  0.321      180
||  5 Central     High Semantic      complex    -1.00  0.272      180
||  6 Central     High Semantic      simple     -0.552 0.380      180
||  7 Central     Low Semantic       complex    -0.294 0.298      180
||  8 Central     Low Semantic       simple     -0.786 0.316      180
||  9 Parietal    High Semantic      complex     1.05  0.255      180
|| 10 Parietal    High Semantic      simple      1.22  0.347      180
|| 11 Parietal    Low Semantic       complex     1.71  0.269      180
|| 12 Parietal    Low Semantic       simple      1.60  0.314      180
```

Diff Scores `complexity | lang_type_semantic * anteriority`

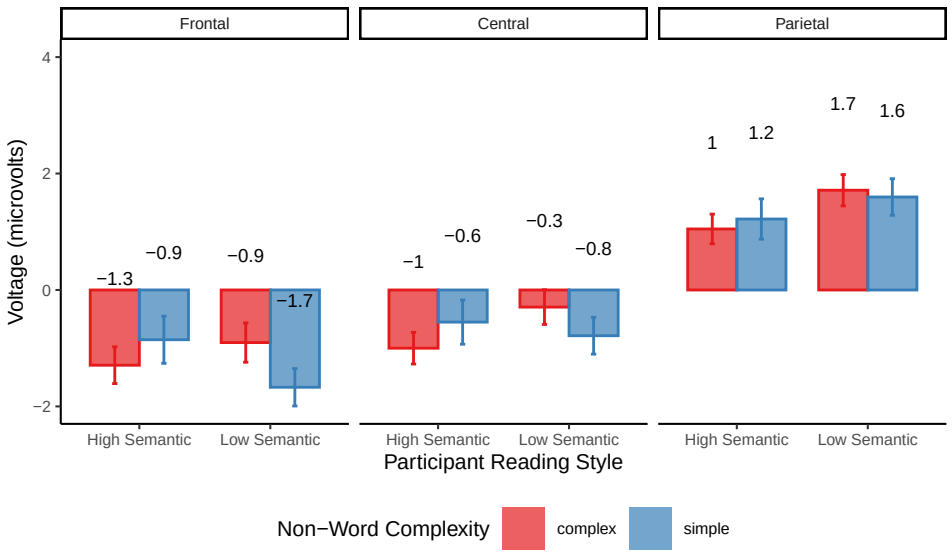
```r
(difference_scores_1.2 <- nw_ltseman_cmplx_ant_1 %>%
  pivot_wider(names_from = complexity, values_from = c(mean, se, num_stim)) %>%
  mutate(mean_diff = `mean_simple` - `mean_complex`,
         avg_se = mean(`se_complex`,`se_simple`),
         total_num_stim = sum(`num_stim_complex`, `num_stim_simple`)))
```

```
|| # A tibble: 6 x 11
|| # Groups:   anteriority, lang_type_semantic [6]
||   anteriority lang_type_semantic mean_complex mean_simple se_complex se_simple
||   <fct>       <chr>                     <dbl>       <dbl>      <dbl>     <dbl>
|| 1 Frontal     High Semantic            -1.29       -0.854      0.315     0.405
|| 2 Frontal     Low Semantic             -0.903      -1.67       0.337     0.321
|| 3 Central     High Semantic            -1.00       -0.552      0.272     0.380
|| 4 Central     Low Semantic             -0.294      -0.786      0.298     0.316
|| 5 Parietal    High Semantic             1.05        1.22       0.255     0.347
|| 6 Parietal    Low Semantic              1.71        1.60       0.269     0.314
|| # i 5 more variables: num_stim_complex <int>, num_stim_simple <int>,
|| #   mean_diff <dbl>, avg_se <dbl>, total_num_stim <int>
```

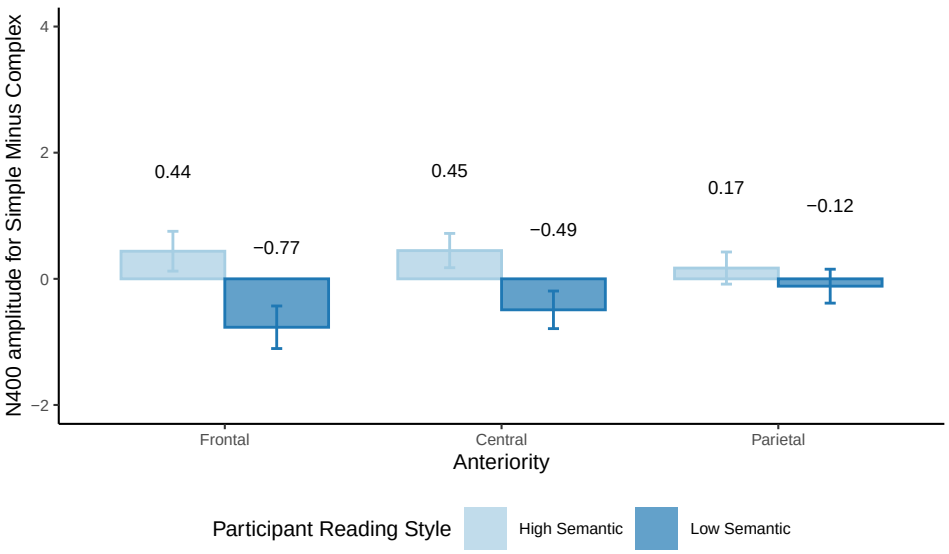
Plot interaction `complexity | lang_type_semantic * anteriority`

```r
# plot raw scores
# facet_wrap() wraps a 1d sequence of panels into 2d. Use vars() to supply faceting variables;
# Control the number of rows and columns with nrow and ncol.


p2.a <-  nw_ltseman_cmplx_ant_1 |> ggplot(aes(x= lang_type_semantic, y=mean,
                                              fill = complexity, colour = complexity,
                                              ymin = mean - se, ymax = mean + se)) +
  facet_wrap(vars(anteriority), ncol = 3, labeller = "label_value") +
  coord_cartesian(xlim = NULL, ylim = c(-2, 4), expand = TRUE, default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = .7)  +
  labs(y = "Voltage (microvolts)", x = "Participant Reading Style")  +
  geom_errorbar(width = .08, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
   geom_text(aes(label = round(mean, digits = 1)), colour = "black",
             size = 2.5,  vjust = -6,
             position = position_dodge(.75))+
  guides(fill=guide_legend(title="Non-Word Complexity"),
         colour= "none") +
  theme(legend.position = "bottom")
p2.a + scale_fill_brewer(palette = "Set1")+
      scale_colour_brewer(palette = "Set1")
```




```r
# plot diff scores
p2.b <- difference_scores_1.2 |> ggplot(aes(x = anteriority,
                                            y = mean_diff,
                                            fill = lang_type_semantic,
                                            colour = lang_type_semantic,
                                            ymin = mean_diff - avg_se,
                                            ymax = mean_diff + avg_se)) +
  coord_cartesian(xlim = NULL,ylim = c(-2, 4), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.7) +
  labs(y = "N400 amplitude for Simple Minus Complex", x = "Anteriority") +
  geom_errorbar(width = .08, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
  geom_text(aes(label = round(mean_diff, digits = 2)),colour = "black",size = 2.5, vjust = -5.5,
            position = position_dodge(.75))+
  guides(fill=guide_legend(title="Participant Reading Style"),
         colour= "none") +
  theme(legend.position = "bottom")
p2.b + scale_fill_brewer(palette = "Paired")+
      scale_colour_brewer(palette = "Paired")
```




```
# grid.arrange(p2.a, p2.b, nrow = 1)
```

### 6.1.3 Language Type Semantic by Complexity by Family Size by Anteriority xLaterality Interaction

Simple Effects `complexity | lang_type_semantic * family_size * laterality * anteriority`

```
# Examine the 4-way interaction between `anteriority`, `laterality`, ` complexity`,
# and `lang_type_semantics` at each level of `family_size`
se_large_1.2 <-n400_1_nonwords |> filter(family_size == "small")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, anteriority, laterality),
          between = .(lang_type_semantic),
          type = 3)
se_large_1.2$`Sphericity Corrections`
```

```
||                                                 Effect       GGe        p[GG]
|| 5                                          anteriority 0.5877977 5.226438e-06
|| 6                        lang_type_semantic:anteriority 0.5877977 4.212926e-01
|| 7                                           laterality 0.9296346 1.417183e-02
|| 8                         lang_type_semantic:laterality 0.9296346 5.257013e-01
|| 9                               complexity:anteriority 0.7315483 2.084201e-01
|| 10            lang_type_semantic:complexity:anteriority 0.7315483 3.409306e-02
|| 11                               complexity:laterality 0.6619652 8.363483e-01
|| 12             lang_type_semantic:complexity:laterality 0.6619652 4.833896e-01
|| 13                              anteriority:laterality 0.8897184 8.029706e-01
|| 14            lang_type_semantic:anteriority:laterality 0.8897184 9.174250e-02
|| 15                     complexity:anteriority:laterality 0.6511878 3.733883e-01
|| 16 lang_type_semantic:complexity:anteriority:laterality 0.6511878 5.648750e-01
||    p[GG]<.05       HFe        p[HF] p[HF]<.05
|| 5          * 0.5927043 4.852480e-06         *
|| 6            0.5927043 4.223687e-01
|| 7          * 0.9591689 1.327969e-02         *
```

```
|| 8            0.9591689 5.304743e-01
|| 9            0.7457315 2.082156e-01
|| 10         * 0.7457315 3.326040e-02         *
|| 11           0.6714642 8.395393e-01
|| 12           0.6714642 4.856050e-01
|| 13           0.9550388 8.163619e-01
|| 14           0.9550388 8.664207e-02
|| 15           0.6845367 3.757644e-01
|| 16           0.6845367 5.723442e-01
```

```
se_small_1.2 <-n400_1_nonwords |> filter(family_size == "large")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, anteriority, laterality),
          between = lang_type_semantic)
se_small_1.2$`Sphericity Corrections`
```

```
||                                                 Effect       GGe        p[GG]
|| 5                                          anteriority 0.5833484 1.306481e-06
|| 6                        lang_type_semantic:anteriority 0.5833484 6.826749e-01
|| 7                                           laterality 0.9382545 1.523694e-02
|| 8                         lang_type_semantic:laterality 0.9382545 1.859127e-01
|| 9                                 complexity:anteriority 0.7257036 7.562029e-01
|| 10            lang_type_semantic:complexity:anteriority 0.7257036 4.829131e-01
|| 11                               complexity:laterality 0.8915579 6.711843e-01
|| 12             lang_type_semantic:complexity:laterality 0.8915579 1.597364e-02
|| 13                               anteriority:laterality 0.7609519 3.867782e-01
|| 14            lang_type_semantic:anteriority:laterality 0.7609519 1.254459e-01
|| 15                     complexity:anteriority:laterality 0.8623185 2.967915e-01
|| 16 lang_type_semantic:complexity:anteriority:laterality 0.8623185 1.153984e-03
||    p[GG]<.05       HFe        p[HF] p[HF]<.05
|| 5          * 0.5879925 1.204685e-06         *
|| 6            0.5879925 6.845975e-01
|| 7          * 0.9685252 1.428896e-02         *
|| 8            0.9685252 1.848623e-01
|| 9            0.7394793 7.606230e-01
|| 10           0.7394793 4.857014e-01
|| 11           0.9179078 6.773569e-01
|| 12         * 0.9179078 1.508526e-02         *
|| 13           0.8078464 3.895622e-01
|| 14           0.8078464 1.214120e-01
|| 15           0.9234853 2.962140e-01
|| 16         * 0.9234853 8.461187e-04         *
```

```
# Examine the 3-way interaction between ` complexity`, `anteriority` and `laterality`
# at each level of `lang_type_semantics` for non-words from large families

se_large_hisem_1.2 <-n400_1_nonwords |> filter(family_size == "large" &
                                                 lang_type_semantic == "High Semantic")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(anteriority, laterality, complexity))
se_large_hisem_1.2$`Sphericity Corrections`
```

```
||                              Effect       GGe        p[GG] p[GG]<.05       HFe
|| 2                       anteriority 0.6023468 0.0001447145         * 0.6141470
|| 3                        laterality 0.8812502 0.4019891769           0.9339149
|| 5            anteriority:laterality 0.7524811 0.9095138521           0.8493408
|| 6            anteriority:complexity 0.7787256 0.4504359268           0.8148575
|| 7             laterality:complexity 0.9231621 0.0755519000           0.9831031
|| 8 anteriority:laterality:complexity 0.6773663 0.0015339911         * 0.7539211
||          p[HF] p[HF]<.05
|| 2 0.0001287756         *
|| 3 0.4069173672
|| 5 0.9272981032
|| 6 0.4559555632
|| 7 0.0717961604
|| 8 0.0009662473         *
```

```
se_large_losem_1.2 <-n400_1_nonwords |> filter(family_size == "large" &
                                                 lang_type_semantic == "Low Semantic")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, anteriority, laterality))
se_large_losem_1.2$`Sphericity Corrections`
```

```
||                              Effect       GGe       p[GG] p[GG]<.05       HFe
|| 3                       anteriority 0.5721683 0.001550498         * 0.5803146
|| 4                        laterality 0.9287134 0.015597325         * 0.9896409
|| 5            complexity:anteriority 0.6653244 0.768354090           0.6852251
|| 6             complexity:laterality 0.8410003 0.153418415           0.8869613
|| 7            anteriority:laterality 0.6895723 0.074052597           0.7692779
|| 8 complexity:anteriority:laterality 0.8438151 0.251937811           0.9683787
||          p[HF] p[HF]<.05
|| 3 0.001468749         *
|| 4 0.013675650         *
|| 5 0.775338472
|| 6 0.151054916
|| 7 0.066766337
|| 8 0.247329543
```

```
# Examine the 2-way interaction between complexity and anteriority
# at each level of laterality for non-words from large families for high semantic readers

# left
se_large_hisem_left_1.2 <-n400_1_nonwords |>
  filter(family_size == "large" &
           lang_type_semantic == "High Semantic" &
           laterality == "Left")|>
    ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, anteriority))
se_large_hisem_left_1.2$`Sphericity Corrections`
```

```
||                   Effect       GGe       p[GG] p[GG]<.05       HFe        p[HF]
|| 3            anteriority 0.6103869 0.000691371         * 0.6231853 0.0006285362
|| 4 complexity:anteriority 0.9038317 0.007020196         * 0.9603791 0.0059447200
```

```
||   p[HF]<.05
|| 3         *
|| 4         *
```

```
# midline
se_large_hisem_mid_1.2 <-n400_1_nonwords |>
    filter(family_size == "large" &
             lang_type_semantic == "High Semantic" &
             laterality == "Midline")|>
    ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, anteriority))
se_large_hisem_mid_1.2$`Sphericity Corrections`
```

```
||                   Effect       GGe        p[GG] p[GG]<.05       HFe
|| 3            anteriority 0.7310120 5.115819e-05         * 0.7600544
|| 4 complexity:anteriority 0.8702103 6.550016e-01           0.9210087
||          p[HF] p[HF]<.05
|| 3 3.877134e-05         *
|| 4 6.667250e-01
```

```
# right
se_large_hisem_right_1.2 <-n400_1_nonwords |>
    filter(family_size == "large" &
             lang_type_semantic == "High Semantic" &
             laterality == "Right")|>
    ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, anteriority))
se_large_hisem_right_1.2$`Sphericity Corrections`
```

```
||                   Effect       GGe          p[GG] p[GG]<.05       HFe
|| 3            anteriority 0.5966206 0.0005195585         * 0.6077162
|| 4 complexity:anteriority 0.8784828 0.4201193338           0.9306777
||          p[HF] p[HF]<.05
|| 3 0.0004752553         *
|| 4 0.4256456127
```

```
# Finally we examine the simple effect of complexity at each level of anteriority
# for non-words from large families for high semantic readers at left sites
# Frontal
se_large_hisem_left_frontal_1.2 <- n400_1_nonwords |>
      filter(family_size == "large" &
               lang_type_semantic == "High Semantic" &
               laterality == "Left" &
               anteriority == "Frontal" )|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity))
se_large_hisem_left_frontal_1.2$ANOVA
```

```
||       Effect DFn DFd        F          p p<.05        ges
|| 2 complexity   1  29 3.014575 0.09313352       0.01384321
```

```
# Central
se_large_hisem_left_central_1.2 <- n400_1_nonwords |>
      filter(family_size == "large" &
               lang_type_semantic == "High Semantic" &
               laterality == "Left" &
               anteriority == "Central" )|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity))
se_large_hisem_left_central_1.2$ANOVA
```

```
||       Effect DFn DFd        F         p p<.05        ges
|| 2 complexity   1  29 2.069132 0.1610126       0.01167704
```

```
# Parietal
se_large_hisem_left_parietal_1.2 <- n400_1_nonwords |>
      filter(family_size == "large" &
               lang_type_semantic == "High Semantic" &
               laterality == "Left" &
               anteriority == "Parietal" )|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity))
se_large_hisem_left_parietal_1.2$ANOVA
```

```
||       Effect DFn DFd          F         p p<.05          ges
|| 2 complexity   1  29 0.01923914 0.8906418       0.0001103723
```

We found a marginally significant effect of complexity for high semantic readers for large morphological families at left frontal sites $F(1, 29) = 3.014575, p = 0.09313352$

Pairwise Comparisons `complexity | lang_type_semantic * family_size * laterality * anteriority`

```
emms <- emmeans(anova_results.1b,~complexity|lang_type_semantic*family_size*laterality*anteriority)
pairwise_results <- pairs(emms,by = c("laterality","anteriority","lang_type_semantic","family_size"))
summary(pairwise_results)
```

```
|| laterality = Left, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.2048 0.596 56  -0.344  0.7324
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.7574 0.652 56  -1.162  0.2503
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.7674 0.694 56  -1.105  0.2737
||
|| laterality = Left, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.6970 0.642 56  -1.086  0.2822
```

```
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = High Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.4612 0.686 56  -0.672  0.5044
||
|| laterality = Right, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.5128 0.852 56  -0.602  0.5499
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.2547 0.709 56  -0.359  0.7207
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.3552 0.746 56  -0.476  0.6357
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.3839 0.677 56  -0.567  0.5728
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.8275 0.592 56   1.398  0.1676
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   1.1027 0.648 56   1.703  0.0942
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.9574 0.690 56   1.388  0.1705
||
|| laterality = Left, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.2168 0.638 56   0.340  0.7351
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.5713 0.682 56   0.838  0.4057
||
|| laterality = Right, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.8043 0.847 56   0.950  0.3462
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.0936 0.704 56  -0.133  0.8947
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.4418 0.741 56  -0.596  0.5533
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
```

```
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.1114 0.672 56   0.166  0.8690
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.9630 0.672 56  -1.432  0.1576
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.0297 0.672 56  -0.044  0.9649
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.0921 0.625 56   0.147  0.8835
||
|| laterality = Left, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.7249 0.564 56  -1.285  0.2042
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = High Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.0967 0.683 56  -0.141  0.8880
||
|| laterality = Right, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.3409 0.617 56  -0.553  0.5825
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.1509 0.539 56   0.280  0.7806
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = larg
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.1920 0.590 56   0.325  0.7461
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple  -0.4429 0.614 56  -0.721  0.4739
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.9361 0.668 56   1.402  0.1665
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.4352 0.667 56   0.652  0.5168
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.1493 0.621 56   0.240  0.8109
||
|| laterality = Left, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.6179 0.560 56   1.103  0.2749
```

```
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.0525 0.679 56   0.077  0.9386
||
|| laterality = Right, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.4399 0.612 56   0.718  0.4755
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.3484 0.536 56   0.651  0.5180
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.3400 0.586 56   0.580  0.5641
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   0.2579 0.610 56   0.423  0.6742
||
|| Results are averaged over the levels of: lang_type_ortho
```

Condition Means `complexity | lang_type_semantic * family_size * laterality * anteriority`

```
(nw_sem_famsize_lat_ant_cmplx_1 <- n400_1_nonwords |>
    na.omit()|>
   group_by( lang_type_semantic, family_size, laterality, anteriority, complexity  ) |>
   summarise(mean = mean(value),
             se = sem(value),
             num_stim = n()))
```

```
|| # A tibble: 72 x 8
|| # Groups:   lang_type_semantic, family_size, laterality, anteriority [36]
||    lang_type_semantic family_size laterality anteriority complexity   mean    se
||    <chr>              <chr>       <fct>      <fct>       <chr>       <dbl> <dbl>
||  1 High Semantic      large       Left       Frontal     complex    -1.66  0.794
||  2 High Semantic      large       Left       Frontal     simple     -0.582 0.884
||  3 High Semantic      large       Left       Central     complex    -1.13  0.638
||  4 High Semantic      large       Left       Central     simple     -0.337 0.716
||  5 High Semantic      large       Left       Parietal    complex     1.26  0.628
||  6 High Semantic      large       Left       Parietal    simple      1.18  0.717
||  7 High Semantic      large       Midline    Frontal     complex    -1.32  0.764
||  8 High Semantic      large       Midline    Frontal     simple     -1.25  0.936
||  9 High Semantic      large       Midline    Central     complex    -1.15  0.798
|| 10 High Semantic      large       Midline    Central     simple     -1.04  0.967
|| # i 62 more rows
|| # i 1 more variable: num_stim <int>
```

Diff Scores `complexity | lang_type_semantic * family_size * laterality * anteriority`

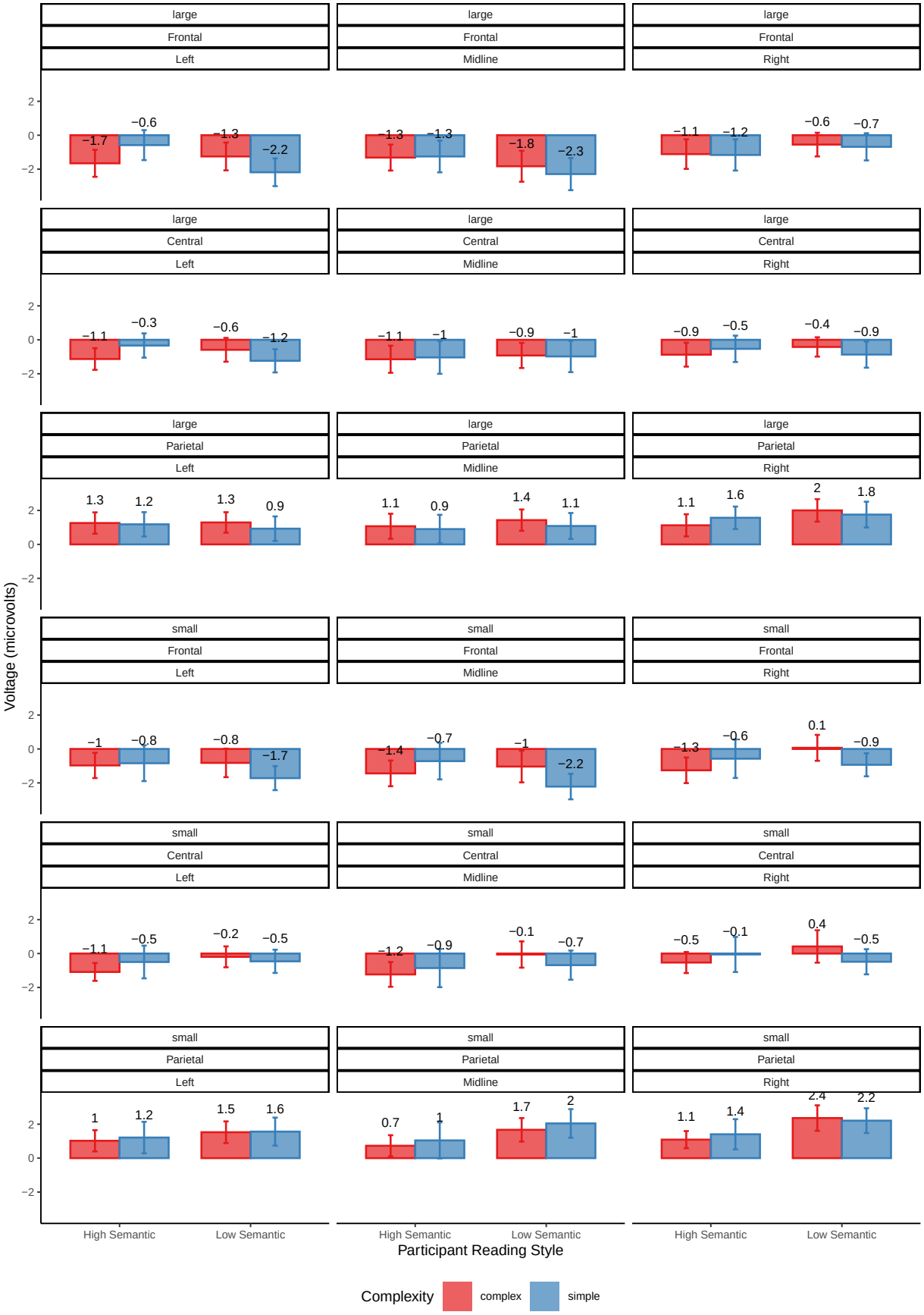
```
(difference_scores_1.3 <- nw_sem_famsize_lat_ant_cmplx_1 %>%
  pivot_wider(names_from = complexity, values_from = c(mean, se, num_stim)) %>%
  mutate(mean_diff = `mean_simple` - `mean_complex`,
         avg_se = mean(`se_complex`,`se_simple`),
         total_num_stim = sum(`num_stim_complex`, `num_stim_simple`)))
```

```
|| # A tibble: 36 x 13
|| # Groups:   lang_type_semantic, family_size, laterality, anteriority [36]
||    lang_type_semantic family_size laterality anteriority mean_complex
||    <chr>              <chr>       <fct>      <fct>              <dbl>
||  1 High Semantic      large       Left       Frontal           -1.66
||  2 High Semantic      large       Left       Central           -1.13
||  3 High Semantic      large       Left       Parietal           1.26
||  4 High Semantic      large       Midline    Frontal           -1.32
||  5 High Semantic      large       Midline    Central           -1.15
||  6 High Semantic      large       Midline    Parietal           1.07
||  7 High Semantic      large       Right      Frontal           -1.11
||  8 High Semantic      large       Right      Central           -0.877
||  9 High Semantic      large       Right      Parietal           1.12
|| 10 High Semantic      small       Left       Frontal           -0.971
|| # i 26 more rows
|| # i 8 more variables: mean_simple <dbl>, se_complex <dbl>, se_simple <dbl>,
|| #   num_stim_complex <int>, num_stim_simple <int>, mean_diff <dbl>,
|| #   avg_se <dbl>, total_num_stim <int>
```

**Plot interaction `complexity | lang_type_semantic * family_size * laterality * anteriority` Raw Scores** `facet_wrap()` wraps a 1d sequence of panels into 2d. Use `vars()` to supply faceting variables; Control the number of rows and columns with `nrow` and `ncol`. `labeller` options are "label_value" and "label_both". The latter prints the name of the variable & its value.

Plot raw scores

```
p3.a <-  nw_sem_famsize_lat_ant_cmplx_1 |> ggplot(aes(x= lang_type_semantic, y=mean,
                                          fill = complexity, colour = complexity,
                                          ymin = mean - se, ymax = mean + se)) +
  facet_wrap(vars(family_size, anteriority, laterality),
             labeller = "label_value", ncol = 3) +
  coord_cartesian(xlim = NULL, ylim = c(-3.5, 3.5), expand=TRUE, default=FALSE, clip="on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.7)  +
  labs(y = "Voltage (microvolts)", x = "Participant Reading Style")  +
  geom_errorbar(width = .08, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
   geom_text(aes(label = round(mean, digits = 1)),
             colour = "black",
             size = 2.5,
             vjust = -2,
             position = position_dodge(.75))+
  guides(fill=guide_legend(title="Complexity"),
         colour= "none") +
  theme(legend.position = "bottom")
p3.a + scale_fill_brewer(palette = "Set1")+
      scale_colour_brewer(palette = "Set1")
```


large
Frontal
Left
large
Frontal
Midline
large
Frontal
Right
large
Central
Left
large
Central
Midline
large
Central
Right
large
Parietal
Left
large
Parietal
Midline
large
Parietal
Right
small
Frontal
Left
small
Frontal
Midline
small
Frontal
Right
small
Central
Left
small
Central
Midline
small
Central
Right
small
Parietal
Left
small
Parietal
Midline
small
Parietal
Right
Voltage (microvolts)
High Semantic
Low Semantic
Participant Reading Style
Complexity
complex
simple

Plot diff scores

```
p3.b <- difference_scores_1.3 |> ggplot(aes(x = family_size, y = mean_diff,
                                    fill = lang_type_semantic, colour = lang_type_semantic,
                                    ymin = mean_diff - avg_se, ymax = mean_diff + avg_se)) +
     facet_wrap(vars(anteriority, laterality),
           labeller = "label_value", ncol = 3) +
  coord_cartesian(xlim = NULL,ylim = c(-4, 4), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.7) +
  labs(y = "N400 amplitude for Simple Minus Complex", x = "Family Size") +
  geom_errorbar(width = .08, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
  geom_text(aes(label = round(mean_diff, digits = 2)),colour = "black",size = 2.5, vjust = -5.5,
            position = position_dodge(.75))+
  guides(fill=guide_legend(title="Participant Reading Style"),
         colour= "none") +
  theme(legend.position = "bottom")
p3.b + scale_fill_brewer(palette = "Paired")+
     scale_colour_brewer(palette = "Paired")
```