m21 LDT ERP analysis N250

Joanna Morris

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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

```
n250_1_words <- n250_1 |> filter(bini %in% c(1:2))
n250_1_nonwords <- n250_1 |> filter(bini %in% c(3:6))
n250_1_diff <- n250_1 |> filter(bini %in% c(9:11))

n250_2_words <- n250_2 |> filter(bini %in% c(1:2))
n250_2_nonwords <- n250_2 |> filter(bini %in% c(3:6))
n250_2_diff <- n250_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 Now we can compute the ANOVA using `ezANOVA` and `aov_ez`

4.1 Group 1

```
anova_results.1a <- ezANOVA(n250_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 5.923851e-01 4.447328e-01       5.231956e-03
```

```
|| 3    1  56 2.527261e+00 1.175246e-01       2.194579e-02
|| 5    1  56 3.114857e-01 5.789945e-01       4.723971e-04
|| 9    1  56 1.851730e-01 6.686164e-01       2.910648e-04
|| 13   2 112 1.005751e+01 9.613578e-05     * 2.260062e-02
|| 17   2 112 1.476640e+00 2.328160e-01       5.760913e-04
|| 4    1  56 4.806680e-01 4.909855e-01       4.249462e-03
|| 6    1  56 2.766313e-01 6.009945e-01       4.195595e-04
|| 7    1  56 7.028264e-01 4.053998e-01       1.065270e-03
|| 10   1  56 6.279683e-01 4.314459e-01       9.863876e-04
|| 11   1  56 1.317063e-01 7.180356e-01       2.070404e-04
|| 14   2 112 6.825905e-02 9.340573e-01       1.569097e-04
|| 15   2 112 1.395414e-01 8.699080e-01       3.207165e-04
|| 18   2 112 9.288165e-02 9.113715e-01       3.625610e-05
|| 19   2 112 5.560171e-01 5.750634e-01       2.170006e-04
|| 21   1  56 9.548137e-01 3.326995e-01       1.429864e-03
|| 25   2 112 1.153696e-01 8.911425e-01       2.470441e-05
|| 29   2 112 1.471373e+00 2.340138e-01       3.174114e-04
|| 33   2 112 1.952539e-02 9.806673e-01       2.254712e-06
|| 37   2 112 5.222836e-01 5.946020e-01       7.478559e-05
|| 41   4 224 9.837849e-01 4.171722e-01       3.482273e-04
|| 8    1  56 4.495542e-01 5.053026e-01       6.816482e-04
|| 12   1  56 1.562321e-01 6.941512e-01       2.455851e-04
|| 16   2 112 2.805294e-01 7.559130e-01       6.445490e-04
|| 20   2 112 4.075575e-01 6.662558e-01       1.590694e-04
|| 22   1  56 3.931095e-04 9.842519e-01       5.895366e-07
|| 23   1  56 7.572899e-02 7.841839e-01       1.135561e-04
|| 26   2 112 2.350406e+00 1.000166e-01       5.030580e-04
|| 27   2 112 2.830246e-01 7.540385e-01       6.060264e-05
|| 30   2 112 2.909670e+00 5.862470e-02       6.274928e-04
|| 31   2 112 4.075641e-02 9.600772e-01       8.794877e-06
|| 34   2 112 2.419010e+00 9.364715e-02       2.792599e-04
|| 35   2 112 2.332859e-01 7.923109e-01       2.693823e-05
|| 38   2 112 5.445966e-01 5.816040e-01       7.798033e-05
|| 39   2 112 1.827437e-01 8.332295e-01       2.616828e-05
|| 42   4 224 2.311072e+00 5.867584e-02       8.176590e-04
|| 43   4 224 6.565069e-01 6.228652e-01       2.324087e-04
|| 45   2 112 3.667501e+00 2.865563e-02     * 7.442768e-04
|| 49   2 112 7.668078e-01 4.669163e-01       7.357447e-05
|| 53   4 224 7.567599e-01 5.544595e-01       9.316782e-05
|| 57   4 224 1.417270e+00 2.290923e-01       1.929653e-04
|| 24   1  56 3.367750e+00 7.179735e-02       5.025155e-03
|| 28   2 112 1.173787e+00 3.129678e-01       2.512893e-04
|| 32   2 112 6.587968e-01 5.194671e-01       1.421436e-04
|| 36   2 112 1.582326e-01 8.538417e-01       1.827176e-05
|| 40   2 112 4.942383e-01 6.113596e-01       7.077007e-05
|| 44   4 224 1.134669e+00 3.409749e-01       4.016138e-04
|| 46   2 112 3.195000e+00 4.472683e-02     * 6.484504e-04
|| 47   2 112 1.404967e-01 8.690794e-01       2.853260e-05
|| 50   2 112 9.516795e-01 3.891916e-01       9.131111e-05
|| 51   2 112 6.072227e-01 5.466458e-01       5.826333e-05
|| 54   4 224 4.402994e-01 7.794051e-01       5.420918e-05
|| 55   4 224 1.657943e+00 1.607691e-01       2.040935e-04
|| 58   4 224 9.222684e-01 4.517284e-01       1.255779e-04
|| 59   4 224 1.935981e+00 1.054039e-01       2.635707e-04
```

```
|| 61   4 224 8.950801e-01 4.676429e-01       8.848617e-05
|| 48   2 112 4.218830e-01 6.568486e-01       8.567268e-05
|| 52   2 112 1.885387e+00 1.565557e-01       1.808817e-04
|| 56   4 224 1.118854e+00 3.483973e-01       1.377405e-04
|| 60   4 224 7.536243e-01 5.565349e-01       1.026174e-04
|| 62   4 224 2.953256e+00 2.091360e-02     * 2.918947e-04
|| 63   4 224 1.270423e+00 2.824838e-01       1.255873e-04
|| 64   4 224 4.912276e-01 7.421871e-01       4.856391e-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 0.5972431 0.001304555         * 0.6029112 0.001257218         *
|| 14 0.5972431 0.837518865           0.6029112 0.839672733
|| 15 0.5972431 0.754896282           0.6029112 0.757222816
|| 16 0.5972431 0.639408974           0.6029112 0.641585728
|| 17 0.9676624 0.233235915           1.0017031 0.232815957
|| 18 0.9676624 0.905858758           1.0017031 0.911371470
|| 19 0.9676624 0.569462988           1.0017031 0.575063438
|| 20 0.9676624 0.659564183           1.0017031 0.666255802
|| 25 0.7502068 0.833213400           0.7662772 0.837863971
|| 26 0.7502068 0.115418277           0.7662772 0.114395461
|| 27 0.7502068 0.689896024           0.7662772 0.694708068
|| 28 0.7502068 0.302915562           0.7662772 0.303770040
|| 29 0.8505385 0.235414362           0.8744316 0.235276279
|| 30 0.8505385 0.067715573           0.8744316 0.066178672
|| 31 0.8505385 0.940469926           0.8744316 0.944187226
|| 32 0.8505385 0.496166867           0.8744316 0.500145938
|| 33 0.8991522 0.972805451           0.9271236 0.975270917
|| 34 0.8991522 0.099780158           0.9271236 0.098048983
|| 35 0.8991522 0.768899059           0.9271236 0.775720472
|| 36 0.8991522 0.831791882           0.9271236 0.838278893
|| 37 0.7663538 0.547312040           0.7836293 0.551250444
|| 38 0.7663538 0.535769584           0.7836293 0.539585895
|| 39 0.7663538 0.774446773           0.7836293 0.779595581
|| 40 0.7663538 0.562273428           0.7836293 0.566364070
|| 41 0.8210441 0.406858787           0.8782850 0.410474245
|| 42 0.8210441 0.071959020           0.8782850 0.067398255
|| 43 0.8210441 0.593354269           0.8782850 0.603395685
|| 44 0.8210441 0.338364356           0.8782850 0.339424158
|| 45 0.7250612 0.043412643         * 0.7392957 0.042492026         *
|| 46 0.7250612 0.061596114           0.7392957 0.060593244
|| 47 0.7250612 0.800367251           0.7392957 0.804843519
|| 48 0.7250612 0.592315817           0.7392957 0.596207686
|| 49 0.8568951 0.448848857           0.8813107 0.452142415
|| 50 0.8568951 0.377678944           0.8813107 0.379811875
|| 51 0.8568951 0.522395952           0.8813107 0.526794692
|| 52 0.8568951 0.163015221           0.8813107 0.161935414
|| 53 0.6942320 0.510664271           0.7341031 0.517326907
|| 54 0.6942320 0.709437807           0.7341031 0.720314914
|| 55 0.6942320 0.181986571           0.7341031 0.179166456
|| 56 0.6942320 0.341071099           0.7341031 0.342510395
|| 57 0.6606241 0.242723922           0.6963514 0.241503347
|| 58 0.6606241 0.422055790           0.6963514 0.425962660
|| 59 0.6606241 0.133771459           0.6963514 0.130493008
|| 60 0.6606241 0.506442583           0.6963514 0.512766465
|| 61 0.9298523 0.461995624           1.0042270 0.467642933
|| 62 0.9298523 0.023983403         * 1.0042270 0.020913597         *
|| 63 0.9298523 0.283813807           1.0042270 0.282483787
```

```
|| 64 0.9298523 0.728778628           1.0042270 0.742187144
```

```r
anova_results.1b <- aov_ez(id = "SubjID",
                           dv = "value",
                           data = n250_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, 56 192.65     0.59  .005    .445
|| 2           1, 56 192.65     2.53  .022    .118
|| 3           1, 56 192.65     0.48  .004    .491
|| 4           1, 56  32.92     0.31 <.001    .579
|| 5           1, 56  32.92     0.28 <.001    .601
|| 6           1, 56  32.92     0.70  .001    .405
|| 7           1, 56  32.92     0.45 <.001    .505
|| 8           1, 56  34.12     0.19 <.001    .669
|| 9           1, 56  34.12     0.63 <.001    .431
|| 10          1, 56  34.12     0.13 <.001    .718
|| 11          1, 56  34.12     0.16 <.001    .694
|| 12  1.19, 66.89  41.76 10.06 **  .023    .001
|| 13  1.19, 66.89  41.76     0.07 <.001    .838
|| 14  1.19, 66.89  41.76     0.14 <.001    .755
|| 15  1.19, 66.89  41.76     0.28 <.001    .639
|| 16 1.94, 108.38   4.38     1.48 <.001    .233
|| 17 1.94, 108.38   4.38     0.09 <.001    .906
|| 18 1.94, 108.38   4.38     0.56 <.001    .569
|| 19 1.94, 108.38   4.38     0.41 <.001    .660
|| 20          1, 56  32.54     0.95  .001    .333
|| 21          1, 56  32.54     0.00 <.001    .984
|| 22          1, 56  32.54     0.08 <.001    .784
|| 23          1, 56  32.54   3.37 +  .005    .072
|| 24  1.50, 84.02   3.10     0.12 <.001    .833
|| 25  1.50, 84.02   3.10     2.35 <.001    .115
|| 26  1.50, 84.02   3.10     0.28 <.001    .690
|| 27  1.50, 84.02   3.10     1.17 <.001    .303
```

```
|| 28  1.70, 95.26   2.75     1.47 <.001    .235
|| 29  1.70, 95.26   2.75   2.91 + <.001    .068
|| 30  1.70, 95.26   2.75     0.04 <.001    .940
|| 31  1.70, 95.26   2.75     0.66 <.001    .496
|| 32 1.80, 100.71   1.39     0.02 <.001    .973
|| 33 1.80, 100.71   1.39   2.42 + <.001    .100
|| 34 1.80, 100.71   1.39     0.23 <.001    .769
|| 35 1.80, 100.71   1.39     0.16 <.001    .832
|| 36  1.53, 85.83   2.03     0.52 <.001    .547
|| 37  1.53, 85.83   2.03     0.54 <.001    .536
|| 38  1.53, 85.83   2.03     0.18 <.001    .774
|| 39  1.53, 85.83   2.03     0.49 <.001    .562
|| 40 3.28, 183.91   2.34     0.98 <.001    .407
|| 41 3.28, 183.91   2.34   2.31 + <.001    .072
|| 42 3.28, 183.91   2.34     0.66 <.001    .593
|| 43 3.28, 183.91   2.34     1.13 <.001    .338
|| 44  1.45, 81.21   3.04   3.67 * <.001    .043
|| 45  1.45, 81.21   3.04   3.20 + <.001    .062
|| 46  1.45, 81.21   3.04     0.14 <.001    .800
|| 47  1.45, 81.21   3.04     0.42 <.001    .592
|| 48  1.71, 95.97   1.21     0.77 <.001    .449
|| 49  1.71, 95.97   1.21     0.95 <.001    .378
|| 50  1.71, 95.97   1.21     0.61 <.001    .522
|| 51  1.71, 95.97   1.21     1.89 <.001    .163
|| 52 2.78, 155.51   0.96     0.76 <.001    .511
|| 53 2.78, 155.51   0.96     0.44 <.001    .709
|| 54 2.78, 155.51   0.96     1.66 <.001    .182
|| 55 2.78, 155.51   0.96     1.12 <.001    .341
|| 56 2.64, 147.98   1.12     1.42 <.001    .243
|| 57 2.64, 147.98   1.12     0.92 <.001    .422
|| 58 2.64, 147.98   1.12     1.94 <.001    .134
|| 59 2.64, 147.98   1.12     0.75 <.001    .506
|| 60 3.72, 208.29   0.58     0.90 <.001    .462
|| 61 3.72, 208.29   0.58   2.95 * <.001    .024
|| 62 3.72, 208.29   0.58     1.27 <.001    .284
|| 63 3.72, 208.29   0.58     0.49 <.001    .729
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
||
|| Sphericity correction method: GG
```

4.2 Group 2

```
anova_results.2a <- ezANOVA(n250_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 7.329838e-03 0.932260782       1.063476e-04
|| 3    1  35 4.992281e-01 0.484516974       7.191901e-03
|| 5    1  35 6.069609e-04 0.980484776       1.022126e-06
|| 9    1  35 1.527592e+00 0.224705301       2.688437e-03
|| 13   2  70 9.398105e-01 0.395575270       3.313964e-03
|| 17   2  70 5.812789e-01 0.561858796       7.189608e-04
|| 4    1  35 1.247201e+00 0.271695865       1.777570e-02
|| 6    1  35 1.452414e-04 0.990452871       2.445878e-07
|| 7    1  35 2.500552e-01 0.620165811       4.209180e-04
|| 10   1  35 3.349912e-02 0.855832466       5.911115e-05
|| 11   1  35 2.126507e+00 0.153686238       3.738539e-03
|| 14   2  70 3.005921e-01 0.741330592       1.062344e-03
|| 15   2  70 8.527887e-01 0.430604514       3.008030e-03
|| 18   2  70 4.433419e+00 0.015386019     * 5.457518e-03
|| 19   2  70 2.617716e+00 0.080102628       3.229614e-03
|| 21   1  35 1.073322e+01 0.002378345     * 9.243002e-03
|| 25   2  70 1.287183e-02 0.987212990       5.575702e-06
|| 29   2  70 7.773803e-01 0.463535207       3.785980e-04
|| 33   2  70 2.134919e+00 0.125890957       6.548924e-04
|| 37   2  70 3.334612e-01 0.717571518       1.710190e-04
|| 41   4 140 3.113302e+00 0.017244137     * 2.656395e-03
|| 8    1  35 6.219095e-01 0.435647897       1.046205e-03
|| 12   1  35 1.768415e+00 0.192180348       3.110947e-03
|| 16   2  70 1.243996e+00 0.294522900       4.381883e-03
|| 20   2  70 1.327439e-01 0.875909220       1.642768e-04
|| 22   1  35 7.885509e-01 0.380600793       6.849326e-04
|| 23   1  35 4.822117e-01 0.492006259       4.189589e-04
|| 26   2  70 2.299300e-01 0.795186947       9.958960e-05
|| 27   2  70 4.394230e-01 0.646173385       1.903100e-04
|| 30   2  70 3.062284e-01 0.737199657       1.491729e-04
|| 31   2  70 3.520506e-01 0.704482491       1.714904e-04
|| 34   2  70 1.173406e+00 0.315320767       3.600516e-04
|| 35   2  70 1.593629e+00 0.210469725       4.889313e-04
|| 38   2  70 1.544660e-01 0.857163881       7.922674e-05
|| 39   2  70 8.594705e-01 0.427805159       4.406694e-04
|| 42   4 140 1.556929e+00 0.189191814       1.330201e-03
|| 43   4 140 5.809358e-01 0.676939272       4.967511e-04
|| 45   2  70 1.100309e+00 0.338453836       4.834596e-04
|| 49   2  70 4.771489e-01 0.622553467       1.282944e-04
|| 53   4 140 7.001974e-01 0.593068044       4.144890e-04
|| 57   4 140 6.347405e-01 0.638540874       3.462414e-04
|| 24   1  35 2.094124e-01 0.650056577       1.819864e-04
|| 28   2  70 1.974503e+00 0.146487182       8.545707e-04
|| 32   2  70 2.957745e+00 0.058461184       1.438946e-03
```

```
|| 36   2  70 3.931016e-01 0.676440733       1.206495e-04
|| 40   2  70 3.401355e-01 0.712843521       1.744414e-04
|| 44   4 140 1.448989e+00 0.221100232       1.238094e-03
|| 46   2  70 1.547373e-01 0.856932424       6.801755e-05
|| 47   2  70 1.564559e+00 0.216406188       6.873041e-04
|| 50   2  70 5.580175e-02 0.945768632       1.500551e-05
|| 51   2  70 4.958779e-01 0.611159086       1.333295e-04
|| 54   4 140 1.409866e+00 0.233811338       8.342338e-04
|| 55   4 140 7.012107e-01 0.592376763       4.150885e-04
|| 58   4 140 1.281112e+00 0.280330380       6.985811e-04
|| 59   4 140 8.890307e-01 0.472327353       4.848856e-04
|| 61   4 140 1.332303e+00 0.260944893       6.993823e-04
|| 48   2  70 2.489995e+00 0.090228414       1.093400e-03
|| 52   2  70 5.628803e-01 0.572122532       1.513421e-04
|| 56   4 140 1.054153e+00 0.381695453       6.238856e-04
|| 60   4 140 6.911396e-01 0.599265642       3.769946e-04
|| 62   4 140 1.220062e+00 0.305064389       6.405001e-04
|| 63   4 140 1.545028e+00 0.192492435       8.109601e-04
|| 64   4 140 1.017442e+00 0.400589826       5.341869e-04
```

```
anova_results.2a$`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 0.6308240 0.35903290           0.6434714 0.36069691
|| 14 0.6308240 0.63919107           0.6434714 0.64365263
|| 15 0.6308240 0.38572862           0.6434714 0.38771716
|| 16 0.6308240 0.28201135           0.6434714 0.28273939
|| 17 0.8640514 0.53814043           0.9048432 0.54560946
|| 18 0.8640514 0.02028186         * 0.9048432 0.01866630         *
|| 19 0.8640514 0.08872018           0.9048432 0.08605364
|| 20 0.8640514 0.84674871           0.9048432 0.85625616
|| 25 0.6478637 0.95041101           0.6623223 0.95315841
|| 26 0.6478637 0.69640799           0.6623223 0.70161960
|| 27 0.6478637 0.56145311           0.6623223 0.56572751
|| 28 0.6478637 0.16353859           0.6623223 0.16291830
|| 29 0.6665744 0.41730550           0.6830659 0.42011736
|| 30 0.6665744 0.64775186           0.6830659 0.65321108
|| 31 0.6665744 0.61800216           0.6830659 0.62323242
|| 32 0.6665744 0.08089363           0.6830659 0.07963205
|| 33 0.6489182 0.14567255           0.6634902 0.14488702
|| 34 0.6489182 0.29923972           0.6634902 0.30024330
|| 35 0.6489182 0.21648304           0.6634902 0.21642768
|| 36 0.6489182 0.58768304           0.6634902 0.59222718
|| 37 0.7166390 0.64557509           0.7387973 0.65220570
|| 38 0.7166390 0.78475858           0.7387973 0.79182101
|| 39 0.7166390 0.39611074           0.7387973 0.39906767
|| 40 0.7166390 0.64120051           0.7387973 0.64779146
|| 41 0.4579444 0.05553246           0.4819673 0.05269779
|| 42 0.4579444 0.21975983           0.4819673 0.21878408
|| 43 0.4579444 0.54775894           0.4819673 0.55606682
|| 44 0.4579444 0.24252372           0.4819673 0.24213169
|| 45 0.6581659 0.31798606           0.6737382 0.31928694
|| 46 0.6581659 0.76438062           0.6737382 0.76996260
|| 47 0.6581659 0.22127363           0.6737382 0.22125664
|| 48 0.6581659 0.11275290           0.6737382 0.11167084
|| 49 0.6987432 0.55559897           0.7188378 0.56085571
|| 50 0.6987432 0.88826850           0.7188378 0.89367641
|| 51 0.6987432 0.54579544           0.7188378 0.55092370
|| 52 0.6987432 0.51261173           0.7188378 0.51727807
```

```
|| 53 0.3059840 0.43504432           0.3113277 0.43732895
|| 54 0.3059840 0.24785931           0.3113277 0.24817860
|| 55 0.3059840 0.43466584           0.3113277 0.43694665
|| 56 0.3059840 0.32540368           0.3113277 0.32653330
|| 57 0.3410440 0.47641257           0.3501500 0.48029066
|| 58 0.3410440 0.27644080           0.3501500 0.27718719
|| 59 0.3410440 0.38156099           0.3501500 0.38398291
|| 60 0.3410440 0.45298325           0.3501500 0.45651609
|| 61 0.3070405 0.26277739           0.3124929 0.26325183
|| 62 0.3070405 0.28619612           0.3124929 0.28691739
|| 63 0.3070405 0.22433727           0.3124929 0.22442385
|| 64 0.3070405 0.33524099           0.3124929 0.33649217
```

```r
anova_results.2b <- aov_ez(id = "SubjID",
                           dv = "value",
                           data = n250_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, 35 276.17     0.01 <.001    .932
|| 2          1, 35 276.17     0.50  .007    .485
|| 3          1, 35 276.17     1.25  .018    .272
|| 4          1, 35  32.05     0.00 <.001    .980
|| 5          1, 35  32.05     0.00 <.001    .990
|| 6          1, 35  32.05     0.25 <.001    .620
|| 7          1, 35  32.05     0.62  .001    .436
|| 8          1, 35  33.59     1.53  .003    .225
|| 9          1, 35  33.59     0.03 <.001    .856
|| 10         1, 35  33.59     2.13  .004    .154
|| 11         1, 35  33.59     1.77  .003    .192
|| 12 1.26, 44.16  53.37     0.94  .003    .359
|| 13 1.26, 44.16  53.37     0.30  .001    .639
|| 14 1.26, 44.16  53.37     0.85  .003    .386
|| 15 1.26, 44.16  53.37     1.24  .004    .282
|| 16 1.73, 60.48  13.63     0.58 <.001    .538
```

```
|| 17 1.73, 60.48  13.63   4.43 *  .005    .020
|| 18 1.73, 60.48  13.63   2.62 +  .003    .089
|| 19 1.73, 60.48  13.63     0.13 <.001    .847
|| 20       1, 35  16.54 10.73 **  .009    .002
|| 21       1, 35  16.54     0.79 <.001    .381
|| 22       1, 35  16.54     0.48 <.001    .492
|| 23       1, 35  16.54     0.21 <.001    .650
|| 24 1.30, 45.35   6.36     0.01 <.001    .950
|| 25 1.30, 45.35   6.36     0.23 <.001    .696
|| 26 1.30, 45.35   6.36     0.44 <.001    .561
|| 27 1.30, 45.35   6.36     1.97 <.001    .164
|| 28 1.33, 46.66   6.96     0.78 <.001    .417
|| 29 1.33, 46.66   6.96     0.31 <.001    .648
|| 30 1.33, 46.66   6.96     0.35 <.001    .618
|| 31 1.33, 46.66   6.96   2.96 +  .001    .081
|| 32 1.30, 45.42   4.50     2.13 <.001    .146
|| 33 1.30, 45.42   4.50     1.17 <.001    .299
|| 34 1.30, 45.42   4.50     1.59 <.001    .216
|| 35 1.30, 45.42   4.50     0.39 <.001    .588
|| 36 1.43, 50.16   6.81     0.33 <.001    .646
|| 37 1.43, 50.16   6.81     0.15 <.001    .785
|| 38 1.43, 50.16   6.81     0.86 <.001    .396
|| 39 1.43, 50.16   6.81     0.34 <.001    .641
|| 40 1.83, 64.11   8.89   3.11 +  .003    .056
|| 41 1.83, 64.11   8.89     1.56  .001    .220
|| 42 1.83, 64.11   8.89     0.58 <.001    .548
|| 43 1.83, 64.11   8.89     1.45  .001    .243
|| 44 1.32, 46.07   6.36     1.10 <.001    .318
|| 45 1.32, 46.07   6.36     0.15 <.001    .764
|| 46 1.32, 46.07   6.36     1.56 <.001    .221
|| 47 1.32, 46.07   6.36     2.49  .001    .113
|| 48 1.40, 48.91   3.66     0.48 <.001    .556
|| 49 1.40, 48.91   3.66     0.06 <.001    .888
|| 50 1.40, 48.91   3.66     0.50 <.001    .546
|| 51 1.40, 48.91   3.66     0.56 <.001    .513
|| 52 1.22, 42.84   9.21     0.70 <.001    .435
|| 53 1.22, 42.84   9.21     1.41 <.001    .248
|| 54 1.22, 42.84   9.21     0.70 <.001    .435
|| 55 1.22, 42.84   9.21     1.05 <.001    .325
|| 56 1.36, 47.75   7.61     0.63 <.001    .476
|| 57 1.36, 47.75   7.61     1.28 <.001    .276
|| 58 1.36, 47.75   7.61     0.89 <.001    .382
|| 59 1.36, 47.75   7.61     0.69 <.001    .453
|| 60 1.23, 42.99   8.14     1.33 <.001    .263
|| 61 1.23, 42.99   8.14     1.22 <.001    .286
|| 62 1.23, 42.99   8.14     1.55 <.001    .224
|| 63 1.23, 42.99   8.14     1.02 <.001    .335
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
||
|| Sphericity correction method: GG
```

5 Examine and plot interactions

5.1 Group 1

5.1.1 Family Size by Complexity by Anteriority Interaction

```
# Examine the 2-way interaction between ` family_size` and `complexity`
# at each level of `Anteriority`
(se_frontal_1.1 <-n250_1_nonwords |> filter(anteriority == "Frontal")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, family_size)))
```

5.1.1.1 Simple Effects complexity| family_size * anteriority

```
|| $ANOVA
||                   Effect DFn DFd         F         p p<.05          ges
|| 2              complexity   1  66 1.0123262 0.3180208       0.0012870537
|| 3             family_size   1  66 0.1344549 0.7150300       0.0001689185
|| 4 complexity:family_size   1  66 0.1623686 0.6882874       0.0002476601
```

```
(se_central_1.1 <-n250_1_nonwords |> filter(anteriority == "Central")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, family_size)))
```

```
|| $ANOVA
||                   Effect DFn DFd          F         p p<.05          ges
|| 2              complexity   1  66 0.01336488 0.9083154       2.478299e-05
|| 3             family_size   1  66 0.22231793 0.6388344       4.309762e-04
|| 4 complexity:family_size   1  66 0.73842072 0.3932777       1.132454e-03
```

```
(se_parietal_1.1 <-n250_1_nonwords |> filter(anteriority == "Parietal")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = .(complexity, family_size)))
```

```
|| $ANOVA
||                   Effect DFn DFd          F          p p<.05          ges
|| 2              complexity   1  66 0.26773166 0.60658740       4.849084e-04
|| 3             family_size   1  66 0.03579367 0.85052283       5.836017e-05
|| 4 complexity:family_size   1  66 3.97705105 0.05025801       6.186163e-03
```

```
# Examine `complexity` at each level of ` family_size` at parietal sites.
(se_parietal_small_1.1 <-n250_1_nonwords |> filter(anteriority == "Parietal" &
                                                   family_size == "small")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity))
```

```
|| $ANOVA
||       Effect DFn DFd        F         p p<.05         ges
|| 2 complexity   1  66 2.621483 0.1101951       0.009714344
```

```
(se_parietal_large_1.1 <-n250_1_nonwords |> filter(anteriority == "Parietal" &
                                                     family_size == "large")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity))
```

```
|| $ANOVA
||       Effect DFn DFd        F         p p<.05         ges
|| 2 complexity   1  66 1.127293 0.2922231       0.003351804
```

There is a significant `complexity` by `family size` interaction only at parietal sites $F(1, 66) = 3.97705105, p = 0.05025801$, where the complexity effect is a slightly more probable for small families $F(1, 66) = 2.621483, p = 0.1101951$ than for large $F(1, 66) = 1.127293, p = 0.2922231$.

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

5.1.1.2 Pairwise Comparisons `complexity| family_size * anteriority`

```
|| anteriority = Frontal, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.181 0.368 56   0.492  0.6243
||
|| anteriority = Central, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.079 0.411 56  -0.192  0.8483
||
|| anteriority = Parietal, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.500 0.411 56  -1.215  0.2295
||
|| anteriority = Frontal, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.334 0.349 56   0.957  0.3426
||
|| anteriority = Central, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.252 0.358 56   0.704  0.4841
||
|| anteriority = Parietal, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.464 0.357 56   1.300  0.1990
||
|| Results are averaged over the levels of: lang_type_semantic, lang_type_ortho, laterality
```

```r
(nw_famsize_cmplx_ant_1 <- n250_1_nonwords |>
    na.omit()|>
   group_by(family_size, anteriority, complexity) |>
   summarise(mean = mean(value),
             se = sem(value),
             num_stim = n()))
```

5.1.1.3 Condition Means

```
|| # A tibble: 12 x 6
|| # Groups:   family_size, anteriority [6]
||    family_size anteriority complexity    mean    se num_stim
||    <chr>       <fct>       <chr>        <dbl> <dbl>    <int>
||  1 large       Frontal     complex    -0.752  0.253      180
||  2 large       Frontal     simple     -1.05   0.237      180
||  3 large       Central     complex    -0.976  0.225      180
||  4 large       Central     simple     -1.21   0.232      180
||  5 large       Parietal    complex     0.248  0.234      180
||  6 large       Parietal    simple     -0.171  0.253      180
||  7 small       Frontal     complex    -0.703  0.230      180
||  8 small       Frontal     simple     -0.940  0.245      180
||  9 small       Central     complex    -0.951  0.232      180
|| 10 small       Central     simple     -0.931  0.268      180
|| 11 small       Parietal    complex    -0.0755 0.215      180
|| 12 small       Parietal    simple      0.371  0.284      180
```

```r
(difference_scores_1.1 <- nw_famsize_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`)))
```

5.1.1.4 Diff Scores

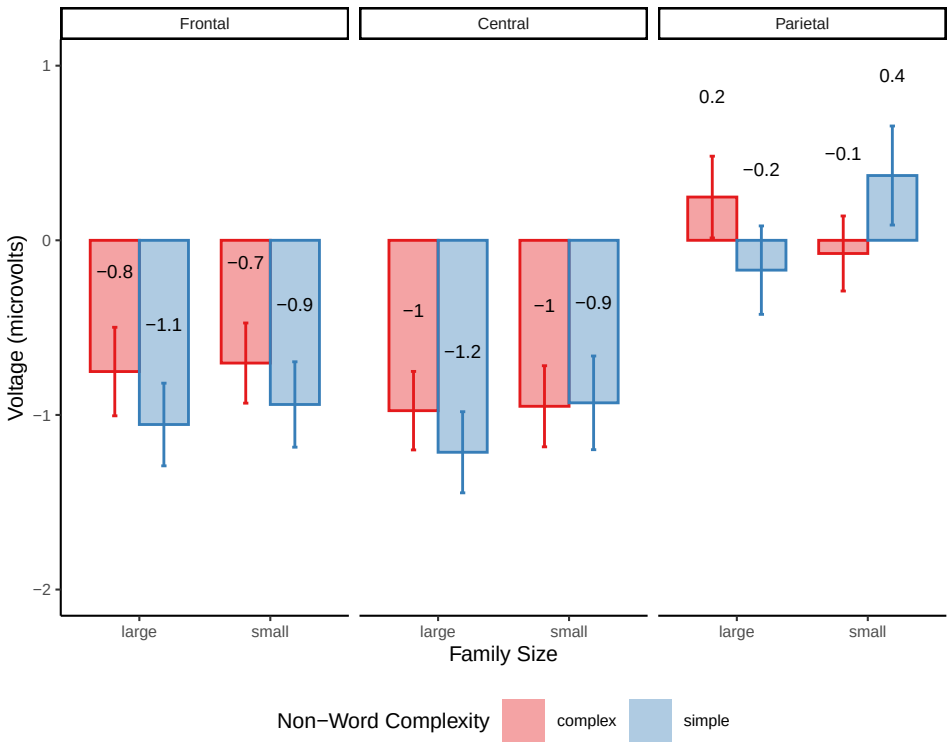
```
|| # A tibble: 6 x 11
|| # Groups:   family_size, anteriority [6]
||   family_size anteriority mean_complex mean_simple se_complex se_simple
||   <chr>       <fct>              <dbl>       <dbl>      <dbl>     <dbl>
|| 1 large       Frontal          -0.752       -1.05       0.253     0.237
|| 2 large       Central          -0.976       -1.21       0.225     0.232
|| 3 large       Parietal          0.248       -0.171      0.234     0.253
|| 4 small       Frontal          -0.703       -0.940      0.230     0.245
|| 5 small       Central          -0.951       -0.931      0.232     0.268
|| 6 small       Parietal         -0.0755       0.371      0.215     0.284
|| # i 5 more variables: num_stim_complex <int>, num_stim_simple <int>,
|| #   mean_diff <dbl>, avg_se <dbl>, total_num_stim <int>
```

5.1.1.5 Plots

First we plot the raw scores then the difference scores

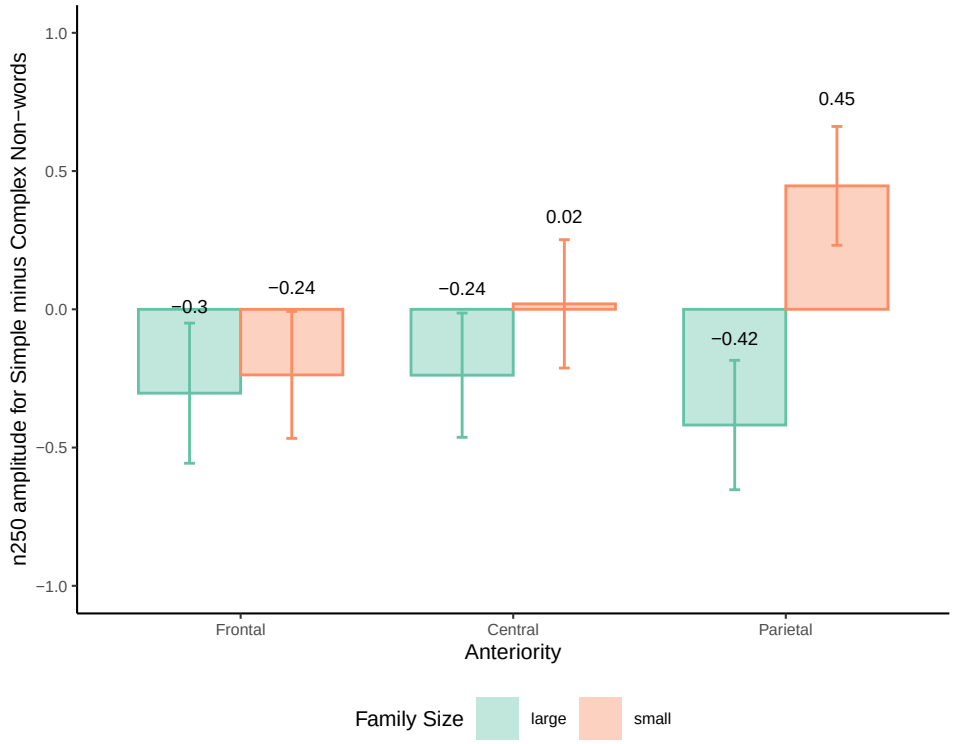
```
# plot raw scores
# facet_wrap() wraps a 1d sequence of panels into 2d. Use vars() to supply faceting variables;
# Control the number of rows and columns with nrow and ncol.


p1.a <-  nw_famsize_cmplx_ant_1 |> ggplot(aes(x= family_size, 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, 1), expand = TRUE, default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = .4)  +
  labs(y = "Voltage (microvolts)", x = "Family Size")  +
  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 = -7,
             position = position_dodge(.75))+
  guides(fill=guide_legend(title="Non-Word Complexity"),
         colour= "none") +
  theme(legend.position = "bottom")
p1.a + scale_fill_brewer(palette = "Set1")+
      scale_colour_brewer(palette = "Set1")
```




```
# plot diff scores
p1.b <- difference_scores_1.1 |> ggplot(aes(x = anteriority,
                                            y = mean_diff,
                                            fill = family_size,
```

```
                                          colour = family_size,
                                          ymin = mean_diff - avg_se,
                                          ymax = mean_diff + avg_se)) +
  coord_cartesian(xlim = NULL,ylim = c(-1, 1), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.4) +
  labs(y = "n250 amplitude for Simple minus Complex Non-words", 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 = -6,
            position = position_dodge(.75))+
  guides(fill=guide_legend(title="Family Size"),
         colour= "none") +
  theme(legend.position = "bottom")
p1.b + scale_fill_brewer(palette = "Set2")+
      scale_colour_brewer(palette = "Set2")
```



5.1.2 Language Type Semantic by Complexity by Family Size by Anteriority xLaterality Interaction

```
# Examine the 4-way interaction between `anteriority`, `laterality`, ` complexity`,
# and `lang_type_semantics` at each level of `family_size`
se_large_1.2 <-n250_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`
```

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

```
||                                                 Effect       GGe        p[GG]
|| 5                                          anteriority 0.6420185 0.0006468489
|| 6                         lang_type_semantic:anteriority 0.6420185 0.8969800170
|| 7                                           laterality 0.9497291 0.2894057610
|| 8                           lang_type_semantic:laterality 0.9497291 0.6172478894
|| 9                                 complexity:anteriority 0.8377386 0.0178795376
|| 10              lang_type_semantic:complexity:anteriority 0.8377386 0.0072212665
|| 11                               complexity:laterality 0.7471483 0.3305037994
|| 12               lang_type_semantic:complexity:laterality 0.7471483 0.5152148668
|| 13                               anteriority:laterality 0.8519658 0.7110158444
|| 14              lang_type_semantic:anteriority:laterality 0.8519658 0.1056260982
|| 15                      complexity:anteriority:laterality 0.6938894 0.2714100076
|| 16 lang_type_semantic:complexity:anteriority:laterality 0.6938894 0.3781100282
||    p[GG]<.05       HFe        p[HF] p[HF]<.05
|| 5          * 0.6502418 0.0006103261         *
|| 6            0.6502418 0.8993752116
|| 7            0.9809890 0.2899966187
|| 8            0.9809890 0.6234363611
|| 9          * 0.8597778 0.0170414357         *
|| 10         * 0.8597778 0.0067500799         *
|| 11           0.7624319 0.3316615514
|| 12           0.7624319 0.5185158604
|| 13           0.9115961 0.7235423754
|| 14           0.9115961 0.1007803592
|| 15           0.7322749 0.2708036651
|| 16           0.7322749 0.3806240337
```

```
se_small_1.2 <-n250_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 0.5954644 0.002232974
|| 6                         lang_type_semantic:anteriority 0.5954644 0.513478455
|| 7                                           laterality 0.9564988 0.414803890
|| 8                           lang_type_semantic:laterality 0.9564988 0.389741357
|| 9                                 complexity:anteriority 0.7614393 0.639974214
|| 10              lang_type_semantic:complexity:anteriority 0.7614393 0.886320231
|| 11                               complexity:laterality 0.8649282 0.880900161
|| 12               lang_type_semantic:complexity:laterality 0.8649282 0.332825187
|| 13                               anteriority:laterality 0.7843992 0.194956664
|| 14              lang_type_semantic:anteriority:laterality 0.7843992 0.181594680
|| 15                      complexity:anteriority:laterality 0.8966788 0.321410726
|| 16 lang_type_semantic:complexity:anteriority:laterality 0.8966788 0.013587141
```

```
||    p[GG]<.05       HFe       p[HF] p[HF]<.05
|| 5          * 0.6008266 0.002165149         *
|| 6            0.6008266 0.515087060
|| 7            0.9883472 0.417763501
|| 8            0.9883472 0.392224709
|| 9            0.7777471 0.644501670
|| 10           0.7777471 0.890363334
|| 11           0.8891174 0.886140731
|| 12           0.8891174 0.334174970
|| 13           0.8344431 0.191850888
|| 14           0.8344431 0.178202807
|| 15           0.9630745 0.321595863
|| 16         * 0.9630745 0.011485622         *
```

```
# 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 <-n250_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 0.6110393 0.005812212         * 0.6239192
|| 3                       laterality 0.7877555 0.791690570           0.8252721
|| 5            anteriority:laterality 0.8015027 0.075135208           0.9128127
|| 6            anteriority:complexity 0.7243769 0.676748688           0.7524635
|| 7             laterality:complexity 0.8457392 0.460557823           0.8924752
|| 8 anteriority:laterality:complexity 0.7942870 0.014072816         * 0.9034095
||         p[HF] p[HF]<.05
|| 2 0.005492252         *
|| 3 0.802157676
|| 5 0.066153967
|| 6 0.685275708
|| 7 0.467096302
|| 8 0.010357847         *
```

```
se_large_losem_1.2 <-n250_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 0.5835088 0.1058768           0.5930110
|| 4                       laterality 0.9887507 0.2035848           1.0606910
|| 5            complexity:anteriority 0.7962426 0.8286265           0.8350731
|| 6             complexity:laterality 0.8910445 0.6677000           0.9453824
|| 7            anteriority:laterality 0.7255469 0.3300543           0.8148732
|| 8 complexity:anteriority:laterality 0.8165460 0.3079664           0.9324843
```

```
||       p[HF] p[HF]<.05
|| 3 0.1051529
|| 4 0.2032465
|| 5 0.8388942
|| 6 0.6800471
|| 7 0.3316478
|| 8 0.3074230
```

```
# 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 <-n250_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 0.6254110 0.03982631         * 0.6401030 0.03877314
|| 4 complexity:anteriority 0.8400725 0.09421697           0.8858823 0.09115917
||   p[HF]<.05
|| 3         *
|| 4
```

```
# midline
se_large_hisem_mid_1.2 <-n250_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       p[HF]
|| 3            anteriority 0.6878769 0.00893451         * 0.7108360 0.008255881
|| 4 complexity:anteriority 0.8055359 0.59499271           0.8458191 0.604317874
||   p[HF]<.05
|| 3         *
|| 4
```

```
# right
se_large_hisem_right_1.2 <-n250_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       p[HF]
|| 3            anteriority 0.594651 0.001884944         * 0.6055055 0.001763554
|| 4 complexity:anteriority 0.837690 0.572013472           0.8831120 0.581452330
||   p[HF]<.05
|| 3         *
|| 4
```

```
# 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 <- n250_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 0.1946546 0.6623425       0.001206553
```

```
# Central
se_large_hisem_left_central_1.2 <- n250_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 0.3014515 0.5871769       0.002813469
```

```
# Parietal
se_large_hisem_left_parietal_1.2 <- n250_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 0.8494285 0.3643184       0.00653431
```

```r
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)
```

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

```
|| laterality = Left, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.281 0.525 56  -0.536  0.5944
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.480 0.563 56  -0.854  0.3966
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.327 0.578 56  -0.565  0.5741
||
|| laterality = Left, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.555 0.539 56  -1.029  0.3079
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = High Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.213 0.621 56  -0.343  0.7330
||
|| laterality = Right, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.357 0.763 56  -0.468  0.6419
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.278 0.574 56  -0.484  0.6303
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = smal
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.343 0.630 56  -0.545  0.5883
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.205 0.608 56  -0.337  0.7370
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.470 0.521 56   0.903  0.3706
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.918 0.559 56   1.643  0.1059
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
```

```
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.788 0.574 56   1.373  0.1752
||
|| laterality = Left, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.277 0.535 56  -0.518  0.6064
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.257 0.617 56   0.416  0.6790
||
|| laterality = Right, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.671 0.758 56   0.886  0.3796
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.614 0.570 56  -1.077  0.2862
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -1.028 0.626 56  -1.641  0.1064
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.530 0.604 56  -0.879  0.3833
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.138 0.539 56  -0.256  0.7987
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.408 0.552 56   0.739  0.4632
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.252 0.475 56   0.531  0.5978
||
|| laterality = Left, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.236 0.521 56  -0.452  0.6528
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = High Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.116 0.604 56   0.191  0.8489
||
|| laterality = Right, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.148 0.505 56   0.293  0.7708
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.548 0.480 56   1.141  0.2586
```

```
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.401 0.555 56   0.722  0.4731
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.107 0.555 56  -0.193  0.8474
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.707 0.535 56   1.320  0.1921
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.480 0.549 56   0.875  0.3851
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.294 0.472 56   0.622  0.5364
||
|| laterality = Left, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.587 0.517 56   1.135  0.2612
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.260 0.600 56   0.433  0.6666
||
|| laterality = Right, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.640 0.501 56   1.276  0.2073
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.523 0.477 56   1.098  0.2768
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.613 0.552 56   1.112  0.2709
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    0.804 0.551 56   1.459  0.1501
||
|| Results are averaged over the levels of: lang_type_ortho
```

```
(nw_sem_famsize_lat_ant_cmplx_1 <- n250_1_nonwords |>
    na.omit()|>
   group_by( lang_type_semantic, family_size, laterality, anteriority, complexity  ) |>
   summarise(mean = mean(value),
```

```
            se = sem(value),
            num_stim = n()))
```

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

```
|| # 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    -0.557 0.507
||  2 High Semantic      large       Left       Frontal     simple     -0.354 0.575
||  3 High Semantic      large       Left       Central     complex    -0.789 0.454
||  4 High Semantic      large       Left       Central     simple     -0.522 0.481
||  5 High Semantic      large       Left       Parietal    complex     0.615 0.495
||  6 High Semantic      large       Left       Parietal    simple      0.141 0.586
||  7 High Semantic      large       Midline    Frontal     complex    -0.554 0.544
||  8 High Semantic      large       Midline    Frontal     simple     -0.949 0.555
||  9 High Semantic      large       Midline    Central     complex    -0.694 0.509
|| 10 High Semantic      large       Midline    Central     simple     -0.818 0.573
|| # i 62 more rows
|| # i 1 more variable: num_stim <int>
```

```
(difference_scores_1.2 <- 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`)))
```

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

```
|| # 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           -0.557
||  2 High Semantic      large       Left       Central           -0.789
||  3 High Semantic      large       Left       Parietal           0.615
||  4 High Semantic      large       Midline    Frontal           -0.554
||  5 High Semantic      large       Midline    Central           -0.694
||  6 High Semantic      large       Midline    Parietal           0.700
||  7 High Semantic      large       Right      Frontal           -0.756
||  8 High Semantic      large       Right      Central           -0.742
||  9 High Semantic      large       Right      Parietal           0.633
|| 10 High Semantic      small       Left       Frontal           -0.525
|| # 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>
```

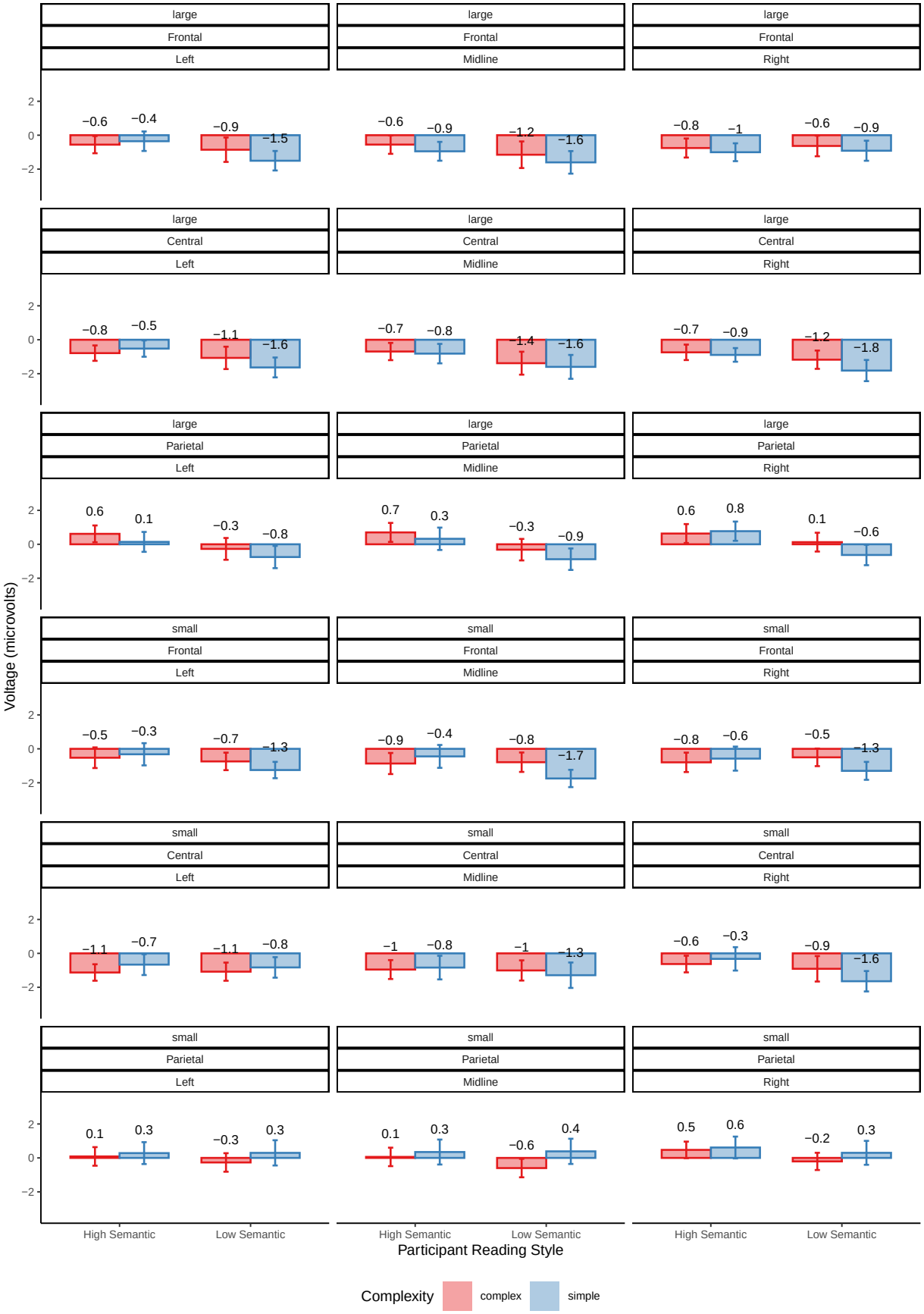
5.1.2.5 Plots `complexity | lang_type_semantic * family_size * laterality * anteriority`

First we plot the raw scores then the difference scores

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.

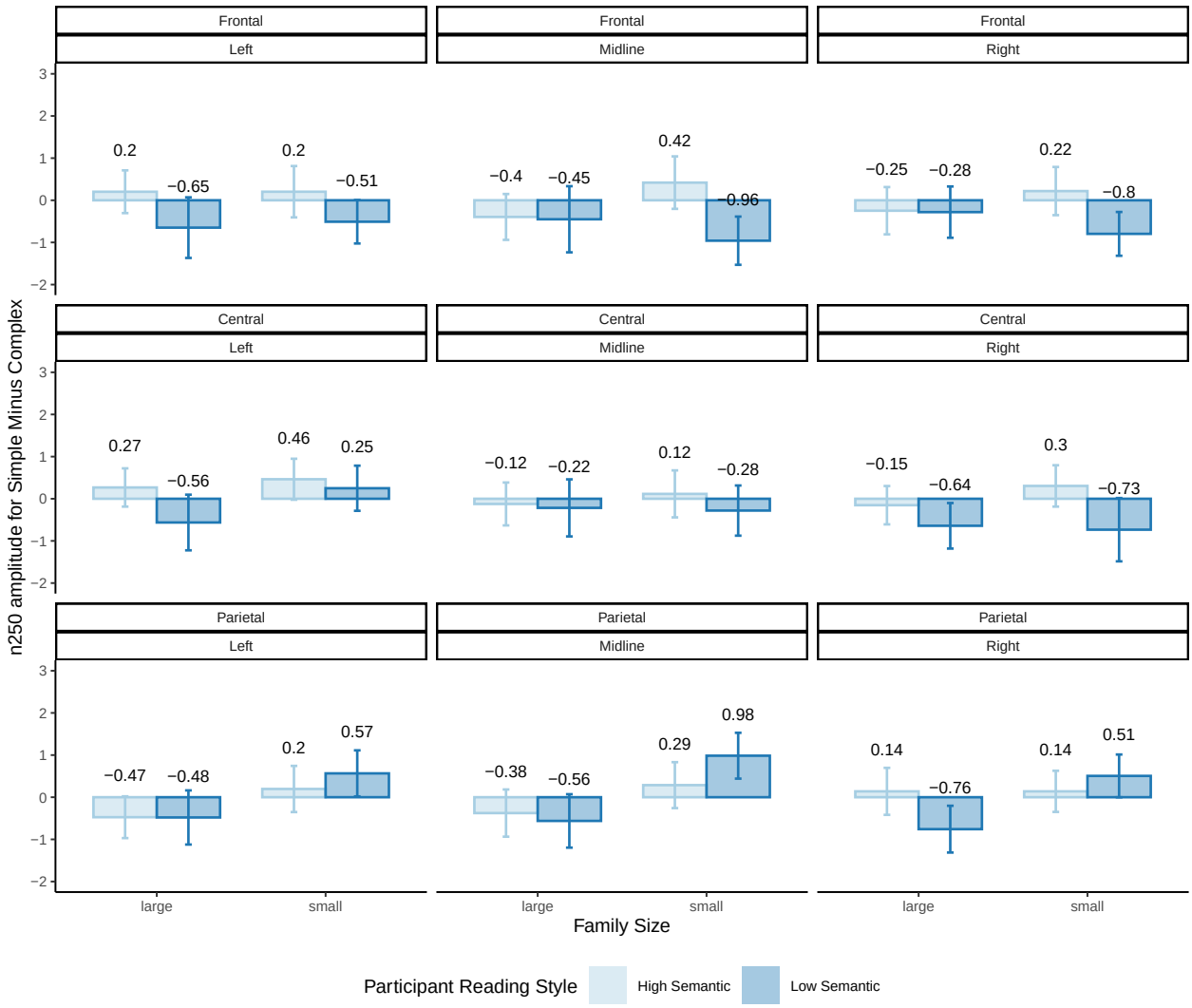
Plot raw scores

```
p2.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 = 0.4)  +
  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")
p2.a + scale_fill_brewer(palette = "Set1")+
      scale_colour_brewer(palette = "Set1")
```


large
Frontal
Left
−0.6
−0.4
−0.9
−1.5
large
Frontal
Midline
−0.6
−0.9
−1.2
−1.6
large
Frontal
Right
−0.8
−1
−0.6
−0.9
large
Central
Left
−0.8
−0.5
−1.1
−1.6
large
Central
Midline
−0.7
−0.8
−1.4
−1.6
large
Central
Right
−0.7
−0.9
−1.2
−1.8
large
Parietal
Left
0.6
0.1
−0.3
−0.8
large
Parietal
Midline
0.7
0.3
−0.3
−0.9
large
Parietal
Right
0.6
0.8
0.1
−0.6
small
Frontal
Left
−0.5
−0.3
−0.7
−1.3
small
Frontal
Midline
−0.9
−0.4
−0.8
−1.7
small
Frontal
Right
−0.8
−0.6
−0.5
−1.3
small
Central
Left
−1.1
−0.7
−1.1
−0.8
small
Central
Midline
−1
−0.8
−1
−1.3
small
Central
Right
−0.6
−0.3
−0.9
−1.6
small
Parietal
Left
0.1
0.3
−0.3
0.3
small
Parietal
Midline
0.1
0.3
−0.6
0.4
small
Parietal
Right
0.5
0.6
−0.2
0.3
2
0
−2
Voltage (microvolts)
High Semantic
Low Semantic
Participant Reading Style
Complexity
complex
simple

Plot diff scores

```
p2.b <- difference_scores_1.2 |> 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(-2, 3), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.4) +
  labs(y = "n250 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 = -3,
            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")
```



5.2 Group 2

5.2.1 Language Type Semantic by Laterality Interaction

```
# Examine the diffence between `lang_type_semantic` at each level of `laterality`

se_left_2.1 <-n250_2_nonwords |> filter(laterality == "Left")|>
  ezANOVA(dv = value,
          wid = SubjID,
          between = lang_type_semantic)
se_left_2.1$ANOVA
```

5.2.1.1 Simple Effects lang_type_semantic| laterality

```
||               Effect DFn DFd         F         p p<.05         ges
|| 1 lang_type_semantic   1  37 0.2837876 0.5974145       0.007611555
```

```
se_mid_2.1 <-n250_2_nonwords |> filter(laterality == "Midline")|>
  ezANOVA(dv = value,
          wid = SubjID,
          between = lang_type_semantic)
se_mid_2.1$ANOVA
```

```
||               Effect DFn DFd          F         p p<.05          ges
|| 1 lang_type_semantic   1  37 0.02925513 0.8651233       0.0007900544
```

```
se_right_2.1 <-n250_2_nonwords |> filter(laterality == "Right")|>
  ezANOVA(dv = value,
          wid = SubjID,
          between = lang_type_semantic)
se_right_2.1$ANOVA
```

```
||               Effect DFn DFd         F         p p<.05        ges
|| 1 lang_type_semantic   1  37 0.6945411 0.4099719       0.01842551
```

No significant effect of lang_type_semantic at any laterality, but the effect is less probable at midline sites ($F(1, 37) = 0.02925513, p = 0.8651233$) than at left ($F(1, 37) = 0.2837876, p = 0.5974145$) or right ($F(1, 37) = 0.6945411, p = 0.4099719$) sites

```
emms <- emmeans(anova_results.2b, ~ lang_type_semantic | laterality )
pairwise_results <- pairs(emms, by = c("laterality"))
summary(pairwise_results)
```

5.2.1.2 Pairwise Comparisons lang_type_semantic | laterality

```
|| laterality = Left:
||  contrast                      estimate    SE df t.ratio p.value
||  High Semantic - Low Semantic   -0.619 0.868 35  -0.713  0.4806
||
|| laterality = Midline:
||  contrast                      estimate    SE df t.ratio p.value
||  High Semantic - Low Semantic   -0.288 1.000 35  -0.287  0.7755
||
|| laterality = Right:
||  contrast                      estimate    SE df t.ratio p.value
||  High Semantic - Low Semantic    0.677 0.920 35   0.736  0.4668
||
|| Results are averaged over the levels of: lang_type_ortho, anteriority, complexity, family_size
```

```
(nw_langsem_lat_2 <- n250_2_nonwords |>
    na.omit()|>
   group_by(laterality, lang_type_semantic) |>
   summarise(mean = mean(value),
             se = sem(value),
             num = n()))
```

5.2.1.3 Condition Means

```
|| # A tibble: 6 x 5
|| # Groups:   laterality [3]
||   laterality lang_type_semantic  mean    se   num
||   <fct>      <chr>              <dbl> <dbl> <int>
|| 1 Left       High Semantic       2.74 0.180   252
|| 2 Left       Low Semantic        3.21 0.266   216
|| 3 Midline    High Semantic       3.07 0.196   252
|| 4 Midline    Low Semantic        3.24 0.304   216
|| 5 Right      High Semantic       3.53 0.191   252
|| 6 Right      Low Semantic        2.78 0.367   216
```

```
(difference_scores_2.1 <- nw_langsem_lat_2 %>%
  pivot_wider(names_from = lang_type_semantic, values_from = c(mean, se, num)) %>%
  mutate(mean_diff = `mean_Low Semantic` - `mean_High Semantic`,
         avg_se = mean(`se_Low Semantic`,`se_High Semantic`),
         total_num_stim = sum(`num_Low Semantic`, `num_High Semantic`)))
```

5.2.1.4 Diff Scores

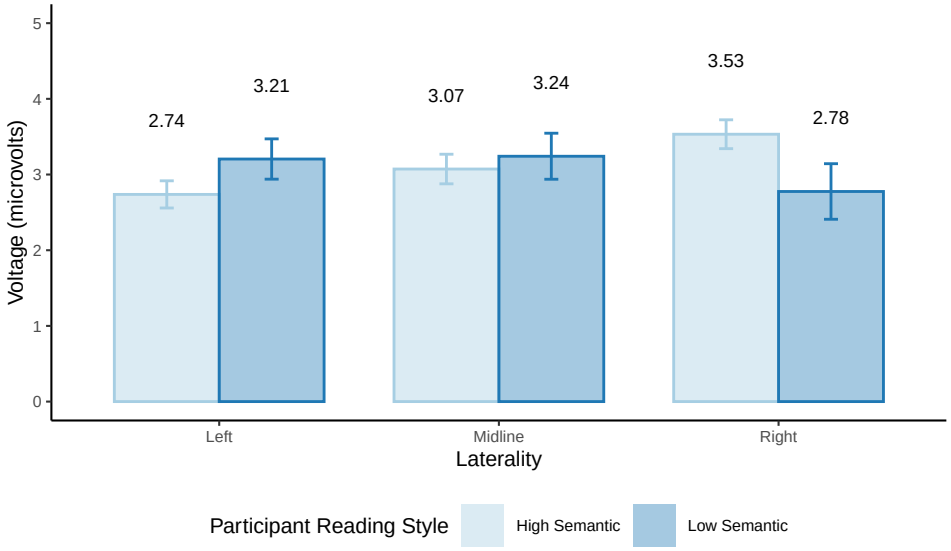
```
|| # A tibble: 3 x 10
|| # Groups:   laterality [3]
||   laterality `mean_High Semantic` `mean_Low Semantic` `se_High Semantic`
||   <fct>                     <dbl>               <dbl>              <dbl>
|| 1 Left                       2.74                3.21              0.180
|| 2 Midline                    3.07                3.24              0.196
```

```
|| 3 Right                       3.53                2.78              0.191
|| # i 6 more variables: 'se_Low Semantic' <dbl>, 'num_High Semantic' <int>,
|| #   'num_Low Semantic' <int>, mean_diff <dbl>, avg_se <dbl>,
|| #   total_num_stim <int>
```

5.2.1.5 Plotslang_type_ortho | anteriority

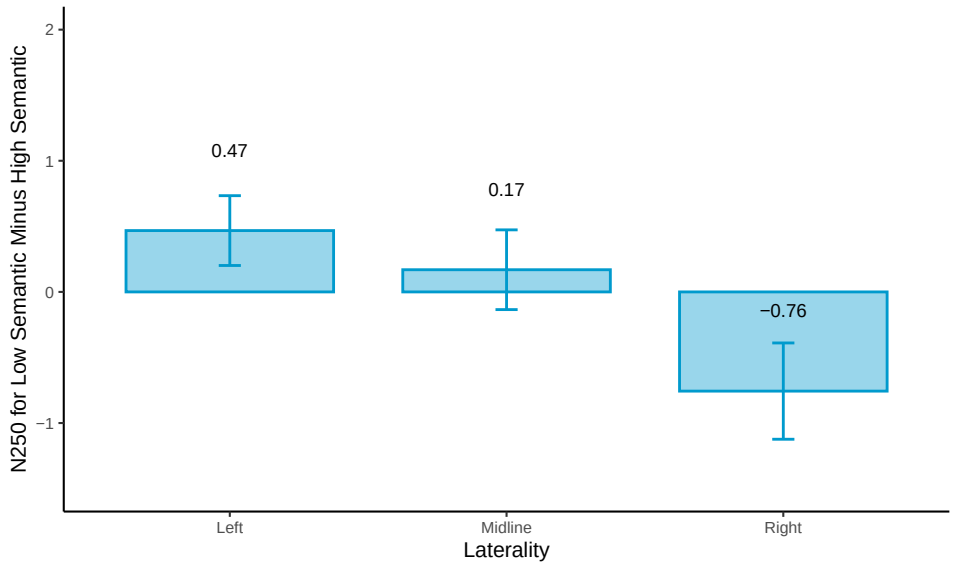
First we plot the raw scores then the difference scores

```
# plot raw scores
p3.a <-  nw_langsem_lat_2 |> ggplot(aes(x=laterality,
                                        y=mean,
                                        fill = lang_type_semantic,
                                        colour = lang_type_semantic,
                                        ymin = mean - se,
                                        ymax = mean + se)) +
  coord_cartesian(xlim = NULL,ylim = c(0, 5), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = .75,  alpha = 0.4)  +
  labs(y = "Voltage (microvolts)", x = "Laterality")  +
  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 = -5,
             position = position_dodge(.75))+
  guides(fill=guide_legend(title="Participant Reading Style"),
         colour= "none") +
  theme(legend.position = "bottom")
p3.a + scale_fill_brewer(palette = "Paired")+
      scale_colour_brewer(palette = "Paired")
```




```
# plot diff scores
p3.b <- difference_scores_2.1 |> ggplot(aes(x = laterality,
                                            y = mean_diff,
                                            ymin = mean_diff - avg_se,
                                            ymax = mean_diff + avg_se)) +
  coord_cartesian(xlim = NULL,ylim = c(-1.5, 2), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.4,
           colour = "deepskyblue3", fill= "deepskyblue3") +
```

```
  labs(y = "N250 for Low Semantic Minus High Semantic", x = "Laterality") +
  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 = -5.5,
            position = position_dodge(.75))+
    guides(fill=guide_legend(title="Laterality"),
           colour= "none") +
  theme(legend.position = "bottom")
p3.b
```




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

5.2.2 Family Size by Complexity Interaction

```
# Examine the diffence between `complexity` at each level of `family_size`

se_smlfam_2.2 <-n250_2_nonwords |> filter(family_size == "small")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity)
se_smlfam_2.2$ANOVA
```

5.2.2.1 Simple Effects complexity | family_size

```
||       Effect DFn DFd        F          p p<.05        ges
|| 2 complexity   1  39 6.963152 0.01189552     * 0.02683827
```

```
se_lrgfam_2.2 <-n250_2_nonwords |> filter(family_size == "large")|>
  ezANOVA(dv = value,
          wid = SubjID,
          within = complexity)
se_lrgfam_2.2$ANOVA
```

```
||       Effect DFn DFd         F         p p<.05         ges
|| 2 complexity   1  39 0.9821524 0.3277772       0.003372297
```

No significant effect of `lang_type_semantic` at any laterality, but the effect is less probable at midline sites ($F(1, 37) = 0.02925513, p = 0.8651233$) than at left ($F(1, 37) = 0.2837876, p = 0.5974145$) or right ($F(1, 37) = 0.6945411, p = 0.4099719$) sites

```
emms <- emmeans(anova_results.2b, ~ complexity | family_size )
pairwise_results <- pairs(emms, by = c("family_size"))
summary(pairwise_results)
```

5.2.2.2 Pairwise Comparisons `complexity | family_size`

```
|| family_size = small:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple    1.102 0.407 35   2.708  0.0104
||
|| family_size = large:
||  contrast         estimate    SE df t.ratio p.value
||  complex - simple   -0.331 0.353 35  -0.939  0.3540
||
|| Results are averaged over the levels of: lang_type_semantic, lang_type_ortho, laterality, anteriorit
```

```
(nw_cmplx_famsize_2 <- n250_2_nonwords |>
    na.omit()|>
   group_by(family_size, complexity) |>
   summarise(mean = mean(value),
             se = sem(value),
             num_stim = n()))
```

5.2.2.3 Condition Means `complexity | family_size`

```
|| # A tibble: 4 x 5
|| # Groups:   family_size [2]
||   family_size complexity  mean    se num_stim
||   <chr>       <chr>      <dbl> <dbl>    <int>
|| 1 large       complex     2.95 0.189      351
|| 2 large       simple      3.25 0.186      351
|| 3 small       complex     3.62 0.194      351
|| 4 small       simple      2.56 0.243      351
```

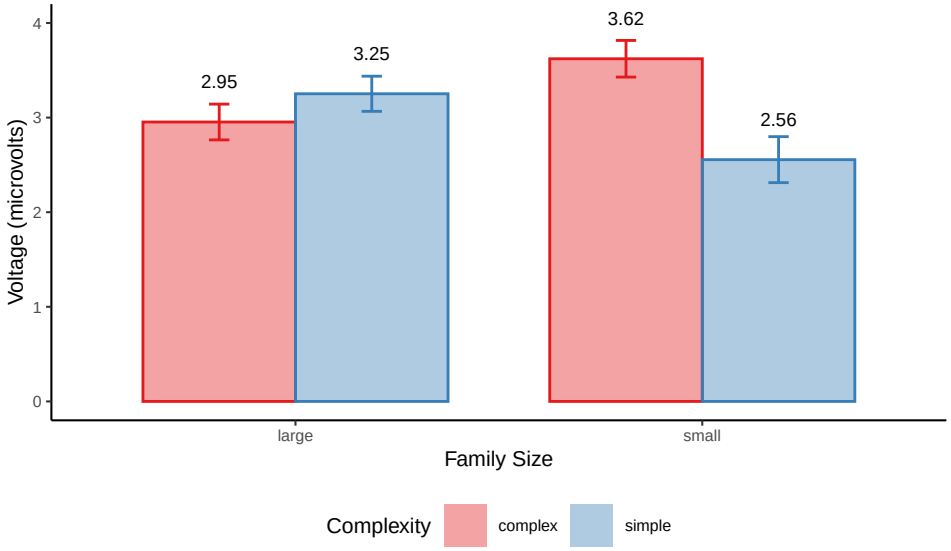
```
(difference_scores_2.2 <- nw_cmplx_famsize_2 %>%
  pivot_wider(names_from = complexity, values_from = c(mean, se, num_stim)) %>%
  mutate(mean_diff = `mean_simple` - `mean_complex`,
         avg_se = mean(`se_simple`,`se_complex`),
         total_num_stim = sum(`num_stim_simple`, `num_stim_complex`)))
```

5.2.2.4 Diff Scores `complexity | family_size`

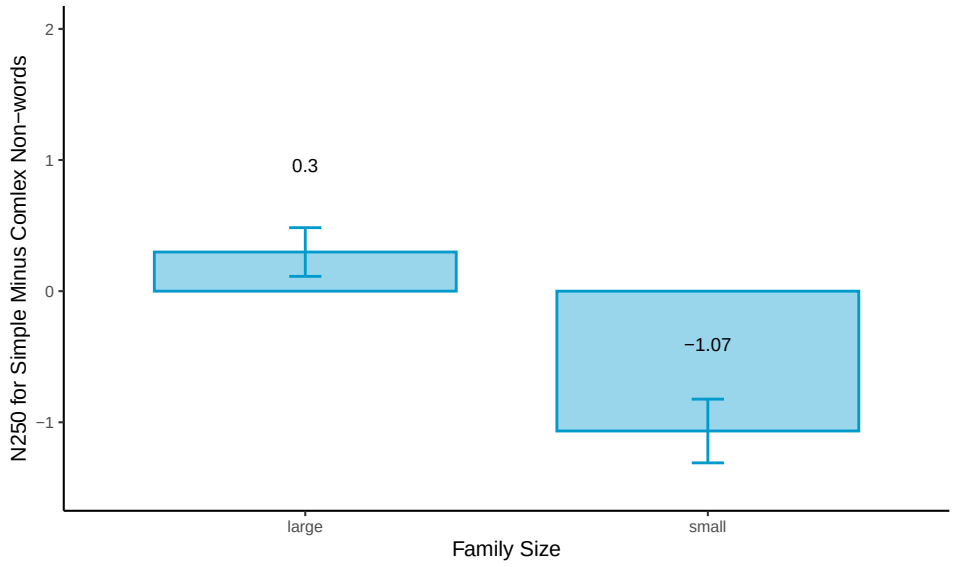
```
|| # A tibble: 2 x 10
|| # Groups:   family_size [2]
||   family_size mean_complex mean_simple se_complex se_simple num_stim_complex
||   <chr>              <dbl>       <dbl>      <dbl>     <dbl>            <int>
|| 1 large               2.95        3.25      0.189     0.186              351
|| 2 small               3.62        2.56      0.194     0.243              351
|| # i 4 more variables: num_stim_simple <int>, mean_diff <dbl>, avg_se <dbl>,
|| #   total_num_stim <int>
```

5.2.2.5 Plots`complexity | family_size` First we plot the raw scores then the difference scores

```
# plot raw scores
p4.a <-  nw_cmplx_famsize_2 |> ggplot(aes(x=family_size,
                                    y=mean,
                                    fill = complexity,
                                    colour = complexity,
                                    ymin = mean - se,
                                    ymax = mean + se)) +
  coord_cartesian(xlim = NULL,ylim = c(0, 4), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = .75,  alpha = .4)  +
  labs(y = "Voltage (microvolts)", x = "Family Size")  +
  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 = -2.5,
             position = position_dodge(.75))+
  guides(fill=guide_legend(title="Complexity"),
         colour= "none") +
  theme(legend.position = "bottom")
p4.a + scale_fill_brewer(palette = "Set1")+
      scale_colour_brewer(palette = "Set1")
```



```r
# plot diff scores
p4.b <- difference_scores_2.2 |> ggplot(aes(x = family_size,
                                        y = mean_diff,
                                        ymin = mean_diff - avg_se,
                                        ymax = mean_diff + avg_se)) +
  coord_cartesian(xlim = NULL,ylim = c(-1.5, 2), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.4,
           colour = "deepskyblue3", fill= "deepskyblue3") +
  labs(y = "N250 for Simple Minus Comlex Non-words", 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 = -6,
            position = position_dodge(.75))+
    guides(fill=guide_legend(title="Complexity Effect"),
           colour= "none") +
  theme(legend.position = "bottom")
p4.b
```




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