

m21 LDT ERP analysis N400

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1 Load libraries

Load libraries

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

2 Set ggplot2 parameters

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

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

```
#Define standard error of the mean function
```

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

3 Load and format data files

First we load the data files

Now we extract SubjID from the ERPset column

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

Divide into word, non-word and difference wave dataframes

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

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

Then we do some more formatting and cleanup of the dataframes. We create separate columns, one for each independent variable (anteriority, laterality, morphological family size). To do this we have to use `separate` 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(n400_1_nonwords,
  dv = value,
  wid = SubjID,
  within = .(family_size, complexity, anteriority, laterality),
  between = .(lang_type_semantic, lang_type_ortho),
  type = 3)
anova_results.1a$ANOVA
```

```
||
|| 2                                lang_type_semantic
|| 3                                lang_type_ortho
|| 5                                family_size
|| 9                                complexity
|| 13                               anteriority
|| 17                               laterality
|| 4                                lang_type_semantic:lang_type_ortho
|| 6                                lang_type_semantic:family_size
|| 7                                lang_type_ortho:family_size
|| 10                               lang_type_semantic:complexity
|| 11                               lang_type_ortho:complexity
|| 14                               lang_type_semantic:anteriority
|| 15                               lang_type_ortho:anteriority
|| 18                               lang_type_semantic:laterality
|| 19                               lang_type_ortho:laterality
```

```

|| 21                                     family_size:complexity
|| 25                                     family_size:anteriority
|| 29                                     complexity:anteriority
|| 33                                     family_size:laterality
|| 37                                     complexity:laterality
|| 41                                     anteriority:laterality
|| 8      lang_type_semantic:lang_type_ortho:family_size
|| 12      lang_type_semantic:lang_type_ortho:complexity
|| 16      lang_type_semantic:lang_type_ortho:anteriority
|| 20      lang_type_semantic:lang_type_ortho:laterality
|| 22      lang_type_semantic:family_size:complexity
|| 23      lang_type_ortho:family_size:complexity
|| 26      lang_type_semantic:family_size:anteriority
|| 27      lang_type_ortho:family_size:anteriority
|| 30      lang_type_semantic:complexity:anteriority
|| 31      lang_type_ortho:complexity:anteriority
|| 34      lang_type_semantic:family_size:laterality
|| 35      lang_type_ortho:family_size:laterality
|| 38      lang_type_semantic:complexity:laterality
|| 39      lang_type_ortho:complexity:laterality
|| 42      lang_type_semantic:anteriority:laterality
|| 43      lang_type_ortho:anteriority:laterality
|| 45      family_size:complexity:anteriority
|| 49      family_size:complexity:laterality
|| 53      family_size:anteriority:laterality
|| 57      complexity:anteriority:laterality
|| 24      lang_type_semantic:lang_type_ortho:family_size:complexity
|| 28      lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 32      lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 36      lang_type_semantic:lang_type_ortho:family_size:laterality
|| 40      lang_type_semantic:lang_type_ortho:complexity:laterality
|| 44      lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 46      lang_type_semantic:family_size:complexity:anteriority
|| 47      lang_type_ortho:family_size:complexity:anteriority
|| 50      lang_type_semantic:family_size:complexity:laterality
|| 51      lang_type_ortho:family_size:complexity:laterality
|| 54      lang_type_semantic:family_size:anteriority:laterality
|| 55      lang_type_ortho:family_size:anteriority:laterality
|| 58      lang_type_semantic:complexity:anteriority:laterality
|| 59      lang_type_ortho:complexity:anteriority:laterality
|| 61      family_size:complexity:anteriority:laterality
|| 48      lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 52      lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 56      lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 60      lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 62      lang_type_semantic:family_size:complexity:anteriority:laterality
|| 63      lang_type_ortho:family_size:complexity:anteriority:laterality
|| 64 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||      DFn DFd      F      p p<.05      ges
|| 2      1 56 1.012796e-01 7.514833e-01      9.672072e-04
|| 3      1 56 1.069044e+00 3.056060e-01      1.011574e-02
|| 5      1 56 1.189231e+00 2.801549e-01      1.567831e-03
|| 9      1 56 1.038188e-02 9.192067e-01      1.242449e-05
|| 13     2 112 2.568706e+01 6.575766e-10      * 6.476117e-02

```

17	2	112	5.130254e+00	7.382143e-03	* 3.076214e-03
4	1	56	1.403661e-02	9.061143e-01	1.341596e-04
6	1	56	2.363497e-01	6.287522e-01	3.119853e-04
7	1	56	1.055863e+00	3.085788e-01	1.392249e-03
10	1	56	1.806149e+00	1.843908e-01	2.156868e-03
11	1	56	5.288218e-01	4.701319e-01	6.324734e-04
14	2	112	7.639941e-01	4.682141e-01	2.055295e-03
15	2	112	4.604372e+00	1.197590e-02	* 1.226001e-02
18	2	112	1.096564e+00	3.375755e-01	6.591184e-04
19	2	112	6.278264e-02	9.391806e-01	3.776060e-05
21	1	56	2.734967e-02	8.692426e-01	3.297632e-05
25	2	112	4.305109e-01	6.512482e-01	6.086088e-05
29	2	112	7.586406e-01	4.706936e-01	1.004265e-04
33	2	112	1.010474e-01	9.039725e-01	6.857270e-06
37	2	112	2.352401e-02	9.767553e-01	2.474757e-06
41	4	224	7.839296e-01	5.366662e-01	2.934025e-04
8	1	56	2.215417e+00	1.422483e-01	2.916764e-03
12	1	56	1.077120e+00	3.038033e-01	1.287397e-03
16	2	112	7.186107e-01	4.896624e-01	1.933441e-03
20	2	112	3.115665e-01	7.329315e-01	1.873636e-04
22	1	56	6.538181e-02	7.991204e-01	7.882921e-05
23	1	56	2.193267e-04	9.882367e-01	2.644575e-07
26	2	112	8.522900e-01	4.291841e-01	1.204802e-04
27	2	112	9.164566e-02	9.124968e-01	1.295647e-05
30	2	112	3.812708e+00	2.500894e-02	* 5.045106e-04
31	2	112	8.846276e-02	9.154011e-01	1.171147e-05
34	2	112	6.176632e-01	5.410294e-01	4.191433e-05
35	2	112	6.489225e-01	5.245621e-01	4.403548e-05
38	2	112	6.539335e-01	5.219701e-01	6.879011e-05
39	2	112	6.143275e-01	5.428174e-01	6.462405e-05
42	4	224	2.564519e+00	3.918905e-02	* 9.591872e-04
43	4	224	1.402300e+00	2.340966e-01	5.247194e-04
45	2	112	1.002638e+00	3.701793e-01	1.414131e-04
49	2	112	3.281261e-01	7.209622e-01	2.675197e-05
53	4	224	9.718584e-01	4.237135e-01	7.597103e-05
57	4	224	6.765466e-01	6.088752e-01	6.904026e-05
24	1	56	1.903181e+00	1.732069e-01	2.289544e-03
28	2	112	7.798169e-01	4.609632e-01	1.102365e-04
32	2	112	4.665531e-01	6.283736e-01	6.176326e-05
36	2	112	1.105094e+00	3.347633e-01	7.498868e-05
40	2	112	1.215350e-01	8.856767e-01	1.278551e-05
44	4	224	1.748748e+00	1.402529e-01	6.542704e-04
46	2	112	8.177233e-01	4.440534e-01	1.153356e-04
47	2	112	1.503948e-02	9.850750e-01	2.121480e-06
50	2	112	2.961022e+00	5.583277e-02	2.413590e-04
51	2	112	2.086973e+00	1.288604e-01	1.701256e-04
54	4	224	2.340249e-01	9.190016e-01	1.829499e-05
55	4	224	1.258241e+00	2.873608e-01	9.835559e-05
58	4	224	1.244564e+00	2.929214e-01	1.269979e-04
59	4	224	1.906320e+00	1.103208e-01	1.945118e-04
61	4	224	1.864227e+00	1.176699e-01	1.003203e-04
48	2	112	2.132169e-01	8.083081e-01	3.007568e-05
52	2	112	4.693951e-01	6.266051e-01	3.826913e-05
56	4	224	9.663091e-01	4.267831e-01	7.553727e-05

```

|| 60 4 224 4.313437e-01 7.859139e-01 4.401888e-05
|| 62 4 224 4.163821e+00 2.841620e-03 * 2.240413e-04
|| 63 4 224 1.816049e+00 1.266439e-01 9.772791e-05
|| 64 4 224 6.396776e-01 6.347208e-01 3.442545e-05

```

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

```

||
||
||                                     Effect
|| 13                                anteriority
|| 14                   lang_type_semantic:anteriority
|| 15                   lang_type_ortho:anteriority
|| 16                   lang_type_semantic:lang_type_ortho:anteriority
|| 17                                laterality
|| 18                   lang_type_semantic:laterality
|| 19                   lang_type_ortho:laterality
|| 20                   lang_type_semantic:lang_type_ortho:laterality
|| 25                                family_size:anteriority
|| 26                   lang_type_semantic:family_size:anteriority
|| 27                   lang_type_ortho:family_size:anteriority
|| 28                   lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 29                                complexity:anteriority
|| 30                   lang_type_semantic:complexity:anteriority
|| 31                   lang_type_ortho:complexity:anteriority
|| 32                   lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 33                                family_size:laterality
|| 34                   lang_type_semantic:family_size:laterality
|| 35                   lang_type_ortho:family_size:laterality
|| 36                   lang_type_semantic:lang_type_ortho:family_size:laterality
|| 37                                complexity:laterality
|| 38                   lang_type_semantic:complexity:laterality
|| 39                   lang_type_ortho:complexity:laterality
|| 40                   lang_type_semantic:lang_type_ortho:complexity:laterality
|| 41                                anteriority:laterality
|| 42                   lang_type_semantic:anteriority:laterality
|| 43                   lang_type_ortho:anteriority:laterality
|| 44                   lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 45                                family_size:complexity:anteriority
|| 46                   lang_type_semantic:family_size:complexity:anteriority
|| 47                   lang_type_ortho:family_size:complexity:anteriority
|| 48                   lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 49                                family_size:complexity:laterality
|| 50                   lang_type_semantic:family_size:complexity:laterality
|| 51                   lang_type_ortho:family_size:complexity:laterality
|| 52                   lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 53                                family_size:anteriority:laterality
|| 54                   lang_type_semantic:family_size:anteriority:laterality
|| 55                   lang_type_ortho:family_size:anteriority:laterality
|| 56                   lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 57                                complexity:anteriority:laterality
|| 58                   lang_type_semantic:complexity:anteriority:laterality
|| 59                   lang_type_ortho:complexity:anteriority:laterality
|| 60                   lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 61                                family_size:complexity:anteriority:laterality
|| 62                   lang_type_semantic:family_size:complexity:anteriority:laterality

```

	lang_type_ortho:family_size:complexity:anteriority:laterality					
	lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality					
	GGe	p[GG]	p[GG]<.05	HFe	p[HF]	p[HF]<.05
13	0.5665160	1.430722e-06	*	0.5703142	1.337065e-06	*
14	0.5665160	4.008280e-01		0.5703142	4.016293e-01	
15	0.5665160	3.131379e-02	*	0.5703142	3.105250e-02	*
16	0.5665160	4.163572e-01		0.5703142	4.172209e-01	
17	0.9247835	8.986180e-03	*	0.9549814	8.303575e-03	*
18	0.9247835	3.340956e-01		0.9549814	3.355514e-01	
19	0.9247835	9.280039e-01		0.9549814	9.327354e-01	
20	0.9247835	7.159134e-01		0.9549814	7.229287e-01	
25	0.7890239	6.040884e-01		0.8080262	6.088174e-01	
26	0.7890239	4.061656e-01		0.8080262	4.085086e-01	
27	0.7890239	8.689941e-01		0.8080262	8.737684e-01	
28	0.7890239	4.339403e-01		0.8080262	4.366680e-01	
29	0.8466263	4.508798e-01		0.8701994	4.541541e-01	
30	0.8466263	3.206071e-02	*	0.8701994	3.085924e-02	*
31	0.8466263	8.861892e-01		0.8701994	8.913268e-01	
32	0.8466263	5.965347e-01		0.8701994	6.017766e-01	
33	0.9553502	8.959829e-01		0.9882723	9.019418e-01	
34	0.9553502	5.339610e-01		0.9882723	5.392024e-01	
35	0.9553502	5.178595e-01		0.9882723	5.228299e-01	
36	0.9553502	3.328293e-01		0.9882723	3.342710e-01	
37	0.6555688	9.286399e-01		0.6649877	9.308549e-01	
38	0.6555688	4.609162e-01		0.6649877	4.629669e-01	
39	0.6555688	4.776495e-01		0.6649877	4.798322e-01	
40	0.6555688	7.958798e-01		0.6649877	7.992511e-01	
41	0.8128803	5.134378e-01		0.8689194	5.208944e-01	
42	0.8128803	5.145044e-02		0.8689194	4.740640e-02	*
43	0.8128803	2.416327e-01		0.8689194	2.394555e-01	
44	0.8128803	1.541066e-01		0.8689194	1.498414e-01	
45	0.6606367	3.422384e-01		0.6703940	3.433036e-01	
46	0.6606367	4.001430e-01		0.6703940	4.017238e-01	
47	0.6606367	9.476738e-01		0.6703940	9.495715e-01	
48	0.6606367	7.136463e-01		0.6703940	7.171464e-01	
49	0.8337484	6.814995e-01		0.8562767	6.873260e-01	
50	0.8337484	6.593432e-02		0.8562767	6.447133e-02	
51	0.8337484	1.378875e-01		0.8562767	1.366629e-01	
52	0.8337484	5.919601e-01		0.8562767	5.970288e-01	
53	0.7890040	4.104261e-01		0.8415949	4.141519e-01	
54	0.7890040	8.814998e-01		0.8415949	8.924202e-01	
55	0.7890040	2.902079e-01		0.8415949	2.896998e-01	
56	0.7890040	4.131239e-01		0.8415949	4.169469e-01	
57	0.6502020	5.473162e-01		0.6846829	5.546211e-01	
58	0.6502020	2.950072e-01		0.6846829	2.952170e-01	
59	0.6502020	1.393956e-01		0.6846829	1.362647e-01	
60	0.6502020	7.028017e-01		0.6846829	7.129763e-01	
61	0.9111706	1.244055e-01		0.9824546	1.189706e-01	
62	0.9111706	3.927780e-03	*	0.9824546	3.028835e-03	*
63	0.9111706	1.332843e-01		0.9824546	1.279292e-01	
64	0.9111706	6.203270e-01		0.9824546	6.319751e-01	

```
anova_results.1b <- aov_ez(id = "SubjID",
                             dv = "value",
```

```

data = n400_1_nonwords,
within = c("family_size",
           "complexity",
           "anteriority",
           "laterality"),
between = c("lang_type_semantic", "lang_type_ortho"),
type = 3)
anova_results.1b

```

```

|| Anova Table (Type 3 tests)
||
|| Response: value
||
||                                     Effect
|| 1                                lang_type_semantic
|| 2                                lang_type_ortho
|| 3                        lang_type_semantic:lang_type_ortho
|| 4                                family_size
|| 5                        lang_type_semantic:family_size
|| 6                        lang_type_ortho:family_size
|| 7                lang_type_semantic:lang_type_ortho:family_size
|| 8                                complexity
|| 9                        lang_type_semantic:complexity
|| 10                       lang_type_ortho:complexity
|| 11                lang_type_semantic:lang_type_ortho:complexity
|| 12                                anteriority
|| 13                       lang_type_semantic:anteriority
|| 14                       lang_type_ortho:anteriority
|| 15                lang_type_semantic:lang_type_ortho:anteriority
|| 16                                laterality
|| 17                       lang_type_semantic:laterality
|| 18                       lang_type_ortho:laterality
|| 19                lang_type_semantic:lang_type_ortho:laterality
|| 20                       family_size:complexity
|| 21                lang_type_semantic:family_size:complexity
|| 22                lang_type_ortho:family_size:complexity
|| 23                lang_type_semantic:lang_type_ortho:family_size:complexity
|| 24                       family_size:anteriority
|| 25                lang_type_semantic:family_size:anteriority
|| 26                lang_type_ortho:family_size:anteriority
|| 27                lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 28                       complexity:anteriority
|| 29                lang_type_semantic:complexity:anteriority
|| 30                lang_type_ortho:complexity:anteriority
|| 31                lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 32                       family_size:laterality
|| 33                lang_type_semantic:family_size:laterality
|| 34                lang_type_ortho:family_size:laterality
|| 35                lang_type_semantic:lang_type_ortho:family_size:laterality
|| 36                       complexity:laterality
|| 37                lang_type_semantic:complexity:laterality
|| 38                lang_type_ortho:complexity:laterality
|| 39                lang_type_semantic:lang_type_ortho:complexity:laterality
|| 40                       anteriority:laterality

```



```

|| 41 lang_type_semantic:anteriority:laterality
|| 42 lang_type_ortho:anteriority:laterality
|| 43 lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 44 family_size:complexity:anteriority
|| 45 lang_type_semantic:family_size:complexity:anteriority
|| 46 lang_type_ortho:family_size:complexity:anteriority
|| 47 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority
|| 48 family_size:complexity:laterality
|| 49 lang_type_semantic:family_size:complexity:laterality
|| 50 lang_type_ortho:family_size:complexity:laterality
|| 51 lang_type_semantic:lang_type_ortho:family_size:complexity:laterality
|| 52 family_size:anteriority:laterality
|| 53 lang_type_semantic:family_size:anteriority:laterality
|| 54 lang_type_ortho:family_size:anteriority:laterality
|| 55 lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality
|| 56 complexity:anteriority:laterality
|| 57 lang_type_semantic:complexity:anteriority:laterality
|| 58 lang_type_ortho:complexity:anteriority:laterality
|| 59 lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality
|| 60 family_size:complexity:anteriority:laterality
|| 61 lang_type_semantic:family_size:complexity:anteriority:laterality
|| 62 lang_type_ortho:family_size:complexity:anteriority:laterality
|| 63 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||
|| df MSE F ges p.value
|| 1 1, 56 366.93 0.10 <.001 .751
|| 2 1, 56 366.93 1.07 .010 .306
|| 3 1, 56 366.93 0.01 <.001 .906
|| 4 1, 56 50.68 1.19 .002 .280
|| 5 1, 56 50.68 0.24 <.001 .629
|| 6 1, 56 50.68 1.06 .001 .309
|| 7 1, 56 50.68 2.22 .003 .142
|| 8 1, 56 45.94 0.01 <.001 .919
|| 9 1, 56 45.94 1.81 .002 .184
|| 10 1, 56 45.94 0.53 <.001 .470
|| 11 1, 56 45.94 1.08 .001 .304
|| 12 1.13, 63.45 91.33 25.69 *** .065 <.001
|| 13 1.13, 63.45 91.33 0.76 .002 .401
|| 14 1.13, 63.45 91.33 4.60 * .012 .031
|| 15 1.13, 63.45 91.33 0.72 .002 .416
|| 16 1.85, 103.58 12.48 5.13 ** .003 .009
|| 17 1.85, 103.58 12.48 1.10 <.001 .334
|| 18 1.85, 103.58 12.48 0.06 <.001 .928
|| 19 1.85, 103.58 12.48 0.31 <.001 .716
|| 20 1, 56 46.28 0.03 <.001 .869
|| 21 1, 56 46.28 0.07 <.001 .799
|| 22 1, 56 46.28 0.00 <.001 .988
|| 23 1, 56 46.28 1.90 .002 .173
|| 24 1.58, 88.37 3.44 0.43 <.001 .604
|| 25 1.58, 88.37 3.44 0.85 <.001 .406
|| 26 1.58, 88.37 3.44 0.09 <.001 .869
|| 27 1.58, 88.37 3.44 0.78 <.001 .434
|| 28 1.69, 94.82 3.00 0.76 <.001 .451
|| 29 1.69, 94.82 3.00 3.81 * <.001 .032
|| 30 1.69, 94.82 3.00 0.09 <.001 .886

```

```

|| 31 1.69, 94.82 3.00 0.47 <.001 .597
|| 32 1.91, 107.00 1.36 0.10 <.001 .896
|| 33 1.91, 107.00 1.36 0.62 <.001 .534
|| 34 1.91, 107.00 1.36 0.65 <.001 .518
|| 35 1.91, 107.00 1.36 1.11 <.001 .333
|| 36 1.31, 73.42 3.08 0.02 <.001 .929
|| 37 1.31, 73.42 3.08 0.65 <.001 .461
|| 38 1.31, 73.42 3.08 0.61 <.001 .478
|| 39 1.31, 73.42 3.08 0.12 <.001 .796
|| 40 3.25, 182.09 4.42 0.78 <.001 .513
|| 41 3.25, 182.09 4.42 2.56 + <.001 .051
|| 42 3.25, 182.09 4.42 1.40 <.001 .242
|| 43 3.25, 182.09 4.42 1.75 <.001 .154
|| 44 1.32, 73.99 4.10 1.00 <.001 .342
|| 45 1.32, 73.99 4.10 0.82 <.001 .400
|| 46 1.32, 73.99 4.10 0.02 <.001 .948
|| 47 1.32, 73.99 4.10 0.21 <.001 .714
|| 48 1.67, 93.38 1.88 0.33 <.001 .681
|| 49 1.67, 93.38 1.88 2.96 + <.001 .066
|| 50 1.67, 93.38 1.88 2.09 <.001 .138
|| 51 1.67, 93.38 1.88 0.47 <.001 .592
|| 52 3.16, 176.74 0.95 0.97 <.001 .410
|| 53 3.16, 176.74 0.95 0.23 <.001 .881
|| 54 3.16, 176.74 0.95 1.26 <.001 .290
|| 55 3.16, 176.74 0.95 0.97 <.001 .413
|| 56 2.60, 145.65 1.51 0.68 <.001 .547
|| 57 2.60, 145.65 1.51 1.24 <.001 .295
|| 58 2.60, 145.65 1.51 1.91 <.001 .139
|| 59 2.60, 145.65 1.51 0.43 <.001 .703
|| 60 3.64, 204.10 0.57 1.86 <.001 .124
|| 61 3.64, 204.10 0.57 4.16 ** <.001 .004
|| 62 3.64, 204.10 0.57 1.82 <.001 .133
|| 63 3.64, 204.10 0.57 0.64 <.001 .620
|| ---
|| Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
||
|| Sphericity correction method: GG

```

4.2 Group 2

```

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

```

```

||
|| 2 lang_type_semantic
|| 3 lang_type_ortho
|| 5 family_size

```

```

|| 9 complexity
|| 13 anteriority
|| 17 laterality
|| 4 lang_type_semantic:lang_type_ortho
|| 6 lang_type_semantic:family_size
|| 7 lang_type_ortho:family_size
|| 10 lang_type_semantic:complexity
|| 11 lang_type_ortho:complexity
|| 14 lang_type_semantic:anteriority
|| 15 lang_type_ortho:anteriority
|| 18 lang_type_semantic:laterality
|| 19 lang_type_ortho:laterality
|| 21 family_size:complexity
|| 25 family_size:anteriority
|| 29 complexity:anteriority
|| 33 family_size:laterality
|| 37 complexity:laterality
|| 41 anteriority:laterality
|| 8 lang_type_semantic:lang_type_ortho:family_size
|| 12 lang_type_semantic:lang_type_ortho:complexity
|| 16 lang_type_semantic:lang_type_ortho:anteriority
|| 20 lang_type_semantic:lang_type_ortho:laterality
|| 22 lang_type_semantic:family_size:complexity
|| 23 lang_type_ortho:family_size:complexity
|| 26 lang_type_semantic:family_size:anteriority
|| 27 lang_type_ortho:family_size:anteriority
|| 30 lang_type_semantic:complexity:anteriority
|| 31 lang_type_ortho:complexity:anteriority
|| 34 lang_type_semantic:family_size:laterality
|| 35 lang_type_ortho:family_size:laterality
|| 38 lang_type_semantic:complexity:laterality
|| 39 lang_type_ortho:complexity:laterality
|| 42 lang_type_semantic:anteriority:laterality
|| 43 lang_type_ortho:anteriority:laterality
|| 45 family_size:complexity:anteriority
|| 49 family_size:complexity:laterality
|| 53 family_size:anteriority:laterality
|| 57 complexity:anteriority:laterality
|| 24 lang_type_semantic:lang_type_ortho:family_size:complexity
|| 28 lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 32 lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 36 lang_type_semantic:lang_type_ortho:family_size:laterality
|| 40 lang_type_semantic:lang_type_ortho:complexity:laterality
|| 44 lang_type_semantic:lang_type_ortho:anteriority:laterality
|| 46 lang_type_semantic:family_size:complexity:anteriority
|| 47 lang_type_ortho:family_size:complexity:anteriority
|| 50 lang_type_semantic:family_size:complexity:laterality
|| 51 lang_type_ortho:family_size:complexity:laterality
|| 54 lang_type_semantic:family_size:anteriority:laterality
|| 55 lang_type_ortho:family_size:anteriority:laterality
|| 58 lang_type_semantic:complexity:anteriority:laterality
|| 59 lang_type_ortho:complexity:anteriority:laterality
|| 61 family_size:complexity:anteriority:laterality
|| 48 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority

```

52	lang_type_semantic:lang_type_ortho:family_size:complexity:laterality					
56	lang_type_semantic:lang_type_ortho:family_size:anteriority:laterality					
60	lang_type_semantic:lang_type_ortho:complexity:anteriority:laterality					
62	lang_type_semantic:family_size:complexity:anteriority:laterality					
63	lang_type_ortho:family_size:complexity:anteriority:laterality					
64	lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality					
	DFn	DFd		F	p p<.05	ges
2	1	35	6.985461e-01	4.089424e-01		1.103839e-02
3	1	35	1.608032e+00	2.131394e-01		2.505003e-02
5	1	35	8.590813e-06	9.976780e-01		1.364393e-08
9	1	35	2.117362e+00	1.545482e-01		2.547424e-03
13	2	70	4.750670e+01	9.231223e-14	*	1.795487e-01
17	2	70	2.637710e+00	7.862668e-02		2.887182e-03
4	1	35	7.612059e-02	7.842477e-01		1.214802e-03
6	1	35	5.817963e-01	4.507196e-01		9.231556e-04
7	1	35	2.693391e-01	6.070417e-01		4.275814e-04
10	1	35	5.333730e-01	4.700528e-01		6.429327e-04
11	1	35	1.523834e+00	2.252644e-01		1.834653e-03
14	2	70	4.576340e-01	6.346586e-01		2.103673e-03
15	2	70	6.421585e-01	5.292266e-01		2.949402e-03
18	2	70	7.567219e-01	4.730011e-01		8.300008e-04
19	2	70	1.081698e+00	3.446179e-01		1.186024e-03
21	1	35	8.236043e+00	6.920894e-03	*	5.788081e-03
25	2	70	8.824656e-02	9.156368e-01		2.484703e-05
29	2	70	8.716391e-02	9.166262e-01		2.854520e-05
33	2	70	1.217289e+00	3.022204e-01		2.262341e-04
37	2	70	3.917181e-01	6.773668e-01		1.036081e-04
41	4	140	5.983784e+00	1.786168e-04	*	4.643660e-03
8	1	35	7.070515e-03	9.334669e-01		1.122926e-05
12	1	35	1.756564e+00	1.936406e-01		2.114261e-03
16	2	70	1.398208e+00	2.538526e-01		6.399676e-03
20	2	70	4.749062e-01	6.239325e-01		5.210559e-04
22	1	35	2.524968e+00	1.210509e-01		1.781634e-03
23	1	35	1.695908e+00	2.013290e-01		1.197344e-03
26	2	70	1.289683e-01	8.792102e-01		3.631238e-05
27	2	70	7.383565e-02	9.288966e-01		2.078952e-05
30	2	70	1.016749e+00	3.670486e-01		3.328727e-04
31	2	70	1.336810e-01	8.750919e-01		4.377837e-05
34	2	70	9.570160e-01	3.890040e-01		1.778708e-04
35	2	70	1.536775e+00	2.222410e-01		2.855939e-04
38	2	70	6.236392e-01	5.389415e-01		1.649404e-04
39	2	70	1.211172e+00	3.040125e-01		3.202814e-04
42	4	140	2.166914e+00	7.581763e-02		1.686610e-03
43	4	140	9.783793e-01	4.214832e-01		7.622230e-04
45	2	70	1.406225e+00	2.519034e-01		3.847017e-04
49	2	70	8.099137e-01	4.490213e-01		1.226574e-04
53	4	140	5.369208e-01	7.088300e-01		2.085877e-04
57	4	140	6.461044e-01	6.305385e-01		2.420151e-04
24	1	35	3.082204e-01	5.823055e-01		2.178231e-04
28	2	70	2.690729e+00	7.484673e-02		7.570568e-04
32	2	70	2.512027e+00	8.839201e-02		8.220078e-04
36	2	70	7.861796e-01	4.595627e-01		1.461238e-04
40	2	70	3.296992e-01	7.202507e-01		8.720576e-05
44	4	140	1.036461e+00	3.907118e-01		8.074358e-04

```

|| 46 2 70 5.440184e-02 9.470915e-01 1.488825e-05
|| 47 2 70 2.477740e+00 9.126675e-02 6.776383e-04
|| 50 2 70 1.498835e+00 2.304712e-01 2.269673e-04
|| 51 2 70 5.332237e-01 5.890744e-01 8.075744e-05
|| 54 4 140 1.156170e+00 3.329078e-01 4.490511e-04
|| 55 4 140 7.659243e-01 5.491302e-01 2.975266e-04
|| 58 4 140 5.134807e-01 7.259198e-01 1.923470e-04
|| 59 4 140 6.434233e-01 6.324227e-01 2.410110e-04
|| 61 4 140 1.062570e+00 3.774637e-01 3.824285e-04
|| 48 2 70 1.919202e+00 1.543657e-01 5.249637e-04
|| 52 2 70 4.259145e-01 6.548534e-01 6.450636e-05
|| 56 4 140 1.040733e+00 3.885193e-01 4.042340e-04
|| 60 4 140 4.792059e-01 7.509562e-01 1.795102e-04
|| 62 4 140 1.522891e+00 1.987713e-01 5.480113e-04
|| 63 4 140 1.198644e+00 3.141711e-01 4.313814e-04
|| 64 4 140 1.105971e+00 3.562373e-01 3.980426e-04

```

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

```

||
||
||                                     Effect
|| 13                                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 0.5673693 8.749078e-09          * 0.5736053 7.411747e-09          *
|| 14 0.5673693 5.267595e-01          0.5736053 5.288098e-01
|| 15 0.5673693 4.465544e-01          0.5736053 4.481339e-01
|| 16 0.5673693 2.483636e-01          0.5736053 2.486201e-01
|| 17 0.9659122 8.071280e-02          1.0213094 7.862668e-02
|| 18 0.9659122 4.689022e-01          1.0213094 4.730011e-01
|| 19 0.9659122 3.430290e-01          1.0213094 3.446179e-01
|| 20 0.9659122 6.173996e-01          1.0213094 6.239325e-01
|| 25 0.6610669 8.353027e-01          0.6769553 8.405974e-01
|| 26 0.6610669 7.906257e-01          0.6769553 7.962163e-01
|| 27 0.6610669 8.530501e-01          0.6769553 8.581556e-01
|| 28 0.6610669 9.778628e-02          0.6769553 9.661057e-02
|| 29 0.5882717 8.096206e-01          0.5965618 8.129412e-01
|| 30 0.5882717 3.323350e-01          0.5965618 3.333475e-01
|| 31 0.5882717 7.576542e-01          0.5965618 7.610916e-01
|| 32 0.5882717 1.159249e-01          0.5965618 1.153450e-01
|| 33 0.6736463 2.904944e-01          0.6909181 2.914427e-01
|| 34 0.6736463 3.593046e-01          0.6909181 3.613113e-01
|| 35 0.6736463 2.260405e-01          0.6909181 2.260537e-01
|| 36 0.6736463 4.153478e-01          0.6909181 4.182112e-01
|| 37 0.7214981 6.102446e-01          0.7442241 6.166210e-01
|| 38 0.7214981 4.896299e-01          0.7442241 4.942863e-01
|| 39 0.7214981 2.944905e-01          0.7442241 2.955880e-01
|| 40 0.7214981 6.495379e-01          0.7442241 6.563118e-01
|| 41 0.5918948 2.237230e-03          * 0.6376546 1.679736e-03          *
|| 42 0.5918948 1.120363e-01          0.6376546 1.072561e-01
|| 43 0.5918948 3.918347e-01          0.6376546 3.964063e-01
|| 44 0.5918948 3.688032e-01          0.6376546 3.723867e-01
|| 45 0.7422897 2.513287e-01          0.7674804 2.516219e-01
|| 46 0.7422897 9.014586e-01          0.7674804 9.073963e-01
|| 47 0.7422897 1.079421e-01          0.7674804 1.062306e-01
|| 48 0.7422897 1.663703e-01          0.7674804 1.652656e-01
|| 49 0.7287837 4.154271e-01          0.7523668 4.188466e-01
|| 50 0.7287837 2.329813e-01          0.7523668 2.329752e-01
|| 51 0.7287837 5.341844e-01          0.7523668 5.396692e-01
|| 52 0.7287837 5.920452e-01          0.7523668 5.983488e-01
|| 53 0.3319166 5.163948e-01          0.3400120 5.205000e-01
|| 54 0.3319166 3.044437e-01          0.3400120 3.055720e-01
|| 55 0.3319166 4.209716e-01          0.3400120 4.238037e-01

```

```

|| 56 0.3319166 3.342785e-01      0.3400120 3.358447e-01
|| 57 0.3330719 4.681510e-01      0.3412940 4.716722e-01
|| 58 0.3330719 5.283807e-01      0.3412940 5.326745e-01
|| 59 0.3330719 4.692738e-01      0.3412940 4.728102e-01
|| 60 0.3330719 5.456947e-01      0.3412940 5.501912e-01
|| 61 0.3140015 3.249027e-01      0.3201771 3.261320e-01
|| 62 0.3140015 2.281671e-01      0.3201771 2.282787e-01
|| 63 0.3140015 2.919270e-01      0.3201771 2.927636e-01
|| 64 0.3140015 3.139148e-01      0.3201771 3.150126e-01

```

```

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

anova_results.2b

```

```

|| Anova Table (Type 3 tests)
||
|| Response: value
||
||                                     Effect
|| 1                                     lang_type_semantic
|| 2                                     lang_type_ortho
|| 3                                lang_type_semantic:lang_type_ortho
|| 4                                     family_size
|| 5                                lang_type_semantic:family_size
|| 6                                lang_type_ortho:family_size
|| 7                                lang_type_semantic:lang_type_ortho:family_size
|| 8                                     complexity
|| 9                                lang_type_semantic:complexity
|| 10                                lang_type_ortho:complexity
|| 11                                lang_type_semantic:lang_type_ortho:complexity
|| 12                                     anteriority
|| 13                                lang_type_semantic:anteriority
|| 14                                lang_type_ortho:anteriority
|| 15                                lang_type_semantic:lang_type_ortho:anteriority
|| 16                                     laterality
|| 17                                lang_type_semantic:laterality
|| 18                                lang_type_ortho:laterality
|| 19                                lang_type_semantic:lang_type_ortho:laterality
|| 20                                     family_size:complexity
|| 21                                lang_type_semantic:family_size:complexity
|| 22                                lang_type_ortho:family_size:complexity
|| 23                                lang_type_semantic:lang_type_ortho:family_size:complexity
|| 24                                     family_size:anteriority
|| 25                                lang_type_semantic:family_size:anteriority
|| 26                                lang_type_ortho:family_size:anteriority
|| 27                                lang_type_semantic:lang_type_ortho:family_size:anteriority
|| 28                                     complexity:anteriority
|| 29                                lang_type_semantic:complexity:anteriority

```

```

|| 30                                lang_type_ortho:complexity:anteriority
|| 31                    lang_type_semantic:lang_type_ortho:complexity:anteriority
|| 32                                family_size:lateralality
|| 33                    lang_type_semantic:family_size:lateralality
|| 34                                lang_type_ortho:family_size:lateralality
|| 35                    lang_type_semantic:lang_type_ortho:family_size:lateralality
|| 36                                complexity:lateralality
|| 37                    lang_type_semantic:complexity:lateralality
|| 38                                lang_type_ortho:complexity:lateralality
|| 39                    lang_type_semantic:lang_type_ortho:complexity:lateralality
|| 40                                anteriority:lateralality
|| 41                    lang_type_semantic:anteriority:lateralality
|| 42                                lang_type_ortho:anteriority:lateralality
|| 43                    lang_type_semantic:lang_type_ortho:anteriority:lateralality
|| 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:lateralality
|| 49                    lang_type_semantic:family_size:complexity:lateralality
|| 50                                lang_type_ortho:family_size:complexity:lateralality
|| 51                    lang_type_semantic:lang_type_ortho:family_size:complexity:lateralality
|| 52                                family_size:anteriority:lateralality
|| 53                    lang_type_semantic:family_size:anteriority:lateralality
|| 54                                lang_type_ortho:family_size:anteriority:lateralality
|| 55                    lang_type_semantic:lang_type_ortho:family_size:anteriority:lateralality
|| 56                                complexity:anteriority:lateralality
|| 57                    lang_type_semantic:complexity:anteriority:lateralality
|| 58                                lang_type_ortho:complexity:anteriority:lateralality
|| 59                    lang_type_semantic:lang_type_ortho:complexity:anteriority:lateralality
|| 60                                family_size:complexity:anteriority:lateralality
|| 61                    lang_type_semantic:family_size:complexity:anteriority:lateralality
|| 62                                lang_type_ortho:family_size:complexity:anteriority:lateralality
|| 63 lang_type_semantic:lang_type_ortho:family_size:complexity:anteriority:laterality
||
||      df      MSE      F      ges p.value
|| 1      1, 35 548.70      0.70 .011 .409
|| 2      1, 35 548.70      1.61 .025 .213
|| 3      1, 35 548.70      0.08 .001 .784
|| 4      1, 35 54.54      0.00 <.001 .998
|| 5      1, 35 54.54      0.58 <.001 .451
|| 6      1, 35 54.54      0.27 <.001 .607
|| 7      1, 35 54.54      0.01 <.001 .933
|| 8      1, 35 41.42      2.12 .003 .155
|| 9      1, 35 41.42      0.53 <.001 .470
|| 10     1, 35 41.42      1.52 .002 .225
|| 11     1, 35 41.42      1.76 .002 .194
|| 12 1.13, 39.72 139.41 47.51 *** .180 <.001
|| 13 1.13, 39.72 139.41      0.46 .002 .527
|| 14 1.13, 39.72 139.41      0.64 .003 .447
|| 15 1.13, 39.72 139.41      1.40 .006 .248
|| 16 1.93, 67.61 19.51      2.64 + .003 .081
|| 17 1.93, 67.61 19.51      0.76 <.001 .469
|| 18 1.93, 67.61 19.51      1.08 .001 .343
|| 19 1.93, 67.61 19.51      0.47 <.001 .617

```


20	1, 35	24.27	8.24 **	.006	.007
21	1, 35	24.27	2.52	.002	.121
22	1, 35	24.27	1.70	.001	.201
23	1, 35	24.27	0.31	<.001	.582
24	1.32, 46.27	7.31	0.09	<.001	.835
25	1.32, 46.27	7.31	0.13	<.001	.791
26	1.32, 46.27	7.31	0.07	<.001	.853
27	1.32, 46.27	7.31	2.69 +	<.001	.098
28	1.18, 41.18	9.56	0.09	<.001	.810
29	1.18, 41.18	9.56	1.02	<.001	.332
30	1.18, 41.18	9.56	0.13	<.001	.758
31	1.18, 41.18	9.56	2.51	<.001	.116
32	1.35, 47.16	4.74	1.22	<.001	.290
33	1.35, 47.16	4.74	0.96	<.001	.359
34	1.35, 47.16	4.74	1.54	<.001	.226
35	1.35, 47.16	4.74	0.79	<.001	.415
36	1.44, 50.50	6.30	0.39	<.001	.610
37	1.44, 50.50	6.30	0.62	<.001	.490
38	1.44, 50.50	6.30	1.21	<.001	.294
39	1.44, 50.50	6.30	0.33	<.001	.650
40	2.37, 82.87	11.31	5.98 **	.005	.002
41	2.37, 82.87	11.31	2.17	.002	.112
42	2.37, 82.87	11.31	0.98	<.001	.392
43	2.37, 82.87	11.31	1.04	<.001	.369
44	1.48, 51.96	6.33	1.41	<.001	.251
45	1.48, 51.96	6.33	0.05	<.001	.901
46	1.48, 51.96	6.33	2.48	<.001	.108
47	1.48, 51.96	6.33	1.92	<.001	.166
48	1.46, 51.01	3.57	0.81	<.001	.415
49	1.46, 51.01	3.57	1.50	<.001	.233
50	1.46, 51.01	3.57	0.53	<.001	.534
51	1.46, 51.01	3.57	0.43	<.001	.592
52	1.33, 46.47	10.05	0.54	<.001	.516
53	1.33, 46.47	10.05	1.16	<.001	.304
54	1.33, 46.47	10.05	0.77	<.001	.421
55	1.33, 46.47	10.05	1.04	<.001	.334
56	1.33, 46.63	9.66	0.65	<.001	.468
57	1.33, 46.63	9.66	0.51	<.001	.528
58	1.33, 46.63	9.66	0.64	<.001	.469
59	1.33, 46.63	9.66	0.48	<.001	.546
60	1.26, 43.96	9.84	1.06	<.001	.325
61	1.26, 43.96	9.84	1.52	<.001	.228
62	1.26, 43.96	9.84	1.20	<.001	.292
63	1.26, 43.96	9.84	1.11	<.001	.314

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
Sphericity correction method: GG

5 Examine and plot interactions

5.1 Group 2

5.1.1 Language Type Orthographic by Anteriority Interaction

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

5.1.1.1 Pairwise Comparisons lang_type_ortho | anteriority

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

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

5.1.1.2 Condition Means lang_type_ortho | anteriority

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

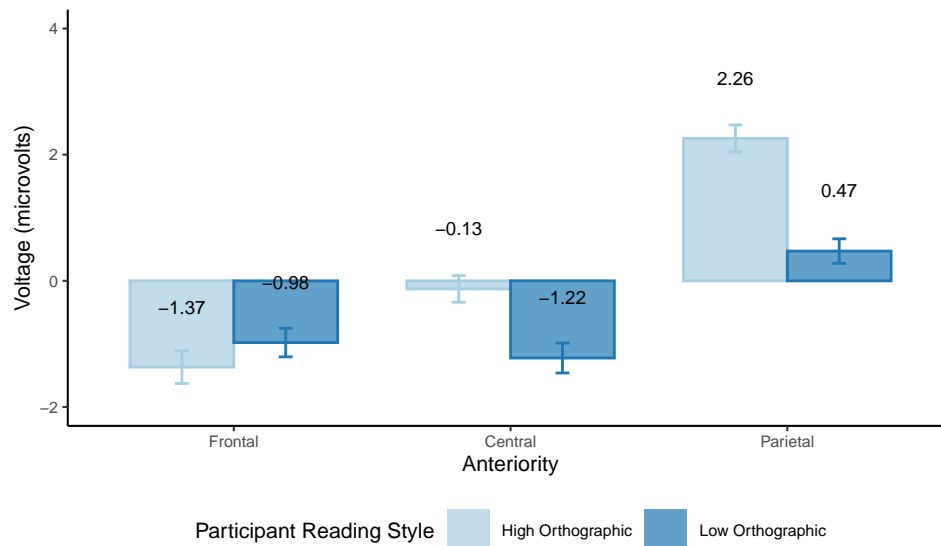
```
(difference_scores_1.1 <- nw_ltortho_ant_1 %>%
  pivot_wider(names_from = lang_type_ortho, values_from = c(mean, se, num_stim)) %>%
  mutate(mean_diff = `mean_Low Orthographic` - `mean_High Orthographic`,
         avg_se = mean(`se_Low Orthographic`, `se_High Orthographic`),
         total_num_stim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

5.1.1.3 Diff Scores lang_type_ortho | anteriority

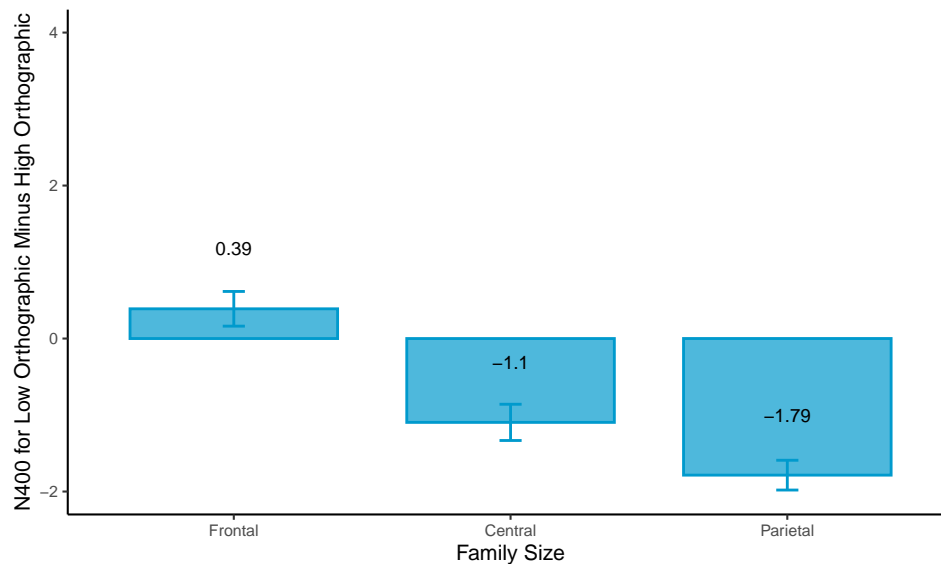
```
|| # A tibble: 3 x 10
|| # Groups:   anteriority [3]
||   anteriority 'mean_High Orthographic' 'mean_Low Orthographic'
||   <fct>                <dbl>                <dbl>
|| 1 Frontal             -1.37             -0.979
|| 2 Central             -0.128            -1.22
|| 3 Parietal            2.26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

5.1.1.4 Plots lang_type_ortho | anteriority First we plot the raw scores then the difference scores

```
# plot raw scores
p1.a <- nw_ltortho_ant_1 |> ggplot(aes(x=anteriority,
                                       y=mean,
                                       fill = lang_type_ortho,
                                       colour = lang_type_ortho,
                                       ymin = mean - se,
                                       ymax = mean + se)) +
  coord_cartesian(xlim = NULL, ylim = c(-2, 4), expand = TRUE, default = FALSE, clip = "on") +
  geom_col(position = "dodge", width = .75, alpha = .7) +
  labs(y = "Voltage (microvolts)", x = "Anteriority") +
  geom_errorbar(width = .1, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
  geom_text(aes(label = round(mean, digits = 2)), colour = "black", size = 2.5, vjust = -4,
            position = position_dodge(.75)) +
  guides(fill=guide_legend(title="Participant Reading Style"),
         colour= "none") +
  theme(legend.position = "bottom")
p1.a + scale_fill_brewer(palette = "Paired") +
  scale_colour_brewer(palette = "Paired")
```



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



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

5.1.2 Language Type Semantic by Complexity by Anteriority Interaction

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

5.1.2.1 Simple Effects complexity | lang_type_semantic * anteriority

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

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

```
|| $ANOVA
||
||           Effect DFn DFd           F           p p<.05
|| 2           lang_type_semantic      1  58 0.068996897 0.7937337
|| 3           complexity              1  58 0.004955495 0.9441212
|| 4 lang_type_semantic:complexity      1  58 2.313923826 0.1336535
||           ges
|| 2 1.063029e-03
|| 3 9.009375e-06
|| 4 4.189261e-03
```

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

```
|| $ANOVA
||
||           Effect DFn DFd           F           p p<.05
```

```

|| 2          lang_type_semantic  1  58 0.395056322 0.5321210
|| 3          complexity        1  58 0.007765497 0.9300832
|| 4 lang_type_semantic:complexity 1  58 0.216326500 0.6435949
||
||      ges
|| 2 5.948399e-03
|| 3 1.626214e-05
|| 4 4.528230e-04

```

```

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

```

```

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

```

```

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

```

```

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

```

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

```

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

```

5.1.2.2 Pairwise Comparisons complexity | lang_type_semantic * anteriority

```

|| lang_type_semantic = High Semantic, anteriority = Frontal:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.4384 0.432 56 -1.016 0.3141
||
|| lang_type_semantic = Low Semantic, anteriority = Frontal:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 0.7347 0.429 56 1.714 0.0921
||
|| lang_type_semantic = High Semantic, anteriority = Central:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.4723 0.440 56 -1.073 0.2878

```

```

||
|| lang_type_semantic = Low Semantic, anteriority = Central:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.4505 0.437 56   1.031  0.3072
||
|| lang_type_semantic = High Semantic, anteriority = Parietal:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.1823 0.444 56  -0.410  0.6831
||
|| lang_type_semantic = Low Semantic, anteriority = Parietal:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.0871 0.441 56   0.197  0.8443
||
|| Results are averaged over the levels of: lang_type_ortho, laterality, family_size

```

```

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

```

5.1.2.3 Condition Means complexity | lang_type_semantic * anteriority

```

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

```

```

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

```

5.1.2.4 Diff Scores complexity | lang_type_semantic * anteriority

```

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

```

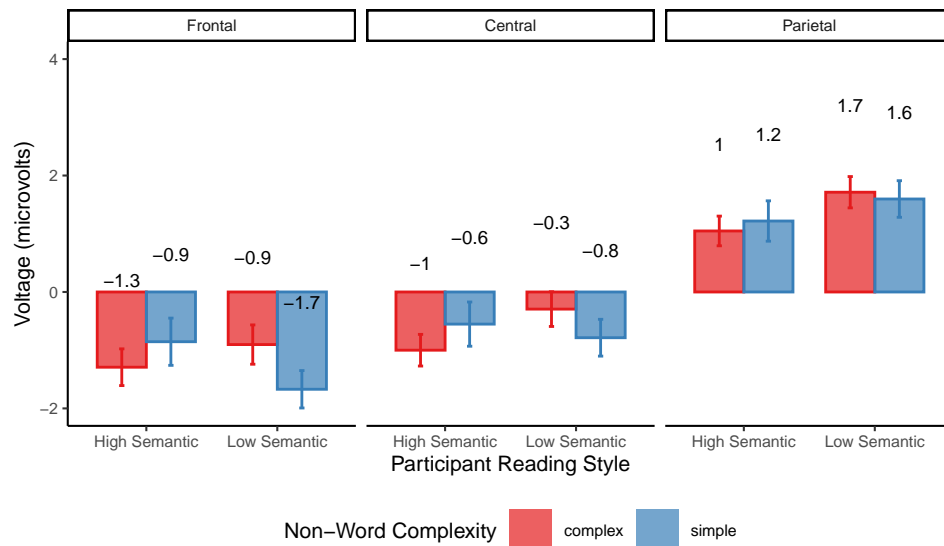
5.1.2.5 Plots complexity | lang_type_semantic * anteriority First we plot the raw scores then the difference scores

```

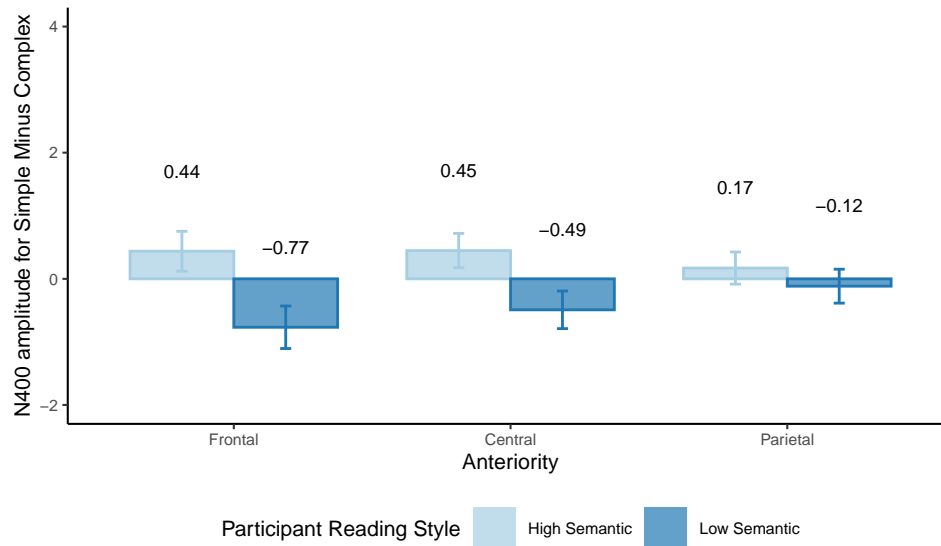
# plot raw scores
# facet_wrap() wraps a 1d sequence of panels into 2d. Use vars() to supply faceting variables;
# Control the number of rows and columns with nrow and ncol.

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

```

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



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

5.1.3 Language Type Semantic by Complexity by Family Size by Anteriority x Laterality Interaction

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

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

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

```

|| 5      * 0.5927043 4.852480e-06      *
|| 6      0.5927043 4.223687e-01
|| 7      * 0.9591689 1.327969e-02      *
|| 8      0.9591689 5.304743e-01
|| 9      0.7457315 2.082156e-01
|| 10     * 0.7457315 3.326040e-02      *
|| 11     0.6714642 8.395393e-01
|| 12     0.6714642 4.856050e-01
|| 13     0.9550388 8.163619e-01
|| 14     0.9550388 8.664207e-02
|| 15     0.6845367 3.757644e-01
|| 16     0.6845367 5.723442e-01

```

```

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

```

```

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

```

```

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

```

```

se_large_hisem_1.2 <-n400_1_nonwords |> filter(family_size == "large" &
  lang_type_semantic == "High Semantic")|>
  ezANOVA(dv = value,

```

```

      wid = SubjID,
      within = .(anteriority, laterality, complexity))
se_large_hisem_1.2$`Sphericity Corrections`

```

```

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

```

```

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

```

```

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

```

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

```

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

```

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

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

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

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

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

```
# Finally we examine the simple effect of complexity at each level of anteriority
# for non-words from large families for high semantic readers at left sites
# Frontal
```

```
se_large_hisem_left_frontal_1.2 <- n400_1_nonwords |>
  filter(family_size == "large" &
    lang_type_semantic == "High Semantic" &
    laterality == "Left" &
    anteriority == "Frontal" )|>
  ezANOVA(dv = value,
    wid = SubjID,
    within = .(complexity))
se_large_hisem_left_frontal_1.2$ANOVA
```

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

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

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

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

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

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

```
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)
```

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

	laterality	anteriority	lang_type_semantic	family_size	small:
	contrast	estimate	SE	df	t.ratio p.value
	complex - simple	-0.2048	0.596	56	-0.344 0.7324
	laterality	Midline	anteriority	Frontal	lang_type_semantic = High Semantic, family_size = small:
	contrast	estimate	SE	df	t.ratio p.value
	complex - simple	-0.7574	0.652	56	-1.162 0.2503

```

|| laterality = Right, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.7674 0.694 56 -1.105 0.2737
||
|| laterality = Left, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.6970 0.642 56 -1.086 0.2822
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.4612 0.686 56 -0.672 0.5044
||
|| laterality = Right, anteriority = Central, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.5128 0.852 56 -0.602 0.5499
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.2547 0.709 56 -0.359 0.7207
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.3552 0.746 56 -0.476 0.6357
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple -0.3839 0.677 56 -0.567 0.5728
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 0.8275 0.592 56 1.398 0.1676
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 1.1027 0.648 56 1.703 0.0942
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 0.9574 0.690 56 1.388 0.1705
||
|| laterality = Left, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 0.2168 0.638 56 0.340 0.7351
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 0.5713 0.682 56 0.838 0.4057
||
|| laterality = Right, anteriority = Central, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple 0.8043 0.847 56 0.950 0.3462
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
|| contrast      estimate    SE df t.ratio p.value

```

```

|| complex - simple -0.0936 0.704 56 -0.133 0.8947
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.4418 0.741 56 -0.596 0.5533
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = small:
|| contrast estimate SE df t.ratio p.value
|| complex - simple 0.1114 0.672 56 0.166 0.8690
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.9630 0.672 56 -1.432 0.1576
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.0297 0.672 56 -0.044 0.9649
||
|| laterality = Right, anteriority = Frontal, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple 0.0921 0.625 56 0.147 0.8835
||
|| laterality = Left, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.7249 0.564 56 -1.285 0.2042
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.0967 0.683 56 -0.141 0.8880
||
|| laterality = Right, anteriority = Central, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.3409 0.617 56 -0.553 0.5825
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple 0.1509 0.539 56 0.280 0.7806
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple 0.1920 0.590 56 0.325 0.7461
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = High Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple -0.4429 0.614 56 -0.721 0.4739
||
|| laterality = Left, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple 0.9361 0.668 56 1.402 0.1665
||
|| laterality = Midline, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
|| contrast estimate SE df t.ratio p.value
|| complex - simple 0.4352 0.667 56 0.652 0.5168
||

```



```

|| laterality = Right, anteriority = Frontal, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.1493 0.621 56   0.240  0.8109
||
|| laterality = Left, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.6179 0.560 56   1.103  0.2749
||
|| laterality = Midline, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.0525 0.679 56   0.077  0.9386
||
|| laterality = Right, anteriority = Central, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.4399 0.612 56   0.718  0.4755
||
|| laterality = Left, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.3484 0.536 56   0.651  0.5180
||
|| laterality = Midline, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.3400 0.586 56   0.580  0.5641
||
|| laterality = Right, anteriority = Parietal, lang_type_semantic = Low Semantic, family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple  0.2579 0.610 56   0.423  0.6742
||
|| Results are averaged over the levels of: lang_type_ortho

```

```

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

```

5.1.3.3 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    -1.66  0.794
|| 2 High Semantic      large      Left      Frontal    simple     -0.582 0.884
|| 3 High Semantic      large      Left      Central    complex    -1.13  0.638
|| 4 High Semantic      large      Left      Central    simple     -0.337 0.716
|| 5 High Semantic      large      Left      Parietal   complex     1.26  0.628
|| 6 High Semantic      large      Left      Parietal   simple     1.18  0.717
|| 7 High Semantic      large      Midline    Frontal    complex    -1.32  0.764

```

```

|| 8 High Semantic      large      Midline   Frontal   simple   -1.25  0.936
|| 9 High Semantic      large      Midline   Central   complex  -1.15  0.798
|| 10 High Semantic     large      Midline   Central   simple   -1.04  0.967
|| # i 62 more rows
|| # i 1 more variable: num_stim <int>

```

5.1.3.4 Plots `complexity | lang_type_semantic * family_size * laterality * anteriority`
First we plot the raw scores then the difference scores Diff Scores `complexity | lang_type_semantic * family_size * laterality * anteriority`

```

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

```

```

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

```

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

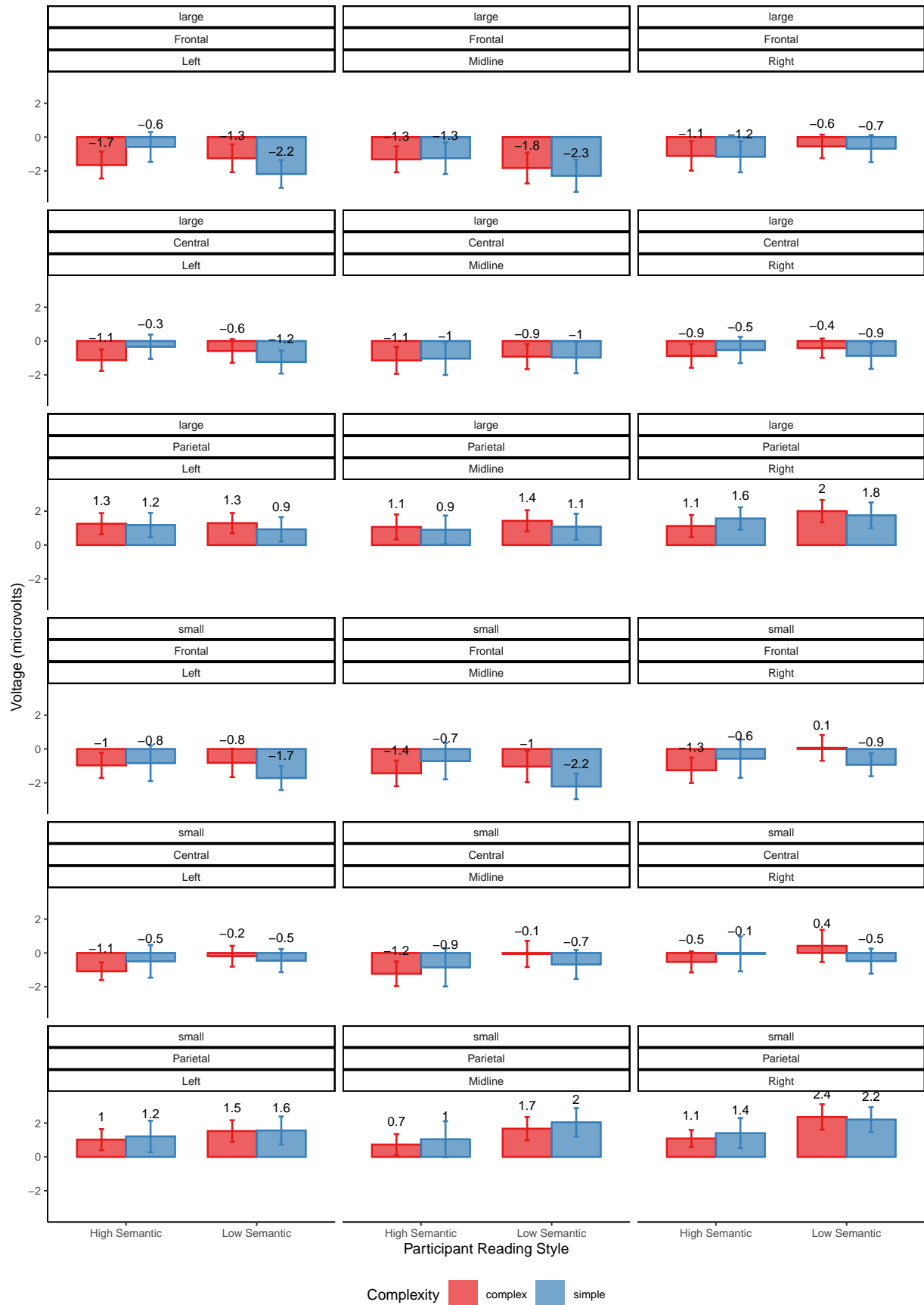
Plot raw scores

```

p3.a <- nw_sem_famsize_lat_ant_cmplx_1 |> ggplot(aes(x= lang_type_semantic, y=mean,
  fill = complexity, colour = complexity,
  ymin = mean - se, ymax = mean + se)) +
  facet_wrap(vars(family_size, anteriority, laterality),
    labeller = "label_value", ncol = 3) +
  coord_cartesian(xlim = NULL, ylim = c(-3.5, 3.5), expand=TRUE, default=FALSE, clip="on") +
  geom_col(position = "dodge", width = 0.75, alpha = 0.7) +
  labs(y = "Voltage (microvolts)", x = "Participant Reading Style") +
  geom_errorbar(width = .08, position = position_dodge(0.75)) +
  theme_classic(base_size = 8) +
  geom_text(aes(label = round(mean, digits = 1)),

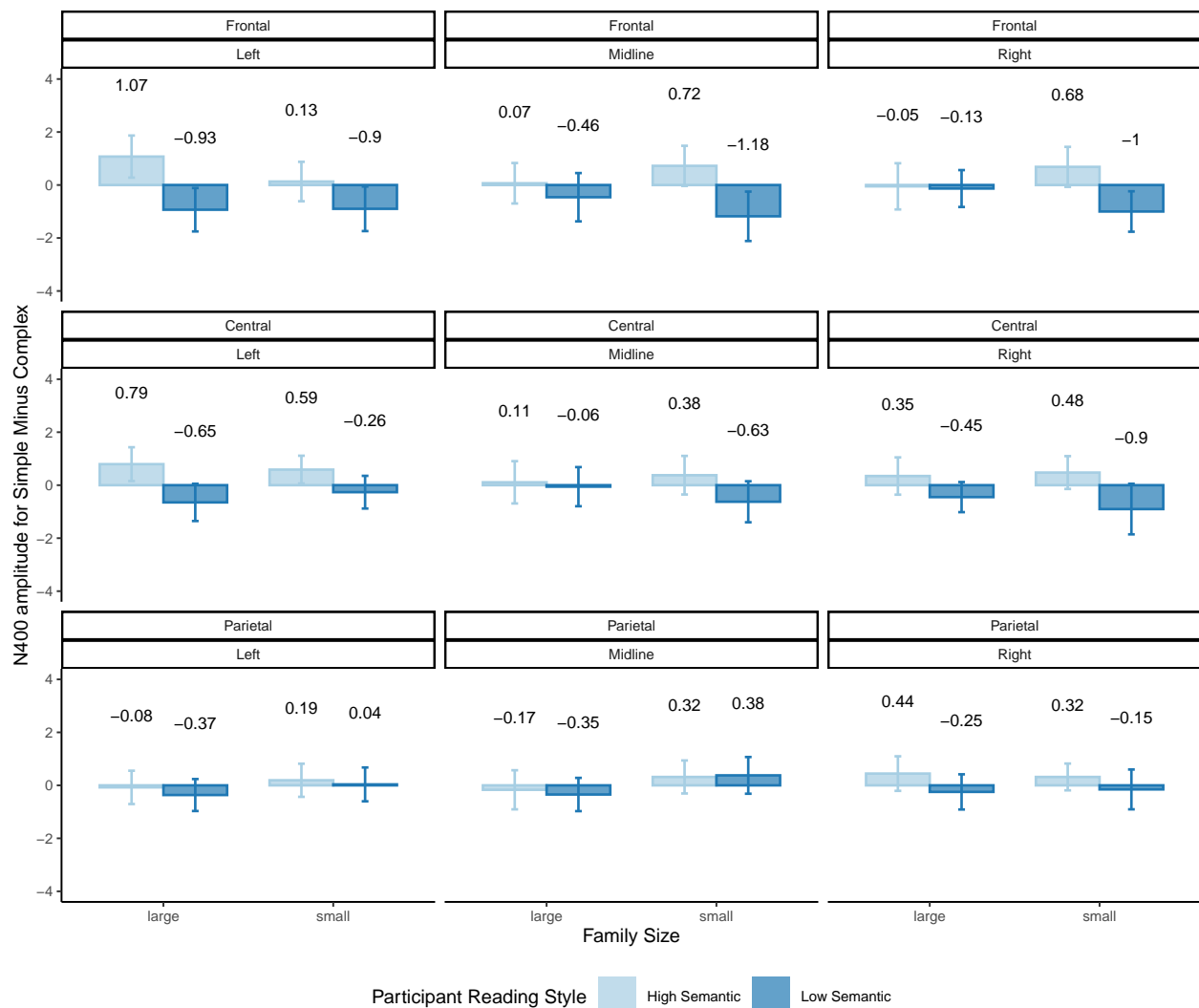
```

```
    colour = "black",
    size = 2.5,
    vjust = -2,
    position = position_dodge(.75))+
  guides(fill=guide_legend(title="Complexity"),
    colour= "none") +
  theme(legend.position = "bottom")
p3.a + scale_fill_brewer(palette = "Set1")+
  scale_colour_brewer(palette = "Set1")
```



Plot diff scores

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



5.2 Group 2

5.2.1 Family Size by Complexity Interaction

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

5.2.1.1 Pairwise Comparisons complexity | family_size

```
|| family_size = small:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple    1.264 0.474 35   2.666  0.0115
||
|| family_size = large:
|| contrast      estimate    SE df t.ratio p.value
|| complex - simple   -0.257 0.394 35   -0.652  0.5189
||
|| Results are averaged over the levels of: lang_type_semantic, lang_type_ortho, laterality, anteriority
```

```
(nw_cmplx_famsize_2 <- n400_2_nonwords |>
  na.omit()|>
  group_by(family_size, complexity) |>
  summarise(mean = mean(value),
            se = sem(value),
            num_stim = n()))
```

5.2.1.2 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    0.674 0.301     351
|| 2 large       simple    0.882 0.292     351
|| 3 small       complex    1.36  0.281     351
|| 4 small       simple    0.186 0.327     351
```

```
(difference_scores_2.1 <- 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`)))
```

5.2.1.3 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           0.674           0.882           0.301           0.292           351
|| 2 small           1.36            0.186           0.281           0.327           351
|| # i 4 more variables: num_stim_simple <int>, mean_diff <dbl>, avg_se <dbl>,
|| #   total_num_stim <int>

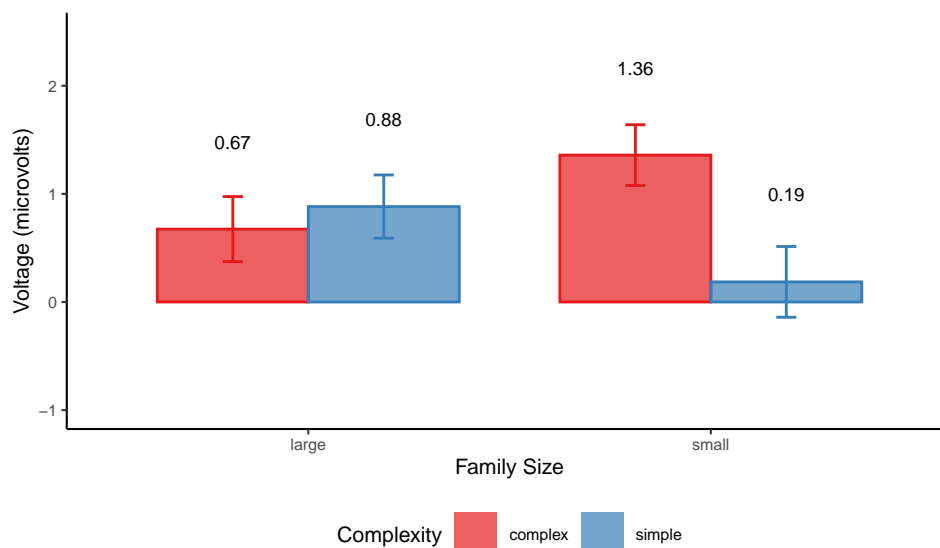
```

5.2.1.4 Plotscomplexity | family_size First we plot the raw scores then the difference scores

```

# plot raw scores
p2.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(-1, 2.5), expand = TRUE,default = FALSE,clip = "on") +
  geom_col(position = "dodge", width = .75, alpha = .7) +
  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 = -6,
    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")

```



```

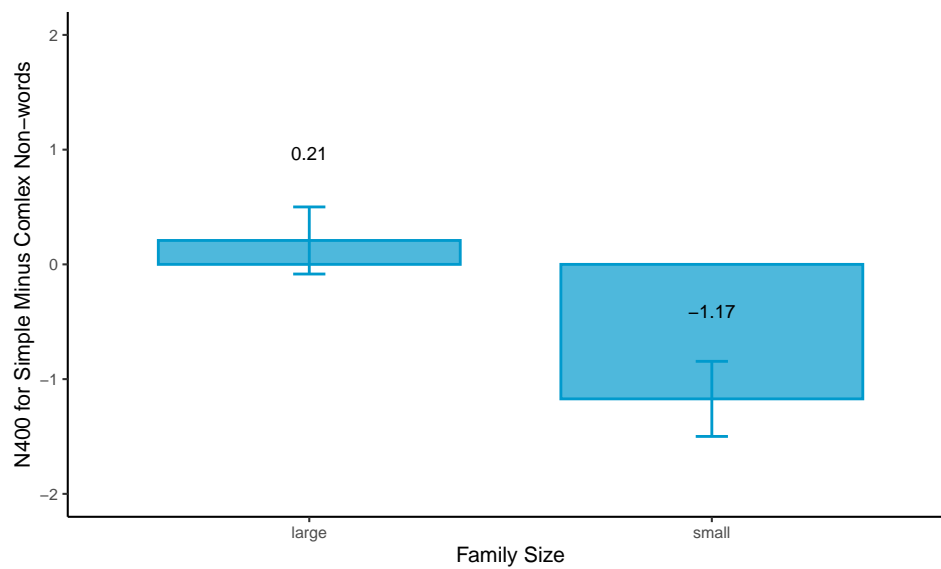
# plot diff scores
p2.b <- difference_scores_2.1 |> ggplot(aes(x = family_size,
      y = mean_diff,
      ymin = mean_diff - avg_se,

```

```

                                ymax = mean_diff + avg_se)) +
coord_cartesian(xlim = NULL,ylim = c(-2, 2), expand = TRUE,default = FALSE,clip = "on") +
geom_col(position = "dodge", width = 0.75, alpha = 0.7,
          colour = "deepskyblue3", fill= "deepskyblue3") +
labs(y = "N400 for Simple Minus Complex 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")
p2.b

```



```

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

```