

M21 RT (Continuous Predictors)

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Setup

Load libraries

1. Set ggplot2 parameters

1 Load Files and Format Files

1.1 Load Files

```
rt <- read_csv("rt_data_chrt1.csv", show_col_types = FALSE)
frq_w <- read_csv("frq_cw.csv", show_col_types = FALSE)
frq_nw <- read_csv("frq_nw.csv", show_col_types = FALSE)
dmg <- read_csv("demo_lang_vsl_pca_hc.csv", show_col_types = FALSE)
```

1.2 Format Files

```
# Concatenate datasets

rt_dmg<- right_join(dmg, rt, join_by(SubjID == subject_nr)) # Join Participant Demographic and Lang Data
rt_dmg <- rt_dmg |> mutate(target = tolower(target))
rt_dmg_cor <- rt_dmg |> filter(correct == 1)

# Divide into Experimental and Filler Items
rt_fill <- rt_dmg_cor |> filter(str_detect(targ_type, "^FILL"))
rt_exp <- rt_dmg_cor |> filter(!str_detect(targ_type, "^FILL"))

# Define Factors and Conditions
rt_exp_cln <- rt_exp |>
  separate(targ_type, into = c("trial_type", "family_size", "complexity"), sep = "_",
    remove = TRUE,
    extra = "drop",
```

```

fill = "right")

# Divide into Words and Nonwords
rt_words <- rt_exp_cln |> filter(trial_type == "CW") |> select(- complexity)
rt_nwords <- rt_exp_cln |> filter(trial_type == "NW")

# Join Stimulus Frequency Data
rt_words_frq <- left_join(rt_words, frq_w, join_by(target))|>
  select(-cond_trig.y, -word_trig.y) |>
  rename(cond_trig = cond_trig.x, word_trig = word_trig.x) # remove duplicate columns

rt_nwords_frq <- left_join(rt_nwords, frq_nw, join_by(target==word))

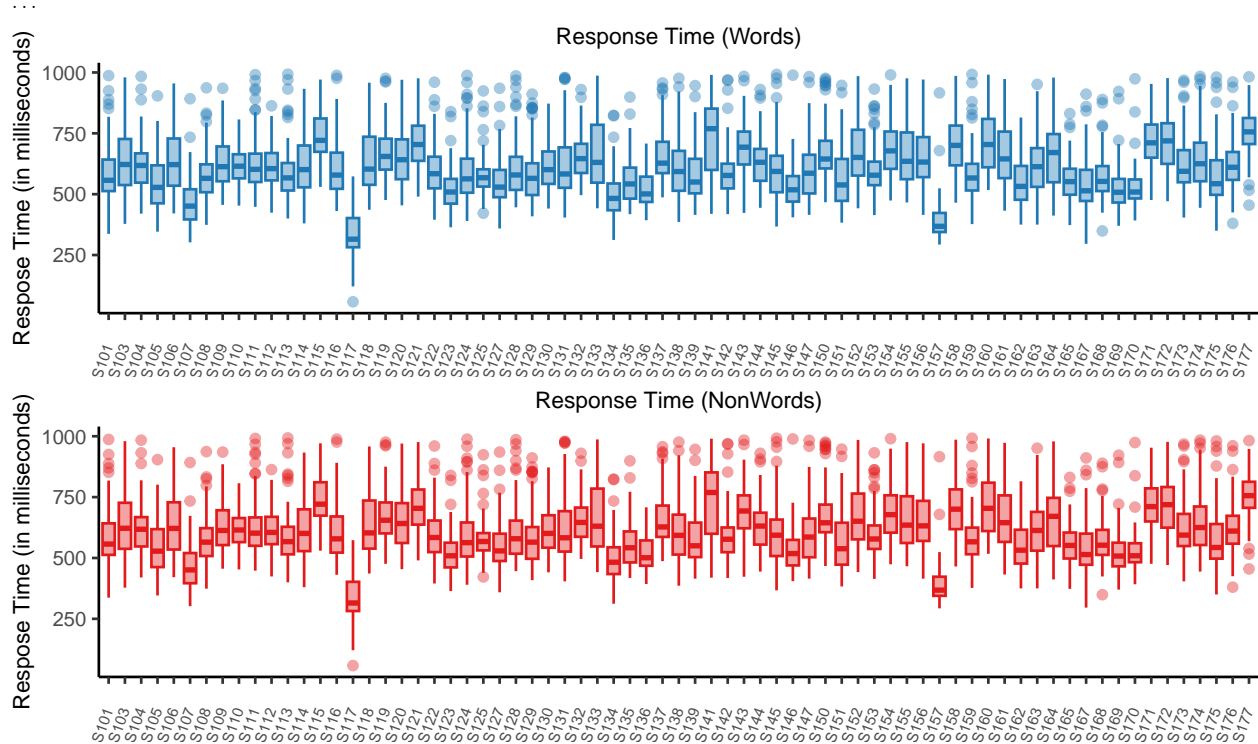
# Create a median-split factor for base frequency
rt_words_frq$BF_MedianSplit <- ifelse(
  rt_words_frq$Log10BF <= median(rt_words_frq$Log10BF, na.rm = TRUE),
  "Low", "High")

rt_words_frq$BF_Split <- factor(rt_words_frq$BF_Split)
rt_words_frq$FS_Split <- factor(rt_words_frq$FS_Split)

rt_nwords_frq$BF_Split <- factor(rt_nwords_frq$BF_Split)
rt_nwords_frq$FS_Split <- factor(rt_nwords_frq$FS_Split)

```

1.3 Plot RT distributions



1.4 Test for Skewness

```

Response Time
# Words Skewness values
skewness(rt_words_frq$response_time, na.rm = TRUE)

|| [1] 0.4868724
skewness(rt_words_frq$LogRT, na.rm = TRUE)

|| [1] -0.4362045

# Words Raw RT Distribution
p1 <- rt_words_frq |> ggplot(aes(x = response_time)) +
  geom_density(colour = "#1F78B4", fill = "#1F78B4", alpha = .4) +
  labs(title = "Raw RT Distribution (Words)") +
  theme(plot.title = element_text(size = 9, hjust = .5),

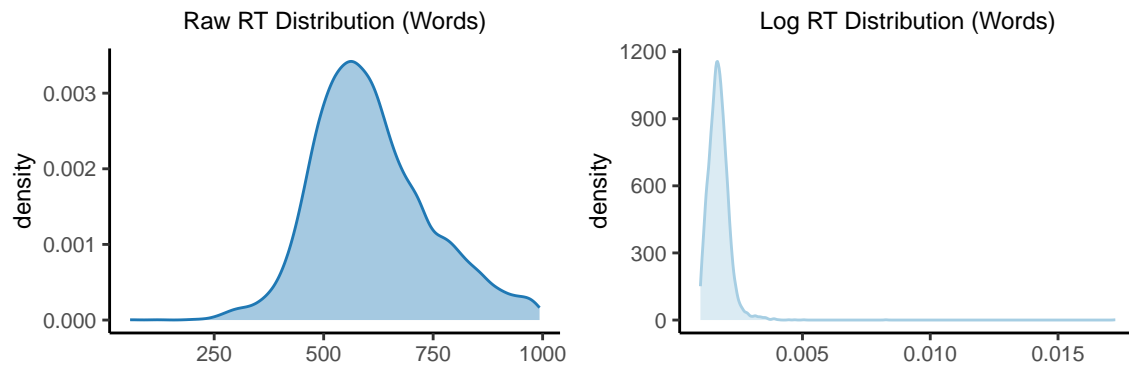
```

```

    legend.title = element_blank(),
    axis.title.x = element_blank(),
    axis.text.x = element_text(size = 8))

# Words Log RT Distribution
p2 <- rt_words_frq |> ggplot(aes(x = InvRT)) +
  geom_density(colour = "#A6CEE3", fill = "#A6CEE3", alpha = .4) +
  labs(title = "Log RT Distribution (Words)") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))
plot_grid(p1, p2, ncol = 2)

```



```

# NONWORDS
# Skewness values
skewness(rt_nwords_frq$response_time, na.rm = TRUE)

```

```

|| [1] 0.1000102

```

```

skewness(rt_nwords_frq$LogRT, na.rm = TRUE)

```

```

|| [1] -0.3817821

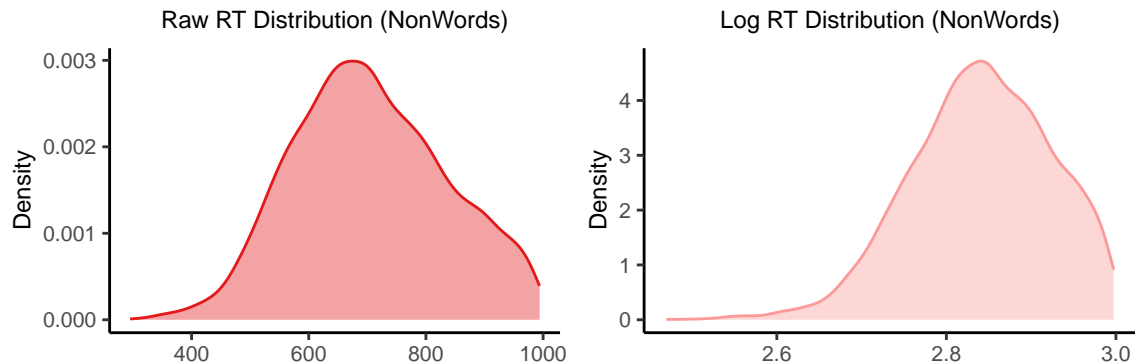
```

```

# Raw RT
p1 <- rt_nwords_frq |> ggplot(aes(x = response_time)) +
  geom_density(colour = "#E31A1C", fill = "#E31A1C", alpha = .4) +
  labs(y = "Density", title = "Raw RT Distribution (NonWords)") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))

# LogRT
p2 <- rt_nwords_frq |> ggplot(aes(x = LogRT)) +
  geom_density(colour = "#FB9A99", fill = "#FB9A99", alpha = .4) +
  labs(y = "Density", title = "Log RT Distribution (NonWords)") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))
plot_grid(p1, p2, ncol = 2)

```



```

Base Frequency

```

```

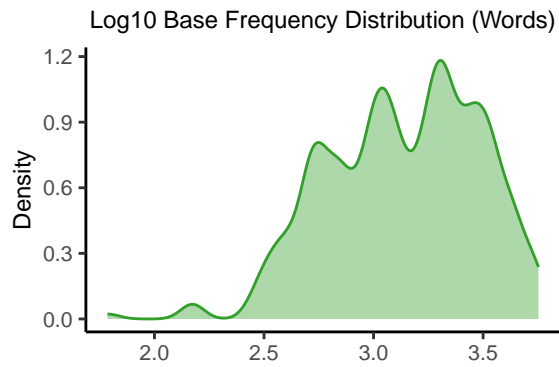
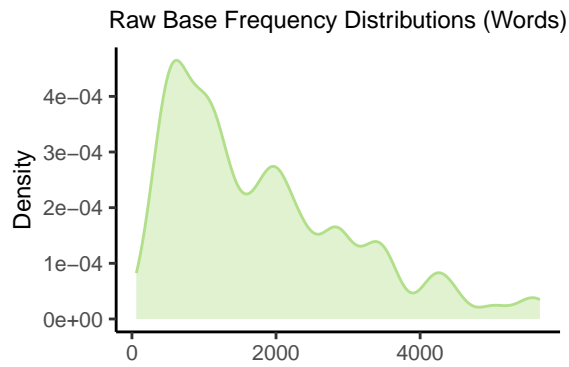
|| [1] 0.9870676

```

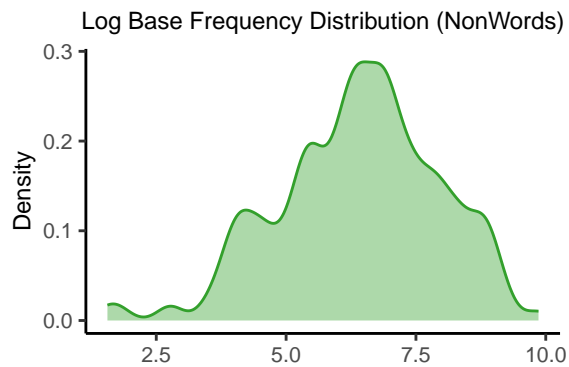
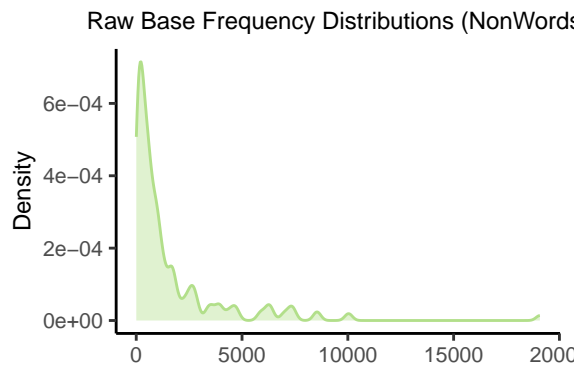
```

|| [1] -0.4166518

```



```
[[ [1] 3.404106
[[ [1] -0.3931931
```



Family Size

```
# Words
# Skewness values
rt_words_frq <- rt_words_frq |> mutate(Log10FS = log10(FS))
skewness(rt_words_frq$FS, na.rm = TRUE)
```

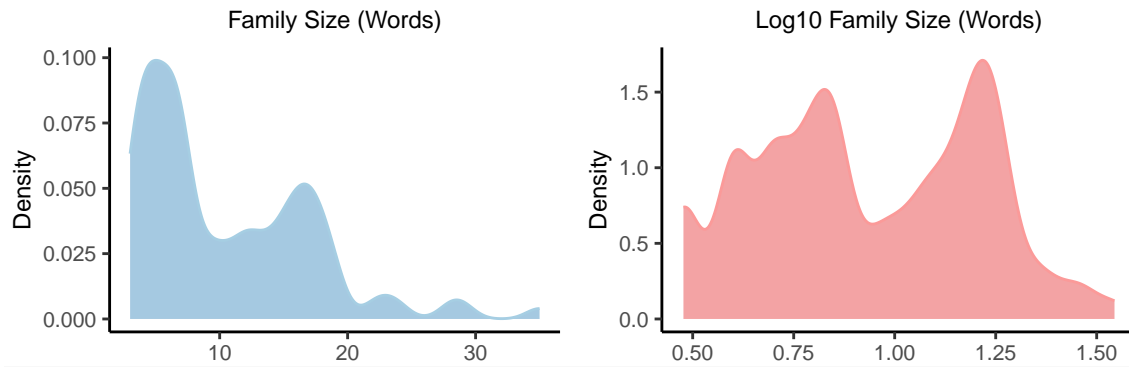
```
[[ [1] 1.101473
```

```
skewness(rt_words_frq$Log10FS, na.rm = TRUE)
```

```
[[ [1] 0.05781409
```

```
# Raw FS
p1 <- ggplot(rt_words_frq, aes(x = FS)) +
  geom_density(colour = "#A6CEE3", fill = "#1F78B4", alpha = .4) +
  labs(title = "Family Size (Words)", y = "Density") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))

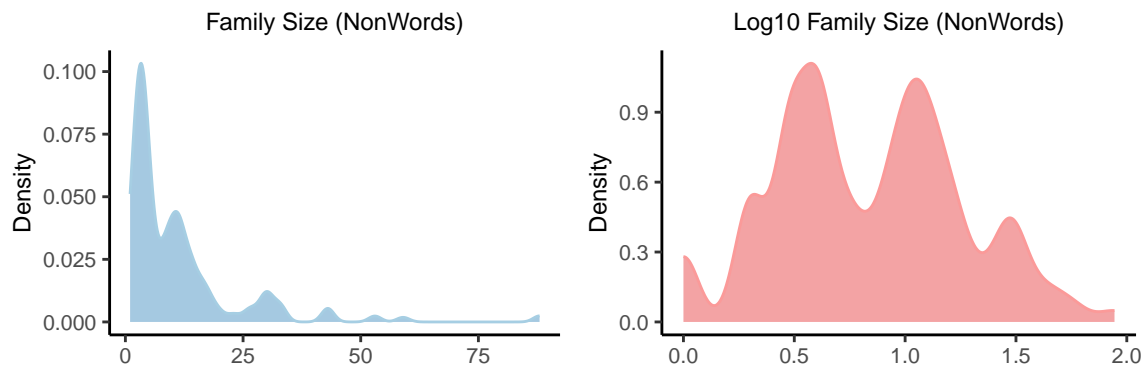
# Log10 FS
p2 <- ggplot(rt_words_frq, aes(x = Log10FS)) +
  geom_density(colour = "#FB9A99", fill = "#E31A1C", alpha = .4) +
  labs(title = "Log10 Family Size (Words)", y = "Density") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))
plot_grid(p1, p2, ncol = 2)
```



```
# NonWords
# Skewness values
rt_nwords_frq <- rt_nwords_frq |> mutate(Log10FS = log10(FS))
skewness(rt_nwords_frq$FS, na.rm = TRUE)
```

```
## [1] 2.909422
skewness(rt_nwords_frq$Log10FS, na.rm = TRUE)
```

```
## [1] 0.1536901
# Raw FS
p1 <- ggplot(rt_nwords_frq, aes(x = FS)) +
  geom_density(colour = "#A6CEE3", fill = "#1F78B4", alpha = .4) +
  labs(title = "Family Size (NonWords)", y = "Density") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))
# Log10 FS
p2 <- ggplot(rt_nwords_frq, aes(x = Log10FS)) +
  geom_density(colour = "#FB9A99", fill = "#E31A1C", alpha = .4) +
  labs(title = "Log10 Family Size (NonWords)", y = "Density") +
  theme(plot.title = element_text(size = 9, hjust = .5),
        legend.title = element_blank(),
        axis.title.x = element_blank(),
        axis.text.x = element_text(size = 8))
plot_grid(p1, p2, ncol = 2)
```



1.5 ANOVA Words

Use `complete.cases()` to find which rows had missing data in the model-relevant variables:

Standardize the predictors

```
rt_words_cmpl$Log10BF_std <- as.numeric(scale(rt_words_cmpl$Log10BF, center = TRUE, scale = TRUE))
rt_words_cmpl$FS_std <- as.numeric(scale(rt_words_cmpl$FS, center = TRUE, scale = TRUE))
rt_words_cmpl$Log10WF_std <- as.numeric(scale(rt_words_cmpl$Log10WF, center = TRUE, scale = TRUE))
rt_words_cmpl$Log10FS_std <- as.numeric(scale(rt_words_cmpl$Log10FS, center = TRUE, scale = TRUE))
rt_words_cmpl$Dim.2_std <- as.numeric(scale(rt_words_cmpl$Dim.2, center = TRUE, scale = TRUE))
```

1.5.1 Anova with Continuous Log10BF and Continuous Log10FS

```
# Anova with Continuous Log10BF AND Continous FS
anova_model <- mixed(
  response_time ~ Log10BF_std * Log10FS_std * Orthographic_Sensitivity + (1 | SubjID),
```

```

data = rt_words_cmpl,
method = "KR"
)
anova_model

|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: response_time ~ Log10BF_std * Log10FS_std * Orthographic_Sensitivity +
|| Model:      (1 | SubjID)
|| Data: rt_words_cmpl
||
||           Effect              df      F p.value
|| 1              Log10BF_std 1, 5792.73 44.34 *** <.001
|| 2              Log10FS_std 1, 5792.42 31.10 *** <.001
|| 3      Orthographic_Sensitivity 1, 64.04 3.48 + .067
|| 4      Log10BF_std:Log10FS_std 1, 5792.49 0.09 .764
|| 5      Log10BF_std:Orthographic_Sensitivity 1, 5792.73 1.80 .180
|| 6      Log10FS_std:Orthographic_Sensitivity 1, 5792.42 0.06 .804
|| 7 Log10BF_std:Log10FS_std:Orthographic_Sensitivity 1, 5792.49 1.00 .317
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

summary(anova_model)

|| Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
|| Formula: response_time ~ Log10BF_std * Log10FS_std * Orthographic_Sensitivity +      (1 | SubjID)
|| Data: data
||
|| REML criterion at convergence: 71992
||
|| Scaled residuals:
||      Min       1Q   Median       3Q      Max
|| -3.0178 -0.6874 -0.1449  0.5139  4.7355
||
|| Random effects:
|| Groups   Name      Variance Std.Dev.
|| SubjID   (Intercept) 5272     72.61
|| Residual                12136    110.16
|| Number of obs: 5864, groups: SubjID, 66
||
|| Fixed effects:
||
||              Estimate Std. Error      df t value Pr(>|t|)
|| (Intercept)      610.6175    9.0723   63.8685  67.306 < 2e-16 ***
|| Log10BF_std      -10.1087    1.5181  5792.5608  -6.659 3.02e-11 ***
|| Log10FS_std       -8.1418    1.4599  5792.2546  -5.577 2.56e-08 ***
|| Orthographic_Sensitivity1 -16.9147    9.0723   63.8685  -1.864 0.0669 .
|| Log10BF_std:Log10FS_std 0.4676    1.5576  5792.3235  0.300 0.7640
|| Log10BF_std:Orthographic_Sensitivity1 -2.0361    1.5181  5792.5608  -1.341 0.1799
|| Log10FS_std:Orthographic_Sensitivity1 0.3628    1.4599  5792.2546  0.248 0.8038
|| Log10BF_std:Log10FS_std:Orthographic_Sensitivity1 -1.5574    1.5576  5792.3235  -1.000 0.3174
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
||
|| Correlation of Fixed Effects:
||              (Intr) Lg10BF_ Lg10FS_ Ort_S1 Lg10BF_:L10FS_ L10BF_:0 L10FS_:
|| Log10BF_std    -0.005
|| Log10FS_std     0.002 -0.134
|| Orthgrph_S1    -0.060 -0.001  0.002
|| Lg10BF_:L10FS_ -0.018 0.298 -0.120  0.000
|| L10BF_:0_S1    -0.001 -0.017  0.000 -0.005 0.007
|| L10FS_:0_S1     0.002  0.000 -0.044  0.002 -0.005 -0.134
|| L10BF_:L10FS_: 0.000  0.007 -0.005 -0.018 -0.022  0.298 -0.120

eta_squared(anova_model, partial = TRUE)

|| # Effect Size for ANOVA (Type III)
||
|| Parameter | Eta2 (partial) | 95% CI
|| -----|-----|-----|
|| Log10BF_std | 7.60e-03 | [0.00, 1.00]
|| Log10FS_std | 5.34e-03 | [0.00, 1.00]
|| Orthographic_Sensitivity | 0.05 | [0.00, 1.00]
|| Log10BF_std:Log10FS_std | 1.56e-05 | [0.00, 1.00]
|| Log10BF_std:Orthographic_Sensitivity | 3.10e-04 | [0.00, 1.00]
|| Log10FS_std:Orthographic_Sensitivity | 1.07e-05 | [0.00, 1.00]
|| Log10BF_std:Log10FS_std:Orthographic_Sensitivity | 1.73e-04 | [0.00, 1.00]
||
|| - One-sided CIs: upper bound fixed at [1.00].

```

1.5.2 Effects

| Effect | df | F | p.value |
|------------------------------|------------|-----------|---------|
| Log10BF_std | 1, 5792.73 | 44.34 *** | <.001 |
| Log10FS_std | 1, 5792.42 | 31.10 *** | <.001 |
| Orthographic_Sensitivity | 1, 64.04 | 3.48 + | .067 |
| Log10BF:FS:Ortho_Sensitivity | 1, 5792.49 | 1.00 | .317 |

Main Effect of Family Size, Orthographic Sensitivity, Base Frequency

```
emm_options(pbkrttest.limit = 5864)
emtrends(anova_model, ~1, var = "Log10FS_std")
```

```
|| 1      Log10FS_std.trend SE df lower.CL upper.CL
|| overall      -8.14 1.46 5792      -11      -5.28
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
emtrends(anova_model, ~1, var = "Log10BF_std")
```

```
|| 1      Log10BF_std.trend SE df lower.CL upper.CL
|| overall     -10.1 1.52 5793     -13.1     -7.13
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
emmmeans_obj <- emmeans(anova_model, pairwise ~ Orthographic_Sensitivity)
cohensd_df <- as.data.frame(cohensd(response_time ~ Orthographic_Sensitivity, data = rt_words_cmpl))
contrasts_df <- as.data.frame(emmeans_obj$contrasts)
(ortho_sens_df <- bind_cols(contrasts_df, cohensd_df))
```

```
|| contrast                estimate      SE df t.ratio p.value Cohens_d CI CI_low CI_high
|| High Orthographic - Low Orthographic -33.82941 18.14466 64.04 -1.864 0.0668 -0.2458167 0.95 -0.2972398 -0.1943728
||
|| Degrees-of-freedom method: kenward-roger
(ortho_sens_means <- as.data.frame(emmeans_obj$emmeans))
```

```
|| Orthographic_Sensitivity emmean      SE df lower.CL upper.CL
|| High Orthographic        593.7028 12.43703 64.07 568.8575 618.5481
|| Low Orthographic         627.5322 13.21170 64.01 601.1388 653.9255
||
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

Base Frequency by Orthographic Sensitivity Interaction

```
# estimate simple slopes of base frequency by group:
emtrends(anova_model, ~ Orthographic_Sensitivity, var = "Log10BF_std")
```

```
|| Orthographic_Sensitivity Log10BF_std.trend SE df lower.CL upper.CL
|| High Orthographic        -12.14 2.13 5793     -16.3     -7.97
|| Low Orthographic         -8.07 2.17 5793     -12.3     -3.83
||
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

```
emtrends(anova_model, pairwise ~ Orthographic_Sensitivity, var = "Log10BF_std")
```

```
|| $emtrends
|| Orthographic_Sensitivity Log10BF_std.trend SE df lower.CL upper.CL
|| High Orthographic        -12.14 2.13 5793     -16.3     -7.97
|| Low Orthographic         -8.07 2.17 5793     -12.3     -3.83
||
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
||
|| $contrasts
|| contrast                estimate SE df t.ratio p.value
|| High Orthographic - Low Orthographic -4.07 3.04 5793 -1.341 0.1799
||
|| Degrees-of-freedom method: kenward-roger
```

```
# Estimate marginal means of RT at the mean of both predictors
emm <- emmeans(anova_model, ~ Orthographic_Sensitivity, at = list(Log10BF_std = 0, Log10FS_std = 0))
emm_df <- as.data.frame(emm)
```

```
print(emm_df)
```

```
|| Orthographic_Sensitivity emmean      SE df lower.CL upper.CL
|| High Orthographic        593.7028 12.43703 64.07 568.8575 618.5481
```

```

|| Low Orthographic          627.5322 13.21170 64.01 601.1388 653.9255
||
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

```

1.5.3 Plots

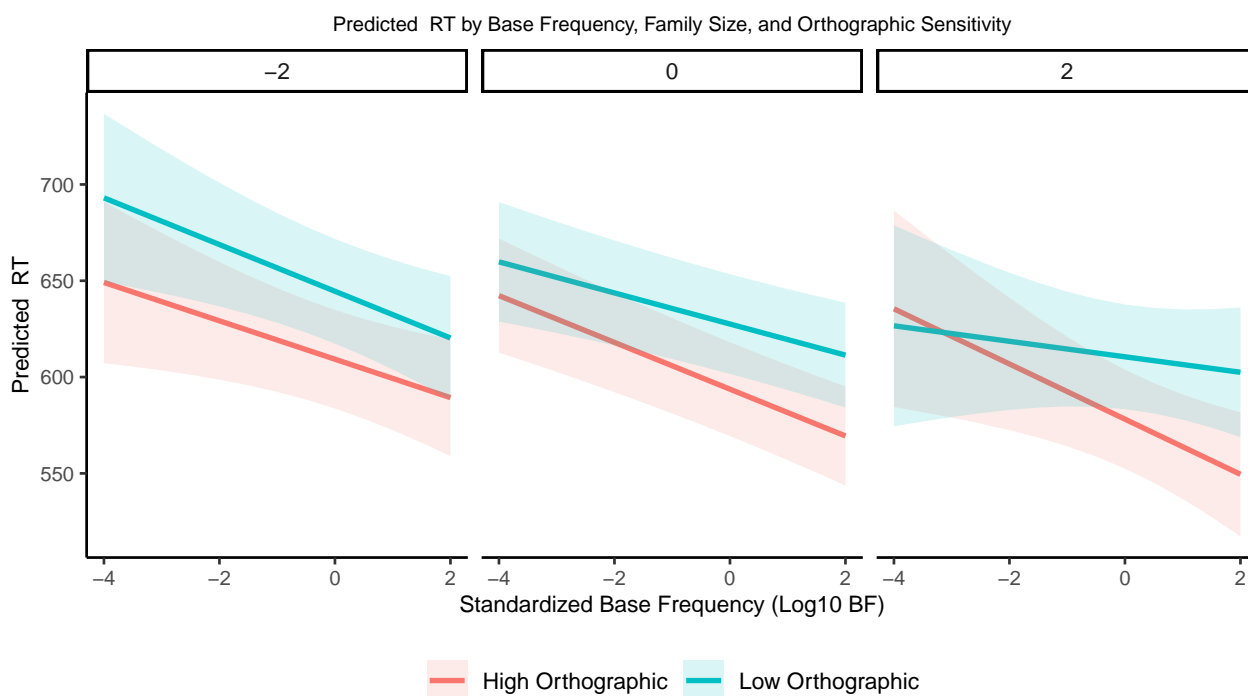
Family Size x Base Frequency x Orthographic Sensitivity

```

# re-run anova with lmer to use `ggeffects`
anova_model_lmer <- lmer(response_time ~ Log10BF_std * Log10FS_std * Orthographic_Sensitivity + (1 | SubjID), data = rt_words_cmpl)
# Generate predicted values
preds <- ggpredict(anova_model_lmer, terms = c("Log10BF_std", "Orthographic_Sensitivity", "Log10FS_std [-2,0,2]"))

# Plot
ggplot(preds, aes(x = x, y = predicted, color = group, fill = group)) +
  geom_line(linewidth = 1) +
  geom_ribbon(aes(ymin = conf.low, ymax = conf.high), alpha = 0.15, color = NA) +
  facet_wrap(~facet, labeller = label_value) +
  labs(x = "Standardized Base Frequency (Log10 BF)",
       y = "Predicted RT",
       color = "Family Size (Log10 FS)",
       fill = "Family Size (Log10 FS)",
       title = "Predicted RT by Base Frequency, Family Size, and Orthographic Sensitivity") +
  theme(plot.title = element_text(size = 8, hjust = .5),
        legend.title = element_blank(),
        axis.text.x = element_text(size = 8))

```



1.6 ANOVA Non-Words

Use `complete.cases()` to find which rows had missing data in the model-relevant variables:

Standardize the predictors

```

rt_nwords_cmpl$Log10BF_std <- as.numeric(scale(rt_nwords_cmpl$Log10BF, center = TRUE, scale = TRUE))
rt_nwords_cmpl$FS_std <- as.numeric(scale(rt_nwords_cmpl$FS, center = TRUE, scale = TRUE))
rt_nwords_cmpl$Log10FS_std <- as.numeric(scale(rt_nwords_cmpl$Log10FS, center = TRUE, scale = TRUE))
rt_nwords_cmpl$BF_std <- as.numeric(scale(rt_nwords_cmpl$BF, center = TRUE, scale = TRUE))
rt_nwords_cmpl$Dim.2_std <- as.numeric(scale(rt_nwords_cmpl$Dim.2, center = TRUE, scale = TRUE))
rt_nwords_cmpl <- rt_nwords_cmpl |> select(-complexity.x)
rt_nwords_cmpl <- rename(rt_nwords_cmpl, complexity = complexity.y)

```

Test Correlation between Base Frequency and Complexity

```
t.test(Log10BF ~ complexity, data = rt_nwords_cmpl)
```

```

||
|| Welch Two Sample t-test

```



```

||
|| data: Log10BF by complexity
|| t = -0.7232, df = 4547.8, p-value = 0.4696
|| alternative hypothesis: true difference in means between group Complex and group Simple is not equal to 0
|| 95 percent confidence interval:
|| -0.05059200 0.02332506
|| sample estimates:
|| mean in group Complex mean in group Simple
|| 2.793225 2.806859
||
|| # Create a contingency table
table_data <- table(rt_nwords_cmpl$complexity, rt_nwords_cmpl$BF_Split)
||
|| # Run the chi-square test
chisq.test(table_data)
||
||
|| Pearson's Chi-squared test with Yates' continuity correction
||
|| data: table_data
|| X-squared = 3.9314, df = 1, p-value = 0.04739

```

1.6.1 Anova with Continuous Log10BF and Categorical Complexity

```

anova_model_2 <- mixed(
  response_time ~ complexity * Log10FS_std * Orthographic_Sensitivity + (1 | SubjID),
  data = rt_nwords_cmpl,
  method = "KR"
)
anova_model_2
||
|| Mixed Model Anova Table (Type 3 tests, KR-method)
||
|| Model: response_time ~ complexity * Log10FS_std * Orthographic_Sensitivity +
|| Model: (1 | SubjID)
|| Data: rt_nwords_cmpl
||
||      Effect      df      F p.value
|| 1      complexity 1, 4601.21 106.13 *** <.001
|| 2      Log10FS_std 1, 4600.02      2.49  .115
|| 3      Orthographic_Sensitivity 1, 64.11      5.32 *  .024
|| 4      complexity:Log10FS_std 1, 4600.65      3.96 *  .047
|| 5      complexity:Orthographic_Sensitivity 1, 4601.21      0.68  .408
|| 6      Log10FS_std:Orthographic_Sensitivity 1, 4600.02      0.04  .846
|| 7      complexity:Log10FS_std:Orthographic_Sensitivity 1, 4600.65      0.29  .590
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '+' 0.1 ' ' 1
summary(anova_model_2)
||
|| Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
|| Formula: response_time ~ complexity * Log10FS_std * Orthographic_Sensitivity + (1 | SubjID)
|| Data: data
||
|| REML criterion at convergence: 56995.5
||
|| Scaled residuals:
||      Min       1Q   Median       3Q      Max
|| -3.1330 -0.7114 -0.0816  0.6377  4.1120
||
|| Random effects:
|| Groups   Name      Variance Std.Dev.
|| SubjID   (Intercept) 7095      84.23
|| Residual              11145    105.57
|| Number of obs: 4671, groups: SubjID, 66
||
|| Fixed effects:
||
||              Estimate Std. Error      df t value Pr(>|t|)
|| (Intercept)      715.6108    10.5228    62.5863   68.006 <2e-16 ***
|| complexity1       16.2736     1.5797  4599.6974   10.302 <2e-16 ***
|| Log10FS_std        2.5006     1.5854  4598.4808    1.577  0.1148
|| Orthographic_Sensitivity1 -24.2792    10.5228    62.5863   -2.307  0.0244 *
|| complexity1:Log10FS_std      3.1569     1.5870  4599.1311    1.989  0.0467 *
|| complexity1:Orthographic_Sensitivity1 -1.3060     1.5797  4599.6974   -0.827  0.4084
|| Log10FS_std:Orthographic_Sensitivity1  0.3085     1.5854  4598.4808    0.195  0.8457
|| complexity1:Log10FS_std:Orthographic_Sensitivity1  0.8552     1.5870  4599.1311    0.539  0.5900
|| ---
|| Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
||
|| Correlation of Fixed Effects:
||      (Intr) cmplx1 Lg10FS_ Ort_S1 cm1:L10FS_ c1:O_S L10FS_
|| complexity1  0.025

```

```

|| Log10FS_std 0.003 0.031
|| Orthgrph_S1 -0.064 -0.006 -0.004
|| cml:L10FS_ 0.005 0.014 0.178 -0.002
|| cmlx1:0_S1 -0.006 -0.123 -0.014 0.025 -0.022
|| L10FS_:0_S1 -0.004 -0.014 -0.125 0.003 -0.024 0.031
|| c1:L10FS_:0 -0.002 -0.022 -0.024 0.005 -0.126 0.014 0.178

```

1.6.2 Effects

| Effect | df | F | p.value |
|--------------------------|------------|------------|---------|
| complexity | 1, 4600.75 | 106.13 *** | <.001 |
| Orthographic_Sensitivity | 1, 64.11 | 5.32 * | .024 |
| complexity:Log10FS_std | 1, 4600.65 | 3.96 * | .047 |

```

# Complexity
emmeans_obj <- emmeans(anova_model_2, pairwise ~ complexity)
cohensd_df <- as.data.frame(cohens_d(response_time ~ complexity, data = rt_nwords_cml))
contrasts_df <- as.data.frame(emmeans_obj$contrasts)
(complexity_df <- bind_cols(contrasts_df, cohensd_df))

|| contrast      estimate      SE      df t.ratio p.value Cohens_d  CI      CI_low  CI_high
|| Complex - Simple 32.54719 3.159352 4601.21 10.302 <.0001 0.21345 0.95 0.1552988 0.2715784
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
(complexity_means <- as.data.frame(emmeans_obj$emmeans))

|| complexity  emmean      SE      df lower.CL upper.CL
|| Complex    731.8844 10.67933 68.01 710.5742 753.1947
|| Simple     699.3372 10.60207 66.07 678.1699 720.5045
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

# Orthographic_Sensitivity
emmeans_obj <- emmeans(anova_model_2, pairwise ~ Orthographic_Sensitivity)
cohensd_df <- as.data.frame(cohens_d(response_time ~ Orthographic_Sensitivity, data = rt_nwords_cml))
contrasts_df <- as.data.frame(emmeans_obj$contrasts)
(ortho_sens_df <- bind_cols(contrasts_df, cohensd_df))

|| contrast      estimate      SE      df t.ratio p.value Cohens_d  CI      CI_low  CI_high
|| High Orthographic - Low Orthographic -48.55848 21.04573 64.11 -2.307 0.0243 -0.2542169 0.95 -0.3121916 -0.1962152
||
|| Results are averaged over the levels of: complexity
|| Degrees-of-freedom method: kenward-roger
(ortho_sens_means <- as.data.frame(emmeans_obj$emmeans))

|| Orthographic_Sensitivity  emmean      SE      df lower.CL upper.CL
|| High Orthographic         691.3316 14.40093 63.72 662.5600 720.1031
|| Low Orthographic          739.8901 15.34718 64.46 709.2348 770.5454
||
|| Results are averaged over the levels of: complexity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

# Estimate the effect of complexity at low, mean, and high FS
em_complexity <- emmeans(anova_model_2, ~ complexity | Log10FS_std, at = list(Log10FS_std = c(-1, 0, 1)))
summary(em_complexity)

|| Log10FS_std = -1:
|| complexity  emmean      SE      df lower.CL upper.CL
|| Complex    726 10.9 74.6      704      748
|| Simple     700 10.8 71.2      678      722
||
|| Log10FS_std = 0:
|| complexity  emmean      SE      df lower.CL upper.CL
|| Complex    732 10.7 68.0      711      753
|| Simple     699 10.6 66.1      678      721
||
|| Log10FS_std = 1:
|| complexity  emmean      SE      df lower.CL upper.CL
|| Complex    738 11.0 75.9      716      759
|| Simple     699 10.8 70.8      677      720
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95

```

```
# Estimate the slope of Log10FS within each complexity level
em_trends <- emtrends(anova_model_2, ~ complexity, var = "Log10FS_std")
summary(em_trends)
```

```
|| complexity Log10FS_std.trend SE df lower.CL upper.CL
|| Complex      5.657 2.43 4601  0.885  10.43
|| Simple     -0.656 2.03 4600 -4.644   3.33
||
|| Results are averaged over the levels of: Orthographic_Sensitivity
|| Degrees-of-freedom method: kenward-roger
|| Confidence level used: 0.95
```

1.6.3 Plots

```
...
# Plot

# Refit the model using lmer()
anova_model_lmer <- lmer(
  response_time ~ complexity * Log10FS_std * Orthographic_Sensitivity + (1 | SubjID),
  data = rt_nwords_cmpl,
  REML = FALSE
)

# Get predicted values
preds <- ggpredict(anova_model_lmer, terms = c("Log10FS_std", "complexity"))

# Plot
ggplot(preds, aes(x = x, y = predicted, color = group, fill = group)) +
  geom_line(linewidth = 1) +
  geom_ribbon(aes(ymin = conf.low, ymax = conf.high), alpha = 0.2, color = NA) +
  labs(x = "Standardized Log Family Size",
       y = "Predicted RT (ms)",
       color = "Complexity",
       fill = "Complexity",
       title = "Interaction of Morphological Complexity and Family Size on RT") +
  theme(plot.title = element_text(size = 8, hjust = .5),
        legend.title = element_blank(),
        axis.text.x = element_text(size = 8))
```

