

R Code

Lobanov Normalization of F1 and F2 Formants per Speaker

```
library(tidyverse)
library(phonR)
```

```
normalization = three_syllable %>% group_by(SPEAKER) %>%
mutate(f1lobanov = normLobanov(F1), f2lobanov = normLobanov(F2))
```

Rescaling of Lobanov-Normalized Formant Frequencies to Hertz-like Values

```
normalization$rescaledF1 <- (500*(normalization$f1lobanov -
min(normalization$f1lobanov))/(max(normalization$f1lobanov) -
min(normalization$f1lobanov))) + 250
```

```
normalization$rescaledF2 <- (1400*(normalization$f2lobanov -
min(normalization$f2lobanov))/(max(normalization$f2lobanov) -
min(normalization$f2lobanov))) + 850
```

Calculating Euclidean Distances of Vowels from the Centroid of the Normalized Acoustic Vowel Space per Speaker

```
ed_gr3 <- normalization_gr3 %>% group_by(SPEAKER) %>%
mutate(ED = sqrt((rescaledF1-mean(rescaledF1))^2+(rescaledF2-
mean(rescaledF2))^2))
```

Libraries for Statistical Analysis

```
library(nlme)
library(phia)
library(emmeans)
library(rstatix)
```

Statistical Analysis of Relative Vowel Duration

Calculation of Mean Relative Vowel Duration by Age and Regression Analysis of Average Relative Vowel Duration with Age

```
ALLMEAN <- three_syllable %>%
group_by(AGE)%>%
summarise(RELDURATION=mean(RELDURATION), .groups = 'drop')
```

```
summary(lm(formula = RELDURATION~as.numeric(AGE), data =
ALLMEAN))
```

Linear Mixed-Effects Modeling, Effect Sizes, and Tukey's Post-Hoc Tests

```
rd3 <- lme(RELDURATION~AGE*GENDER*STRESS*VOWEL-
AGE:STRESS:VOWEL-STRESS:VOWEL-AGE:VOWEL-GENDER-
AGE:GENDER:STRESS:VOWEL-GENDER:STRESS:VOWEL-
AGE:GENDER:VOWEL-AGE:GENDER:STRESS-GENDER:VOWEL-
GENDER:STRESS-AGE:GENDER, random = ~1|SPEAKER,
data=three_syllable, weights = varComb(varIdent(form = ~ 1 | AGE),
varIdent(form = ~ 1 | STRESS), varIdent(form = ~ 1 | VOWEL)), control
=list(msMaxIter = 1000, msMaxEval = 1000))
```

```
anova(rd3)
```

```
effectsize::eta_squared (rd3)
```

```
as.data.frame(pairs(emmeans(rd3, ~ AGE), adjust = "tukey"))  
as.data.frame(pairs(emmeans(rd3, ~ STRESS), adjust = "tukey"))  
as.data.frame(pairs(emmeans(rd3, ~ VOWEL), adjust = "tukey"))  
as.data.frame(pairs(emmeans(rd3, ~ AGE*STRESS), adjust = "tukey"))
```

After Calculating the Percentages for Vowel Reduction Between the Stress Conditions in Excel, we Assessed Age-Related Differences Using Wilcoxon Tests

Creating Dataframes with Percentages for Each Minor Age Group and Adults

```
rd_per_3 <- filter(rd_per, AGE == "3-year-olds" | AGE == "Adults")  
rd_per_5 <- filter(rd_per, AGE == "5-year-olds" | AGE == "Adults")  
rd_per_7 <- filter(rd_per, AGE == "7-year-olds" | AGE == "Adults")  
rd_per_9 <- filter(rd_per, AGE == "9-year-olds" | AGE == "Adults")  
rd_per_11 <- filter(rd_per, AGE == "11-year-olds" | AGE == "Adults")  
rd_per_13 <- filter(rd_per, AGE == "13-year-olds" | AGE == "Adults")  
rd_per_15 <- filter(rd_per, AGE == "15-year-olds" | AGE == "Adults")  
rd_per_17 <- filter(rd_per, AGE == "17-year-olds" | AGE == "Adults")
```

Wilcoxon Tests Comparing Vowel Reduction Between the Pre-Stressed and Post-Stressed Conditions Across Each Age Group and Adults, Including Effect Size Calculation

```
wilcox.test(Pre_post ~ AGE, data = rd_per_3, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_5, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_7, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_9, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_11, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_13, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_15, exact = FALSE)  
wilcox.test(Pre_post ~ AGE, data = rd_per_17, exact = FALSE)
```

```
wilcox_effsize(Pre_post ~ AGE, data = rd_per_gr3, exact = FALSE)
```

Wilcoxon Tests Comparing Vowel Reduction Between the Stressed and Pre-Stressed Conditions Across Each Age Group and Adults, Including Effect Size Calculation

```
wilcox.test(Str_pre ~ AGE, data = rd_per_3, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_5, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_7, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_9, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_11, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_13, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_15, exact = FALSE)  
wilcox.test(Str_pre ~ AGE, data = rd_per_17, exact = FALSE)
```

```
wilcox_effsize(Str_pre ~ AGE, data = rd_per_gr3, exact = FALSE)
```

Wilcoxon Tests Comparing Vowel Reduction Between the Stressed and Post-Stressed Conditions Across Each Age Group and Adults, Including Effect Size Calculation

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wilcox.test(Str_post ~ AGE, data = rd_per_7, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = rd_per_9, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = rd_per_11, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = rd_per_13, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = rd_per_15, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = rd_per_17, exact = FALSE)
```

```
wilcox_effsize(Str_post ~ AGE, data = rd_per_gr3, exact = FALSE)
```

Statistical Analysis of Normalized Vowel Space Areas (Calculated Using Excel)

Calculation of the Means of Normalized Vowel Space Area by Age and Regression Analysis of Average Normalized Vowel Space Area with Age

```
ALLMEAN <- three_syllable_areas %>%
  group_by(AGE)%>%
  summarise(nAREA=mean(nAREA), .groups = 'drop')
```

```
summary(lm(formula = nAREA ~as.numeric(AGE), data = ALLMEAN))
```

Linear Mixed-Effects Modeling, Effect Sizes, and Tukey's Post-Hoc Tests

```
nvsa3 <- lme(nAREA~AGE*GENDER*STRESS-AGE:GENDER, random =
~1|SPEAKER, data=three_syllable_areas, weights =
varComb(varIdent(form = ~ 1 | AGE), varIdent(form = ~ 1 | STRESS)),
control =list(msMaxIter = 1000, msMaxEval = 1000))
```

```
anova(nvsa3)
```

```
effectsize::eta_squared (nvsa3)
```

```
as.data.frame(pairs(emmeans(nvsa3, ~ AGE), adjust = "tukey"))
as.data.frame(pairs(emmeans(nvsa3, ~ GENDER), adjust = "tukey"))
as.data.frame(pairs(emmeans(nvsa3, ~ STRESS), adjust = "tukey"))
as.data.frame(pairs(emmeans(nvsa3, ~ AGE*STRESS), adjust = "tukey"))
as.data.frame(pairs(emmeans(nvsa3, ~ GENDER*STRESS), adjust =
"tukey"))
as.data.frame(pairs(emmeans(nvsa3, ~ AGE:GENDER:STRESS), adjust =
"tukey"))
```

After Calculating the Percentages for Vowel Reduction Between the Stress Conditions in Excel, we Assessed Age-Related Differences Using Wilcoxon Tests

Creating Dataframes with Percentages for Each Minor Age Group and Adults

```
nvsa_per_3 <- filter(nvsa_per_gr3, AGE == "3-year-olds" | AGE == "Adults")
```

```

nvsa_per_5 <- filter(nvsa_per_gr3, AGE == "5-year-olds" | AGE == "Adults")
nvsa_per_7 <- filter(nvsa_per_gr3, AGE == "7-year-olds" | AGE == "Adults")
nvsa_per_9 <- filter(nvsa_per_gr3, AGE == "9-year-olds" | AGE == "Adults")
nvsa_per_11 <- filter(nvsa_per_gr3, AGE == "11-year-olds" | AGE == "Adults")
nvsa_per_13 <- filter(nvsa_per_gr3, AGE == "13-year-olds" | AGE == "Adults")
nvsa_per_15 <- filter(nvsa_per_gr3, AGE == "15-year-olds" | AGE == "Adults")
nvsa_per_17 <- filter(nvsa_per_gr3, AGE == "17-year-olds" | AGE == "Adults")

```

Wilcoxon Tests Comparing Vowel Reduction Between the Pre-Stressed and Post-Stressed Conditions Across Each Age Group and Adults, Including Effect Size Calculation

```

wilcox.test(Pre_post ~ AGE, data = nvsa_per_3, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_5, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_7, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_9, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_11, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_13, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_15, exact = FALSE)
wilcox.test(Pre_post ~ AGE, data = nvsa_per_17, exact = FALSE)

```

```

wilcox_effsize(Pre_post ~ AGE, data = nvsa_per_gr3, exact = FALSE)

```

Wilcoxon Tests Comparing Vowel Reduction Between the Stressed and Pre-Stressed Conditions Across Each Age Group and Adults, Including Effect Size Calculation

```

wilcox.test(Str_pre ~ AGE, data = nvsa_per_3, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_5, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_7, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_9, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_11, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_13, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_15, exact = FALSE)
wilcox.test(Str_pre ~ AGE, data = nvsa_per_17, exact = FALSE)

```

```

wilcox_effsize(Str_pre ~ AGE, data = nvsa_per_gr3, exact = FALSE)

```

Wilcoxon Tests Comparing Vowel Reduction Between the Stressed and Post-Stressed Conditions Across Each Age Group and Adults, Including Effect Size Calculation

```

wilcox.test(Str_post ~ AGE, data = nvsa_per_3, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = nvsa_per_5, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = nvsa_per_7, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = nvsa_per_9, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = nvsa_per_11, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = nvsa_per_13, exact = FALSE)
wilcox.test(Str_post ~ AGE, data = nvsa_per_15, exact = FALSE)

```

```
wilcox.test(Str_post ~ AGE, data = nvsa_per_17, exact = FALSE)
```

```
wilcox_effsize(Str_post ~ AGE, data = nvsa_per_gr3, exact = FALSE)
```

Statistical Analysis of Euclidean Distances

Linear Mixed-Effects Modeling, Effect Sizes, and Tukey's Post-Hoc Tests

```
ed3 <- lme(ED~AGE*GENDER*STRESS*VOWEL-AGE-
GENDER:STRESS:VOWEL-AGE:GENDER:STRESS:VOWEL-
AGE:GENDER:STRESS-AGE:GENDER-GENDER-GENDER:STRESS-
AGE:STRESS-GENDER:VOWEL, random = ~1|SPEAKER, data=ed_gr3,
weights = varComb(varIdent(form = ~ 1 | AGE), varIdent(form = ~ 1 |
STRESS), varIdent(form = ~ 1 | VOWEL)), control =list(msMaxIter = 1000,
msMaxEval = 1000))
anova(ed3)
```

```
effectsize::eta_squared (ed3)
```

```
as.data.frame(pairs(emmeans(ed3, ~ STRESS), adjust = "tukey"))
as.data.frame(pairs(emmeans(ed3, ~ VOWEL), adjust = "tukey"))
as.data.frame(pairs(emmeans(ed3, ~ AGE*VOWEL), adjust = "tukey"))
as.data.frame(pairs(emmeans(ed3, ~ STRESS*VOWEL), adjust = "tukey"))
as.data.frame(pairs(emmeans(ed3, ~ AGE:GENDER:VOWEL), adjust =
"tukey"))
as.data.frame(pairs(emmeans(ed3, ~ AGE:STRESS:VOWEL), adjust =
"tukey"))
```

Pearson's Correlations

Reorganizing Data to Construct a Unified Data Frame

```
data_rd <- three_syllable %>%
  group_by(SPEAKER, AGE, GENDER, REPETITION, STRESS)%>%
  summarise (RELDURATION=mean(RELDURATION), .groups = 'drop')
```

```
data_nvsa <- three_syllable_areas %>%
  group_by(SPEAKER, AGE, GENDER, REPETITION, STRESS)%>%
  summarise (nAREA=mean(nAREA), .groups = 'drop')
```

```
data_ed <- ed_gr3 %>%
  group_by(SPEAKER, AGE, GENDER, REPETITION, STRESS)%>%
  summarise (ED=mean(ED), .groups = 'drop')
```

```
data_cor <- cbind(data_rd, data_nvsa, data_ed)
data_cor <- data_cor[, -c(7:11, 13:17)]
```

Correlation Results Between Relative Vowel Duration and Normalized Vowel Space Areas, and Between Relative Vowel Duration and Euclidean Distances

```
library(ggpubr)
```

```
ggscatter(data_cor, x = "RELDURATION", y = "nAREA", color = "STRESS", ,
size = 1.5)+labs(x= "Relative Vowel Duration", y= "Normalized Vowel Space
```

```
Area", colour = "Stress Condition")+geom_smooth(method = "lm", color =
"black")+facet_wrap (AGE~., ncol = 5)+ stat_cor(method = "pearson",
r.accuracy = 0.01, cor.coef.name = "r", fontface =
"bold")+scale_colour_manual(values =c("grey80", "grey50",
"black"))+theme(legend.position = "bottom")
```

```
ggscatter(data_cor, x = "RELDURATION", y = "ED", color = "STRESS", , size
= 1.5)+labs(x= "Relative Vowel Duration", y= "Euclidean Distance", colour =
"Stress Condition")+geom_smooth(method = "lm", color =
"black")+facet_wrap (AGE~., ncol = 5)+ stat_cor(method = "pearson",
r.accuracy = 0.01, cor.coef.name = "r", fontface =
"bold")+scale_colour_manual(values =c("grey80", "grey50",
"black"))+theme(legend.position = "bottom")
```