R Code Full Analysis Verbal Fluency Average Frequency

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Analysis Verbal Fluency Data - Average Frequency of Correctly Produced Words

```r
#Semantic fluency
VFcat <- read.csv("../Data/Tidy/VFcat_complete_final.csv") %>%
  dplyr::mutate(Type = "VFcat")
# head(VFcat[1:6,1:11]) #reads the top 6 rows of the first 11 columns
# tail(VFcat[1:6,1:11]) #reads the bottom 6 rows of the first 11 columns

#Letter fluency
VFlet <- read.csv("../Data/Tidy/VFlet_complete_final.csv") %>%
  dplyr::mutate(Type = "VFlet")
# head(VFlet[1:6,1:9])
# tail(VFlet[1:6,1:9])

#Action fluency
VFact <- read.csv("../Data/Tidy/VFact_complete_final.csv") %>%
  dplyr::mutate(Type = "VFact")
# head(VFact[1:6,1:8])
# tail(VFact[1:6,1:8])

# # All VF tasks
# VFall <- VFcat %>%
#   left_join(VFlet,by=c("ID","Age.Category","Sex","Edu.Years","Measures","GenCogProc.composite","CR.co
#     "CR.composite.during","OccupationCode","CR.GenAct.before","CR.GenAct.during","CR.Cog.before",
#     "CR.Cog.during","CR.Soc.before","CR.Soc.during","CR.Prod.before","CR.Prod.during",
#     "PA.compound.before","PA.compound.during","Smoking","Sleep","MarStatus",
#     "Edu.Degree","CurrentOccu","Income","zCR.GenAct.before","zCR.GenAct.during",
#     "zCR.PA.before","zCR.PA.during","zCR.edu","zCR.occu"))
```

Read in data

Verbal Fluency - Semantic/Categories

Descriptive Statistics

```r
## Create dataset that only includes data of the Subtlex Average Frequency of the produced words
VFcat_AvFreq <- VFcat %>%
  dplyr::filter(Measures=="AvWordFreq_subtlex") %>%
  #Remove column called Measures (which now only contains "AvWordFreq_subtlex")
  dplyr::select(-Measures) %>%
    #Recode age groups
  dplyr::mutate(Age.Category=as.factor(dplyr::recode(Age.Category, '18 to 30 years old'="Younger",
                                    '40 to 55 years old'="Middle-Aged",
                                    '65 to 80 years old'="Older")))
range(VFcat_AvFreq$zComp.Cat) #No outliers
```

```
## [1] -1.101350  1.092799
```

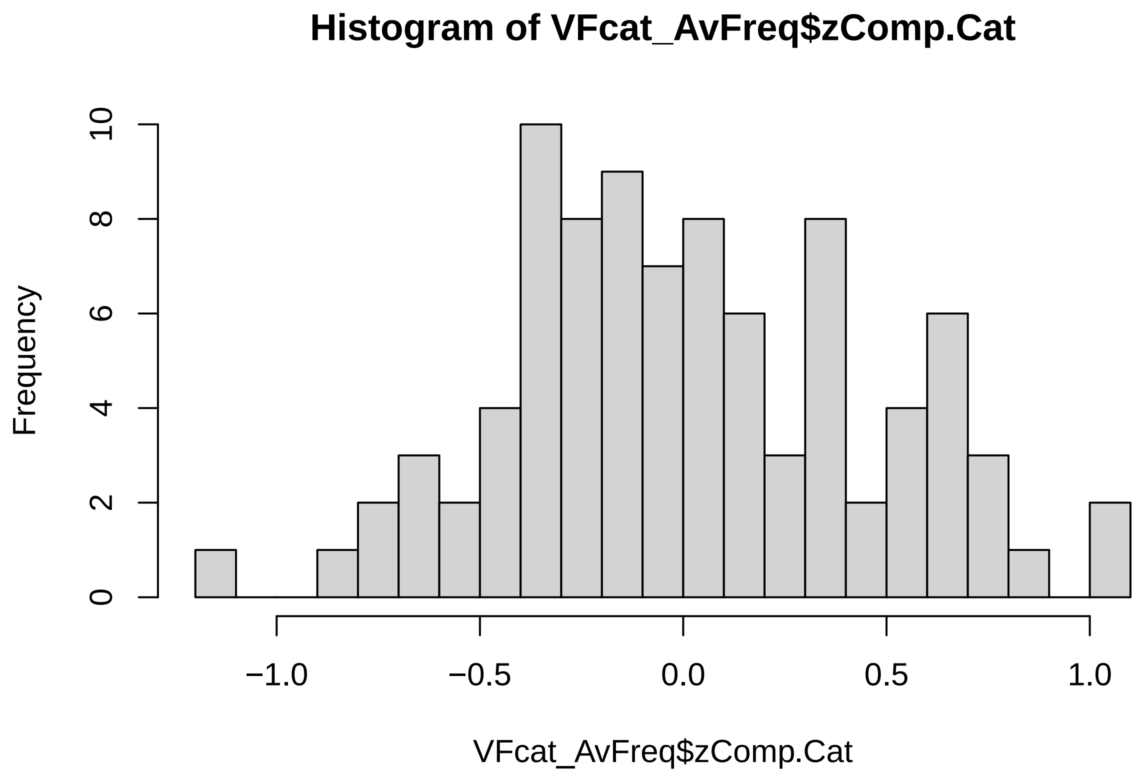
```r
# head(VFcat_AvFreq, L=6)
```

```r
#Create a descriptives table by summarising data of the semantic fluency task
(Descr_VFcat <- VFcat_AvFreq %>%
#Per Age Group
  group_by(Age.Category) %>%
  summarise(Nppt = length(unique(ID)), #Number of participants
            total = round(mean(Total, na.rm=T),2),
            sdtotal = round(sd(Total, na.rm=T),2),#Total words correctly produced
            ztotal = round(mean(zComp.Cat, na.rm=T),2), #Z-score per age group of total words correctly
            animals = round(mean(Animals, na.rm=T),2), #Total words correctly produced in category Anim
            vehicles = round(mean(Vehicles, na.rm=T),2), #Total words correctly produced in category ve
            vandF = round(mean(Fruits.and.Vegetables, na.rm=T),2), #Total words correctly produced in c
            fluid = round(mean(Fluid, na.rm=T),2), #Total words correctly produced in category fluid
            writing = round(mean(Writing.Utensils, na.rm=T),2))) #Total words correctly produced in cat
```

```
## # A tibble: 3 x 10
##   Age.Category  Nppt total sdtotal ztotal animals vehicles vandF fluid writing
##   <fct>        <int> <dbl>   <dbl>  <dbl>   <dbl>    <dbl> <dbl> <dbl>   <dbl>
## 1 Middle-Aged     30  4.4     2.99  -0.05    3.92     3.97  3.73  4.21    3.47
## 2 Older           30  4.23    2.05  -0.06    3.99     3.9   3.75  4.09    3.57
## 3 Younger         30  3.96    0.16   0.16    4.12     4.06  3.79  4.32    3.54
```

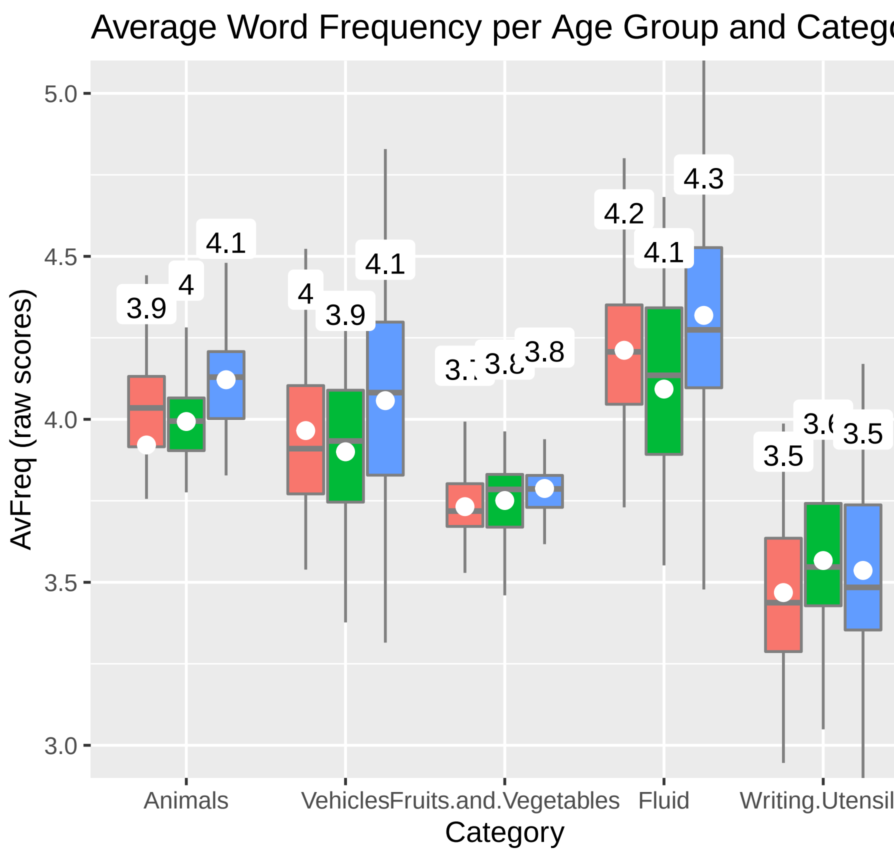
```r
#Write table to file
# write.csv(Descr_VFcat, "./Figures and Tables/Descr_VFcat_AvFreq.csv", row.names = F)
```

```r
#Visualise z-distribution of the composite score for semantic fluency Average word frequency
hist(VFcat_AvFreq$zComp.Cat, breaks=20) #Composite z-score of Semantic Fluency
```




```
#Convert to long format for visualisation
VFcat_AvFreq.long <- VFcat_AvFreq %>%
  pivot_longer(cols=Total:Writing.Utensils, names_to = "category", values_to = "AvFreq")

#Boxplot VF Average frequency (AvFreq)

#Write figure to png file
# png(file="./Figures and Tables/Boxplot_VFcatAvFreq.png",
# width=800, height=350)


(Boxplot_VF <- VFcat_AvFreq.long %>%
    dplyr::filter(category!="Total") %>%
    ggplot(aes(x=factor(category, levels=c("Animals", "Vehicles", "Fruits.and.Vegetables", "Fluid", "Wri
                                                  fill = as.factor(Age.Category))) +
    geom_boxplot(outlier.shape = NA, colour="grey50")+
    stat_summary(aes(label=round(..y..,1), group=as.factor(Age.Category)),
                 fun=mean, geom = "label", size=4,
                 fill="white", show.legend=NA, label.size=NA,
                 position = position_dodge(.75), vjust=-3) +
      stat_summary(fun = "mean", position = position_dodge(.75),
                 show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Category",
```

```
        y = "AvFreq (raw scores)",
        title = "Average Word Frequency per Age Group and Category")+
       scale_fill_discrete(guide=guide_legend(title = "Age Group"), labels=c("18 to 30 years old","40 t
  coord_cartesian(ylim = c(3,5)))
```

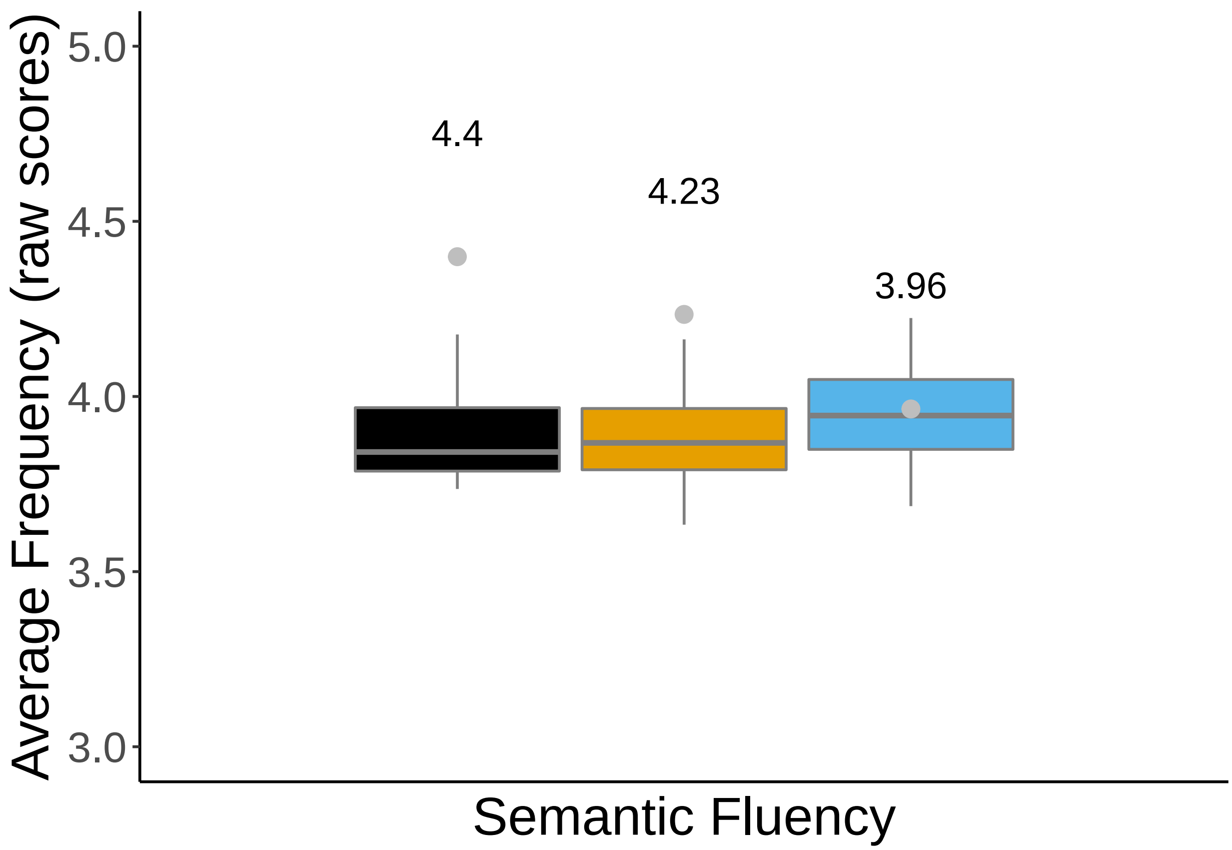


Visualisation AvFreq Semantic Fluency

```
# dev.off() #Closes png() function
```

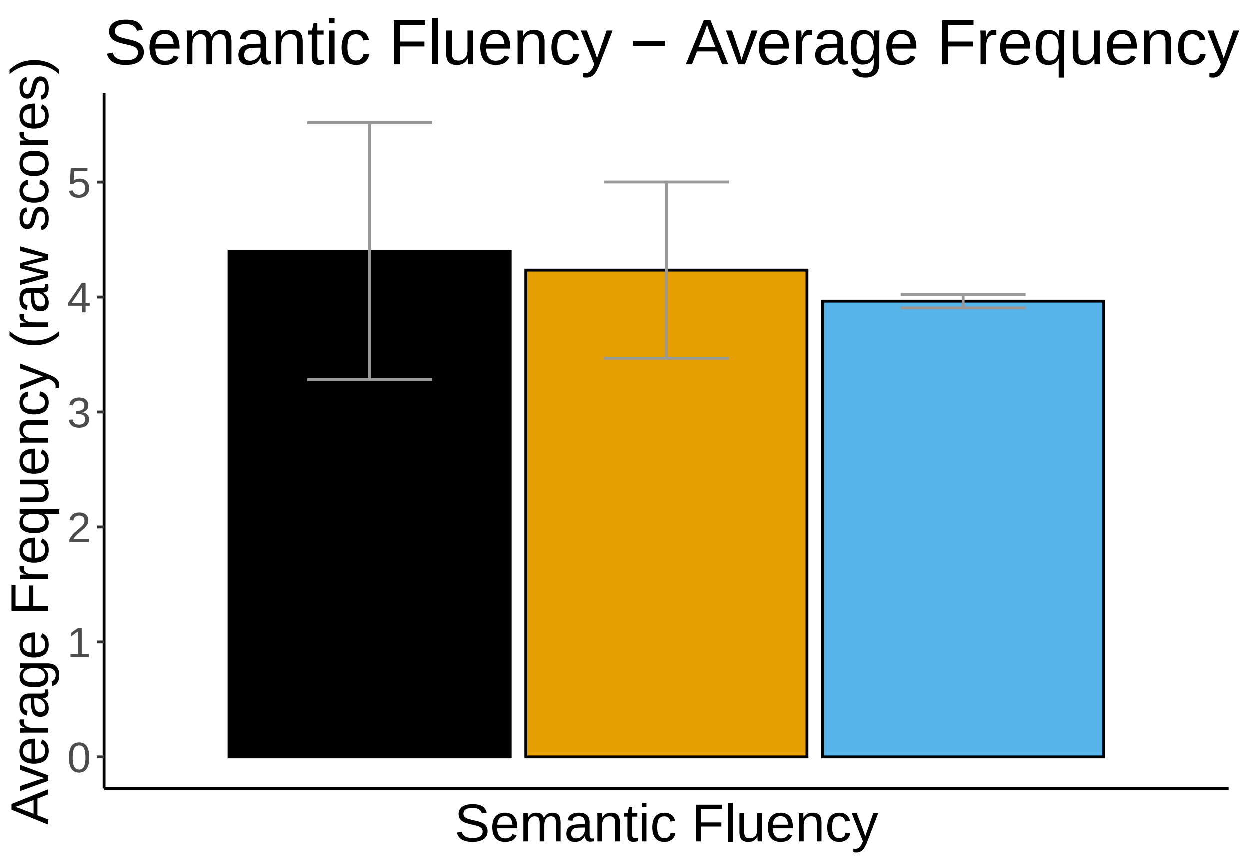
```
#Boxplot VF AvFreq Raw Total
# png(file="./Figures and Tables/Boxplot_VFcatAvFreq_RawTotal.png",
# width=600, height=350)

(Boxplot_VF <- VFcat_AvFreq.long %>%
    dplyr::filter(category=="Total") %>%
    ggplot(aes(x=category, y=AvFreq,fill = as.factor(Age.Category)),show.legend=FALSE) +
    geom_boxplot(outlier.shape = NA, colour="grey50",show.legend=FALSE)+
    stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=5,
               fill="white", show.legend=NA, label.size=NA,
               position = position_dodge(.75), vjust=-2) +
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="grey")+ #Mean as white dot
    labs(x = "Semantic Fluency",
        y = "Average Frequency (raw scores)")+
       scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
      theme(text = element_text(size = 20),
```

```
              axis.ticks.x = element_blank(),
              axis.text.x = element_blank(),
           panel.background  = element_rect(fill="white"),
           plot.background = element_rect(fill = "white"),
           strip.background = element_rect(fill="white"),
           axis.line.x = element_line(color="black"),
          axis.line.y = element_line(color="black")) +
  coord_cartesian(ylim = c(3,5))+
     scale_y_continuous(minor_breaks = seq(3,5,1),
                    breaks = seq(3,5, 0.5)))
```




```
# dev.off()

# tiff(file="../Figures and Tables/descrVFcat_BarPlot.tiff",
# width=800, height=400)

(descr.VFcat_BarPlot <- VFcat_AvFreq.long %>%
    dplyr::filter(category=="Total") %>%
       mutate(Age.Category_ordered = factor(Age.Category, levels=c("Younger", "Middle-Aged", "Older")))
    ggplot(aes(x=category, y=AvFreq,fill = as.factor(Age.Category)),show.legend=FALSE) +
    stat_summary(fun=mean, position=position_dodge(0.95), geom = "bar",show.legend = FALSE , colour = "
    stat_summary(fun.data=mean_cl_normal,position=position_dodge(0.95),geom="errorbar", width=0.4, colo
  # geom_errorbar(stat="summary", fun.data = mean_sdl, fun.args = list(mult=0.5),
  #                width=0.4, position=position_dodge(0.9), colour="grey50") +
    #   stat_summary(fun = "mean", position = position_dodge(.75),
```

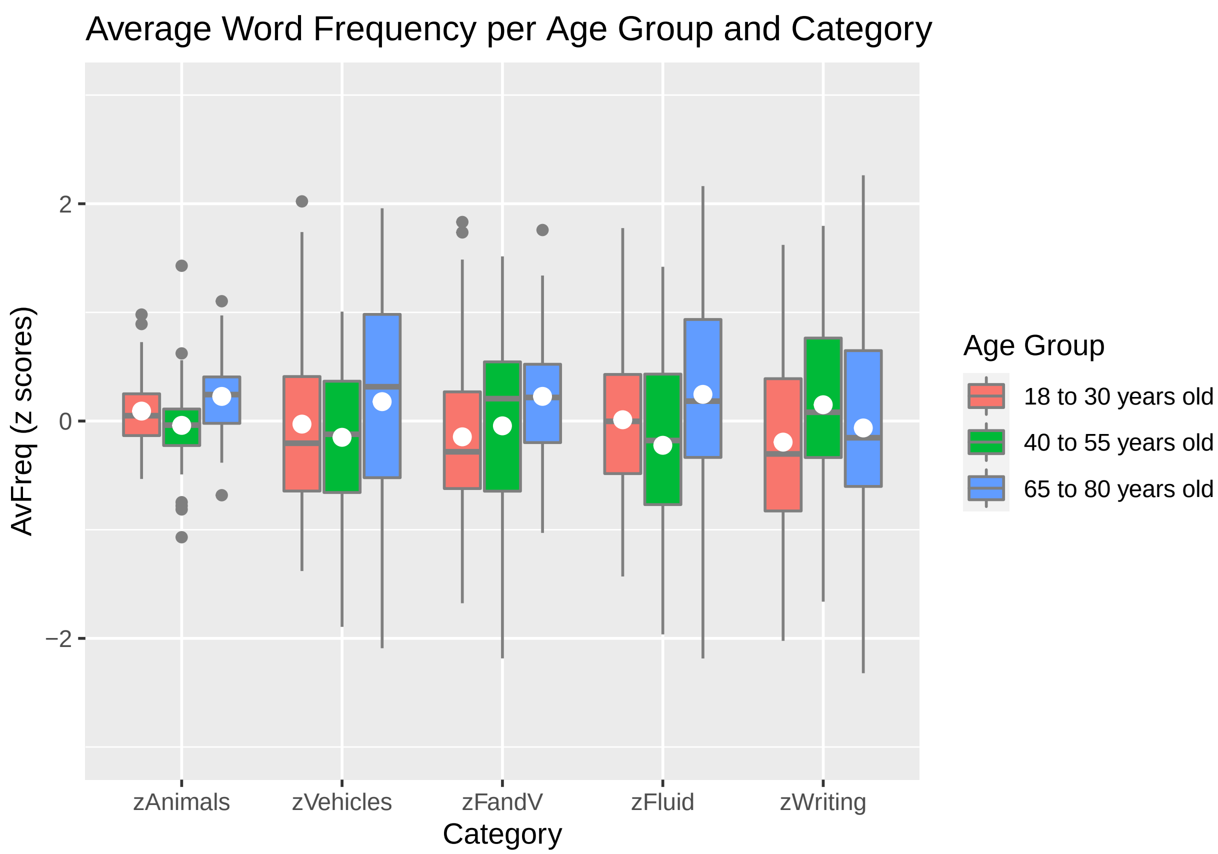
```
#             show.legend=F, colour="grey")+ #Mean as white dot
labs(x = "Semantic Fluency",
     y = "Average Frequency (raw scores)",
     title = "Semantic Fluency - Average Frequency per Age group")+
    scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
   theme(text = element_text(size = 20),
         axis.ticks.x = element_blank(),
         axis.text.x = element_blank(),
      panel.background  = element_rect(fill="white"),
      plot.background = element_rect(fill = "white"),
      strip.background = element_rect(fill="white"),
      axis.line.x = element_line(color="black"),
     axis.line.y = element_line(color="black")) +
coord_cartesian(ylim = c(0,5.5))+
  scale_y_continuous(minor_breaks = seq(0,5,0.1),
                     breaks = seq(0,5,1)))
```




```
# dev.off()

# ggsave(descr.VFcat_BarPlot, filename = "../Figures and Tables/descrVFcat_BarPlot.tiff", height = 15, 
```

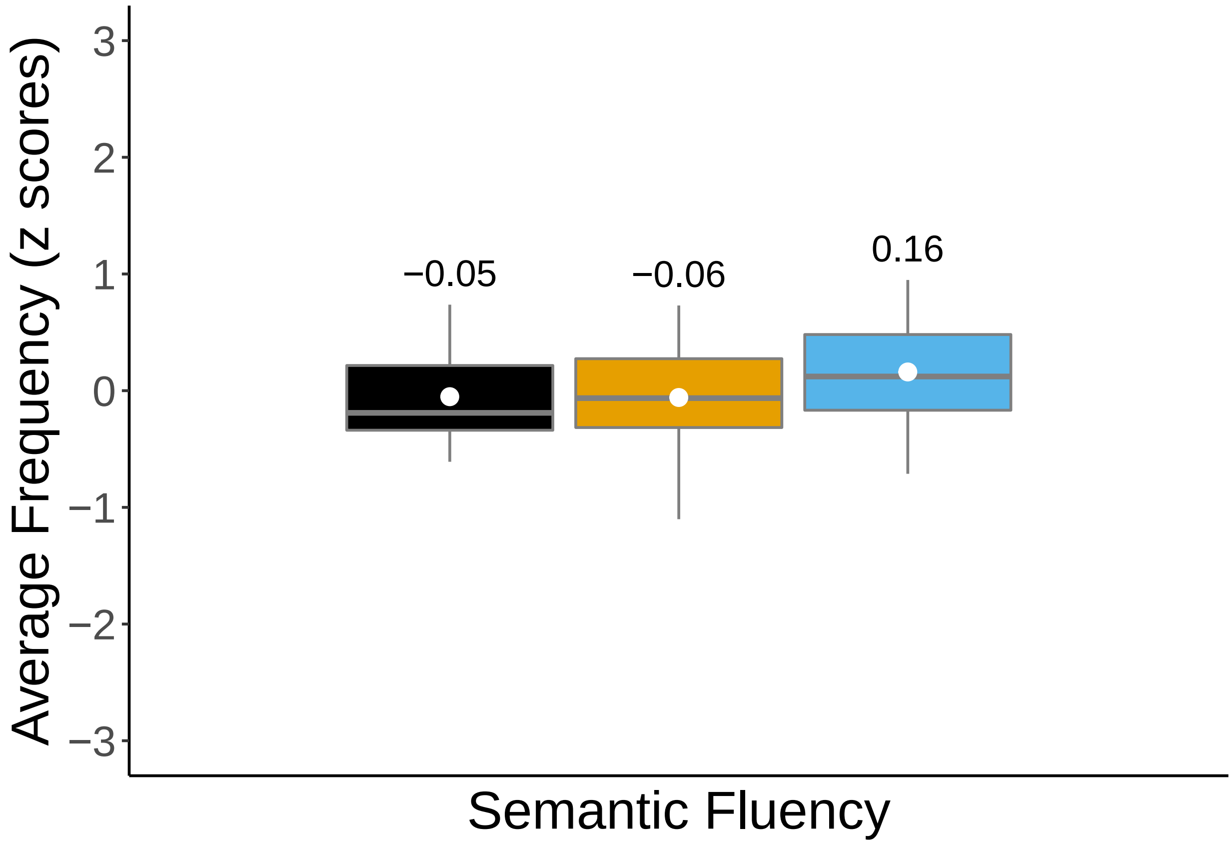
Figures AvFreq Semantic Fluency zscores

```r
#Convert to long format for visualisation
VFcat_AvFreq.long.zscores <- VFcat_AvFreq %>%
  pivot_longer(cols=zComp.Cat:zWriting, names_to = "zcategory", values_to = "zAvFreq")

#Boxplot VF Average frequency (AvFreq)

#Write figure to png file
# png(file="./Figures and Tables/Boxplot_VFcatAvFreq_zscores.png",
# width=800, height=350)

(Boxplot_VFcat.zscores <- VFcat_AvFreq.long.zscores %>%
    dplyr::filter(zcategory!="zComp.Cat") %>%
    ggplot(aes(x=factor(zcategory, levels=c("zAnimals", "zVehicles", "zFandV", "zFluid", "zWriting")), y
                                              fill = as.factor(Age.Category))) +
    geom_boxplot(colour="grey50")+
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Category",
         y = "AvFreq (z scores)",
         title = "Average Word Frequency per Age Group and Category")+
        scale_fill_discrete(guide=guide_legend(title = "Age Group"), labels=c("18 to 30 years old","40 t
  coord_cartesian(ylim = c(-3,3)))
```




```r
# dev.off() #Closes png() function
```

```
#Boxplot VF AvFreq Raw Total
# png(file="./Figures and Tables/Boxplot_VFcatAvFreq_Total_zscores.png",
# width=600, height=350)

(Boxplot_VFcat.Totalzscore <- VFcat_AvFreq.long.zscores %>%
    dplyr::filter(zcategory=="zComp.Cat") %>%
    ggplot(aes(x=zcategory, y=zAvFreq,fill = as.factor(Age.Category)),show.legend=FALSE) +
    geom_boxplot(colour="grey50",show.legend=FALSE)+
    stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
                 fun=mean, geom = "label", size=5,
                 fill="white", show.legend=FALSE, label.size=NA,
                 position = position_dodge(.75), vjust=-2) +
    stat_summary(fun = "mean", position = position_dodge(.75),
                 show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Semantic Fluency",
         y = "Average Frequency (z scores)")+
        scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
       theme(text = element_text(size = 20),
             axis.ticks.x = element_blank(),
             axis.text.x = element_blank(),
          panel.background  = element_rect(fill="white"),
          plot.background = element_rect(fill = "white"),
          strip.background = element_rect(fill="white"),
          axis.line.x = element_line(color="black"),
         axis.line.y = element_line(color="black")) +
  coord_cartesian(ylim = c(-3,3))+
     scale_y_continuous(minor_breaks = seq(-3,3,0.5),
                     breaks = seq(-3,3,1)))
```




```
# dev.off()
```

Multiple Linear Regression - Semantic Fluency

Create user-defined contrasts for the Age Category variable

```
VFcat_AvFreq <- mutate(VFcat_AvFreq,
                     Age.Category =
                       factor(Age.Category, levels = c("Middle-Aged", "Younger", "Older")))

VFcat_AvFreq_coded <- VFcat_AvFreq
contrasts(VFcat_AvFreq_coded$Age.Category) <- contr.helmert(3)
contrasts(VFcat_AvFreq_coded$Age.Category)
```

```
##             [,1] [,2]
## Middle-Aged   -1   -1
## Younger        1   -1
## Older          0    2
```

Unconditional model, i.e. without covariates

```
lmUncond.VFcat.AvFreq <- lm(zComp.Cat ~ Age.Category*CR.composite.before, data = VFcat_AvFreq_coded)
# broom::tidy(lmUncond.VFcat.AvFreq, conf.int=T)
```

Full model of AvFreq in z-distribution, including covariates

```
lmFull.VFcat.AvFreq <- lm(zComp.Cat ~ Age.Category*CR.composite.before + GenCogProc.composite, data = VF
summary(lmFull.VFcat.AvFreq)
```

```
##
## Call:
## lm(formula = zComp.Cat ~ Age.Category * CR.composite.before +
##     GenCogProc.composite, data = VFcat_AvFreq_coded)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -0.97621 -0.27870 -0.06062  0.29881  0.98589
##
## Coefficients:
##                                  Estimate Std. Error t value Pr(>|t|)
## (Intercept)                       0.01654    0.04624   0.358   0.7215
## Age.Category1                     0.12093    0.05983   2.021   0.0465 *
## Age.Category2                    -0.05218    0.03771  -1.384   0.1701
## CR.composite.before              -0.04559    0.04709  -0.968   0.3358
## GenCogProc.composite             -0.08321    0.10726  -0.776   0.4401
## Age.Category1:CR.composite.before -0.05309    0.05778  -0.919   0.3609
## Age.Category2:CR.composite.before -0.04303    0.03325  -1.294   0.1993
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4386 on 83 degrees of freedom
## Multiple R-squared:  0.09732,    Adjusted R-squared:  0.03207
## F-statistic: 1.491 on 6 and 83 DF,  p-value: 0.1912
```

```
#Tidy table output
(tidylmFull.VFcat.AvFreq <- broom::tidy(lmFull.VFcat.AvFreq, conf.int=T)%>%
  mutate_if(is.numeric, round, 3))
```

```
## # A tibble: 7 x 7
##   term                  estimate std.error statistic p.value conf.low conf.high
##   <chr>                    <dbl>     <dbl>     <dbl>   <dbl>    <dbl>     <dbl>
## 1 (Intercept)              0.017     0.046     0.358   0.721   -0.075     0.109
## 2 Age.Category1            0.121     0.06      2.02    0.046    0.002     0.24
## 3 Age.Category2           -0.052     0.038    -1.38    0.17    -0.127     0.023
## 4 CR.composite.before     -0.046     0.047    -0.968   0.336   -0.139     0.048
## 5 GenCogProc.composite    -0.083     0.107    -0.776   0.44    -0.297     0.13
## 6 Age.Category1:CR.comp~  -0.053     0.058    -0.919   0.361   -0.168     0.062
## 7 Age.Category2:CR.comp~  -0.043     0.033    -1.29    0.199   -0.109     0.023
```

```
# write.csv(tidylmFull.VFcat.AvFreq, "./Figures and Tables/VFcat_AvFreq_zlmFull.csv", row.names = F)
```

```
#Look at pairwise comparisons between contrasts
lmFull.VFcat.AvFreq.emmeans <- emmeans::emtrends(lmFull.VFcat.AvFreq, ~Age.Category, var = "CR.composite
pairs(lmFull.VFcat.AvFreq.emmeans)
```

```
##  contrast                 estimate    SE df t.ratio p.value
```

```
##  (Middle-Aged) - Younger    0.106 0.116 83   0.919  0.6300
##  (Middle-Aged) - Older      0.182 0.115 83   1.580  0.2601
##  Younger - Older            0.076 0.115 83   0.659  0.7876
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

Full model of AvFreq as raw score, including covariates

```r
lmFull.VFcat.AvFreq.raw <- lm(Total ~ Age.Category*CR.composite.before + GenCogProc.composite, data = VF

#Tidy table output
broom::tidy(lmFull.VFcat.AvFreq.raw, conf.int=T) %>%
  mutate_if(is.numeric, round, 3)
```

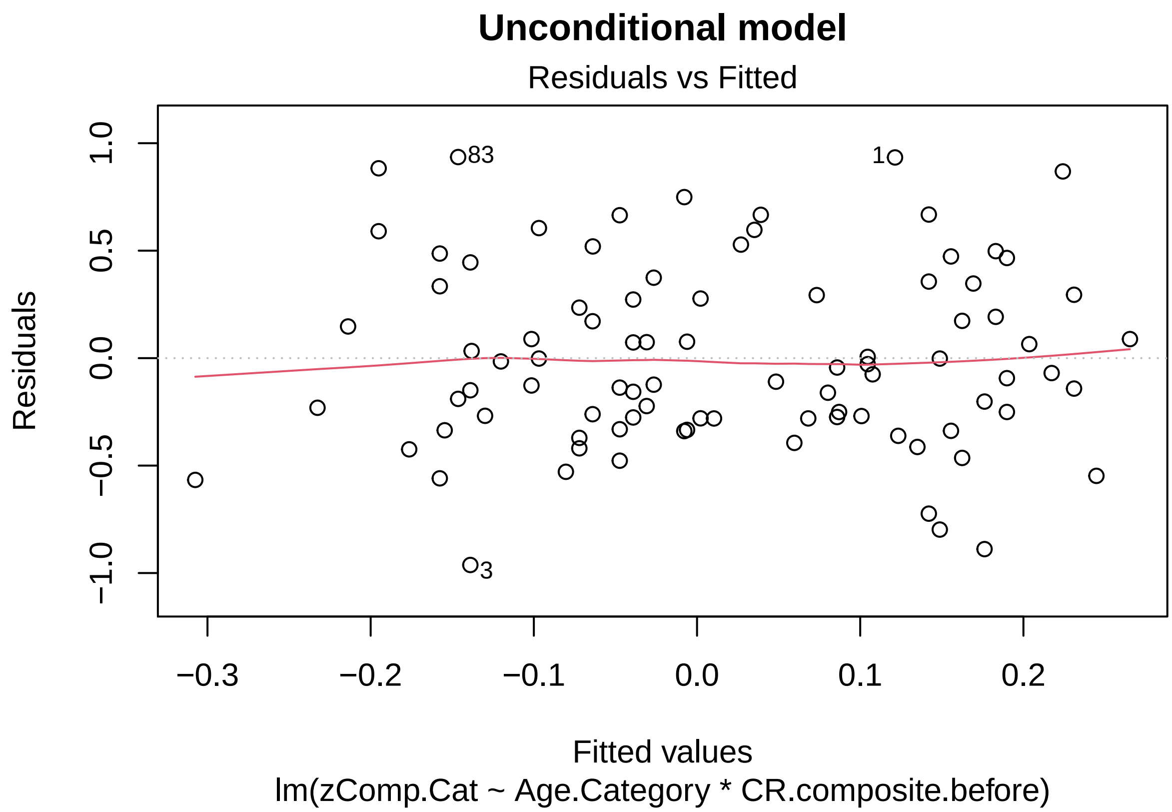
```
## # A tibble: 7 x 7
##   term                  estimate std.error statistic p.value conf.low conf.high
##   <chr>                    <dbl>     <dbl>     <dbl>   <dbl>    <dbl>     <dbl>
## 1 (Intercept)              4.20      0.22     19.1     0        3.76      4.64
## 2 Age.Category1           -0.186     0.285    -0.654   0.515   -0.753     0.381
## 3 Age.Category2           -0.013     0.18     -0.071   0.944   -0.37      0.345
## 4 CR.composite.before      0.265     0.224     1.18    0.241   -0.181     0.711
## 5 GenCogProc.composite    -0.173     0.511    -0.338   0.736   -1.19      0.844
## 6 Age.Category1:CR.comp~  -0.396     0.275    -1.44    0.155   -0.943     0.152
## 7 Age.Category2:CR.comp~  -0.147     0.158    -0.928   0.356   -0.462     0.168
```

The unconditional model and the model with the raw total scores do not seem to predict the outcome variable for Verbal Fluency Categories. In the full model with the average z-score as outcome variable, middle-aged adults seem to significantly produce higher frequency words than young adults.

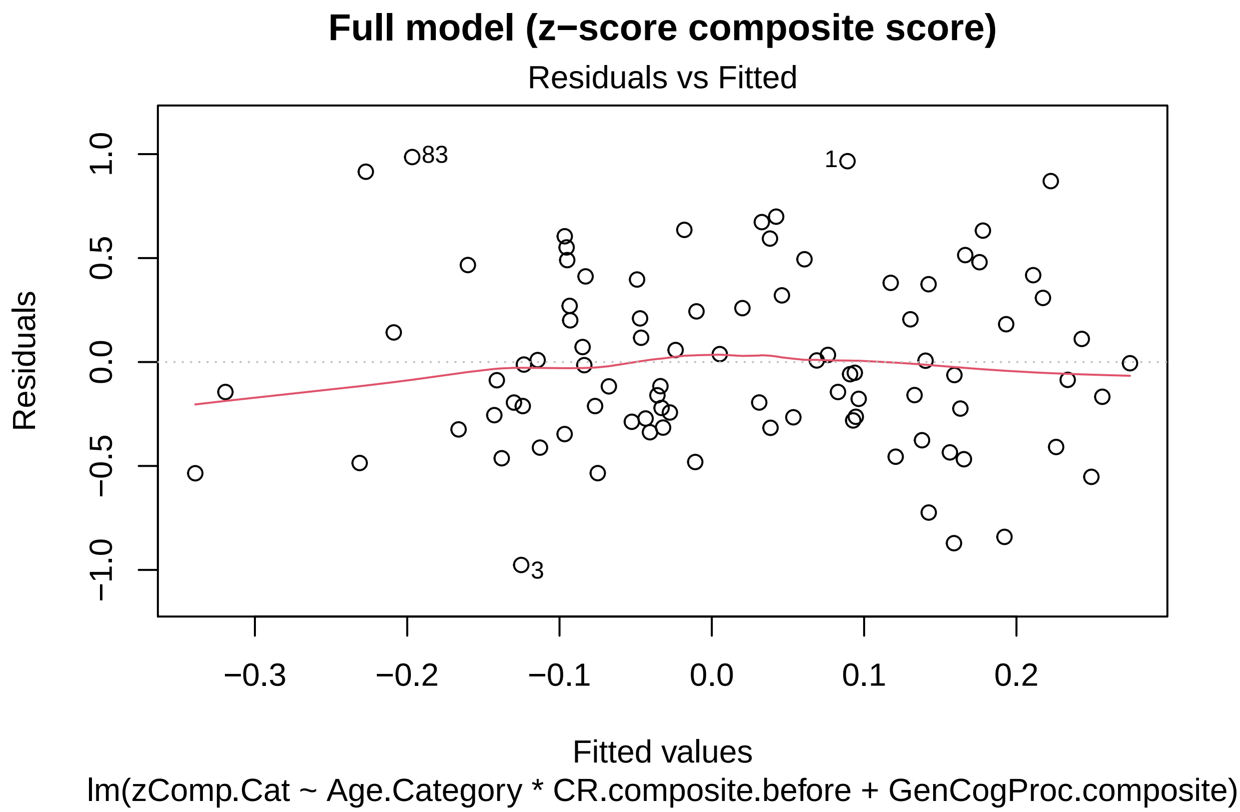
Let's check the model assumptions + fit.

Assumption 1 - Linearity

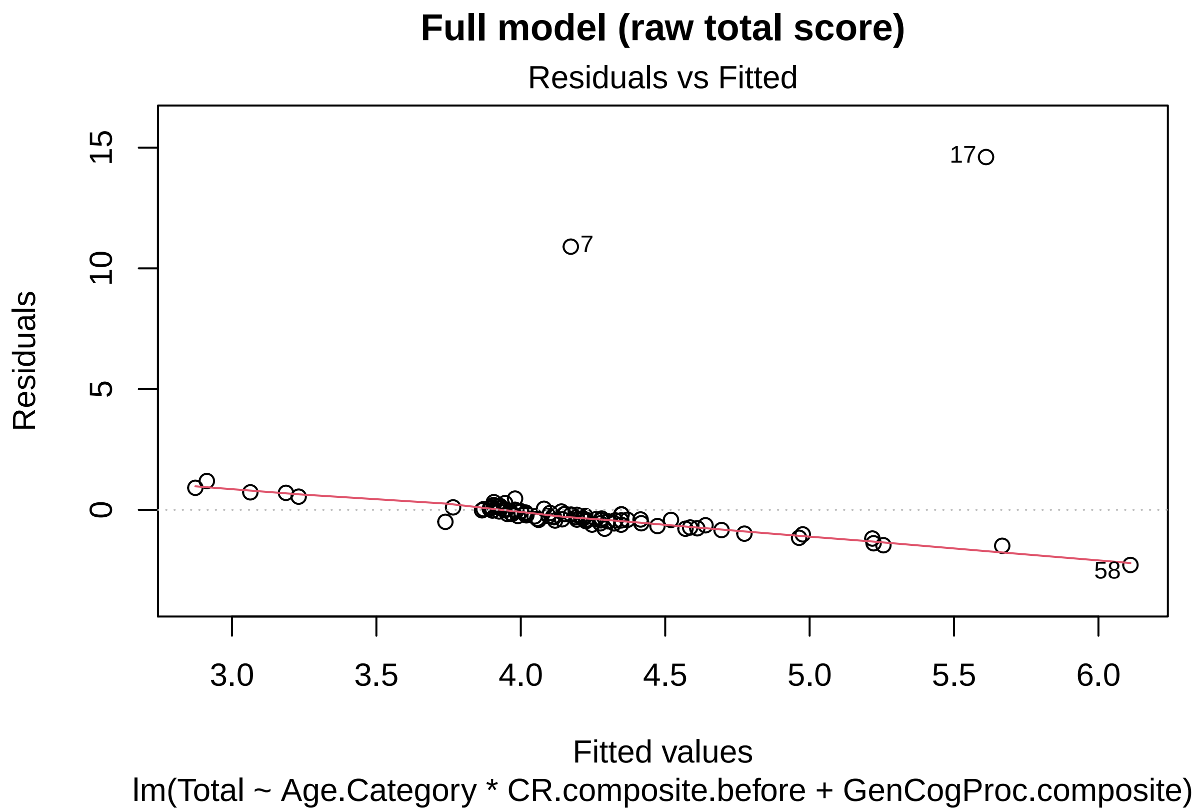
```r
## Unconditional model with z composite score
plot(lmUncond.VFcat.AvFreq, 1, main = "Unconditional model")
```




```
## Full model with z composite score
plot(lmFull.VFcat.AvFreq, 1, main = "Full model (z-score composite score)")
```




```r
## Full model with raw total score
plot(lmFull.VFcat.AvFreq.raw, 1, main = "Full model (raw total score)")
```



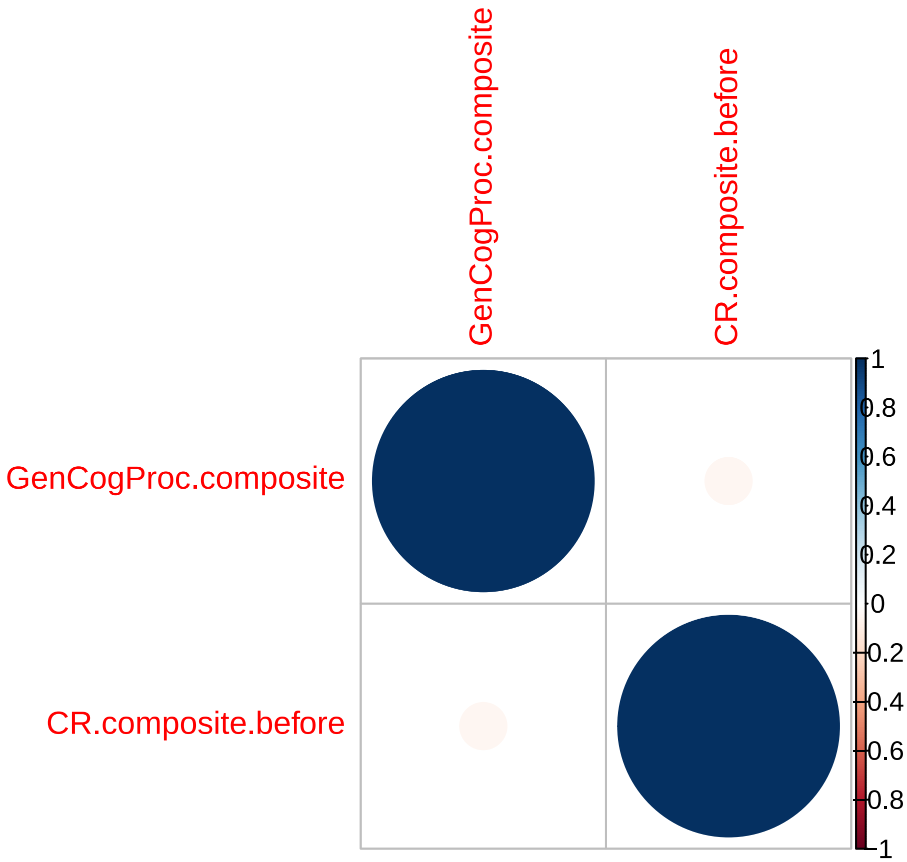
For the models with the z-composite score as outcome variable, the red line is mostly horizontal, meaning that there is a linear relationship between the fitted line and the residual value. The model with the raw average frequency scores seems to violate the assumption.

Assumption 2 - Independence of Variables

```
# Z composite of VF cat
## Create table with correlation values between predictor variables
tibble::as_tibble(cor(VFcat_AvFreq_coded[,c(17,18)]), rownames="rowname")
```

```
## # A tibble: 2 x 3
##   rowname              GenCogProc.composite CR.composite.before
##   <chr>                               <dbl>               <dbl>
## 1 GenCogProc.composite               1                  -0.0439
## 2 CR.composite.before               -0.0439              1
```

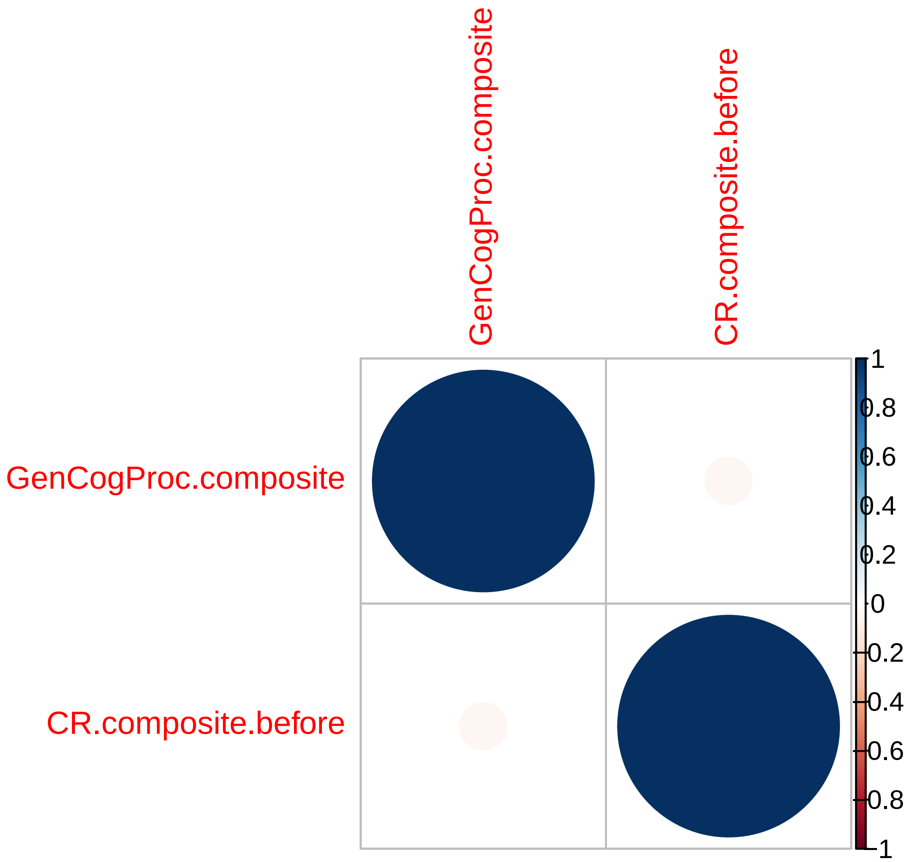
```
## Create correlation plot between predictor variables
corrplot(cor(VFcat_AvFreq_coded[,c(17,18)]),method='circle')
```




```r
## Raw scores
## Create table with correlation values between predictor variables
tibble::as_tibble(cor(VFcat_AvFreq_coded[,c(17,18)]), rownames = "rowname")
```

```
## # A tibble: 2 x 3
##   rowname              GenCogProc.composite CR.composite.before
##   <chr>                               <dbl>               <dbl>
## 1 GenCogProc.composite               1                  -0.0439
## 2 CR.composite.before               -0.0439              1
```

```r
## Create correlation plot between predictor variables
corrplot(cor(VFcat_AvFreq_coded[,c(17,18)]))
```

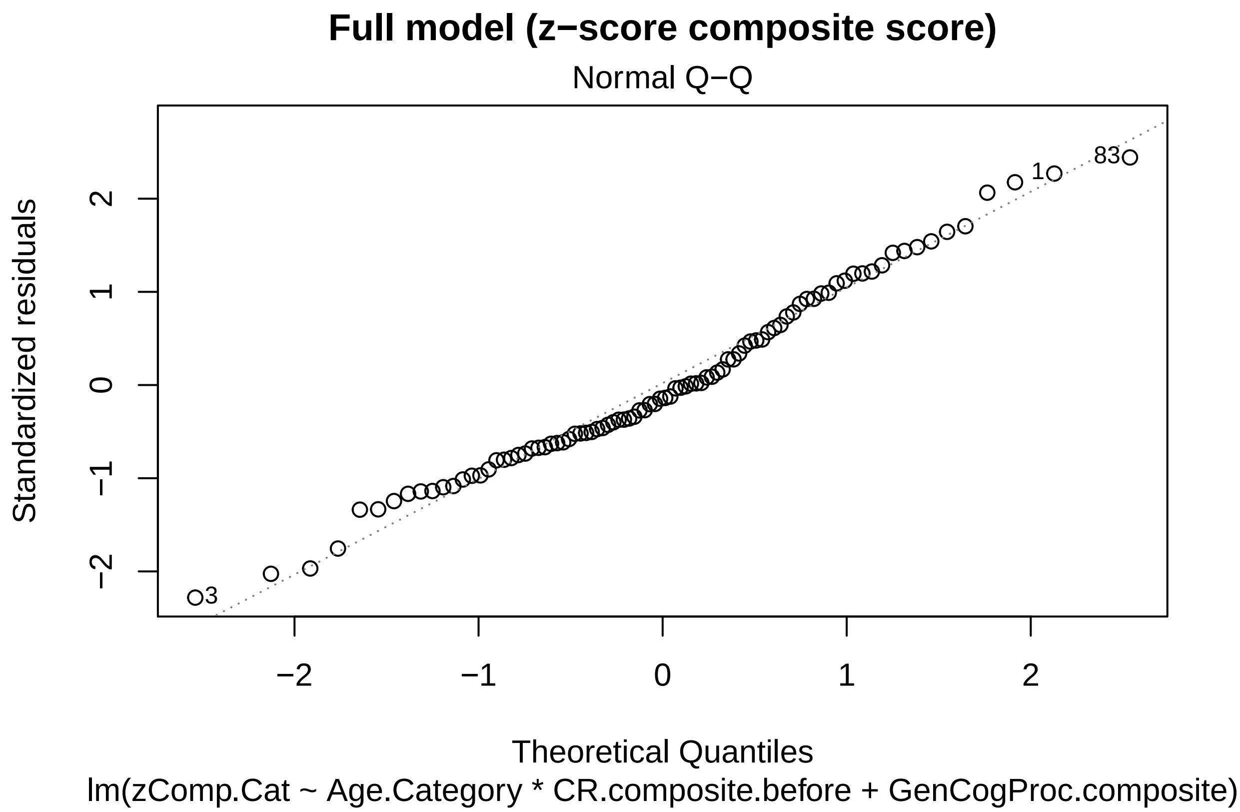


There seems to be no strong relationship between the predictor variables. Hence, we can assume Independence of Variables.

Assumption 3 - Normal Distribution of Residuals

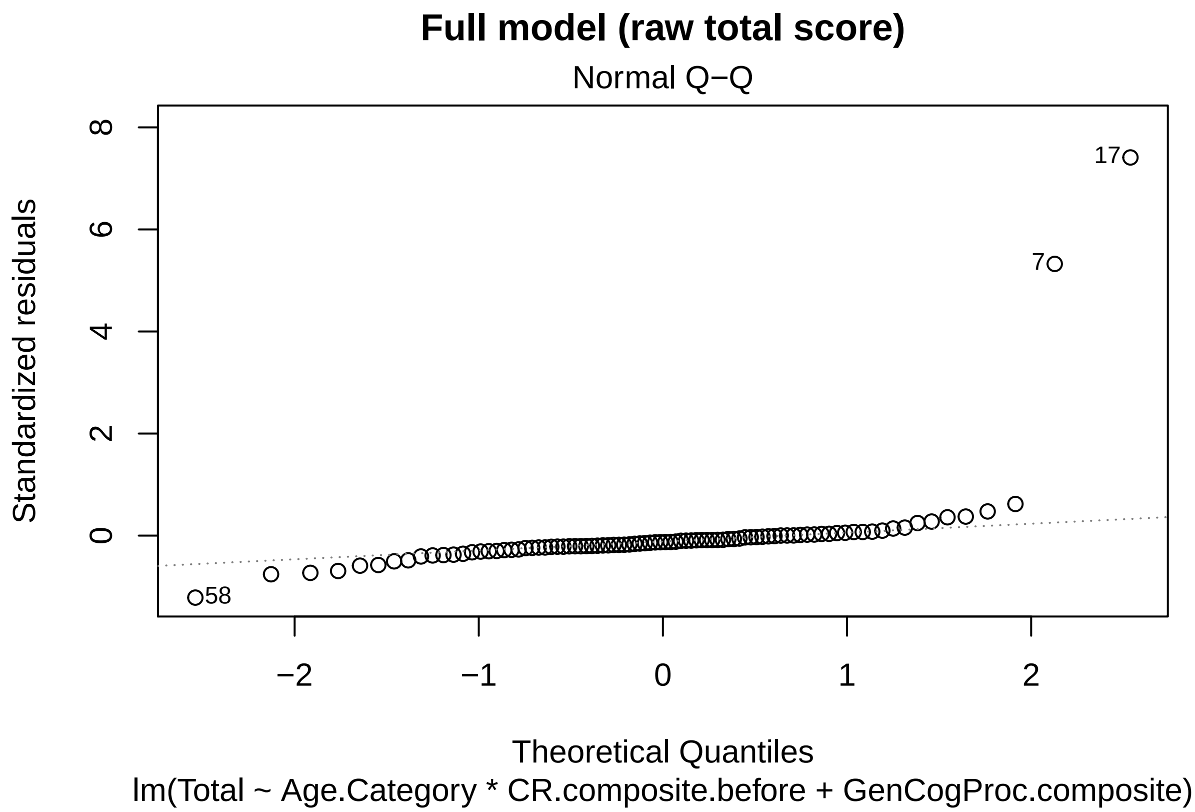
Full model with z composite score

```
plot(lmFull.VFcat.AvFreq, 2, main = "Full model (z-score composite score)")
```



Full model with raw total score

```
plot(lmFull.VFcat.AvFreq.raw, 2, main = "Full model (raw total score)")
```

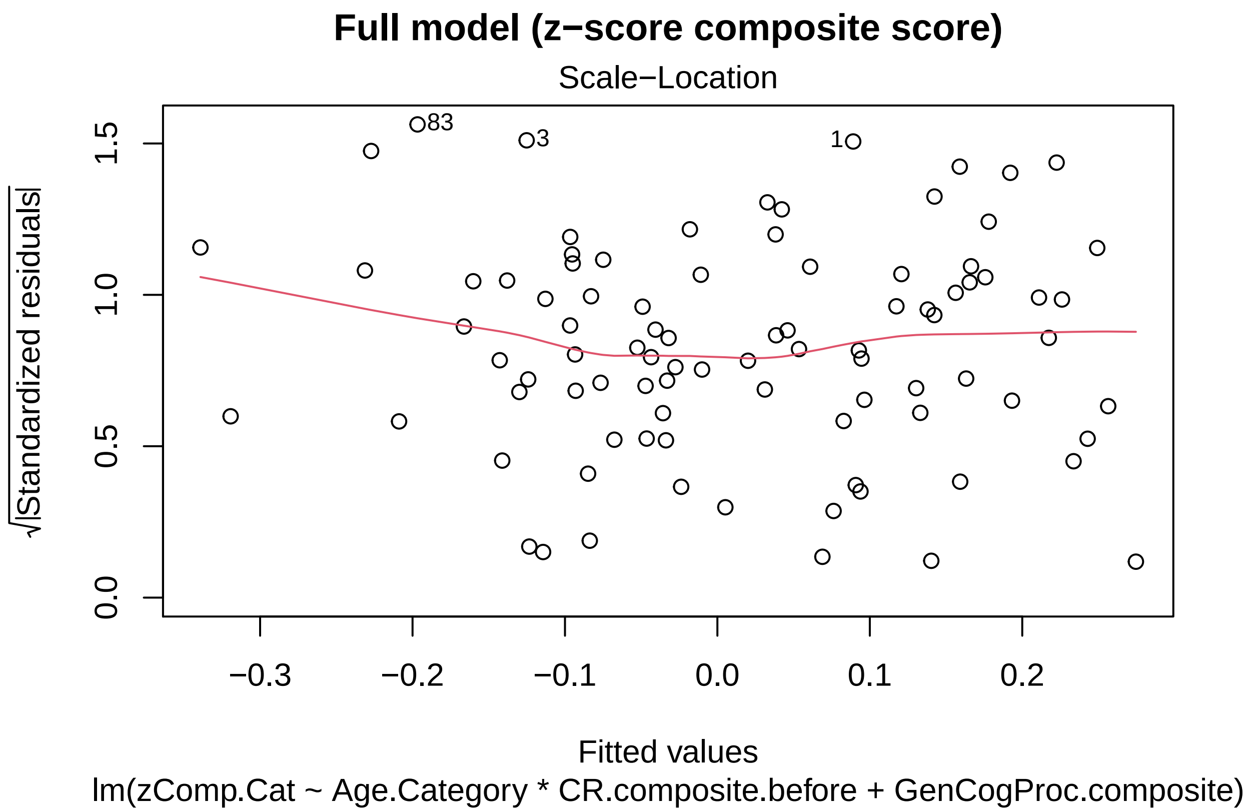


The model with the raw scores violates the assumption. This is likely due to the two outliers on the right (point 7 and 17). The points in both the unconditional and full model with the z-composite score seem to roughly follow the straight line. There's a little bit of a bulk on the right for the full z-model and a small dip in both models. One explanation could be the online format of the study. For example, some participants might have scored lower than they would in a lab-based study, due to unclear instructions. Also, it could have caused more distractions than there would have been in a lab based study.

Assumption 4 - Homoscedasticity or Equal Variance of Variables

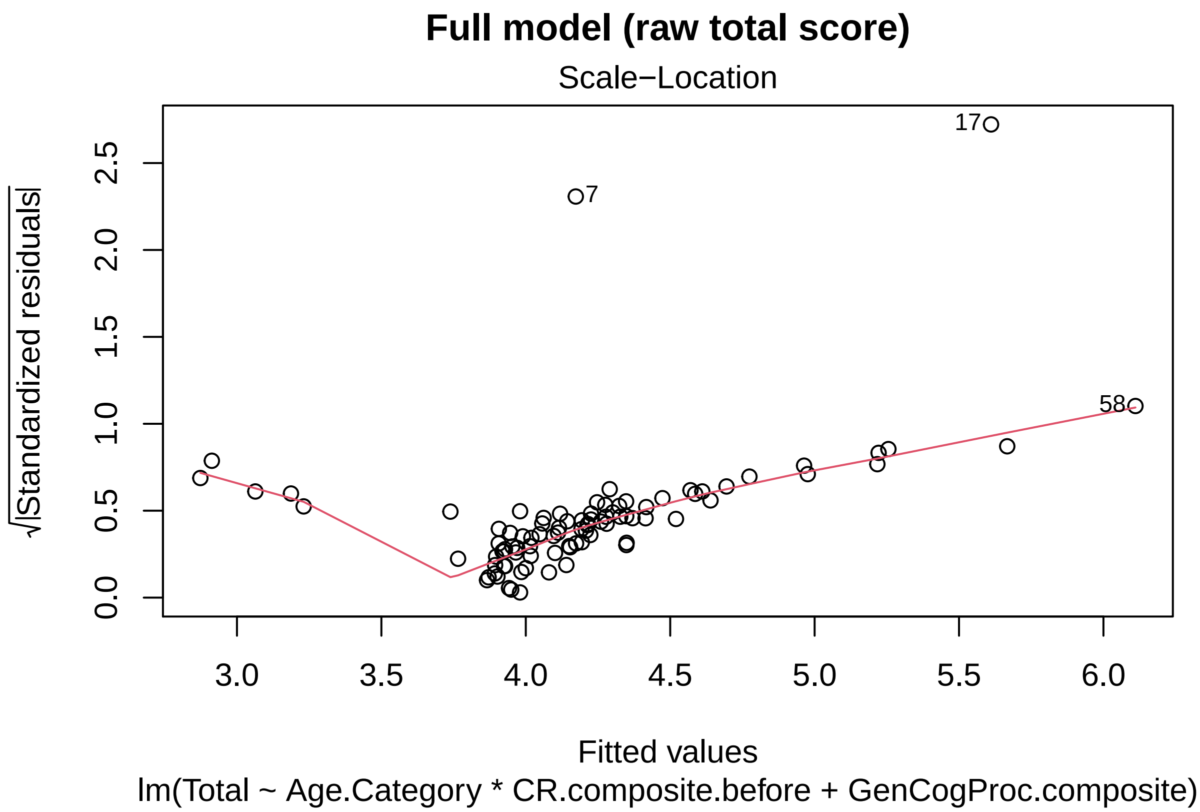
Full model with z composite score

```
plot(lmFull.VFcat.AvFreq, 3, main = "Full model (z-score composite score)")
```



Full model with raw total score

```
plot(lmFull.VFcat.AvFreq.raw, 3, main = "Full model (raw total score)")
```



Again, the full model with the raw total score as outcome variable violates the assumption. For the other two models, the variance of residuals seems relatively equal across the predictors. Hence, the error terms are relatively the same across all values of the independent variable for all three models.

Conclusion: the full model with the z-composite variable as outcome variable seem to meet the assumptions for multiple linear regression.

Model fit diagnostics *Variation Inflation Factor*

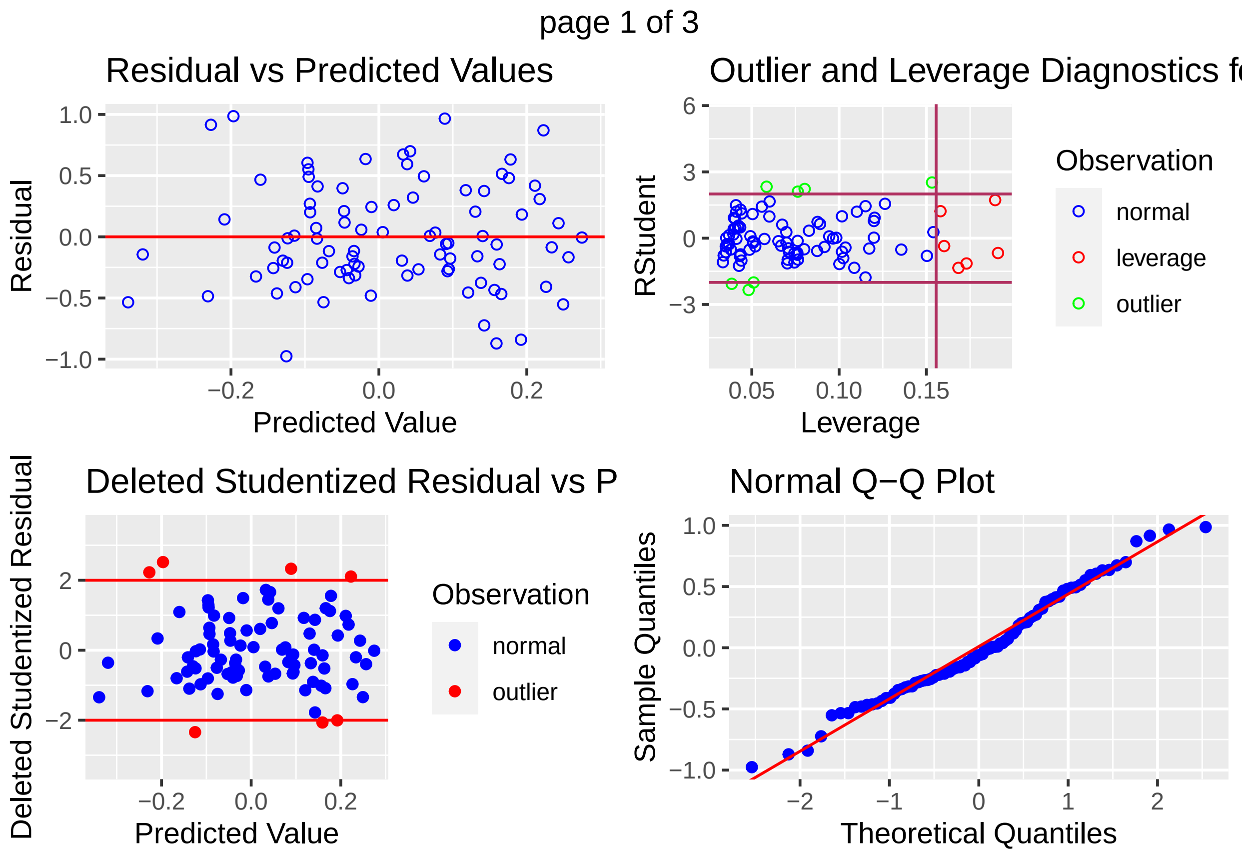
Any VIF value above 4 needs further investigation. There seems to be no concerning signs of collinearity (VIF values higher than 4). The tolerance values indicate the percentage of variance that cannot be explained for by the other predictor variables.

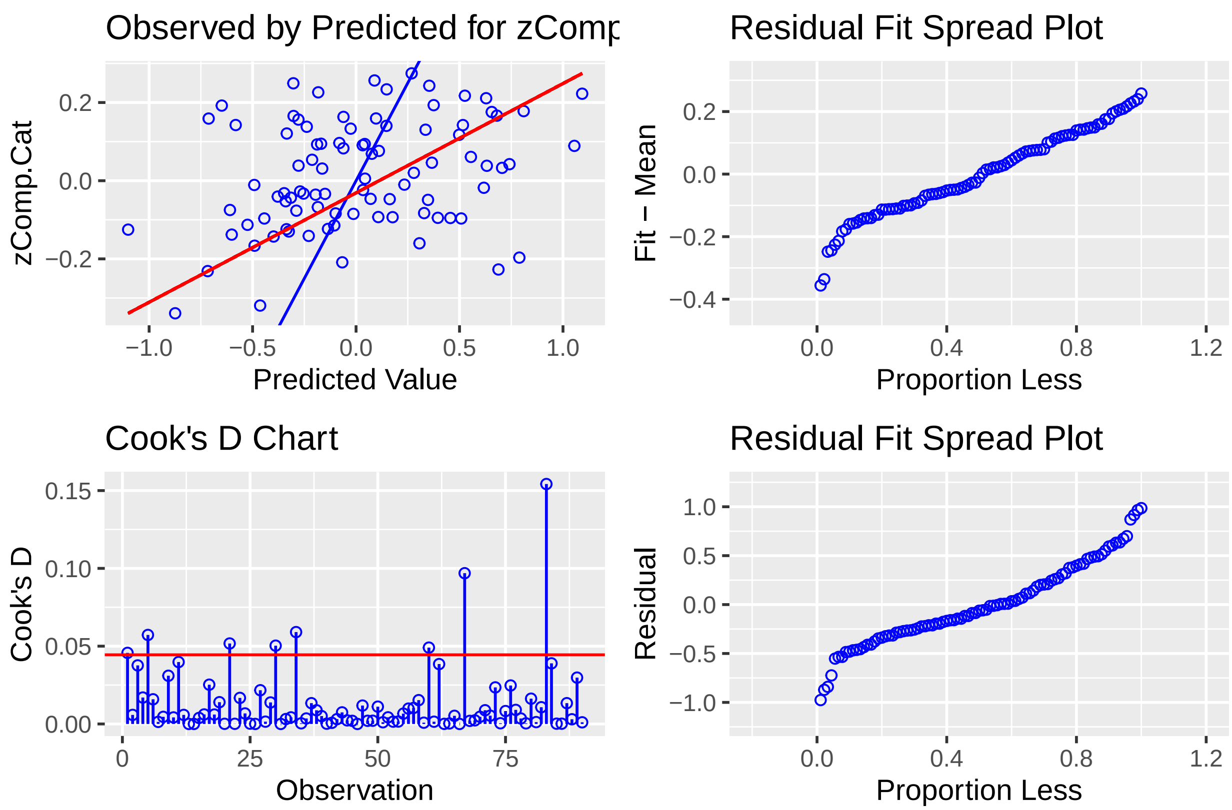
```
ols_vif_tol(lmFull.VFcat.AvFreq)
```

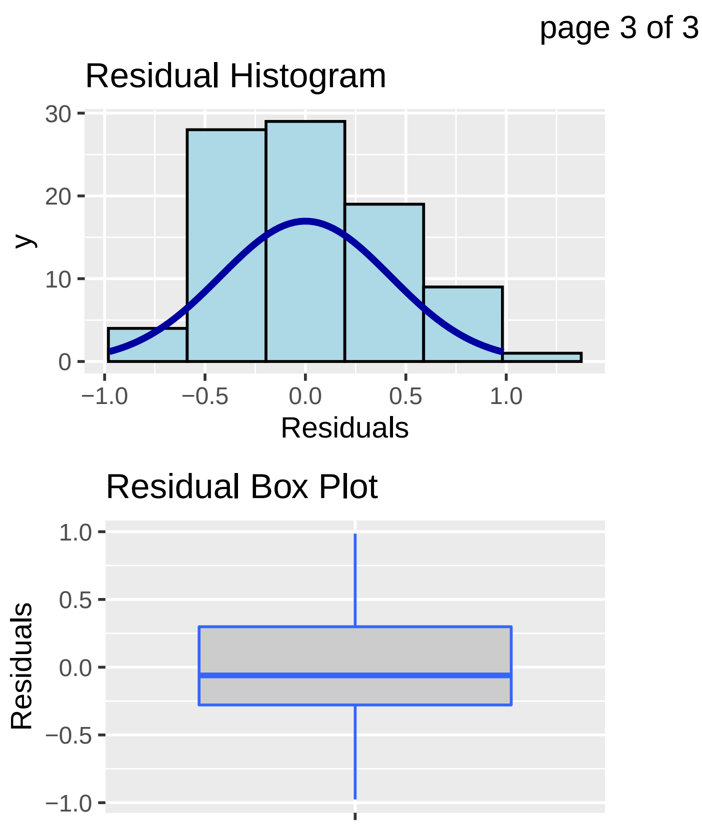
```
##                           Variables Tolerance      VIF
## 1                     Age.Category1 0.8958833 1.116217
## 2                     Age.Category2 0.7518193 1.330107
## 3               CR.composite.before 0.9971961 1.002812
## 4              GenCogProc.composite 0.6869407 1.455730
## 5 Age.Category1:CR.composite.before 0.9935202 1.006522
## 6 Age.Category2:CR.composite.before 0.9999277 1.000072
```

Plot Diagnositcs Full model with z composite score for Semantic Fluency

```
ols_plot_diagnostics(lmFull.VFcat.AvFreq)
```




Observed by Predicted for zComp
zComp.Cat
Predicted Value
Residual Fit Spread Plot
Fit − Mean
Proportion Less
Cook's D Chart
Cook's D
Observation
Residual Fit Spread Plot
Residual
Proportion Less



The Observed vs Predicted Plot shows that the model doesn't fit the data very well (pity) –> due to outliers?? What to do....

Model comparisons for the CR measure preciding and coinciding with the COVID-19 pandemic

The effect of the COVID-19 pandemic on CR and subsequent behavioural performance

```
lmFull.VFcat.AvFreq.during <- lm(zComp.Cat ~ Age.Category*CR.composite.during +
                                   GenCogProc.composite, data =
                                   VFcat_AvFreq_coded)
summary(lmFull.VFcat.AvFreq.during)
```

```
##
## Call:
## lm(formula = zComp.Cat ~ Age.Category * CR.composite.during +
##     GenCogProc.composite, data = VFcat_AvFreq_coded)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.02796 -0.27289 -0.07309  0.28903  0.97745
##
## Coefficients:
##                                     Estimate Std. Error t value Pr(>|t|)
## (Intercept)                          0.01637    0.04683   0.350   0.7275
## Age.Category1                        0.12308    0.06069   2.028   0.0458 *
```

```
## Age.Category2                       -0.05439    0.03833  -1.419   0.1597
## CR.composite.during                 -0.02586    0.04816  -0.537   0.5927
## GenCogProc.composite                -0.09614    0.11021  -0.872   0.3855
## Age.Category1:CR.composite.during -0.03884    0.05939  -0.654   0.5149
## Age.Category2:CR.composite.during -0.02566    0.03421  -0.750   0.4553
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.4442 on 83 degrees of freedom
## Multiple R-squared:  0.07417,    Adjusted R-squared:  0.007237
## F-statistic: 1.108 on 6 and 83 DF,  p-value: 0.3647
```

```
anova(lmFull.VFcat.AvFreq, lmFull.VFcat.AvFreq.during)
```

```
## Analysis of Variance Table
##
## Model 1: zComp.Cat ~ Age.Category * CR.composite.before + GenCogProc.composite
## Model 2: zComp.Cat ~ Age.Category * CR.composite.during + GenCogProc.composite
##   Res.Df    RSS Df Sum of Sq F Pr(>F)
## 1     83 15.969
## 2     83 16.379  0  -0.40961
```

Models are not significantly different from each other.

```
AIC(lmFull.VFcat.AvFreq)
```

```
## [1] 115.7846
```

```
AIC(lmFull.VFcat.AvFreq.during)
```

```
## [1] 118.064
```

Although very similar, the model with the CR composite score pre-pandemic seems to fit the data slightly better. (Lower AIC indicates better fit)

Verbal Fluency - Letters

```
## Create dataset that only includes data of the Subtlex Average Frequency of the produced words
VFlet_AvFreq <- VFlet %>%
  dplyr::filter(Measures=="AvWordFreq_subtlex") %>%
  dplyr::select(-Measures) %>%
    #Recode age groups
  dplyr::mutate(Age.Category=as.factor(dplyr::recode(Age.Category, '18 to 30 years old'="Younger",
                                    '40 to 55 years old'="Middle-Aged",
                                    '65 to 80 years old'="Older")))

range(VFlet_AvFreq$zComp.Let) #No outliers
```

```
## [1] -1.783088  1.961524
```

```r
# head(VFlet_AvFreq, L=6)
```

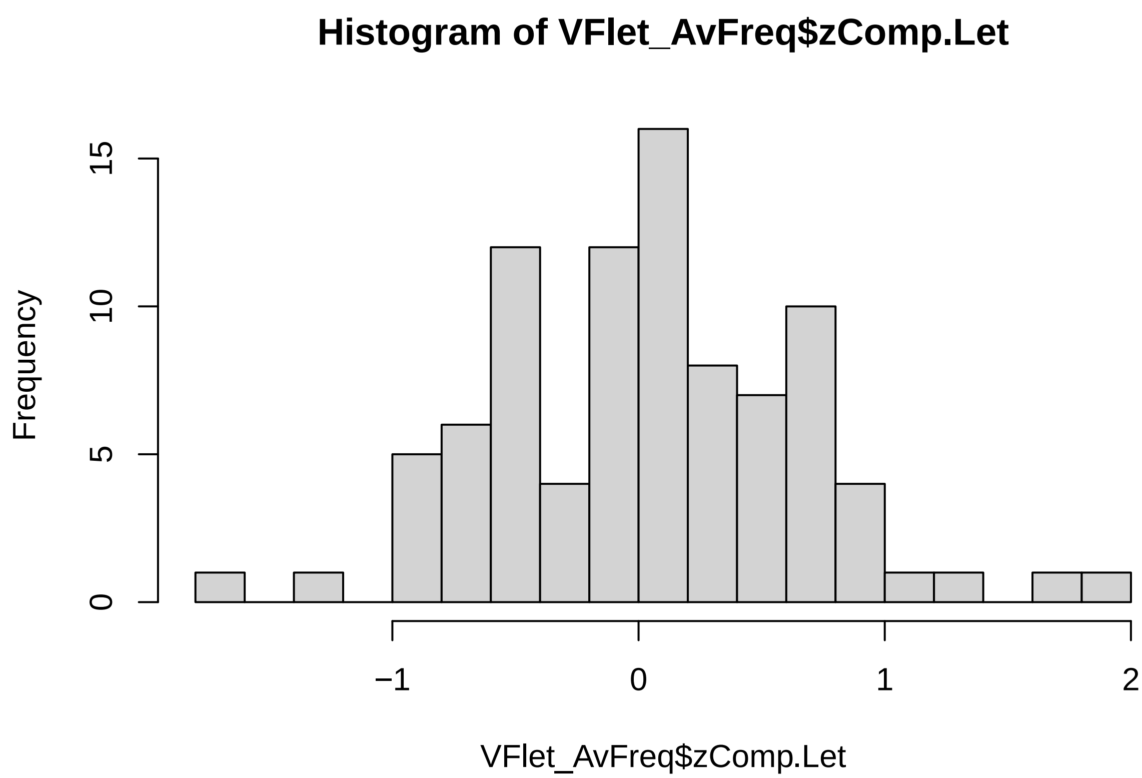
Descriptives

```r
(Descr_VFlet <- VFlet_AvFreq %>%
  #Per Age Group
  group_by(Age.Category) %>%
  summarise(Nppt = length(unique(ID)), #Number of participants
            total = mean(Total, na.rm=T), #Total words correctly produced
            sdtotal = sd(Total, na.rm=T),#Total words correctly produced
            ztotal = mean(zComp.Let, na.rm=T), #Z-score per age group of total words correctly produced
            letterM = mean(M, na.rm=T), #Total words correctly produced for the letter M
            letterS = mean(S, na.rm=T), #Total words correctly produced for the letter S
            letterP = mean(P, na.rm=T))) #Total words correctly produced for the letter P
```

```
## # A tibble: 3 x 8
##   Age.Category  Nppt total sdtotal  ztotal letterM letterS letterP
##   <fct>        <int> <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
## 1 Middle-Aged     30  4.08   0.255 -0.0355    4.07    4.13    4.03
## 2 Older           30  4.92   2.64  -0.0746    4.06    4.21    3.96
## 3 Younger         30  4.22   0.239  0.264     4.25    4.24    4.17
```

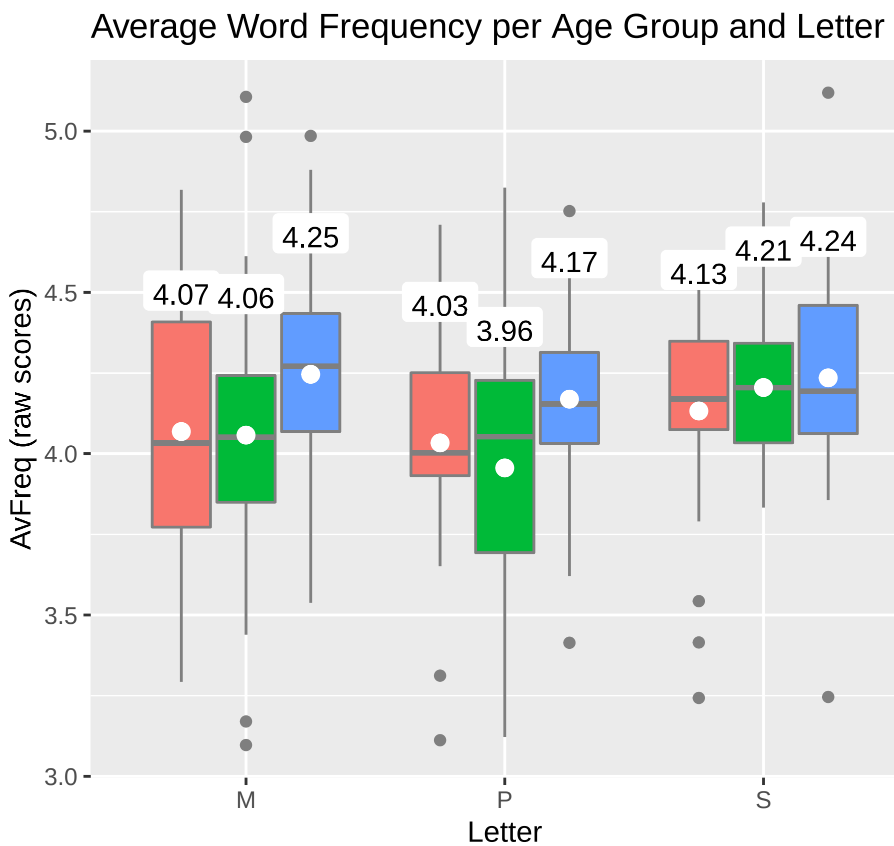
```r
# write.csv(Descr_VFlet, "./Figures and Tables/Descr_VFlet_AvFreq.csv", row.names = F)
```

```r
#Visualise z-distribution of the composite score for letter fluency Average word frequency
hist(VFlet_AvFreq$zComp.Let, breaks=20) #Composite z-score of Letter Fluency
```




```
#Convert to long format for visualisation
VFlet_AvFreq.long <- VFlet_AvFreq %>%
  pivot_longer(cols=Total:S, names_to = "letter", values_to = "AvFreq")

# Boxplot VFlet AvFreq

# png(file="./Figures and Tables/Boxplot_VFletAvFreq.png",
# width=600, height=350)

(Boxplot_VF <- VFlet_AvFreq.long %>%
    dplyr::filter(letter!="Total") %>%
    ggplot(aes(x=letter, y=AvFreq,
                                                fill = as.factor(Age.Category))) +
    geom_boxplot(colour="grey50")+
    stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=4,
               fill="white", show.legend=NA, label.size=NA,
               position = position_dodge(.75), vjust=-3) +
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Letter",
         y = "AvFreq (raw scores)",
         title = "Average Word Frequency per Age Group and Letter")+
```

```
    scale_fill_discrete(guide=guide_legend(title = "Age Group"), labels=c("18 to 30 years old","40 t
```

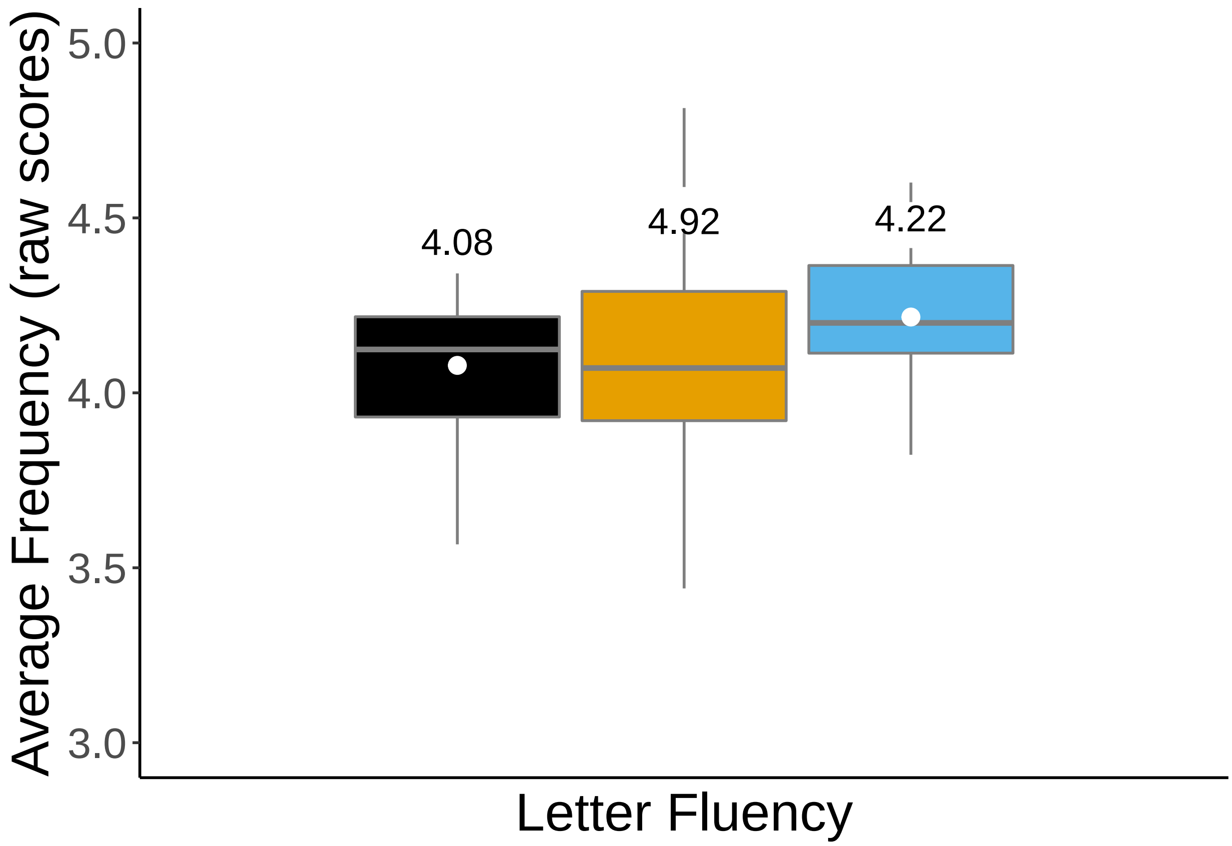


Visualisation AvFreq Semantic Fluency

```
# dev.off()
```

```
# Boxplot VFlet AvFreq raw total
# png(file="./Figures and Tables/Boxplot_VFletAvFreq_RawTotal.png",
# width=600, height=350)

(Boxplot_VF <- VFlet_AvFreq.long %>%
    dplyr::filter(letter=="Total") %>%
    ggplot(aes(x=letter, y=AvFreq,fill = as.factor(Age.Category)), show.legend=FALSE) +
    geom_boxplot(outlier.shape = NA, colour="grey50", show.legend=FALSE)+
    stat_summary(aes(label=round(..y.., 2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=5,
               fill="white", show.legend=NA, label.size=NA,
               position = position_dodge(.75), vjust=c(-2,3.5,-1.5)) +
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Letter Fluency",
         y = "Average Frequency (raw scores)")+
        scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
       theme(text = element_text(size = 20),
            axis.ticks.x = element_blank(),
            axis.text.x = element_blank(),
         panel.background  = element_rect(fill="white"),
```

```
          plot.background = element_rect(fill = "white"),
          strip.background = element_rect(fill="white"),
          axis.line.x = element_line(color="black"),
        axis.line.y = element_line(color="black")) +
  coord_cartesian(ylim = c(3,5))+
     scale_y_continuous(minor_breaks = seq(3,5,1),
                        breaks = seq(3,5, 0.5)))
```

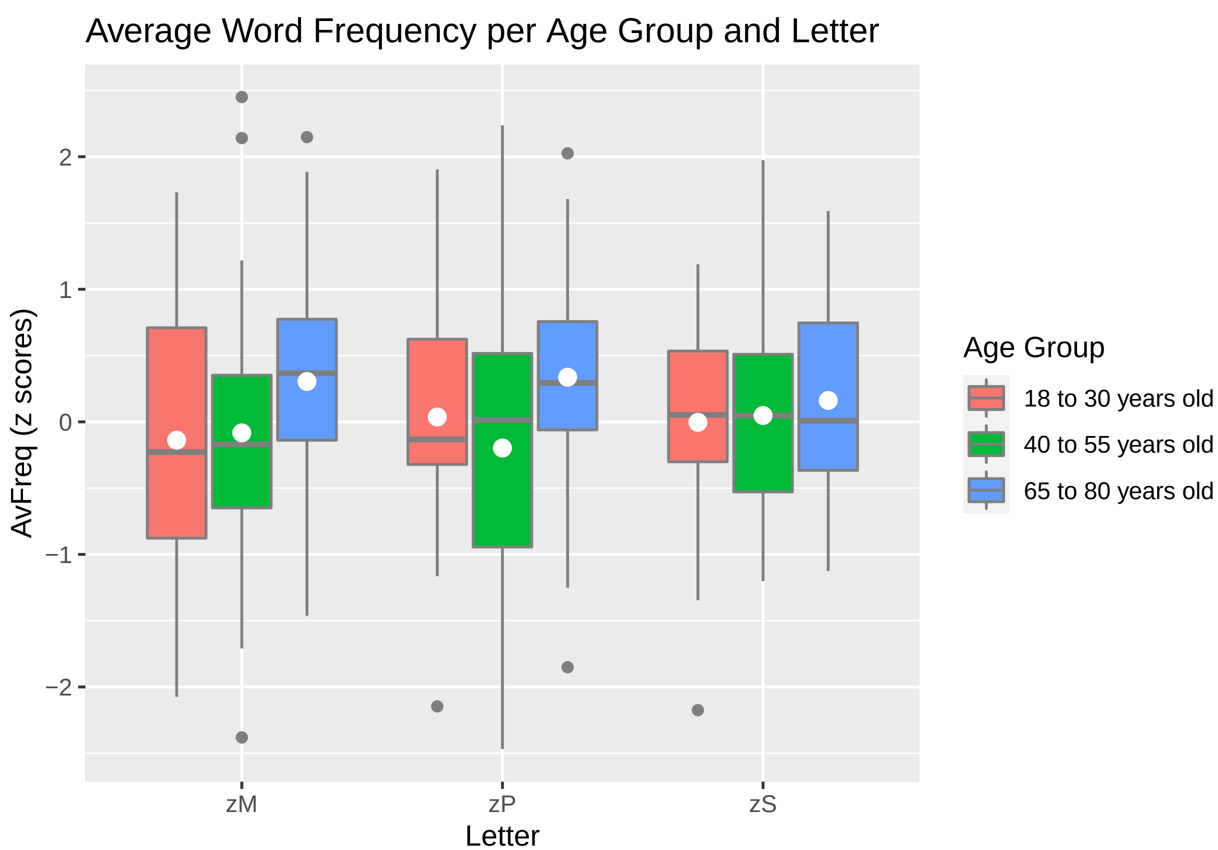



```
# dev.off()
```

Figures AvFreq Letter Fluency zscores

```
#Convert to long format for visualisation
VFlet_AvFreq.long.zscores <- VFlet_AvFreq %>%
  pivot_longer(cols=zComp.Let:zP, names_to = "zletter", values_to = "zAvFreq")

# Boxplot VFlet AvFreq
# png(file="./Figures and Tables/Boxplot_VFletAvFreq_zscores.png",
# width=600, height=350)

(Boxplot_VFlet.zscores <- VFlet_AvFreq.long.zscores %>%
    dplyr::filter(zletter!="zComp.Let") %>%
    ggplot(aes(x=zletter, y=zAvFreq,
                                              fill = as.factor(Age.Category))) +
    geom_boxplot(colour="grey50")+
```

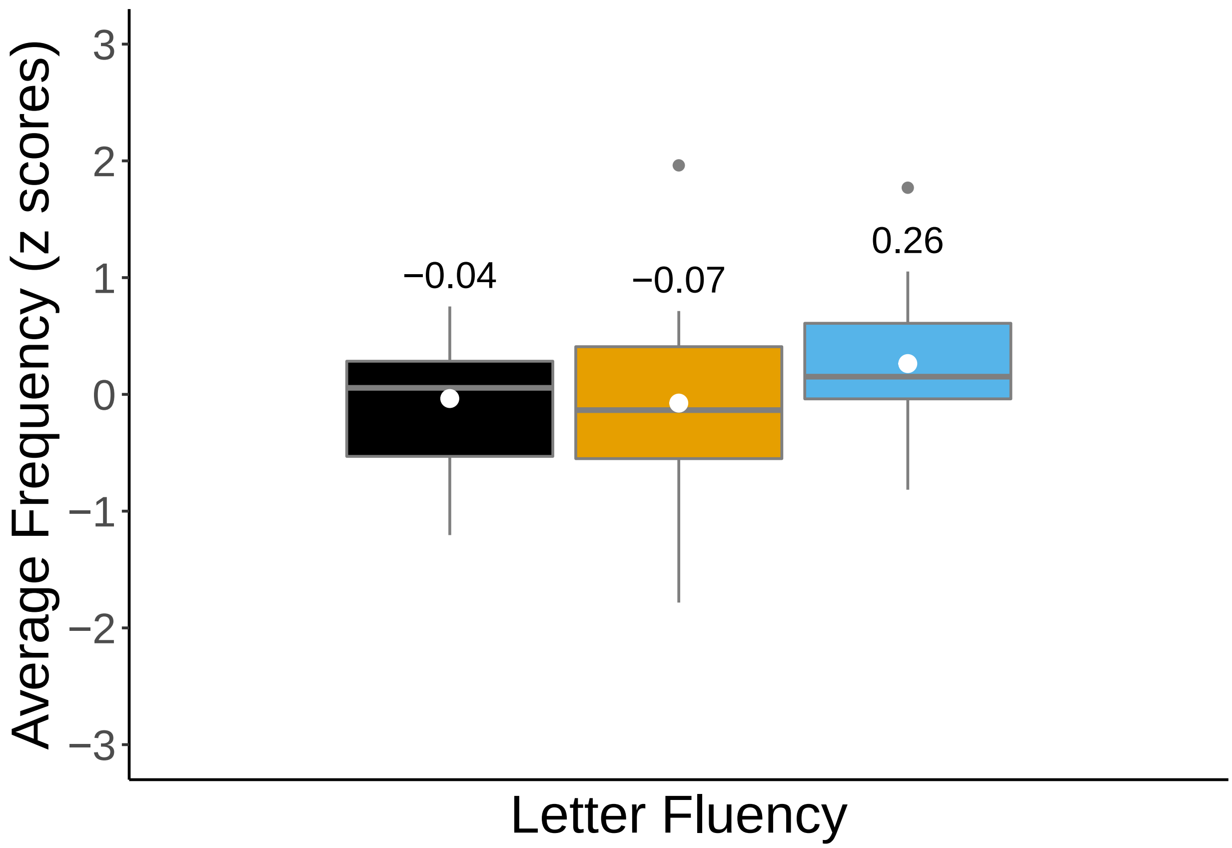
```
    # stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
    #             fun=mean, geom = "label", size=4,
    #             fill="white", show.legend=NA, label.size=NA,
    #             position = position_dodge(.75), vjust=-3) +
      stat_summary(fun = "mean", position = position_dodge(.75),
                show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Letter",
         y = "AvFreq (z scores)",
         title = "Average Word Frequency per Age Group and Letter")+
        scale_fill_discrete(guide=guide_legend(title = "Age Group"), labels=c("18 to 30 years old","40 t
```




```
# dev.off()
```

```
# Boxplot VFlet AvFreq raw total
# png(file="./Figures and Tables/Boxplot_VFletAvFreq_Total_zscores.png",
# width=600, height=350)

(Boxplot_VFlet.zscoreTotal <- VFlet_AvFreq.long.zscores %>%
    dplyr::filter(zletter=="zComp.Let") %>%
    ggplot(aes(x=zletter, y=zAvFreq,fill = as.factor(Age.Category)),show.legend=FALSE) +
    geom_boxplot(colour="grey50",show.legend=FALSE)+
       stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=5,
               fill="white", show.legend=FALSE, label.size=NA,
               position = position_dodge(.75), vjust=-2) +
```

```r
    stat_summary(fun = "mean", position = position_dodge(.75),
             show.legend=F, colour="white")+ #Mean as white dot
  labs(x = "Letter Fluency",
       y = "Average Frequency (z scores)")+
      scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
     theme(text = element_text(size = 20),
           axis.ticks.x = element_blank(),
           axis.text.x = element_blank(),
        panel.background  = element_rect(fill="white"),
        plot.background = element_rect(fill = "white"),
        strip.background = element_rect(fill="white"),
        axis.line.x = element_line(color="black"),
       axis.line.y = element_line(color="black")) +
coord_cartesian(ylim = c(-3,3))+
   scale_y_continuous(minor_breaks = seq(-3,3,0.5),
                     breaks = seq(-3,3,1)))
```




```r
# dev.off()
```

Multiple Linear Regression - Letter Fluency

Create user-defined contrasts for the Age Category variable

```r
VFlet_AvFreq <- mutate(VFlet_AvFreq,
                     Age.Category =
                       factor(Age.Category, levels = c("Middle-Aged", "Younger", "Older")))

VFlet_AvFreq_coded <- VFlet_AvFreq
contrasts(VFlet_AvFreq_coded$Age.Category) <- contr.helmert(3)
contrasts(VFlet_AvFreq_coded$Age.Category)
```

```
##             [,1] [,2]
## Middle-Aged   -1   -1
## Younger        1   -1
## Older          0    2
```

Unconditional model, i.e. without covariates

```r
lmUncond.VFlet.AvFreq <- lm(zComp.Let ~ Age.Category*CR.composite.before, data = VFlet_AvFreq_coded)
# broom::tidy(lmUncond.VFlet.AvFreq, conf.int=T)
```

Full model of AvFreq in z-distribution, including covariates

```r
lmFull.VFlet.AvFreq <- lm(zComp.Let ~ Age.Category*CR.composite.before + GenCogProc.composite, data = VF
summary(lmFull.VFlet.AvFreq)
```

```
##
## Call:
## lm(formula = zComp.Let ~ Age.Category * CR.composite.before +
##     GenCogProc.composite, data = VFlet_AvFreq_coded)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.66527 -0.41451 -0.01097  0.35743  1.82439
##
## Coefficients:
##                                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)                        0.051243   0.066275   0.773   0.4416
## Age.Category1                      0.148597   0.085754   1.733   0.0868 .
## Age.Category2                     -0.061866   0.054046  -1.145   0.2556
## CR.composite.before               -0.009201   0.067500  -0.136   0.8919
## GenCogProc.composite               0.005995   0.153738   0.039   0.9690
## Age.Category1:CR.composite.before  0.052311   0.082823   0.632   0.5294
## Age.Category2:CR.composite.before -0.064943   0.047665  -1.363   0.1767
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.6287 on 83 degrees of freedom
## Multiple R-squared:  0.08272,    Adjusted R-squared:  0.01641
## F-statistic: 1.247 on 6 and 83 DF,  p-value: 0.2908
```

```r
#Tidy table output
(tidylmFull.VFlet.AvFreq <- broom::tidy(lmFull.VFlet.AvFreq, conf.int=T)%>%
  mutate_if(is.numeric, round, 3))
```

```
## # A tibble: 7 x 7
##   term                    estimate std.error statistic p.value conf.low conf.high
##   <chr>                      <dbl>     <dbl>     <dbl>   <dbl>    <dbl>     <dbl>
## 1 (Intercept)                0.051     0.066     0.773   0.442   -0.081     0.183
## 2 Age.Category1              0.149     0.086     1.73    0.087   -0.022     0.319
## 3 Age.Category2             -0.062     0.054    -1.14    0.256   -0.169     0.046
## 4 CR.composite.before       -0.009     0.068    -0.136   0.892   -0.143     0.125
## 5 GenCogProc.composite       0.006     0.154     0.039   0.969   -0.3       0.312
## 6 Age.Category1:CR.comp~     0.052     0.083     0.632   0.529   -0.112     0.217
## 7 Age.Category2:CR.comp~    -0.065     0.048    -1.36    0.177   -0.16      0.03
```

```
# write.csv(tidylmFull.VFlet.AvFreq, "./Figures and Tables/VFlet_zAvFreq_lmFull.csv")
```

Full model of AvFreq as raw score, including covariates

```
lmFull.VFlet.AvFreq.raw <- lm(Total ~ Age.Category*CR.composite.before + GenCogProc.composite, data = VF
summary(lmFull.VFlet.AvFreq.raw)
```

```
##
## Call:
## lm(formula = Total ~ Age.Category * CR.composite.before + GenCogProc.composite,
##     data = VFlet_AvFreq_coded)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7988 -0.6158 -0.1065  0.1666  8.2945
##
## Coefficients:
##                                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)                         4.40304    0.16478  26.721   <2e-16 ***
## Age.Category1                       0.11671    0.21321   0.547    0.586
## Age.Category2                       0.21010    0.13437   1.564    0.122
## CR.composite.before                -0.07834    0.16782  -0.467    0.642
## GenCogProc.composite               -0.26441    0.38223  -0.692    0.491
## Age.Category1:CR.composite.before   0.02017    0.20592   0.098    0.922
## Age.Category2:CR.composite.before  -0.09345    0.11851  -0.789    0.433
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.563 on 83 degrees of freedom
## Multiple R-squared:  0.07011,    Adjusted R-squared:  0.002884
## F-statistic: 1.043 on 6 and 83 DF,  p-value: 0.4038
```

```
#Tidy table output
broom::tidy(lmFull.VFlet.AvFreq.raw, conf.int=T)%>%
  mutate_if(is.numeric, round, 3)
```

```
## # A tibble: 7 x 7
##   term                    estimate std.error statistic p.value conf.low conf.high
##   <chr>                      <dbl>     <dbl>     <dbl>   <dbl>    <dbl>     <dbl>
## 1 (Intercept)                4.40      0.165    26.7     0         4.08      4.73
## 2 Age.Category1              0.117     0.213     0.547   0.586   -0.307     0.541
```

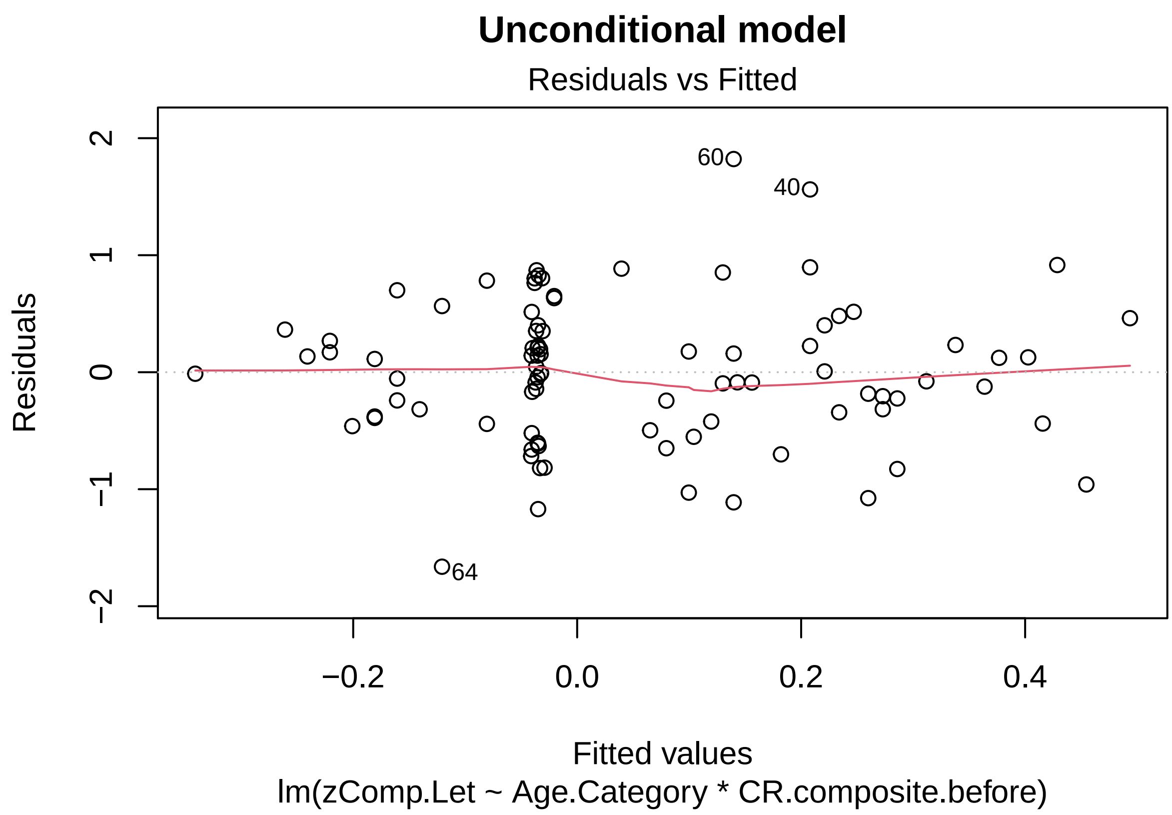
```
## 3 Age.Category2            0.21     0.134    1.56    0.122   -0.057    0.477
## 4 CR.composite.before     -0.078    0.168   -0.467   0.642   -0.412    0.255
## 5 GenCogProc.composite    -0.264    0.382   -0.692   0.491   -1.02     0.496
## 6 Age.Category1:CR.comp~   0.02     0.206    0.098   0.922   -0.389    0.43
## 7 Age.Category2:CR.comp~  -0.093    0.119   -0.789   0.433   -0.329    0.142
```

The model doesn't seem to predict the raw Total score for Verbal Fluency Letter. However, in the Full model with the z-composite score, older adults seem to produce significantly higher frequent words than younger adults.

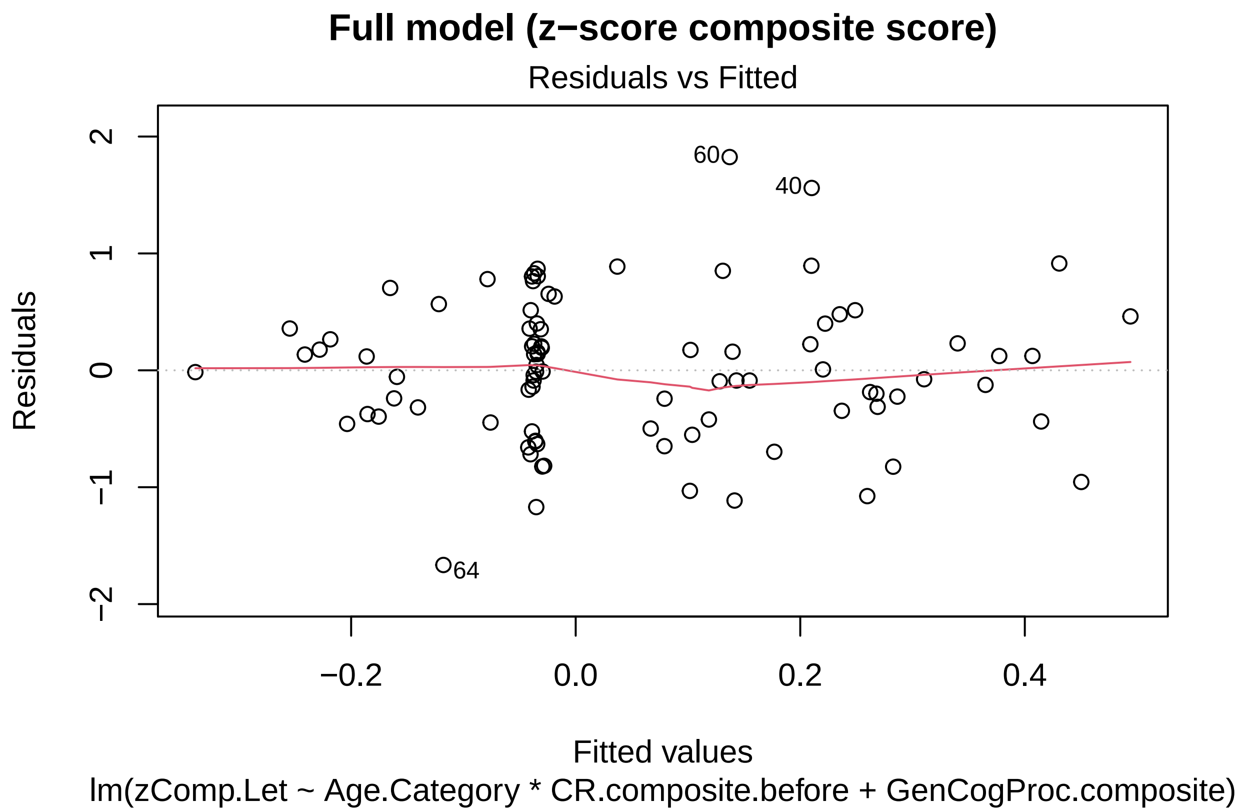
Let's check the model assumptions + fit.

Assumption 1 - Linearity

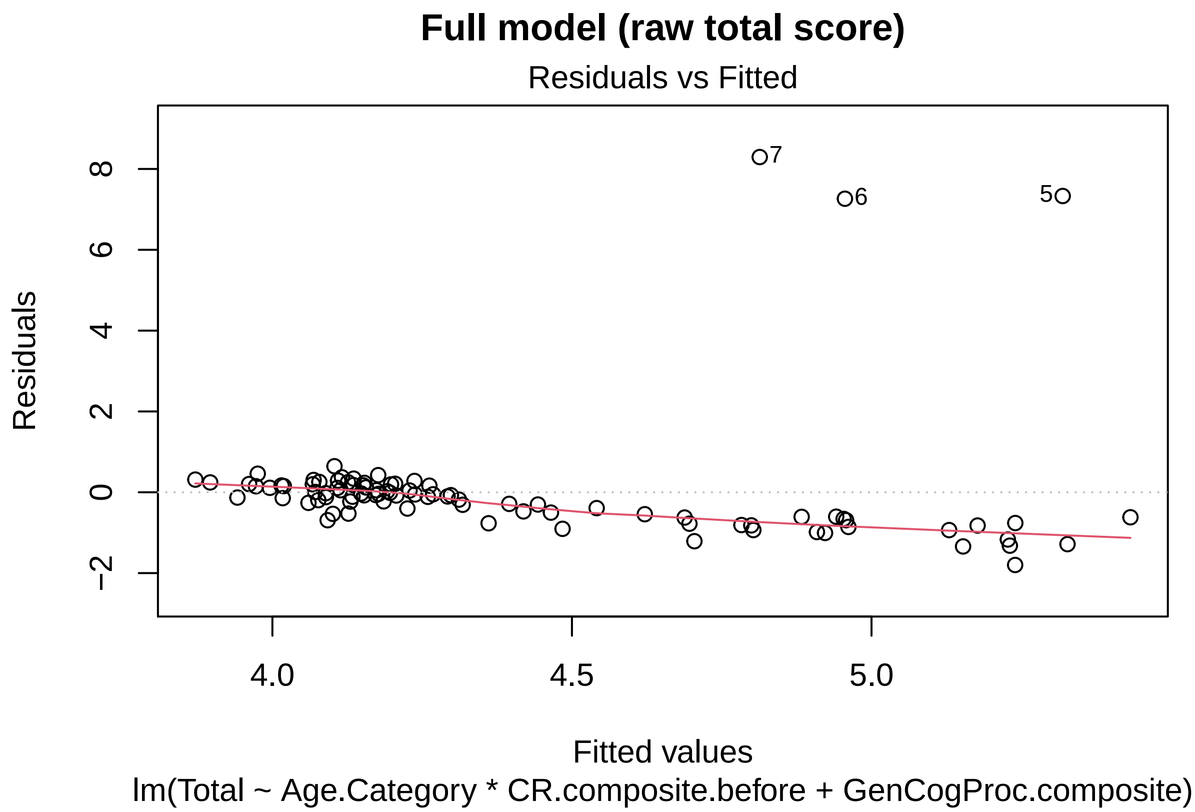
```
## Unconditional model with z composite score
plot(lmUncond.VFlet.AvFreq, 1, main = "Unconditional model")
```




```
## Full model with z composite score
plot(lmFull.VFlet.AvFreq, 1, main = "Full model (z-score composite score)")
```




```r
## Full model with raw total score
plot(lmFull.VFlet.AvFreq.raw, 1, main = "Full model (raw total score)")
```



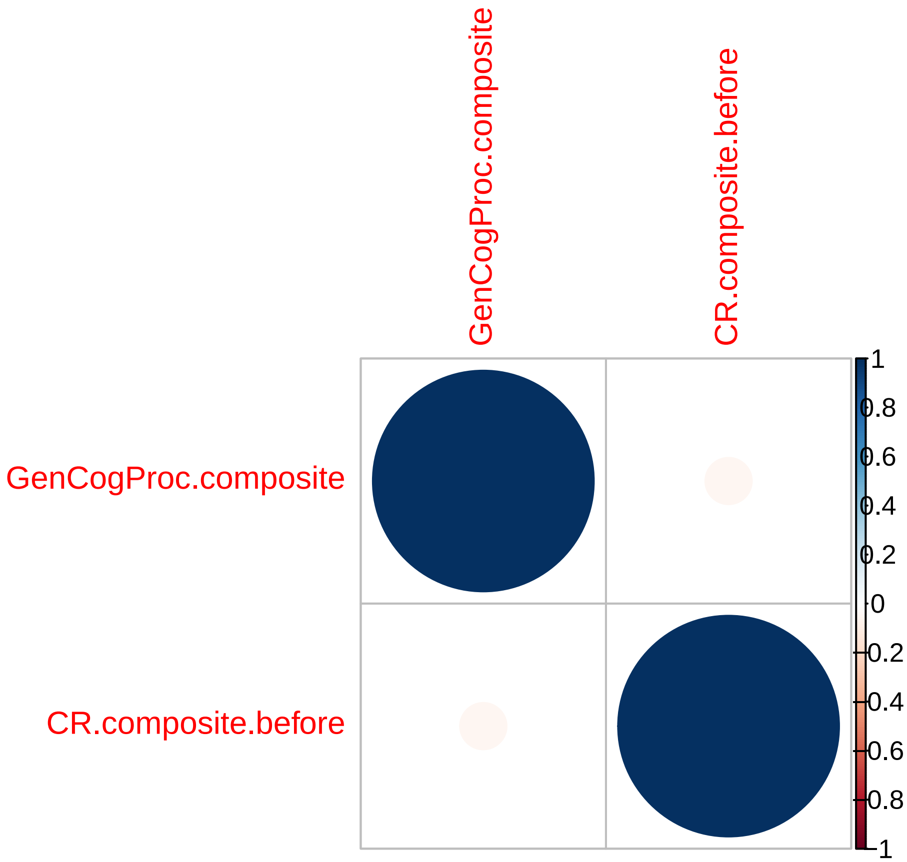
For the models with the z-composite score as outcome variable, the red line is mostly horizontal, meaning that there is a linear relationship between the fitted line and the residual value. The model with the raw average frequency scores seems to violate the assumption.

Assumption 2 - Independence of Variables

```
## z composite of VF let
## Create table with correlation values between predictor variables
tibble::as_tibble(cor(VFlet_AvFreq_coded[,c(13,14)]), rownames="rowname")
```

```
## # A tibble: 2 x 3
##   rowname              GenCogProc.composite CR.composite.before
##   <chr>                               <dbl>               <dbl>
## 1 GenCogProc.composite               1                  -0.0439
## 2 CR.composite.before               -0.0439              1
```

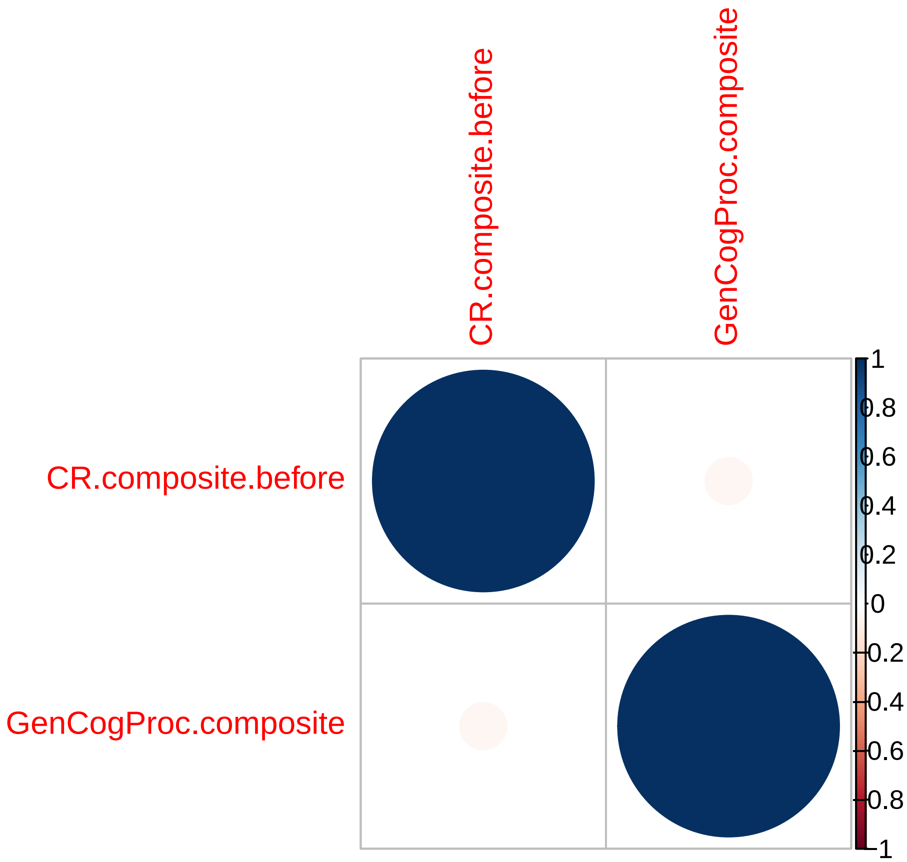
```
## Create correlation plot between predictor variables
corrplot(cor(VFlet_AvFreq_coded[,c(13,14)]),method='circle')
```




```
## Raw scores
## Create table with correlation values between predictor variables
tibble::as_tibble(cor(VFlet_AvFreq_coded[,c(14,13)]), rownames = "rowname")
```

```
## # A tibble: 2 x 3
##   rowname              CR.composite.before GenCogProc.composite
##   <chr>                              <dbl>                <dbl>
## 1 CR.composite.before               1                   -0.0439
## 2 GenCogProc.composite             -0.0439               1
```

```
## Create correlation plot between predictor variables
corrplot(cor(VFlet_AvFreq_coded[,c(14,13)]))
```

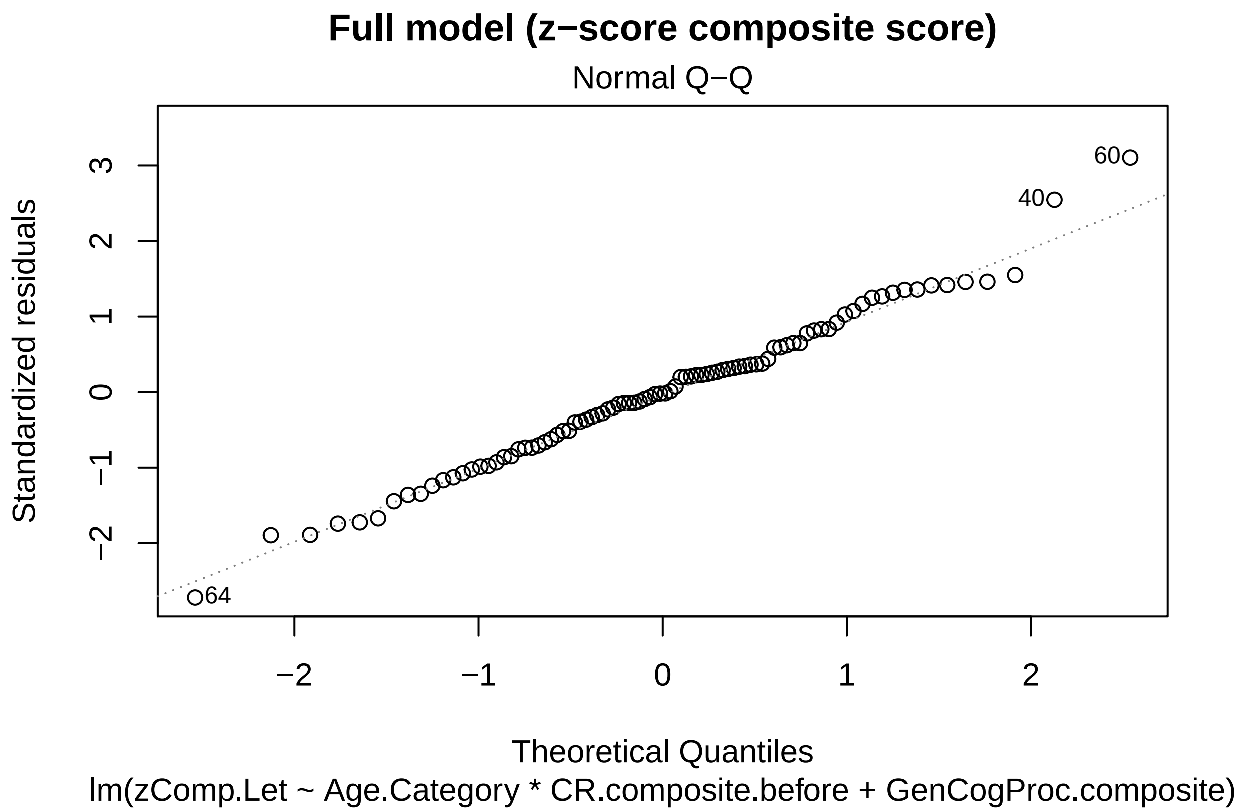


There seems to be no strong relationship between the predictor variables. Hence, we can assume Independence of Variables.

Assumption 3 - Normal Distribution of Residuals

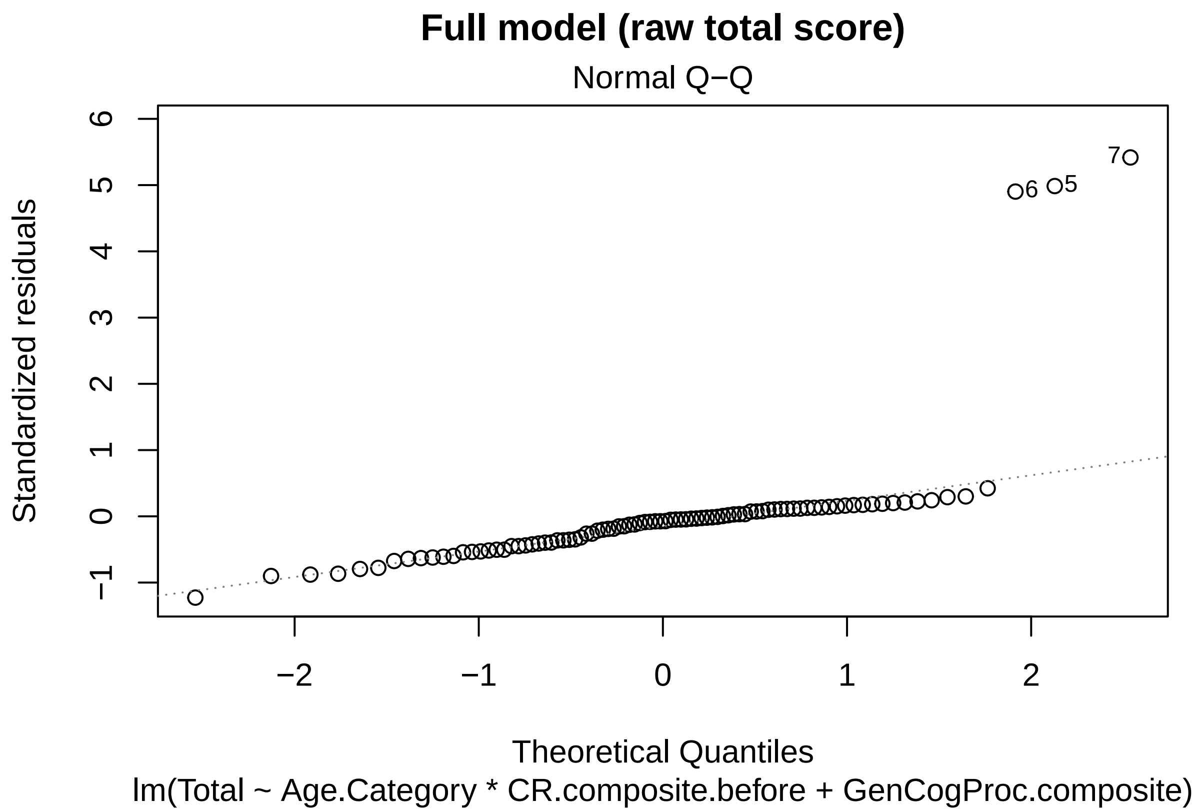
Full model with z composite score

```
plot(lmFull.VFlet.AvFreq, 2, main = "Full model (z-score composite score)")
```



Full model with raw total score

```
plot(lmFull.VFlet.AvFreq.raw, 2, main = "Full model (raw total score)")
```

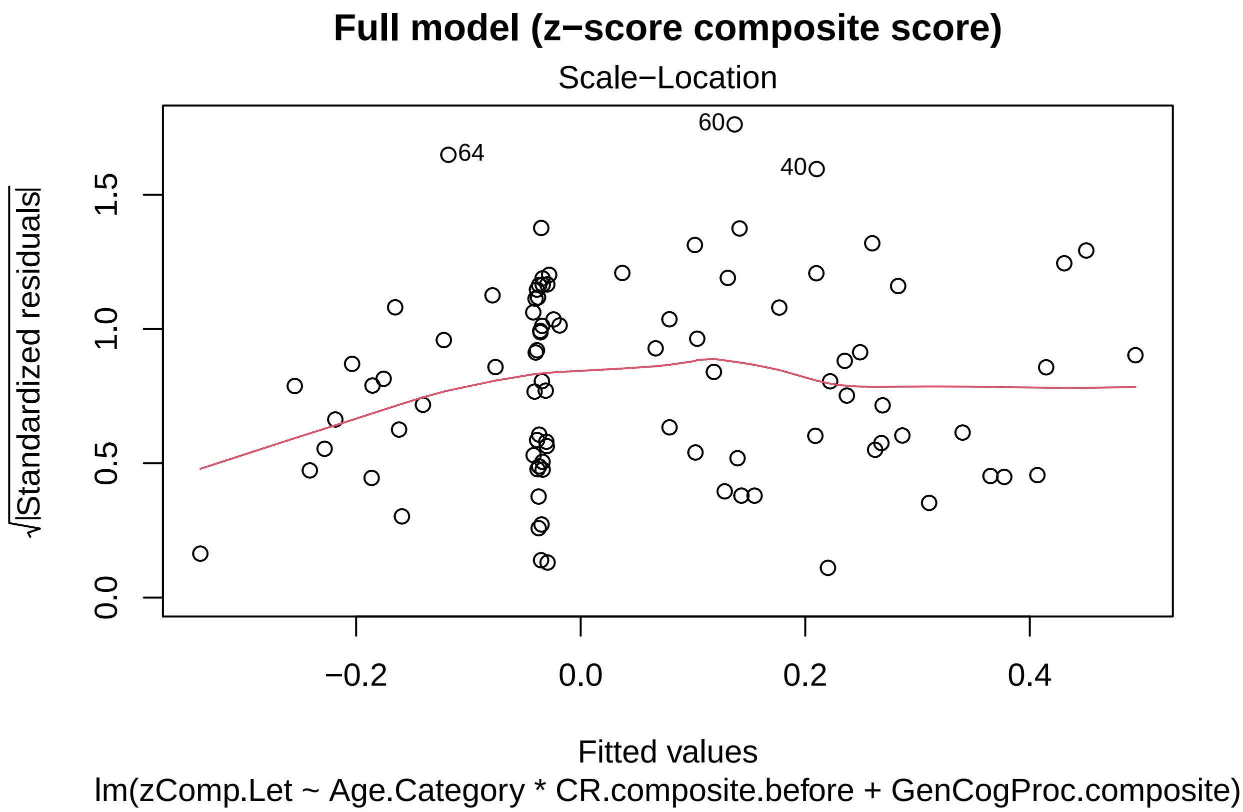


For the unconditional and full model with the z-score as outcome variable, the points seem to roughly follow a straight line, except for two outliers on right. So, these two models seem to roughly meet the assumption. The full model with the raw score as outcome variable, there are three massive outliers on the right. Hence, other relationships/predictors that have not been included into the models could explain the variance.

Assumption 4 - Homoscedasticity or Equal Variance of Variables

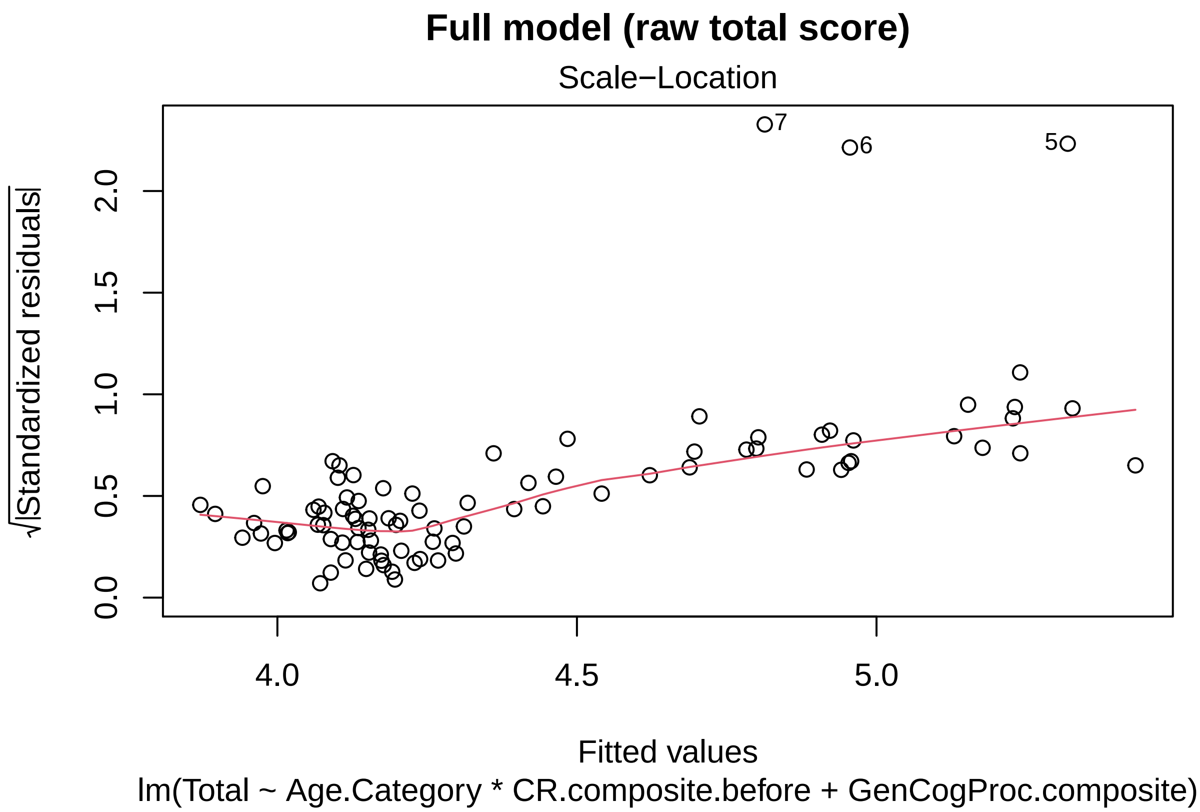
Full model with z composite score

```
plot(lmFull.VFlet.AvFreq, 3, main = "Full model (z-score composite score)")
```



Full model with raw total score

```
plot(lmFull.VFlet.AvFreq.raw, 3, main = "Full model (raw total score)")
```



The full model with the raw score seem to violates the assumption of Homoscedasticity So, the variance of residuals does not seem equal across the predictors. The full model with the z-scores does seem to meet the assumption of Homoscedasticity. Hence, the error terms are relatively the same across all values of the independent variable for this model.

Conclusion: only the full model with the outcome variable along the z-distribution seems to meet all the assumptions.

Model fit diagnostics *Variation Inflation Factor*

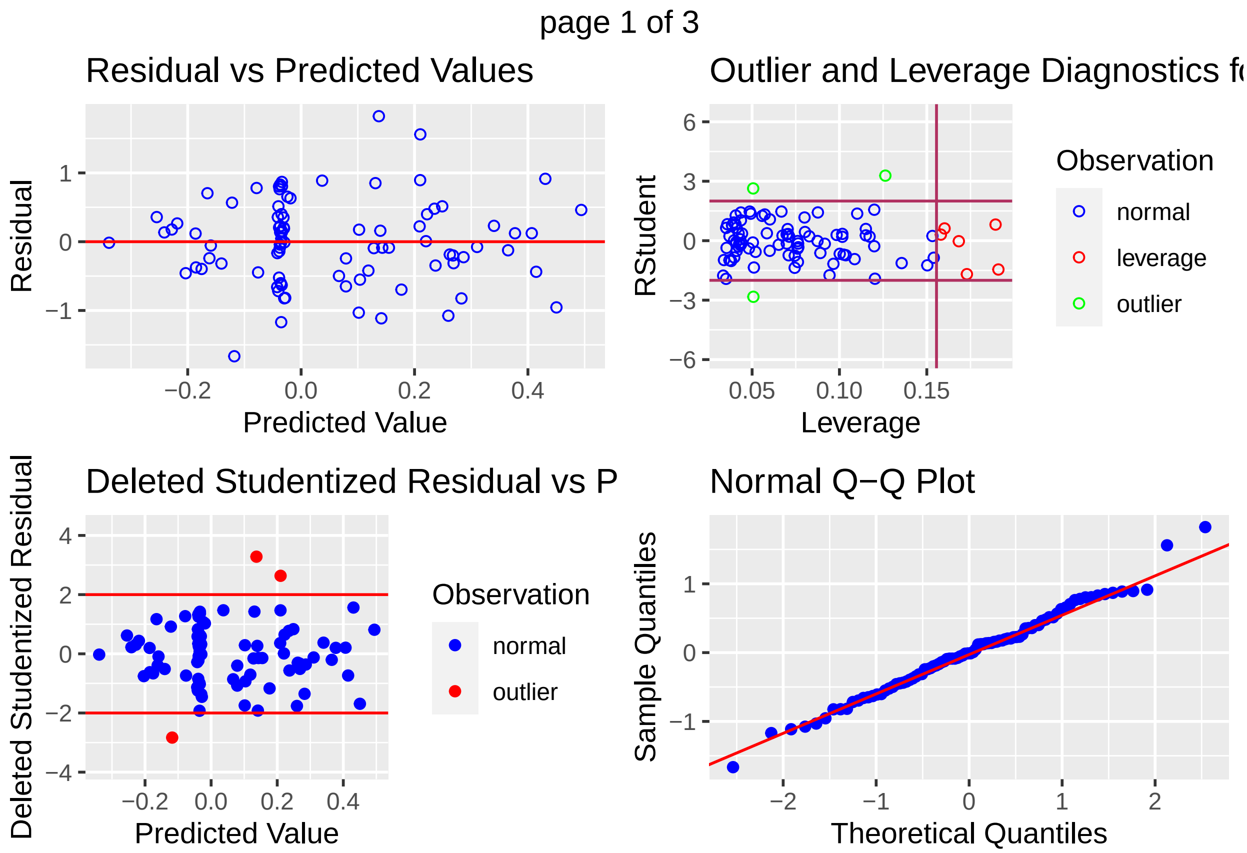
Any VIF value above 4 needs further investigation. There seems to be no concerning signs of collinearity (VIF values higher than 4). The tolerance values indicate the percentage of variance that cannot be explained for by the other predictor variables.

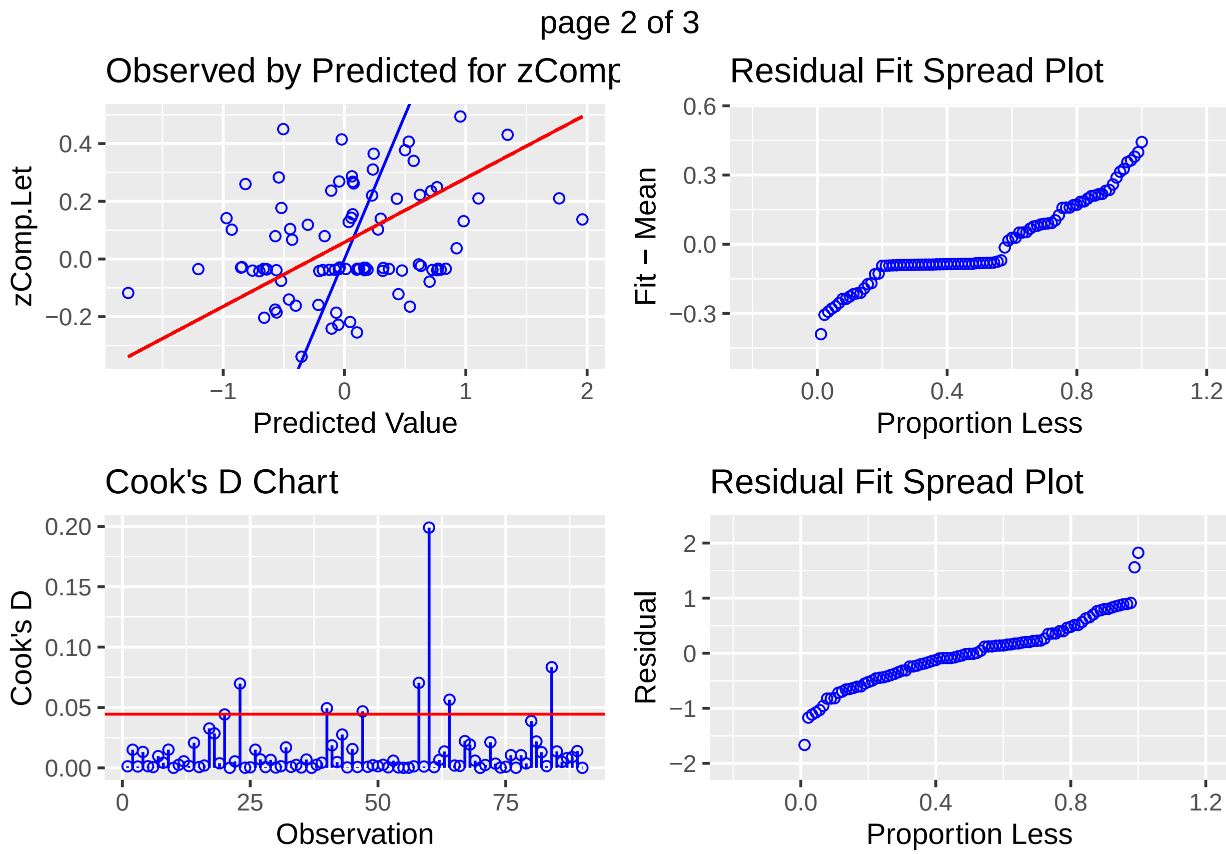
```
ols_vif_tol(lmFull.VFlet.AvFreq)
```

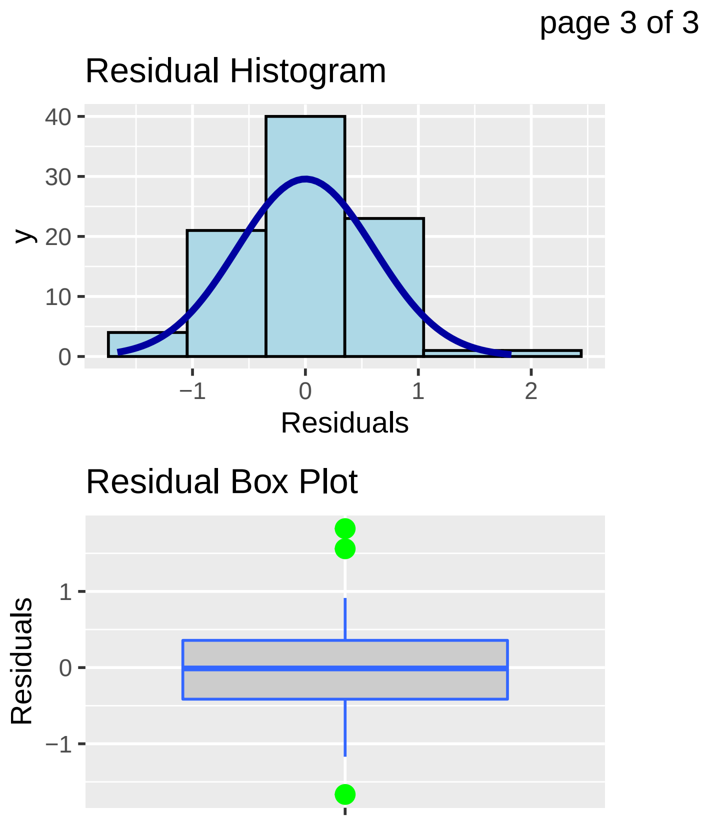
```
##                             Variables Tolerance      VIF
## 1                       Age.Category1 0.8958833 1.116217
## 2                       Age.Category2 0.7518193 1.330107
## 3                 CR.composite.before 0.9971961 1.002812
## 4                GenCogProc.composite 0.6869407 1.455730
## 5 Age.Category1:CR.composite.before 0.9935202 1.006522
## 6 Age.Category2:CR.composite.before 0.9999277 1.000072
```

Plot Diagnositcs Full model with z composite score for Semantic Fluency

```
ols_plot_diagnostics(lmFull.VFlet.AvFreq)
```




page 2 of 3
Observed by Predicted for zComp
zComp.Let
Predicted Value
Residual Fit Spread Plot
Fit − Mean
Proportion Less
Cook's D Chart
Cook's D
Observation
Residual Fit Spread Plot
Residual
Proportion Less



The Observed vs Predicted Plot shows that the model doesn't fit the data very well (pity) –> due to outliers?? What to do.... –> perhaps identify outliers using the Cook chart and residual plot and rerun the models?

Model comparisons for the CR measure preciding and coinciding with the COVID-19 pandemic

The effect of the COVID-19 pandemic on CR and subsequent behavioural performance

```
lmFull.VFlet.AvFreq.during <- lm(zComp.Let ~ Age.Category*CR.composite.during +
                                   GenCogProc.composite, data =
                                   VFlet_AvFreq_coded)
summary(lmFull.VFlet.AvFreq.during)
```

```
##
## Call:
## lm(formula = zComp.Let ~ Age.Category * CR.composite.during +
##     GenCogProc.composite, data = VFlet_AvFreq_coded)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -1.7031 -0.4011 -0.0280  0.3257  1.7996
##
## Coefficients:
##                                       Estimate Std. Error t value Pr(>|t|)
## (Intercept)                           0.051328   0.066556   0.771   0.4428
```

```
## Age.Category1                       0.153172   0.086266   1.776   0.0795 .
## Age.Category2                      -0.066149   0.054480  -1.214   0.2281
## CR.composite.during                -0.007990   0.068445  -0.117   0.9073
## GenCogProc.composite               -0.017966   0.156640  -0.115   0.9090
## Age.Category1:CR.composite.during   0.006183   0.084410   0.073   0.9418
## Age.Category2:CR.composite.during -0.060386   0.048618  -1.242   0.2177
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.6314 on 83 degrees of freedom
## Multiple R-squared:  0.07495,    Adjusted R-squared:  0.008077
## F-statistic: 1.121 on 6 and 83 DF,  p-value: 0.3575
```

```r
# Model comparison
anova(lmFull.VFlet.AvFreq, lmFull.VFlet.AvFreq.during)
```

```
## Analysis of Variance Table
##
## Model 1: zComp.Let ~ Age.Category * CR.composite.before + GenCogProc.composite
## Model 2: zComp.Let ~ Age.Category * CR.composite.during + GenCogProc.composite
##   Res.Df    RSS Df Sum of Sq F Pr(>F)
## 1     83 32.809
## 2     83 33.087  0  -0.27801
```

Models are not significantly different from each other.

```r
# Mode comparison with AIC
AIC(lmFull.VFlet.AvFreq)
```

```
## [1] 180.5884
```

```r
AIC(lmFull.VFlet.AvFreq.during)
```

```
## [1] 181.3478
```

Although very similar, the model with the CR composite score pre-pandemic seems to fit the data slightly better.

Verbal Fluency - Actions

Descriptive Statistics

```r
## Create dataset that only includes data of the Subtlex Average Frequency of the produced words
VFact_AvFreq <- VFact %>%
  dplyr::filter(Measures=="AvWordFreq_subtlex") %>%
  #Remove column called Measures (which now only contains "AvWordFreq_subtlex")
  dplyr::select(-Measures) %>%  #Recode age groups
  dplyr::mutate(Age.Category=as.factor(dplyr::recode(Age.Category, '18 to 30 years old'="Younger",
                                    '40 to 55 years old'="Middle-Aged",
                                    '65 to 80 years old'="Older")))

range(VFact_AvFreq$zComp.Act) #No outliers
```

```
## [1] -1.726795  1.329460
```

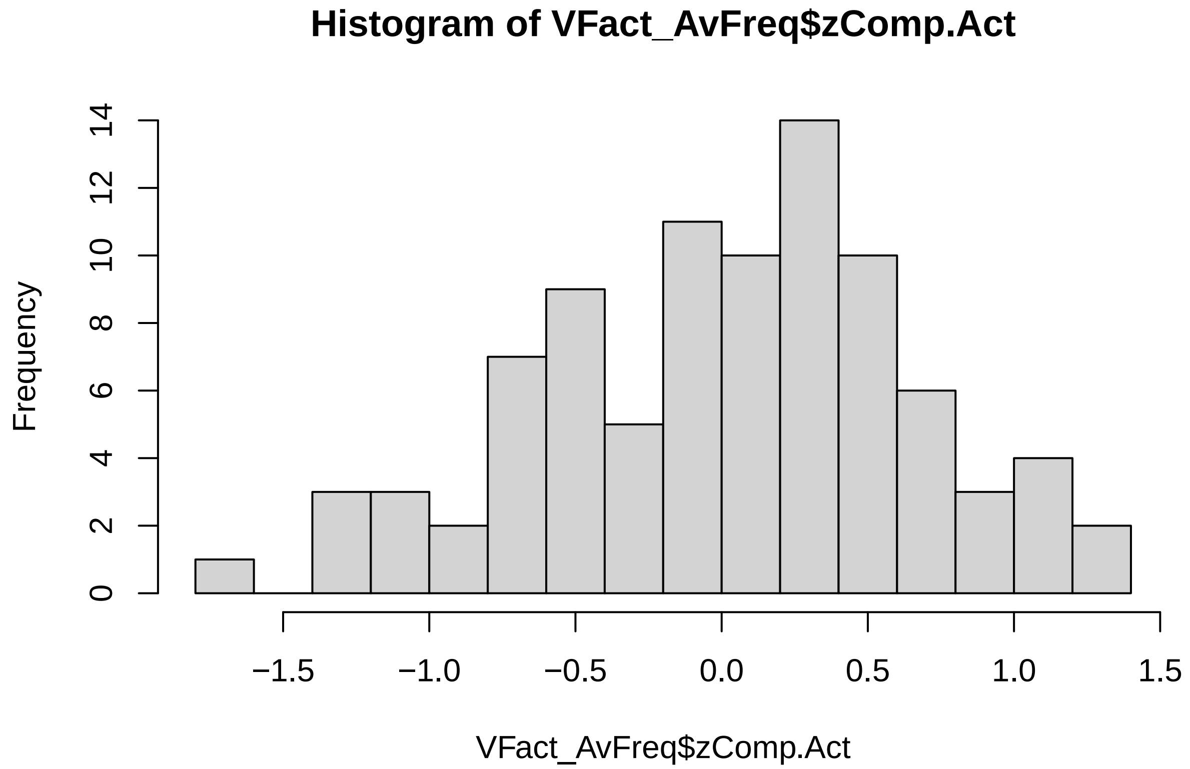
```r
# head(VFact_AvFreq, L=6)
```

```r
#Create a descriptives table by summarising data of the semantic fluency task
(Descr_VFact <- VFact_AvFreq %>%
#Per Age Group
  group_by(Age.Category) %>%
  summarise(Nppt = length(unique(ID)), #Number of participants
            total = round(mean(Total, na.rm=T),2), #Total words correctly produced
            sdtotal = round(sd(Total, na.rm=T),2),#Total words correctly produced
            ztotal = round(mean(zComp.Act, na.rm=T),2), #Z-score per age group of total words correctly
            people = round(mean(Things.people.do, na.rm=T),2), #Total words correctly produced in categ
            eggs = round(mean(Egg, na.rm=T),2))) #Total words correctly produced in category "Things yo
```

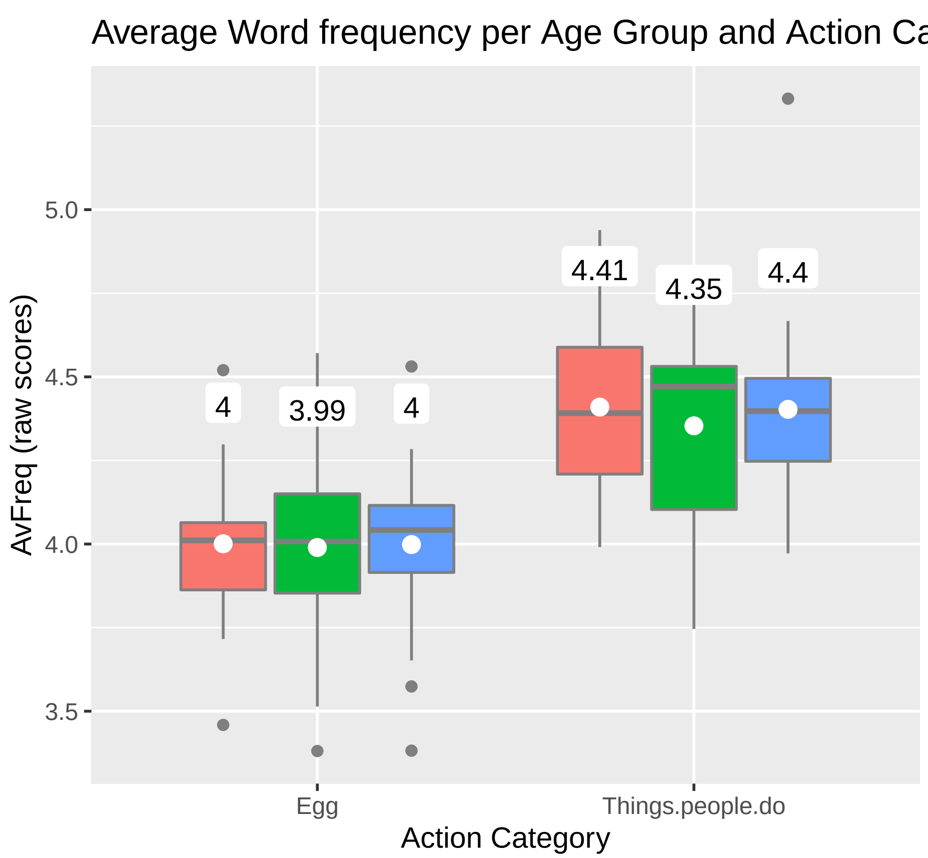
```
## # A tibble: 3 x 7
##   Age.Category  Nppt total sdtotal ztotal people  eggs
##   <fct>        <int> <dbl>   <dbl>  <dbl>  <dbl> <dbl>
## 1 Middle-Aged     30  4.21    0.16   0.05   4.41  4
## 2 Older           30  4.32    0.88   0      4.35  3.99
## 3 Younger         30  4.2     0.17   0.02   4.4   4
```

```r
# write.csv(Descr_VFact, "./Figures and Tables/Descr_VFact_AvFreq.csv")
```

```r
hist(VFact_AvFreq$zComp.Act, breaks=20) #Composite z-score of Semantic Fluency
```



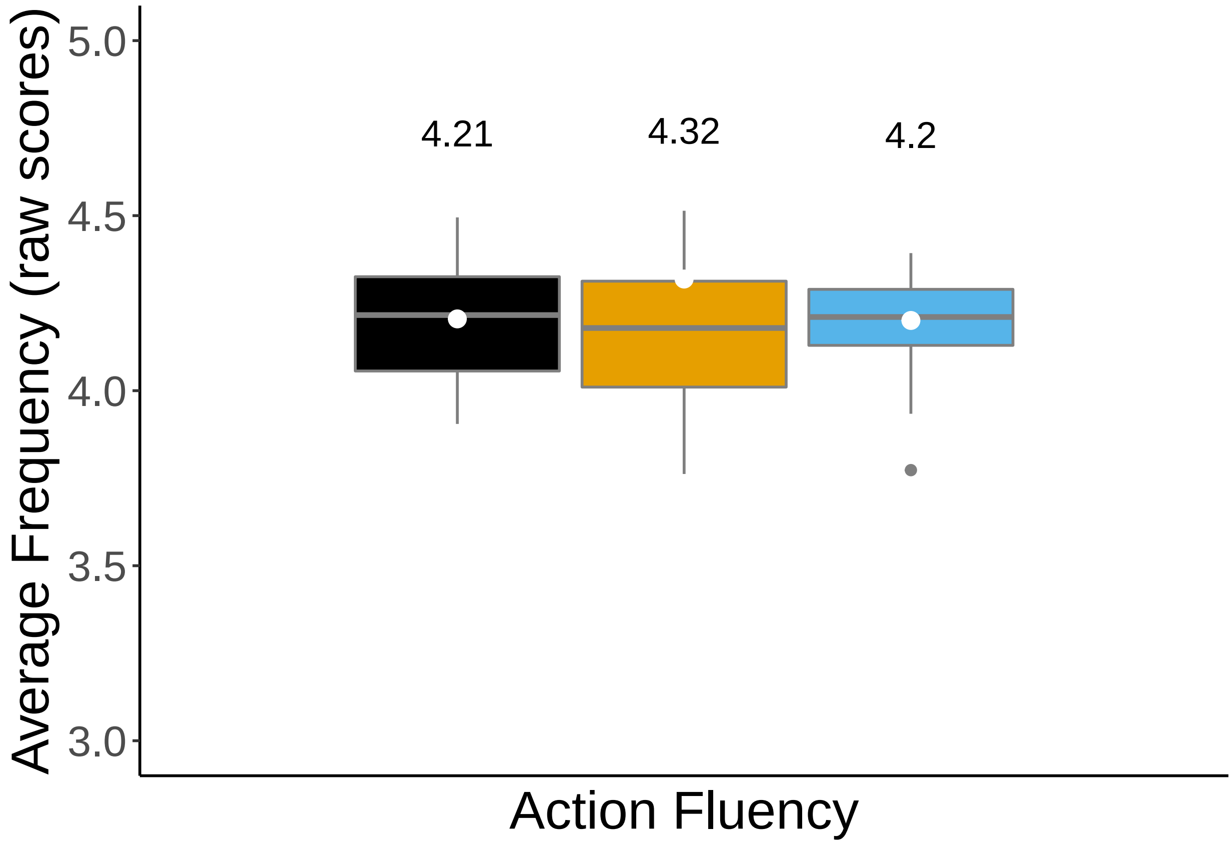
```
#Convert to long format for visualisation
VFact_AvFreq.long <- VFact_AvFreq %>%
  pivot_longer(cols=Total:Egg, names_to = "action", values_to = "AvFreq")

#Boxplot VF act AvFreq
# png(file="./Figures and Tables/Boxplot_VFactAvFreq.png",
# width=600, height=350)

(Boxplot_VF <- VFact_AvFreq.long %>%
    dplyr::filter(action!="Total") %>%
    ggplot(aes(x=factor(action), y=AvFreq,
                                              fill = as.factor(Age.Category))) +
    geom_boxplot(colour="grey50")+
    stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=4,
               fill="white", show.legend=NA, label.size=NA,
               position = position_dodge(.75), vjust=-3) +
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Action Category",
         y = "AvFreq (raw scores)",
         title = "Average Word frequency per Age Group and Action Category")+
      scale_fill_discrete(guide=guide_legend(title = "Age Group"), labels=c("18 to 30 years old","40 t
```



Visualisation AvFreq Action Fluency

```
# dev.off()
```

```
#Boxplot VFact Raw Total
# png(file="./Figures and Tables/Boxplot_VFactAvFreq_RawTotal.png",
# width=600, height=350)

(Boxplot_VF <- VFact_AvFreq.long %>%
    dplyr::filter(action=="Total") %>%
    ggplot(aes(x=action, y=AvFreq,fill = as.factor(Age.Category)), show.legend=FALSE) +
    geom_boxplot(colour="grey50", show.legend=FALSE)+
    stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=5,
               fill="white", show.legend=NA, label.size=NA,
               position = position_dodge(.75), vjust=c(-3.25,-2.5,-3.25)) +
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Action Fluency",
         y = "Average Frequency (raw scores)")+
        scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
       theme(text = element_text(size = 20),
             axis.ticks.x = element_blank(),
             axis.text.x = element_blank(),
          panel.background  = element_rect(fill="white"),
          plot.background = element_rect(fill = "white"),
          strip.background = element_rect(fill="white"),
          axis.line.x = element_line(color="black"),
         axis.line.y = element_line(color="black")) +
  coord_cartesian(ylim = c(3,5))+
     scale_y_continuous(minor_breaks = seq(3,5,1),
                     breaks = seq(3,5, 0.5)))
```

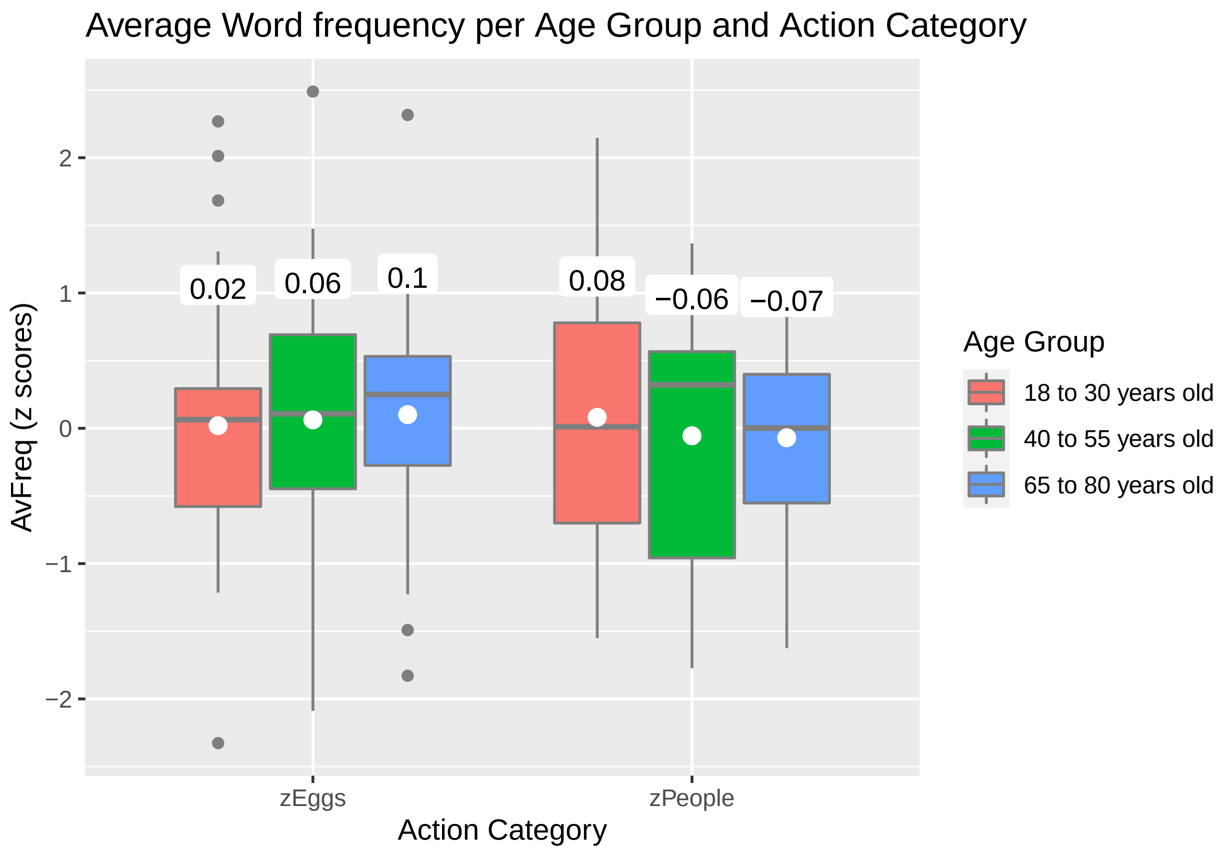



```
# dev.off()
```

Figures AvFreq Action Fluency zscores

```
#Convert to long format for visualisation
VFact_AvFreq.long.zscores <- VFact_AvFreq %>%
  pivot_longer(cols=zComp.Act:zEggs, names_to = "zaction", values_to = "zAvFreq")

#Boxplot VF act AvFreq
# png(file="./Figures and Tables/Boxplot_VFactAvFreq_zscores.png",
# width=600, height=350)

(Boxplot_VF_sub.zscores <- VFact_AvFreq.long.zscores %>%
    dplyr::filter(zaction!="zComp.Act") %>%
    ggplot(aes(x=factor(zaction), y=zAvFreq,
                                                fill = as.factor(Age.Category))) +
    geom_boxplot(colour="grey50")+
    stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
                 fun=mean, geom = "label", size=4,
                 fill="white", show.legend=NA, label.size=NA,
                 position = position_dodge(.75), vjust=-3) +
      stat_summary(fun = "mean", position = position_dodge(.75),
                 show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Action Category",
         y = "AvFreq (z scores)",
```

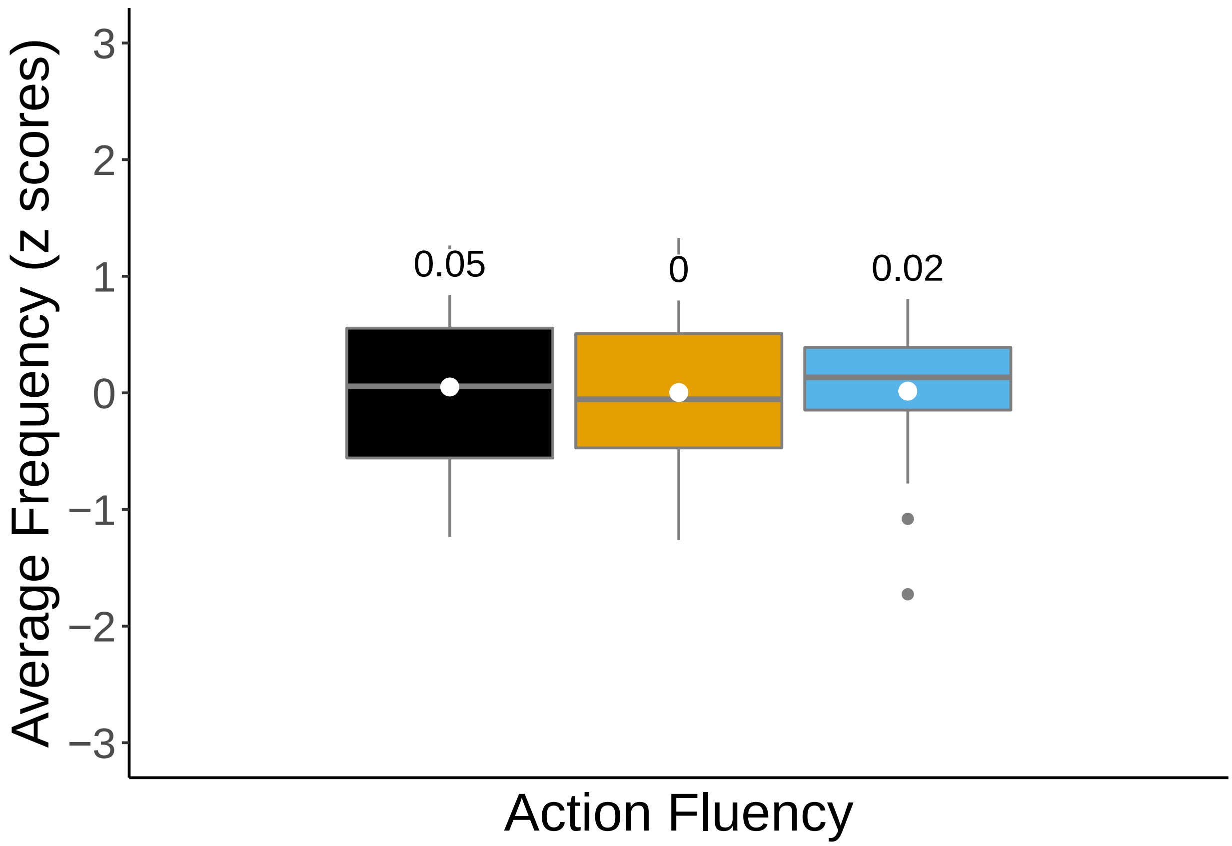
```
     title = "Average Word frequency per Age Group and Action Category")+
    scale_fill_discrete(guide=guide_legend(title = "Age Group"), labels=c("18 to 30 years old","40 t
```




```
# dev.off()
```

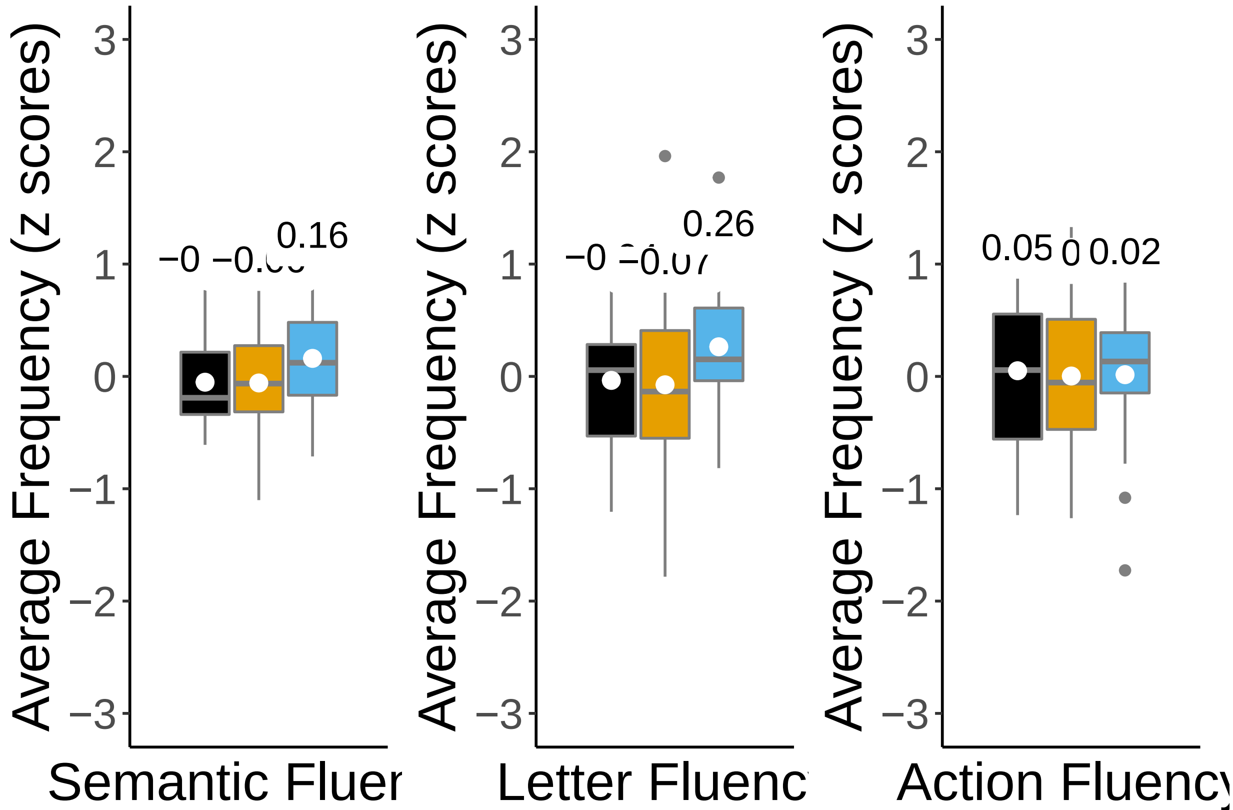
```
#Boxplot VFact Raw Total
# png(file="./Figures and Tables/Boxplot_VFactAvFreq_Total_zscores.png",
# width=600, height=350)

(Boxplot_VFact_zscoreTotal <- VFact_AvFreq.long.zscores %>%
    dplyr::filter(zaction=="zComp.Act") %>%
    ggplot(aes(x=zaction, y=zAvFreq,fill = as.factor(Age.Category)), show.legend=FALSE) +
    geom_boxplot(colour="grey50", show.legend=FALSE)+
       stat_summary(aes(label=round(..y..,2), group=as.factor(Age.Category)),
               fun=mean, geom = "label", size=5,
               fill="white", show.legend=FALSE, label.size=NA,
               position = position_dodge(.75), vjust=-2) +
      stat_summary(fun = "mean", position = position_dodge(.75),
               show.legend=F, colour="white")+ #Mean as white dot
    labs(x = "Action Fluency",
         y = "Average Frequency (z scores)") +
        scale_fill_manual(values = cbPalette) + # , guide=guide_legend(title = "Age Group"), labels=c("
       theme(text = element_text(size = 20),
             axis.ticks.x = element_blank(),
             axis.text.x = element_blank(),
```

```
          panel.background  = element_rect(fill="white"),
          plot.background = element_rect(fill = "white"),
          strip.background = element_rect(fill="white"),
          axis.line.x = element_line(color="black"),
         axis.line.y = element_line(color="black")) +
  coord_cartesian(ylim = c(-3,3))+
     scale_y_continuous(minor_breaks = seq(-3,3,0.5),
                        breaks = seq(-3,3,1)))
```




```
# dev.off()
```

```
(Boxplots.VFall_Totalz <- Boxplot_VFcat.Totalzscore + Boxplot_VFlet.zscoreTotal  + Boxplot_VFact_zscore
```




```
# ggsave(Boxplots.VFall_Totalz, filename = "../Figures and Tables/Boxplots_VFall_Totalz.tiff", height =
```

Multiple Linear Regression - Action Fluency

Create user-defined contrasts for the Age Category variable

```
VFact_AvFreq <- mutate(VFact_AvFreq,
                       Age.Category =
                         factor(Age.Category, levels = c("Middle-Aged", "Younger", "Older")))

VFact_AvFreq_coded <- VFact_AvFreq
contrasts(VFact_AvFreq_coded$Age.Category) <- contr.helmert(3)
contrasts(VFact_AvFreq_coded$Age.Category)
```

```
##              [,1] [,2]
## Middle-Aged   -1   -1
## Younger        1   -1
## Older          0    2
```

Unconditional model, i.e. without covariates

```
lmUncond.VFact.AvFreq <- lm(zComp.Act ~ Age.Category*CR.composite.before, data = VFact_AvFreq_coded)
# broom::tidy(lmUncond.VFact.AvFreq, conf.int=T)
```

Full model of AvFreq in z-distribution, including covariates

```
lmFull.VFact.AvFreq <- lm(zComp.Act ~ Age.Category*CR.composite.before +GenCogProc.composite, data = VFa
summary(lmFull.VFact.AvFreq)
```

```
##
## Call:
## lm(formula = zComp.Act ~ Age.Category * CR.composite.before +
##     GenCogProc.composite, data = VFact_AvFreq_coded)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.65851 -0.47263  0.04028  0.49310  1.29057
##
## Coefficients:
##                                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)                         0.022739   0.070212   0.324    0.747
## Age.Category1                      -0.001872   0.090848  -0.021    0.984
## Age.Category2                      -0.025122   0.057256  -0.439    0.662
## CR.composite.before                -0.004880   0.071510  -0.068    0.946
## GenCogProc.composite               -0.087538   0.162870  -0.537    0.592
## Age.Category1:CR.composite.before   0.046677   0.087743   0.532    0.596
## Age.Category2:CR.composite.before  -0.019476   0.050496  -0.386    0.701
##
## Residual standard error: 0.6661 on 83 degrees of freedom
## Multiple R-squared:  0.009122,   Adjusted R-squared:  -0.06251
## F-statistic: 0.1273 on 6 and 83 DF,  p-value: 0.9926
```

```
#Tidy table output
(tidylmFull.VFact.AvFreq <- broom::tidy(lmFull.VFact.AvFreq, conf.int=T)%>%
  mutate_if(is.numeric, round, 3))
```

```
## # A tibble: 7 x 7
##   term                   estimate std.error statistic p.value conf.low conf.high
##   <chr>                     <dbl>     <dbl>     <dbl>   <dbl>    <dbl>     <dbl>
## 1 (Intercept)               0.023     0.07      0.324   0.747   -0.117     0.162
## 2 Age.Category1            -0.002     0.091    -0.021   0.984   -0.183     0.179
## 3 Age.Category2            -0.025     0.057    -0.439   0.662   -0.139     0.089
## 4 CR.composite.before      -0.005     0.072    -0.068   0.946   -0.147     0.137
## 5 GenCogProc.composite     -0.088     0.163    -0.537   0.592   -0.411     0.236
## 6 Age.Category1:CR.comp~    0.047     0.088     0.532   0.596   -0.128     0.221
## 7 Age.Category2:CR.comp~   -0.019     0.05     -0.386   0.701   -0.12      0.081
```

```
# write.csv(tidylmFull.VFact.AvFreq, "./Figures and Tables/VFact_zAvFreq_lmFull.csv")
```

Full model of AvFreq as raw score, including covariates

```
lmFull.VFact.AvFreq.raw <- lm(Total ~ Age.Category*CR.composite.before + GenCogProc.composite, data = VF
summary(lmFull.VFact.AvFreq.raw)
```

```
##
```

```
## Call:
## lm(formula = Total ~ Age.Category * CR.composite.before + GenCogProc.composite,
##     data = VFact_AvFreq_coded)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -0.6033 -0.1639 -0.0229  0.0741  4.4932
##
## Coefficients:
##                                    Estimate Std. Error t value Pr(>|t|)
## (Intercept)                         4.241752   0.056298  75.345   <2e-16 ***
## Age.Category1                      -0.013872   0.072844  -0.190    0.849
## Age.Category2                       0.050003   0.045910   1.089    0.279
## CR.composite.before                 0.006145   0.057338   0.107    0.915
## GenCogProc.composite                0.064573   0.130594   0.494    0.622
## Age.Category1:CR.composite.before   0.018952   0.070355   0.269    0.788
## Age.Category2:CR.composite.before  -0.009494   0.040489  -0.234    0.815
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.5341 on 83 degrees of freedom
## Multiple R-squared:  0.01596,    Adjusted R-squared:  -0.05517
## F-statistic: 0.2244 on 6 and 83 DF,  p-value: 0.9678
```

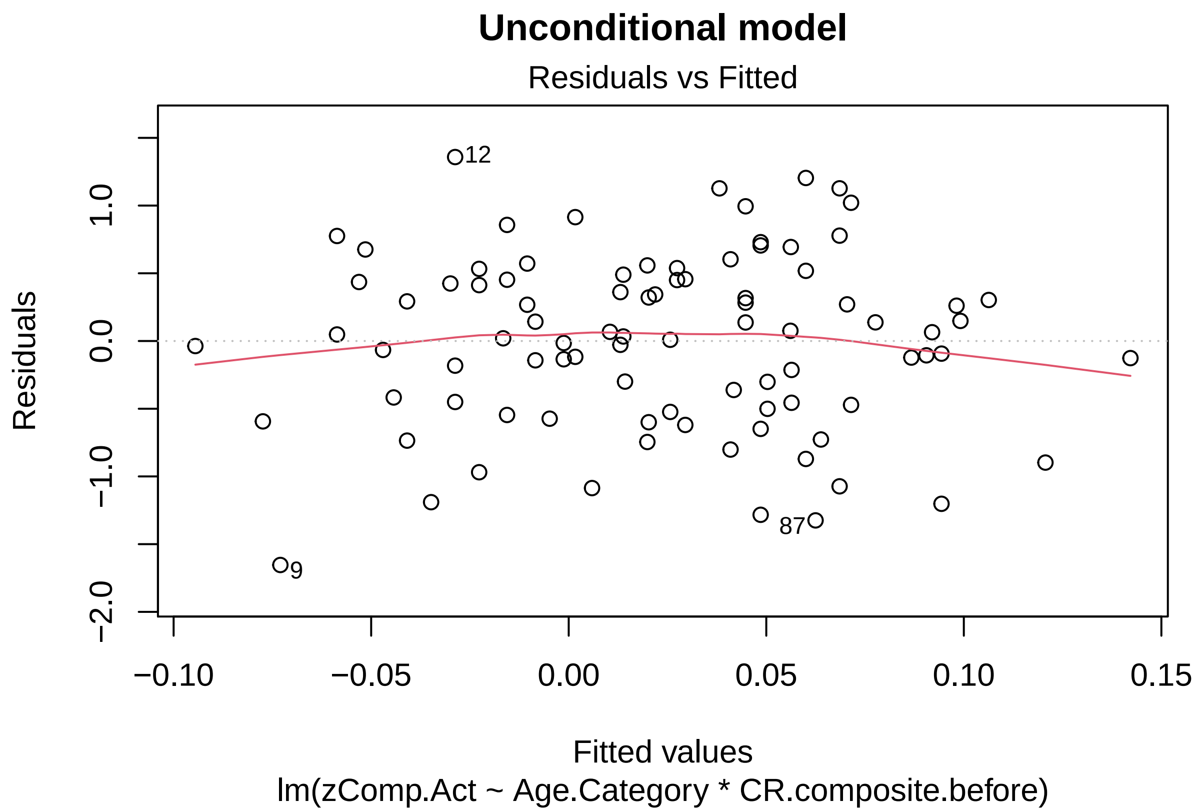
```r
#Tidy table output
broom::tidy(lmFull.VFact.AvFreq.raw, conf.int=T)%>%
  mutate_if(is.numeric, round, 3)
```

```
## # A tibble: 7 x 7
##   term                    estimate std.error statistic p.value conf.low conf.high
##   <chr>                      <dbl>     <dbl>     <dbl>   <dbl>    <dbl>     <dbl>
## 1 (Intercept)                4.24      0.056    75.3     0        4.13      4.35
## 2 Age.Category1             -0.014     0.073    -0.19    0.849   -0.159     0.131
## 3 Age.Category2              0.05      0.046     1.09    0.279   -0.041     0.141
## 4 CR.composite.before        0.006     0.057     0.107   0.915   -0.108     0.12
## 5 GenCogProc.composite       0.065     0.131     0.494   0.622   -0.195     0.324
## 6 Age.Category1:CR.comp~     0.019     0.07      0.269   0.788   -0.121     0.159
## 7 Age.Category2:CR.comp~    -0.009     0.04     -0.234   0.815   -0.09      0.071
```

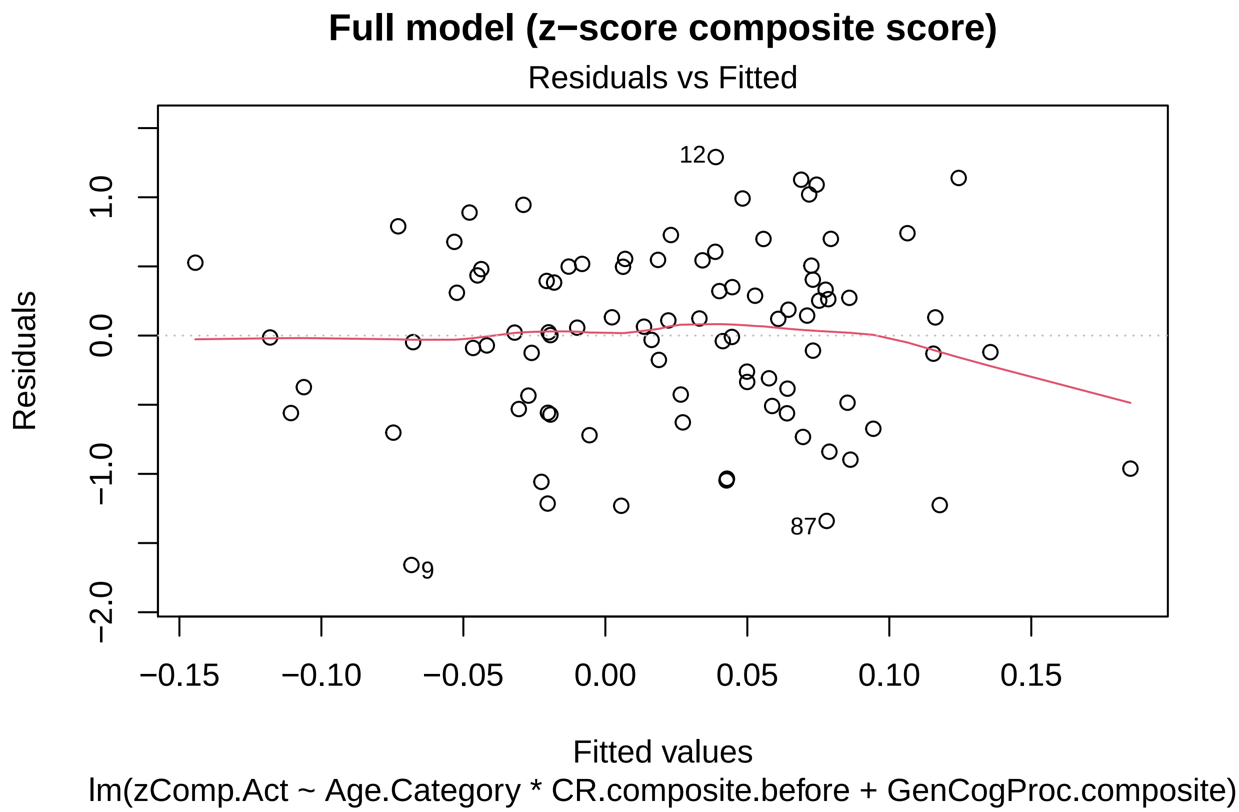
None of the models seem to predict either the outcome variable for Verbal Fluency Action Categories. Let's check the model assumptions + fit.

Assumption 1 - Linearity

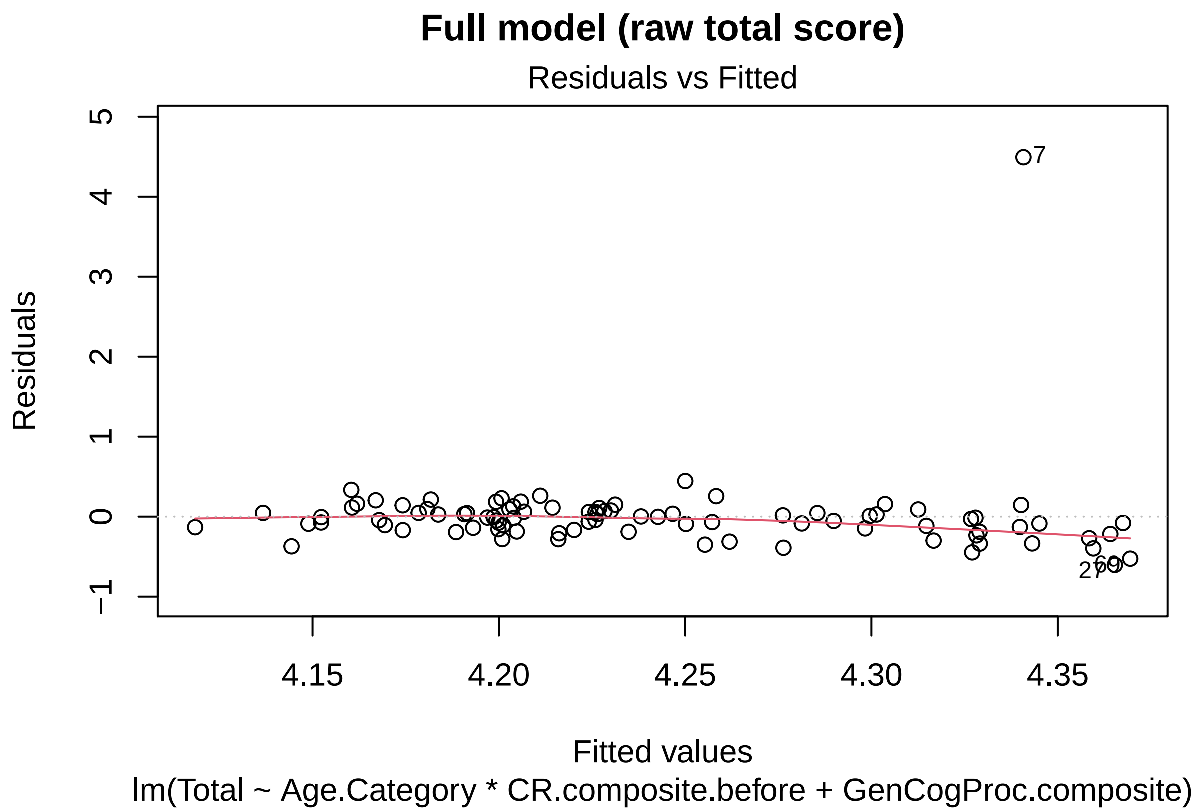
```r
## Unconditional model with z composite score
plot(lmUncond.VFact.AvFreq, 1, main = "Unconditional model")
```




```
## Full model with z composite score
plot(lmFull.VFact.AvFreq, 1, main = "Full model (z-score composite score)")
```




```r
## Full model with raw total score
plot(lmFull.VFact.AvFreq.raw, 1, main = "Full model (raw total score)")
```



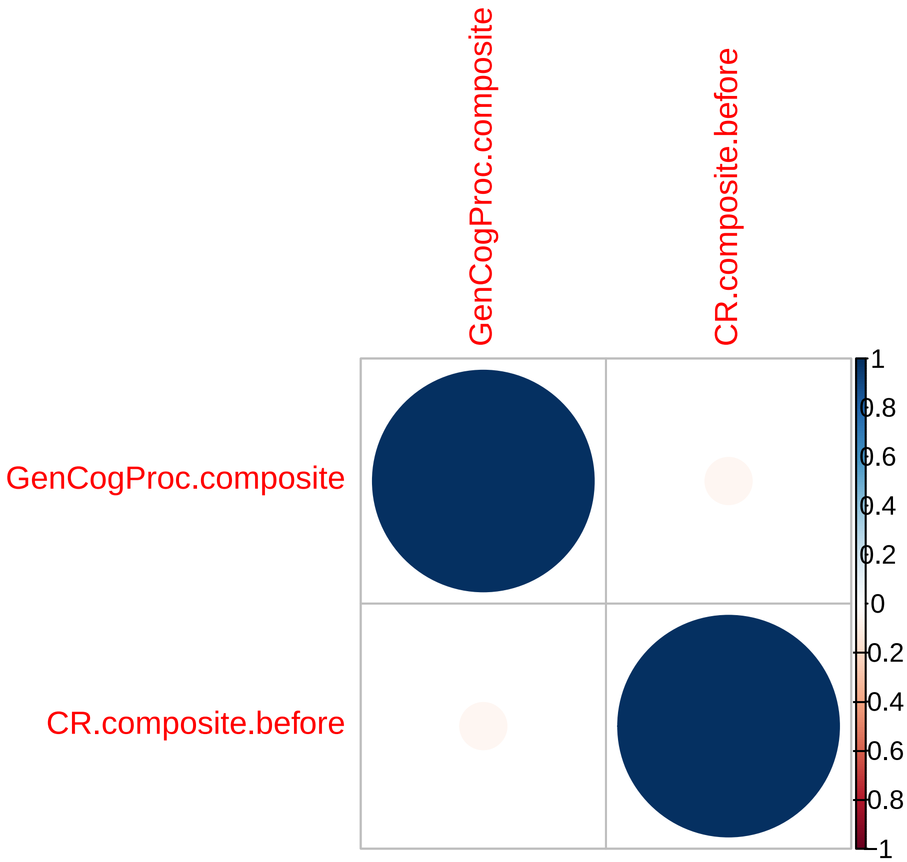
For the unconditional model and the full model with raw scores, the red line is mostly horizontal, meaning that there is a linear relationship between the fitted line and the residual value. However, residuals seem to be higher for the extreme min and max fitted values. Hence, we can't assume linearity. Possibly due to outliers?

Assumption 2 - Independence of Variables

```
# Z composite of VF action
## Create table with correlation values between predictor variables
tibble::as_tibble(cor(VFact_AvFreq_coded[,c(11,13)]), rownames="rowname")
```

```
## # A tibble: 2 x 3
##   rowname              GenCogProc.composite CR.composite.before
##   <chr>                               <dbl>               <dbl>
## 1 GenCogProc.composite               1                  -0.0439
## 2 CR.composite.before               -0.0439              1
```

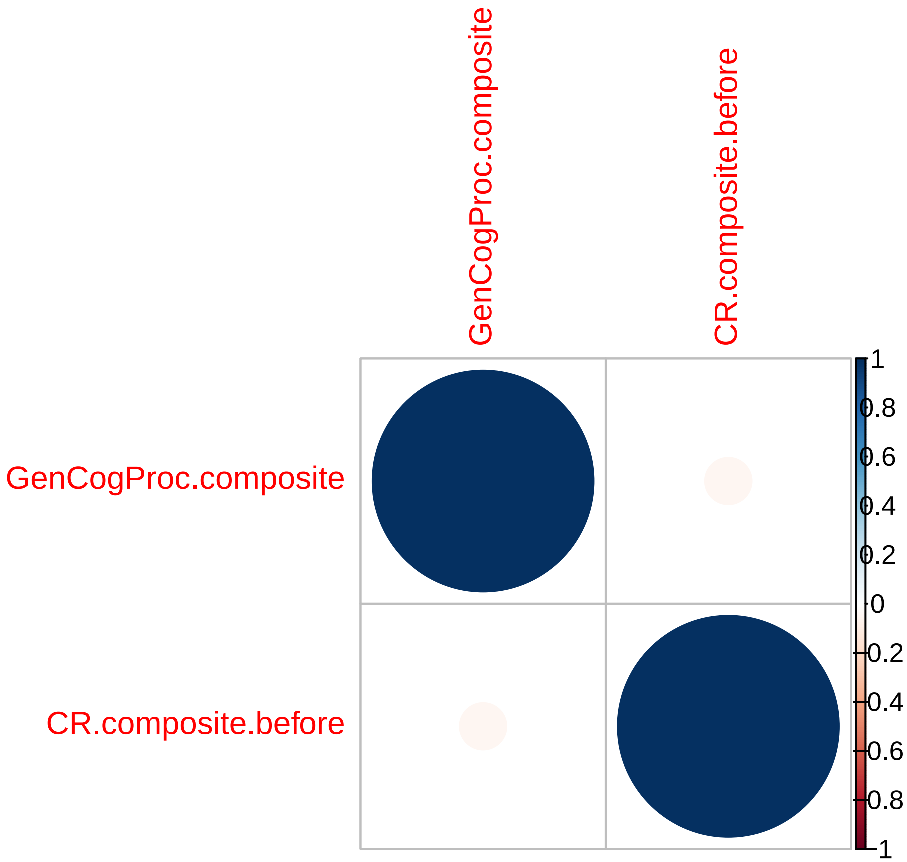
```
## Create correlation plot between predictor variables
corrplot(cor(VFact_AvFreq_coded[,c(11,13)]),method='circle')
```




```r
## Raw scores
## Create table with correlation values between predictor variables
tibble::as_tibble(cor(VFact_AvFreq_coded[,c(11,13)]), rownames = "rowname")
```

```
## # A tibble: 2 x 3
##   rowname              GenCogProc.composite CR.composite.before
##   <chr>                               <dbl>               <dbl>
## 1 GenCogProc.composite               1                  -0.0439
## 2 CR.composite.before               -0.0439               1
```

```r
## Create correlation plot between predictor variables
corrplot(cor(VFact_AvFreq_coded[,c(11,13)]))
```

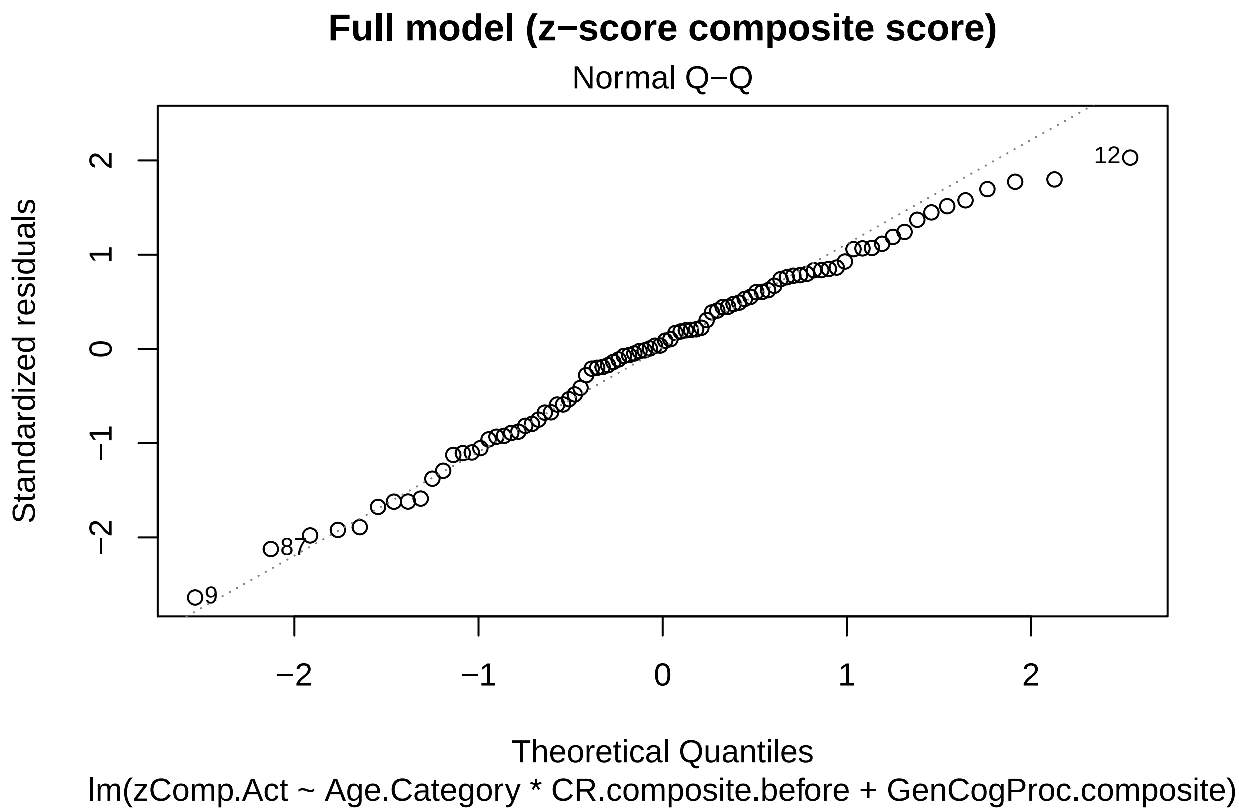


There seems to be no strong relationship between the predictor variables. Hence, we can assume Independence of Variables.

Assumption 3 - Normal Distribution of Residuals

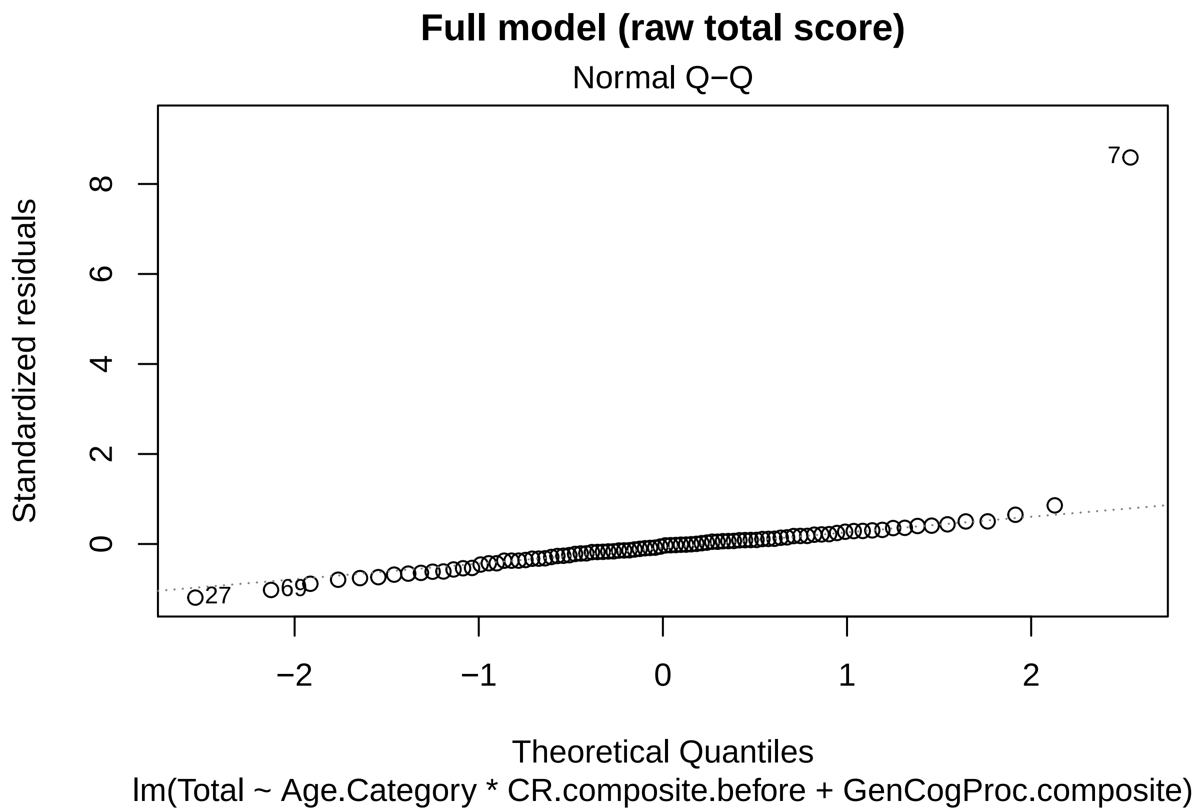
Full model with z composite score

```
## Full model with z composite score
plot(lmFull.VFact.AvFreq, 2, main = "Full model (z-score composite score)")
```



Full model with raw total score

```
plot(lmFull.VFact.AvFreq.raw, 2, main = "Full model (raw total score)")
```

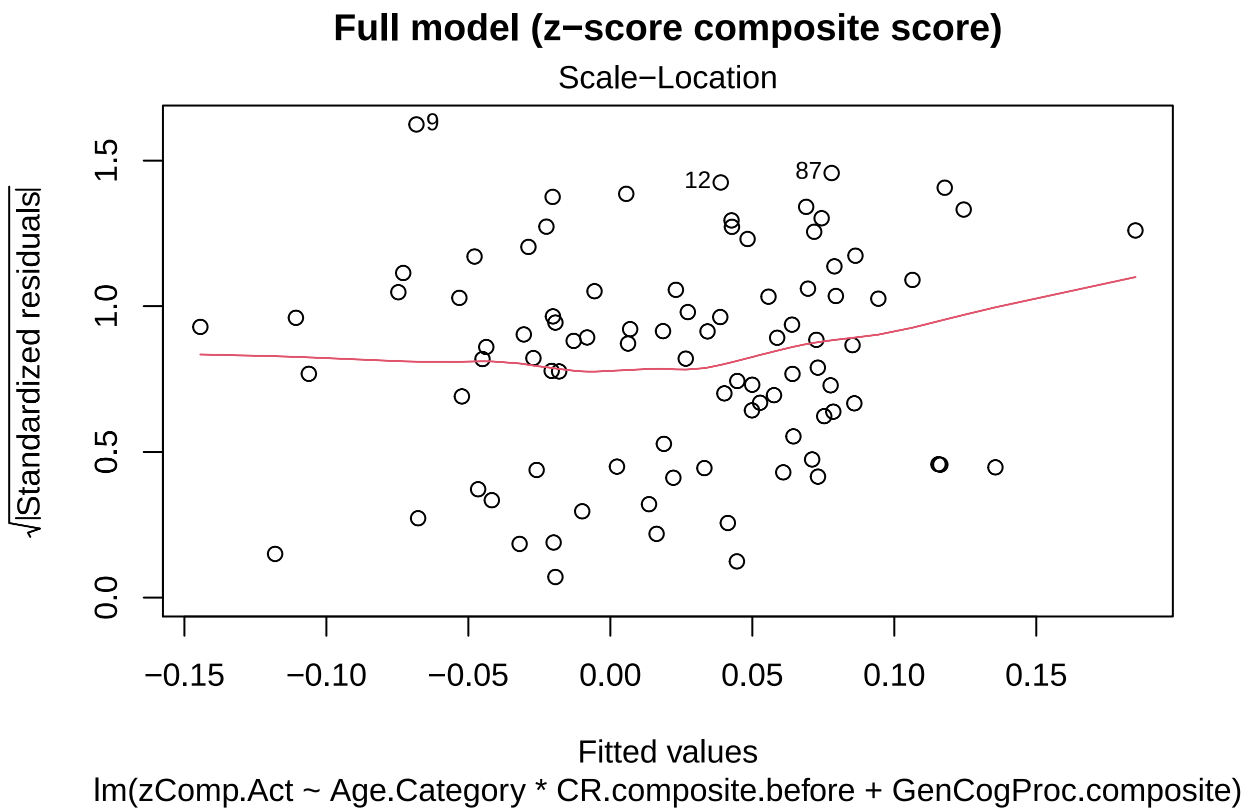


For the unconditional and full model with z-composite score, the points seem to roughly follow a straight line. However, there is a dip on the right and an influential point (point 12). Hence, other relationships/predictors that have not been included into the models could explain the variance for these models. One explanation could be the online format of the study. For example, some participants might have scored lower than they would in a lab-based study, due to unclear instructions. Also, it could have caused more distractions than there would have been in a lab based study. For the full model with the raw scores, there is one massive outlier (point 7).

Assumption 4 - Homoscedasticity or Equal Variance of Variables

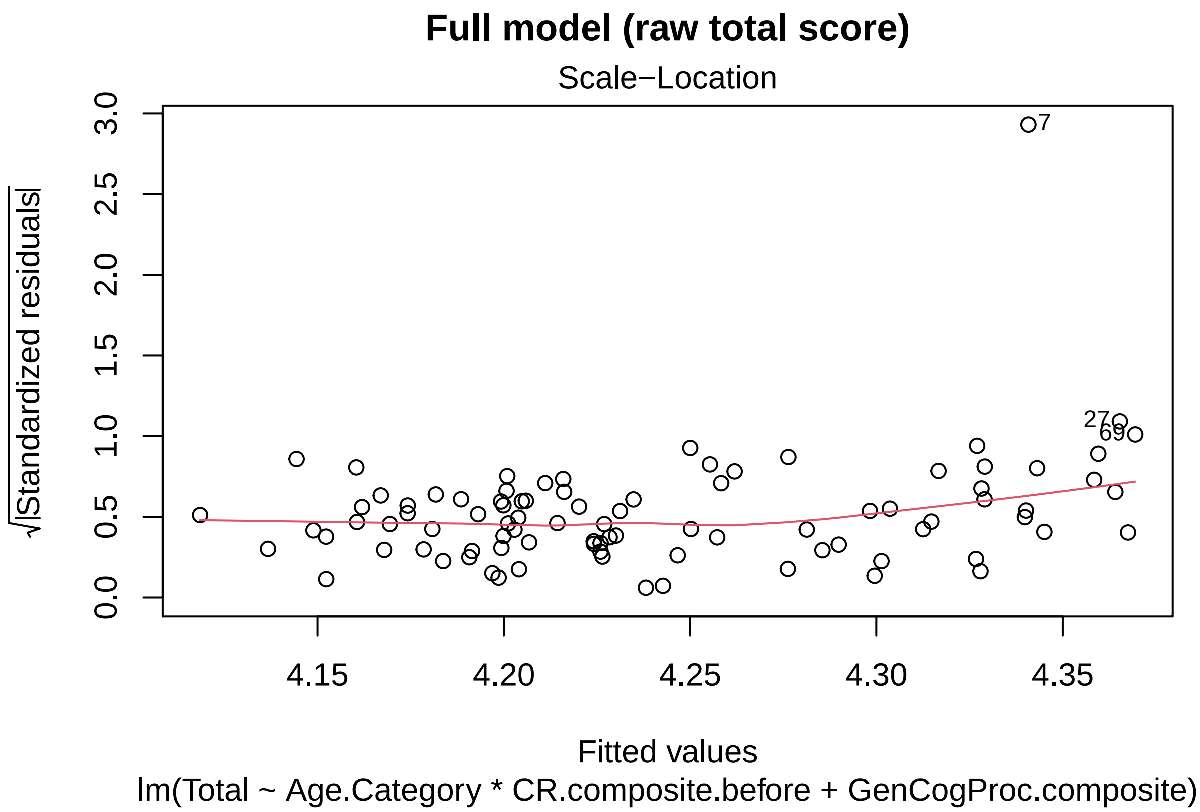
Full model with z composite score

```
plot(lmFull.VFact.AvFreq, 3, main = "Full model (z-score composite score)")
```



Full model with raw total score

```
plot(lmFull.VFact.AvFreq.raw, 3, main = "Full model (raw total score)")
```



Model fit diagnostics *Variation Inflation Factor*

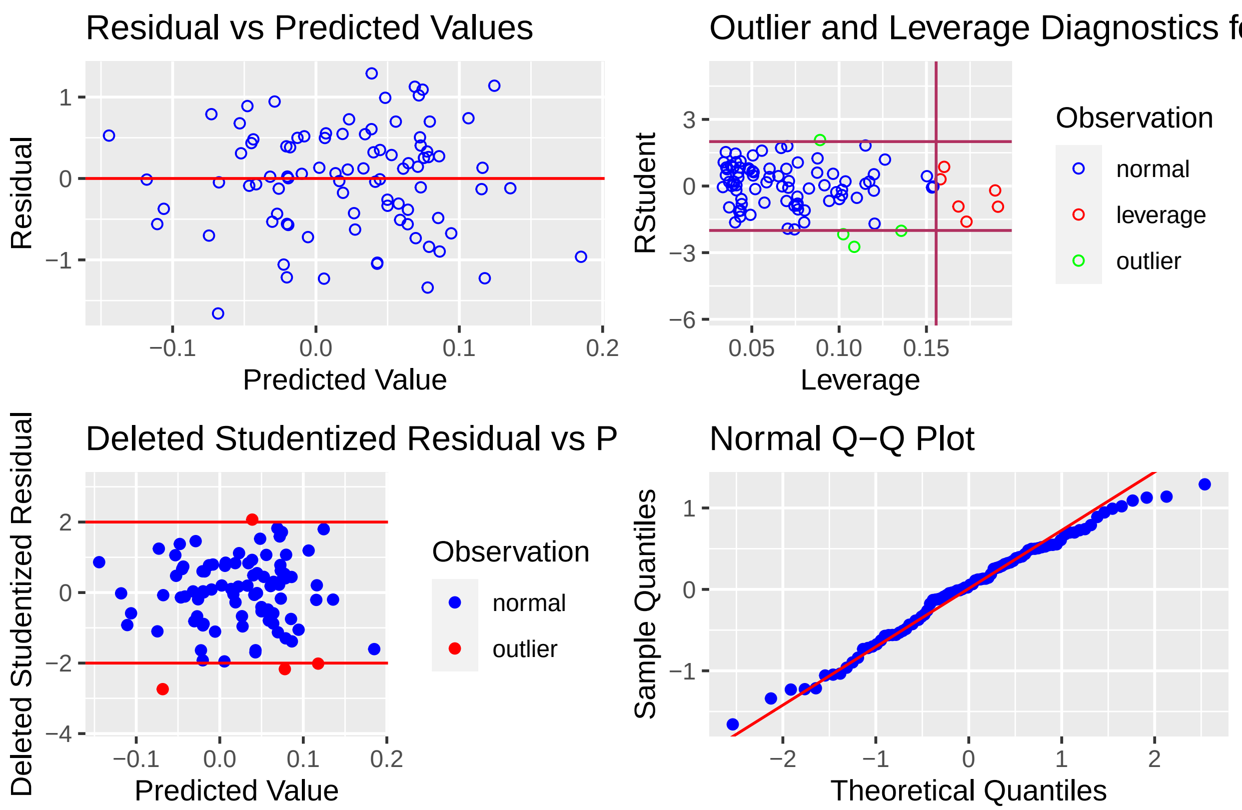
Any VIF value above 4 needs further investigation. There seems to be no concerning signs of collinearity (VIF values higher than 4). The tolerance values indicate the percentage of variance that cannot be explained for by the other predictor variables.

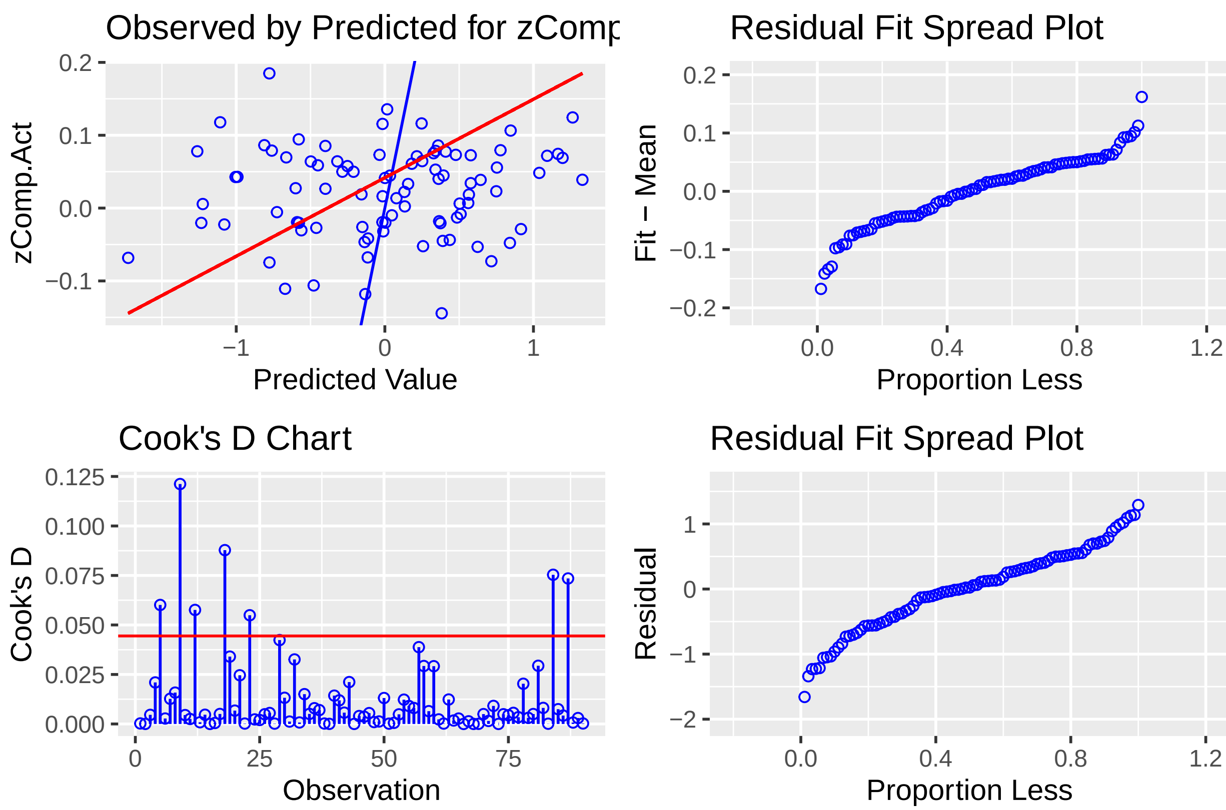
```
ols_vif_tol(lmFull.VFact.AvFreq) #zscores only
```

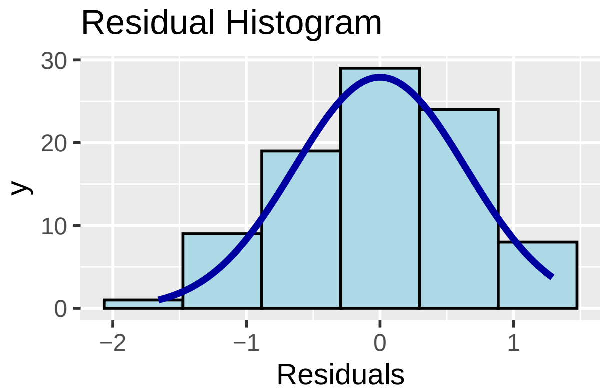
```
##                            Variables Tolerance      VIF
## 1                      Age.Category1 0.8958833 1.116217
## 2                      Age.Category2 0.7518193 1.330107
## 3                CR.composite.before 0.9971961 1.002812
## 4               GenCogProc.composite 0.6869407 1.455730
## 5 Age.Category1:CR.composite.before 0.9935202 1.006522
## 6 Age.Category2:CR.composite.before 0.9999277 1.000072
```

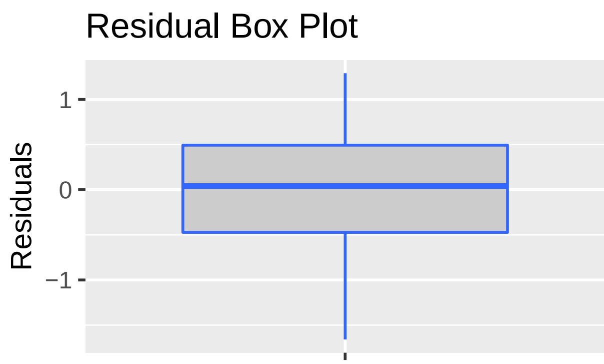
Plot Diagnositcs Full model with z composite score for Action Fluency

```
ols_plot_diagnostics(lmFull.VFact.AvFreq)
```


Residual vs Predicted Values
Residual
Predicted Value
Outlier and Leverage Diagnostics fo
RStudent
Leverage
Observation
normal
leverage
outlier
Deleted Studentized Residual vs P
Deleted Studentized Residual
Predicted Value
Observation
normal
outlier
Normal Q−Q Plot
Sample Quantiles
Theoretical Quantiles


Observed by Predicted for zComp
zComp.Act
Predicted Value
0.2
0.1
0.0
−0.1
−1
0
1
Residual Fit Spread Plot
Fit − Mean
Proportion Less
0.2
0.1
0.0
−0.1
−0.2
0.0
0.4
0.8
1.2
Cook's D Chart
Cook's D
Observation
0.125
0.100
0.075
0.050
0.025
0.000
0
25
50
75
Residual Fit Spread Plot
Residual
Proportion Less
1
0
−1
−2
0.0
0.4
0.8
1.2





For all models, the Observed vs Predicted Plot shows that the model doesn't fit the data very well (pity) –> due to outliers?? What to do. . . .

It can explain the fact that the models do not explain the outcome variable in any case.

Model comparisons for the CR measure preciding and coinciding with the COVID-19 pandemic

The effect of the COVID-19 pandemic on CR and subsequent behavioural performance

```
lmFull.VFact.AvFreq.during <- lm(zComp.Act ~ Age.Category*CR.composite.during +
                                    GenCogProc.composite, data =
                                    VFact_AvFreq_coded)
summary(lmFull.VFact.AvFreq.during)
```

```
##
## Call:
## lm(formula = zComp.Act ~ Age.Category * CR.composite.during +
##     GenCogProc.composite, data = VFact_AvFreq_coded)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -1.68491 -0.43690  0.03357  0.45613  1.24564
##
## Coefficients:
##                                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)                         0.0229924  0.0701166   0.328    0.744
```

```
## Age.Category1                       -0.0006908  0.0908810  -0.008    0.994
## Age.Category2                       -0.0260132  0.0573951  -0.453    0.652
## CR.composite.during                  0.0177849  0.0721062   0.247    0.806
## GenCogProc.composite                -0.0918584  0.1650199  -0.557    0.579
## Age.Category1:CR.composite.during    0.0693409  0.0889255   0.780    0.438
## Age.Category2:CR.composite.during   -0.0031660  0.0512192  -0.062    0.951
##
## Residual standard error: 0.6652 on 83 degrees of freedom
## Multiple R-squared:  0.01183,    Adjusted R-squared:  -0.0596
## F-statistic: 0.1657 on 6 and 83 DF,  p-value: 0.9852
```

```r
#Model comparison
anova(lmFull.VFact.AvFreq, lmFull.VFact.AvFreq.during)
```

```
## Analysis of Variance Table
##
## Model 1: zComp.Act ~ Age.Category * CR.composite.before + GenCogProc.composite
## Model 2: zComp.Act ~ Age.Category * CR.composite.during + GenCogProc.composite
##   Res.Df    RSS Df Sum of Sq F Pr(>F)
## 1     83 36.822
## 2     83 36.721  0   0.10082
```

Models are not significantly different from each other.

```r
#Model comparison through AIC comparison
AIC(lmFull.VFact.AvFreq)
```

```
## [1] 190.9754
```

```r
AIC(lmFull.VFact.AvFreq.during)
```

```
## [1] 190.7286
```

Although very similar, the model with the CR composite score during-pandemic seems to fit the data slightly better.

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