Analysis of Correlated Data
Mixed Linear Models
Assignment 2

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Summary

For Assignment 2's requirements in the Analysis of Correlated Data: Mixed Linear Models class, a statistical examination was executed. In a test conducted, a group of 8 assessors evaluate televisions focusing on their coloursaturation. The structured study involved experimenting with three distinct images and three varied TV settings, running each combination twice. The primary objective was to analyze and contrast the images, TV configurations, and their respective combinations in relation to the coloursaturation they exhibited. The analysis is structured into three sections. The initial segment involves conducting model diagnostics to identify a mixed linear model that accurately reflects our evaluations. The subsequent part encompasses the core statistical analysis, while the final section is dedicated to drawing conclusions based on the findings.

Contents

1 Introduction

Bang & Olufsen started a sensory experiment, aiming to systematically evaluate and understand the colour saturation offered by its television units. Eight evaluators carefully carried out this experiment, each giving their feedback based on a set of rules.
The main goal of the experiment was to explore how different TV settings and pictures affect color saturation. In the experiment, each TV was set to three different settings and showed three different pictures. This process was repeated once, resulting in two tests for each setting-picture combination, to make the collected data more reliable.

2 Exploratory Data Analysis

2.1 Variables in the Dataset:

- `Assessor`: This is a categorical variable with values ranging from 1 to 8. Each number uniquely identifies one of the eight evaluators who assessed color saturation levels.
- `TVset`: This categorical variable represents the specific TV setting used during each evaluation, labeled as TV1, TV2, or TV3.
- `Picture`: The 'Picture' variable is categorical and indicates which picture (1, 2, or 3) is shown during the evaluation.
- `Repeat`: This categorical variable, with values of 0 or 1, shows if the evaluation comes from the first or second run of the experiment.
- `Coloursaturation`: This continuous variable represents the color saturation score given by an assessor for each TVset and Picture combination.

It's important to note that the dataset is balanced. Each Assessor reviewed all combinations of TVset and Picture, and this process was done twice, as shown by the Repeat variable.

2.2 Explorative Data Plots and Diagrams

Fig: 1 reveals that the colour saturation increases with the categories of Pictures while it varies with the categories Assessor and TVset. The distribution of Coloursaturation is not exactly normally distributed and this may be caused because of the influence of Assessor and TVset on the Coloursaturation.
Our initial linear model for a two-way ANOVA is:

$$Y_{ijklm} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + A_l + (A\alpha)_{il} + (A\beta)_{jl} + (A\gamma)_{kl} + \epsilon_{ijklm} \quad (1)$$

Where:

- Y_{ijklm} is the observed Coloursaturation value.
- μ is the overall mean response.
- α_i is the effect of the i-th level of TVset ($i = 1, 2, 3$).
- β_j is the effect of the j-th level of Picture ($j = 1, 2, 3$).
- γ_k is the effect of the k-th level of Repeat ($k = 0, 1$).
- $(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$, and $(\beta\gamma)_{jk}$ are the interaction effects.
- A_l is the random effect of the l-th Assessor ($l = 1, \ldots, 8$).

- $(A\alpha)_{il}$, $(A\beta)_{jl}$, and $(A\gamma)_{kl}$ are the random effects of interactions between Assessor and other factors.

- ϵ_{ijklm} is the random error associated with each observation, assumed to be independently and identically distributed with mean 0 and constant variance σ^2.

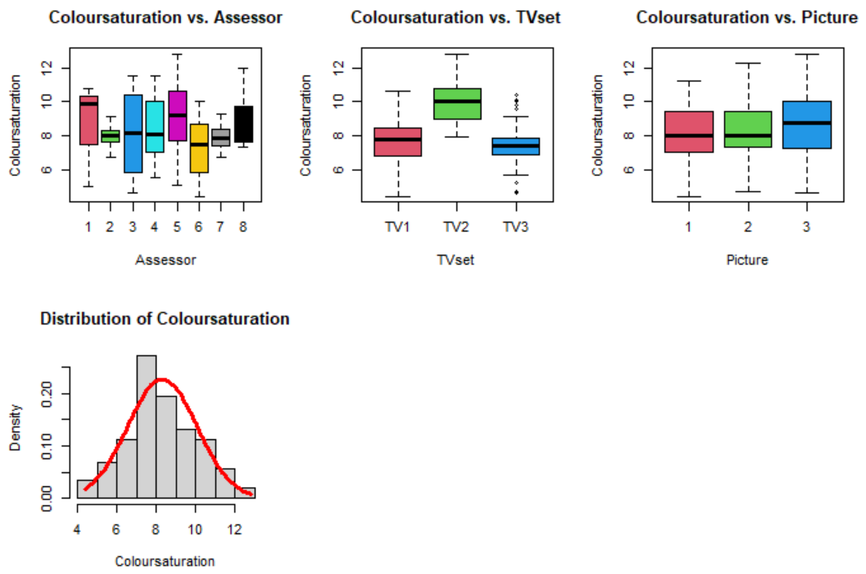

Figure 1: Boxplot and Histogram

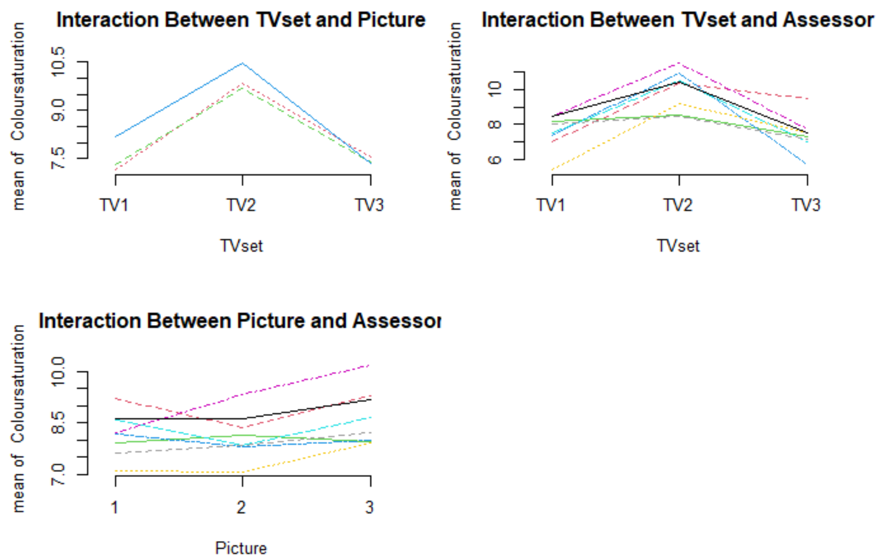

Figure 2: Interaction Plots

	NumDF	F value	Pr(>F)
TVset	2	15.2739	0.0003029***
Picture	2	4.3596	0.0337393*
Repeat	1	0.1543	0.6953265
TVset:Picture	4	2.6568	0.0375286*
TVset:Repeat	2	1.9416	0.1491316
Picture:Repeat	2	1.3316	0.2689359

Table 1: Anova Table

	Df	Pr(>Chisq)
$< none >$		
(1|Assessor)	1	0.9433
(1|Assessor:TVset)	1	$1.631 \times 10^{-12***}$
(1|Assessor:Picture)	1	0.3012
(1|Assessor:Repeat)	1	0.9998

Table 2: Ranova Table

Given the values from Table 1 and Table 2 the p-values of the factors: Repeat, Assessor:Picture, Assessor:Repeat, TVset:Repeat. Picture:Repeat indicate that they are not statistically significant factors. So the final model will be:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + a_k + (a\alpha)_{ik} + \epsilon_{ijk} \tag{2}$$

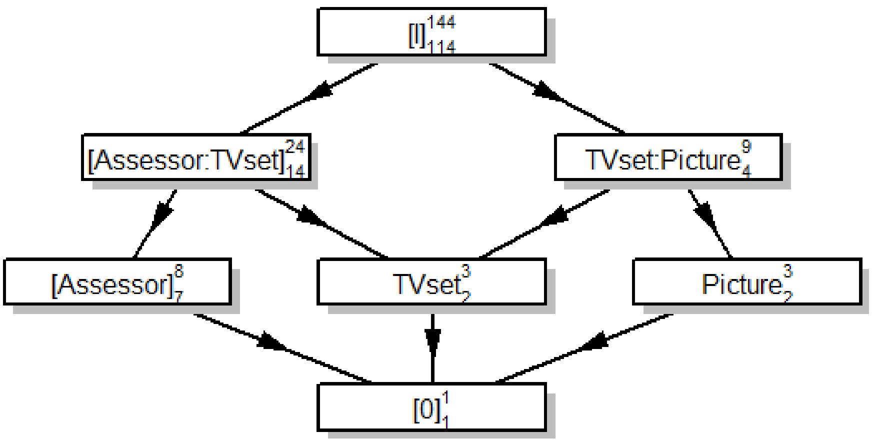

Figure 3: Factor Diagram

Factor Interactions in Final Model:
Aside from the trivial factors [0] and [I] we have:

- `Assessor` is a crossed factor with both `TVset` and `Picture`. This implies that every Assessor evaluates every level of `TVset` and `Picture`.
- `TVset` and `Picture` are also crossed factors. Every level of `TVset` is assessed with every level of `Picture`.
- `TVset:Picture` provide insights into whether the combination of specific television settings and pictures significantly affects the perceived colour saturation.
- `Assessor:TVset`:Represents the combined effects of the Assessor and TVset factors on the dependent variable, capturing how the effect of one factor varies across the levels of the other factor
- There are no nested factors in the model. All the factors interact at the same level, with no factor existing solely within the levels of another factor.

After we removed the factors that were not statistically significant in our analysis we have the factor diagram in Figure 3. The upper numbers indicate the levels of the factor while the sub numbers shows the degrees of freedom.

3 Statistical Analysis

3.1 Model Diagnostics

3.1.1 First Model Diagnosis

We will begin our analysis by conducting some model diagnostics. To do the model diagnostics, we start with the fixed-effects model and plot the four standard diagnostic plots:

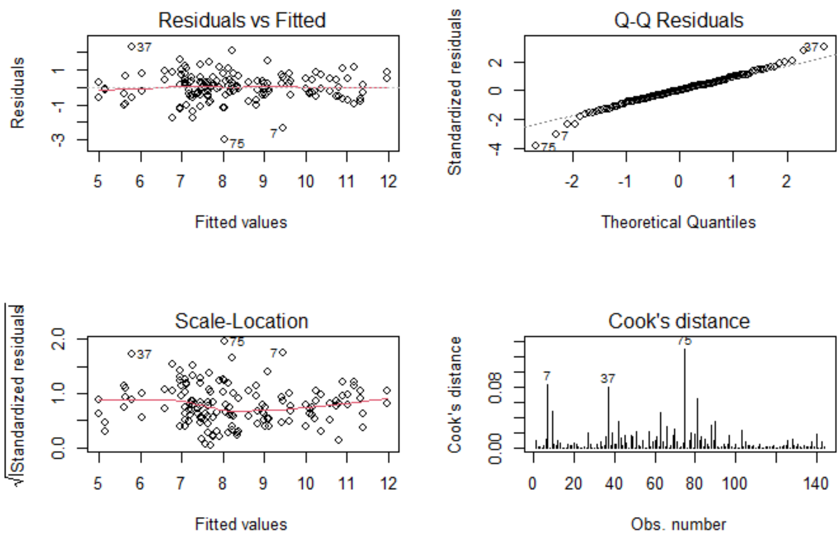

Figure 4: Four Standard Diagnostics Plots

Figure 4 displays residuals that are largely symmetrical in their distribution, closely aligning with a normal distribution, except for a few notable outliers at the extremes. Additionally, the plots comparing residuals to predicted values suggest that the model may have overlooked some significant structures within the data.

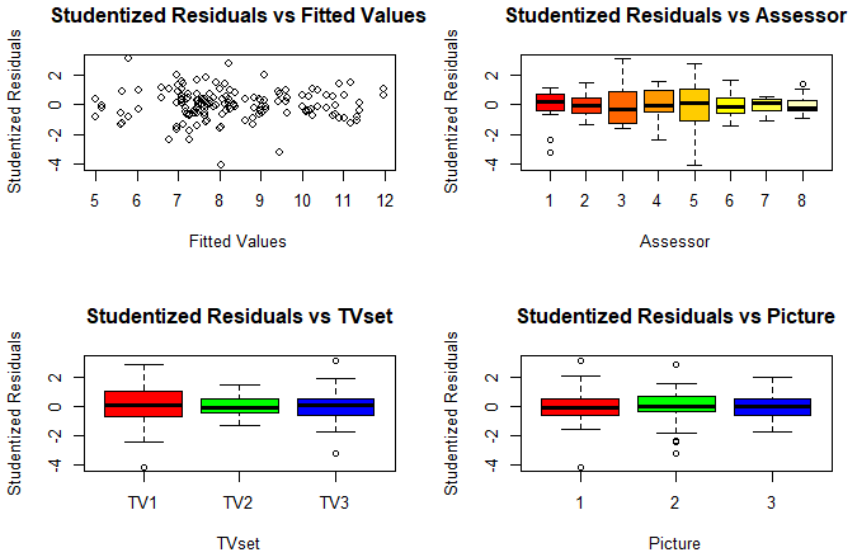

Figure 5: Diagnostic Plots of Studentized Residuals

In Fig: 5 we see the Residuals versus predicted values and factor levels for the model. For the three TVset and Pictures the variance looks similar. For the eight assessors it seems to be differences in variability.

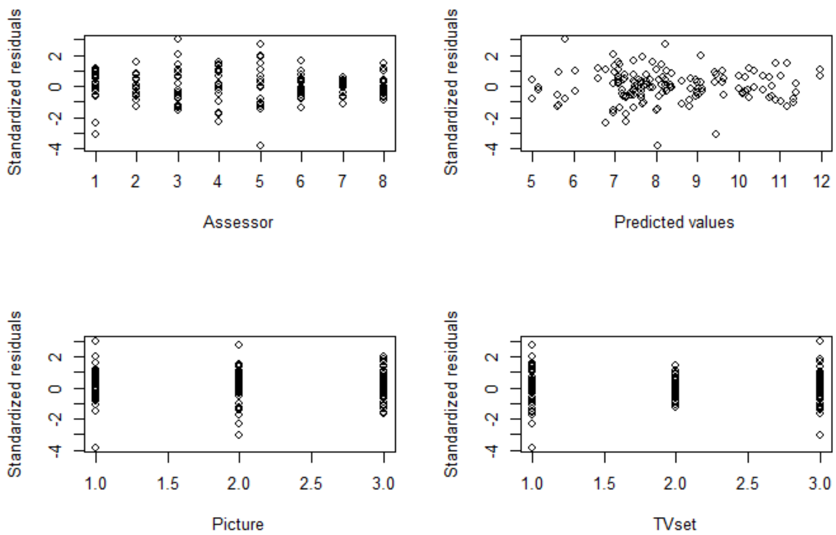

Figure 6: Diagnostic Plots of Standardized Residuals Against Predictors for the Linear Model

The output in Fig: 6 doesn't reveal something critical.

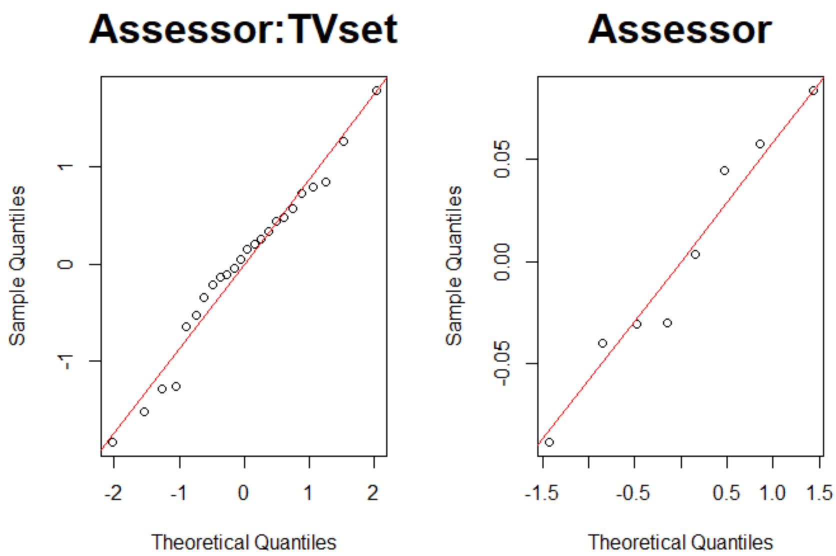

Figure 7: QQ Plot for Random Effects

In the Fig: 7 it seems that the estimated random effects are nicely distributed.

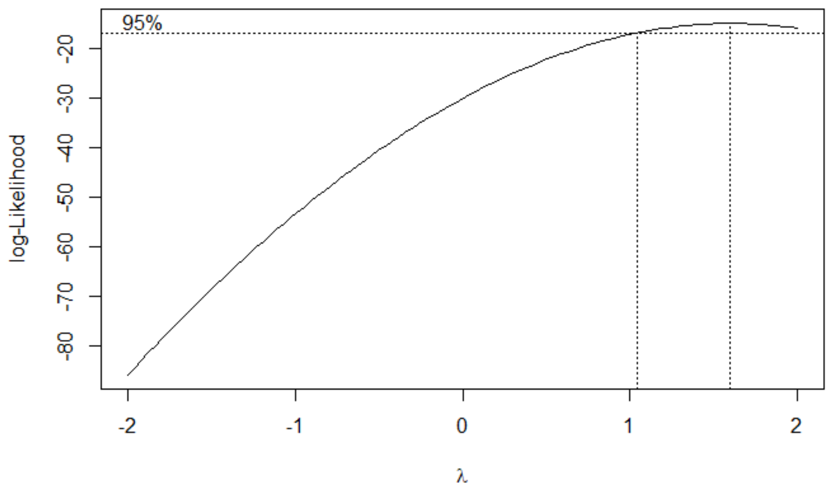

Figure 8: BoxCox

From the Fig: 8 we have to remodel the reciprocal of the maillard and repeat the diagnosis again. We try for (λ=3/2).

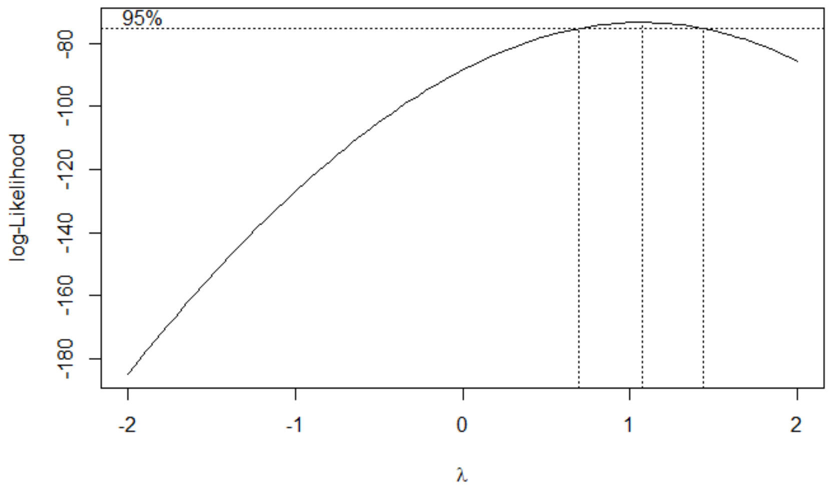

Figure 9: New BoxCox ($\lambda = 3/2$)

3.1.2 Second Model Diagnosis

Here we will do again the same analysis and evaluate the new model.

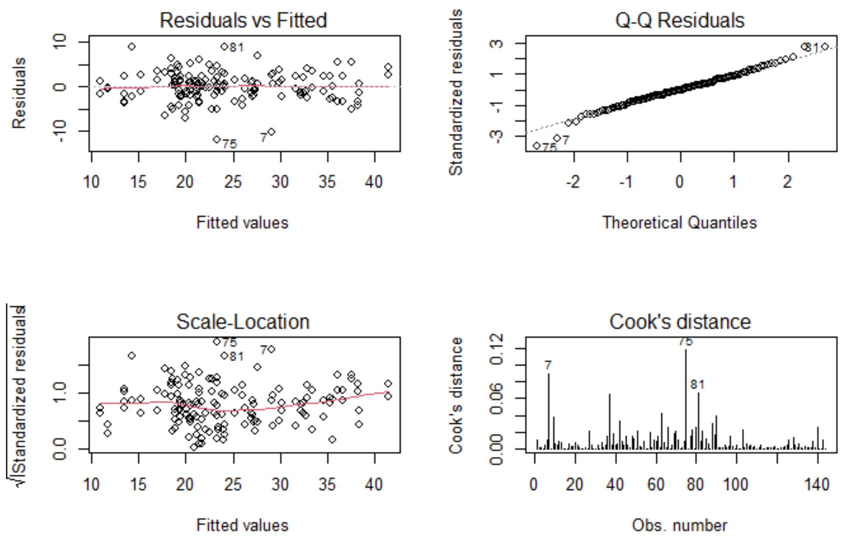

Figure 10: Four Standard Diagnostics Plots

We see that the residuals seem to be symmetrically distributed, and that the normal distribution seems to fit quite well apart from, maybe, a few extremely small and large values. In the two plots that illustrating the residuals versus the predicted values we see that our model doesn't seem to have not taken account important structures in the data.

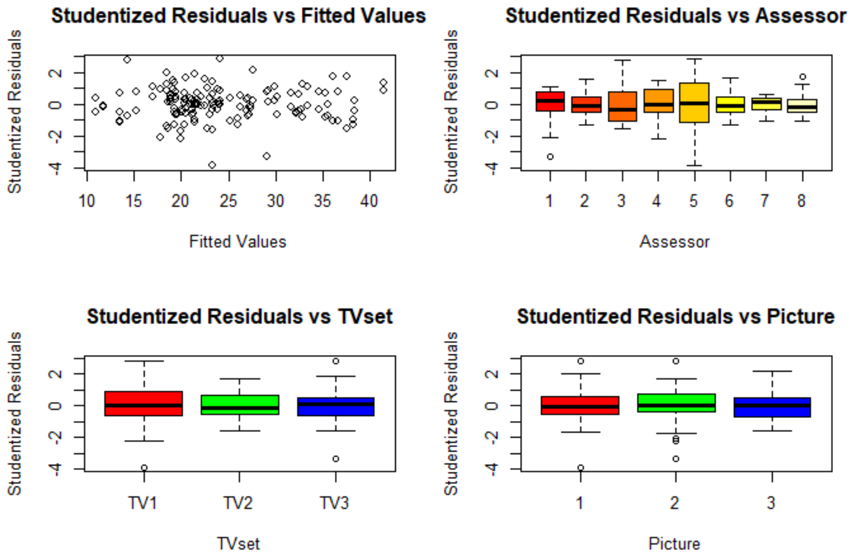

Figure 11: Diagnostic Plots of Studentized Residuals

In Fig: 11 the plots of the residuals versus the factor levels of TVset, Picture and Assessor indicate no problems with heterogeneity.

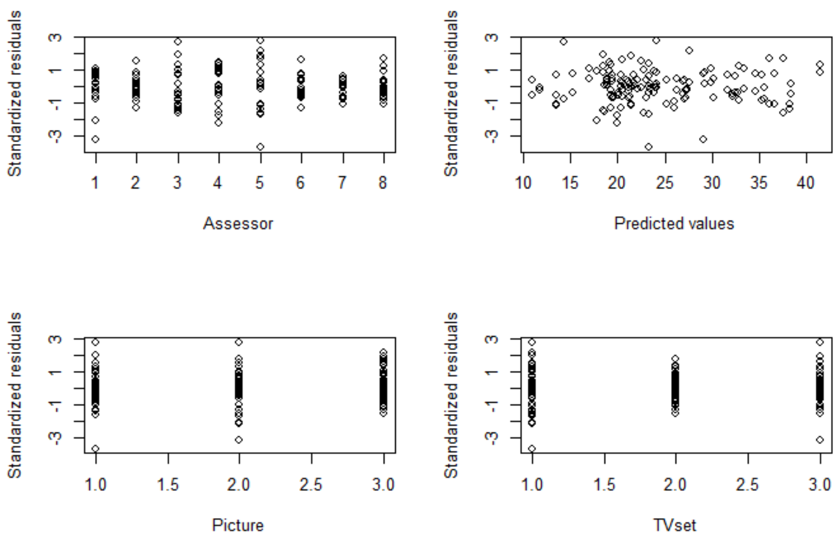

Figure 12: Diagnostic Plots of Standardized Residuals Against Predictors for the Linear Model

The output in Fig: 12 doesn't reveal something critical again.
In Fig: 13 we see that now the estimated randoms effects are distributed even better than previous.

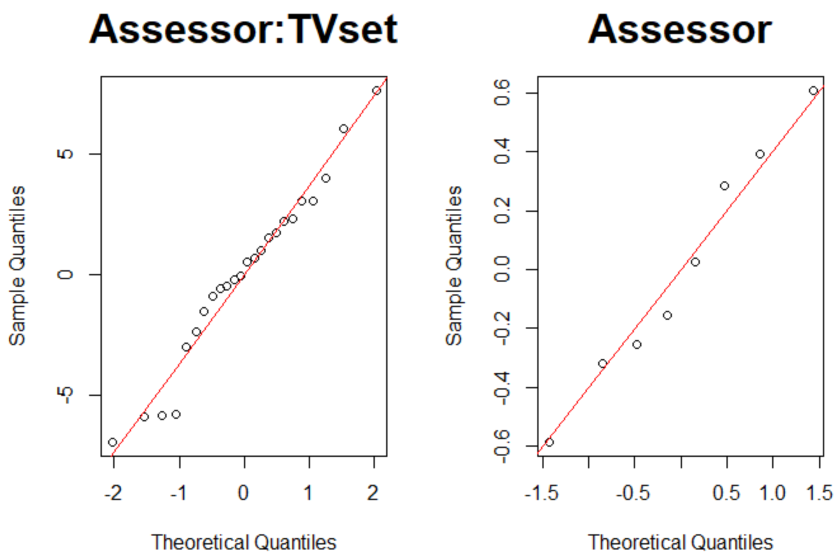

Figure 13: QQ Plot for Random Effects

3.2 Results

3.2.1 Anova

Performing the mixed model analysis as outlined in Equation (2) we have the results in the following ANOVA table for fixed and mixed effects:

	Numerator degrees of freedom	Denominator degrees of freedom	F- statistics	P-value
TVset	2	14	16.1740	0.0002294***
Picture	2	114	6.8228	0.0015895**
TVset:Picture	4	114	2.4373	0.0510831.

Table 3: Anova for Fixed Effects

Model	logLik	AIC	LRT	P-value
<none>	-401.33	826.65	-	-
(1 | Assessor)	-401.35	824.71	0.058	0.8104
(1 | Assessor:TVset)	-426.63	875.26	50.610	$1.127 \times 10^{-12***}$

Table 4: Anova for Random Effects

Our analysis reveals that both TVset and Picture, along with their interaction, are statistically significant, though to different extents. Furthermore, the interaction between Assessor and TVset has a highly significant random effect.

3.2.2 Post-hoc Analysis

Estimation of the Variance Parameters

At a 95% profile likelihood confidence limits, the uncertainties of the estimated values on standard deviation scale are on Table 6.

Groups	Name	Std.Dev.
Assessor:TVset	(Intercept)	4.2146
Assessor	(Intercept)	1.0584
Residual	–	3.6153

Table 5: Standard Deviations

	2.5%	97.5%
Assessor:TVset	2.697648	5.670204
Assessor	0.000000	4.039217

Table 6: Confidence Intervals

Estimation of the Fixed Parameters

Tukey-adjusted pairwise comparisons were used to assess differences between levels of the TVset, Picture, and TVset:Picture variables, providing a detailed evaluation of the distinct categories.

TVset	Estimate	SE	Lower	Upper
TV1	21.0	1.62	17.6	24.4
TV2	31.7	1.62	28.4	35.1
TV3	20.5	1.62	17.1	23.9

Table 7: TVset Estimations

Picture	Estimate	SE	Lower	Upper
1	23.7	1.07	21.3	26.1
2	23.5	1.07	21.1	25.9
3	26.0	1.07	23.6	28.4

Table 8: Picture Estimations

TVset	Picture	Estimate	SE	Lower	Upper
TV1	1	19.3	1.78	15.7	23.0
TV2	1	30.9	1.78	27.3	34.6
TV3	1	21.0	1.78	17.3	24.6
TV1	2	20.1	1.78	16.5	23.8
TV2	2	30.2	1.78	26.6	33.9
TV3	2	20.2	1.78	16.6	23.8
TV1	3	23.6	1.78	20.0	27.2
TV2	3	34.1	1.78	30.4	37.7
TV3	3	20.3	1.78	16.6	23.9

Table 9: TVset:Picture Estimations

Comparisons of the Fixed Parameters

contrast	Estimate	SE	P-value
TV1 - TV2	-10.72	2.23	0.0008
TV1 - TV3	0.54	2.23	0.9684
TV2 - TV3	11.26	2.23	0.0005

Table 10: TVset Contrast

contrast	estimate	SE	P-value
Picture1 - Picture2	0.213	0.738	0.9550
Picture1 - Picture3	-2.247	0.738	0.0081
Picture2 - Picture3	-2.460	0.738	0.0033

Table 11: Picture Contrast

Contrast	Estimate	SE	P-value
TV1 Picture1 - TV2 Picture1	-11.5975	2.46	0.0032
TV1 Picture1 - TV3 Picture1	-1.6385	2.46	0.9988
TV1 Picture1 - TV1 Picture2	-0.8119	1.28	0.9994
TV1 Picture1 - TV2 Picture2	-10.8968	2.46	0.0061
TV1 Picture1 - TV3 Picture2	-0.8871	2.46	1.0000
TV1 Picture1 - TV1 Picture3	-4.2797	1.28	0.0293
TV1 Picture1 - TV2 Picture3	-14.7507	2.46	0.0002
TV1 Picture1 - TV3 Picture3	-0.9463	2.46	1.0000
TV2 Picture1 - TV3 Picture1	9.9590	2.46	0.0142
TV2 Picture1 - TV1 Picture2	10.7856	2.46	0.0068
TV2 Picture1 - TV2 Picture2	0.7007	1.28	0.9998
TV2 Picture1 - TV3 Picture2	10.7104	2.46	0.0072
TV2 Picture1 - TV1 Picture3	7.3179	2.46	0.1284
TV2 Picture1 - TV2 Picture3	-3.1531	1.28	0.2594
TV2 Picture1 - TV3 Picture3	10.6512	2.46	0.0076
TV3 Picture1 - TV1 Picture2	0.8266	2.46	1.0000
TV3 Picture1 - TV2 Picture2	-9.2584	2.46	0.0262
TV3 Picture1 - TV3 Picture2	0.7514	1.28	0.9996
TV3 Picture1 - TV1 Picture3	-2.6412	2.46	0.9723
TV3 Picture1 - TV2 Picture3	-13.1122	2.46	0.0008
TV3 Picture1 - TV3 Picture3	0.6922	1.28	0.9998
TV1 Picture2 - TV2 Picture2	-10.0850	2.46	0.0127
TV1 Picture2 - TV3 Picture2	-0.0752	2.46	1.0000
TV1 Picture2 - TV1 Picture3	-3.4678	1.28	0.1550
TV1 Picture2 - TV2 Picture3	-13.9388	2.46	0.0004
TV1 Picture2 - TV3 Picture3	-0.1344	2.46	1.0000
TV2 Picture2 - TV3 Picture2	10.0097	2.46	0.0136
TV2 Picture2 - TV1 Picture3	6.6172	2.46	0.2127
TV2 Picture2 - TV2 Picture3	-3.8538	1.28	0.0743
TV2 Picture2 - TV3 Picture3	9.9505	2.46	0.0143
TV3 Picture2 - TV1 Picture3	-3.3925	2.46	0.8943
TV3 Picture2 - TV2 Picture3	-13.8635	2.46	0.0004
TV3 Picture2 - TV3 Picture3	-0.0592	1.28	1.0000
TV1 Picture3 - TV2 Picture3	-10.4710	2.46	0.0090
TV1 Picture3 - TV3 Picture3	3.3334	2.46	0.9029
TV2 Picture3 - TV3 Picture3	13.8043	2.46	0.0004

Table 12: TVset:Picture Contrast

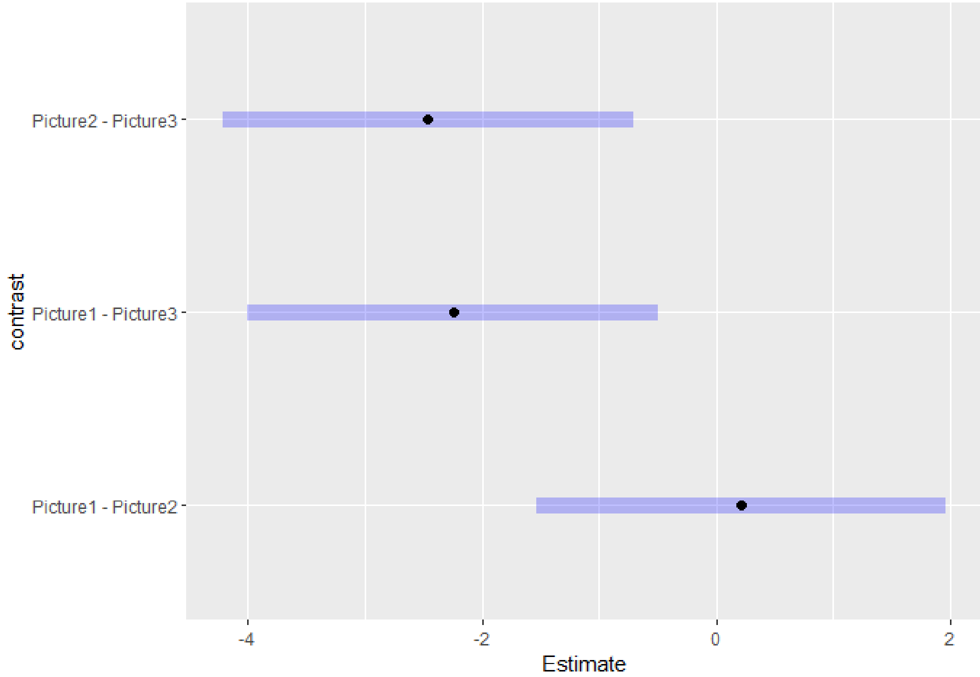

Figure 15: Contrast Plot for Picture

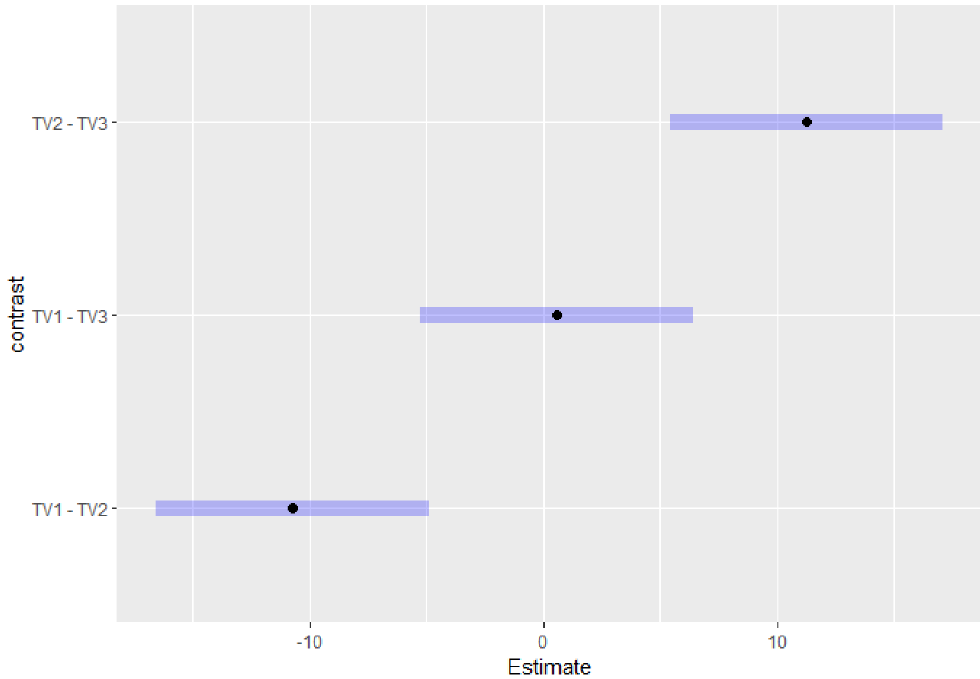

Figure 14: Contrast Plot for TVset

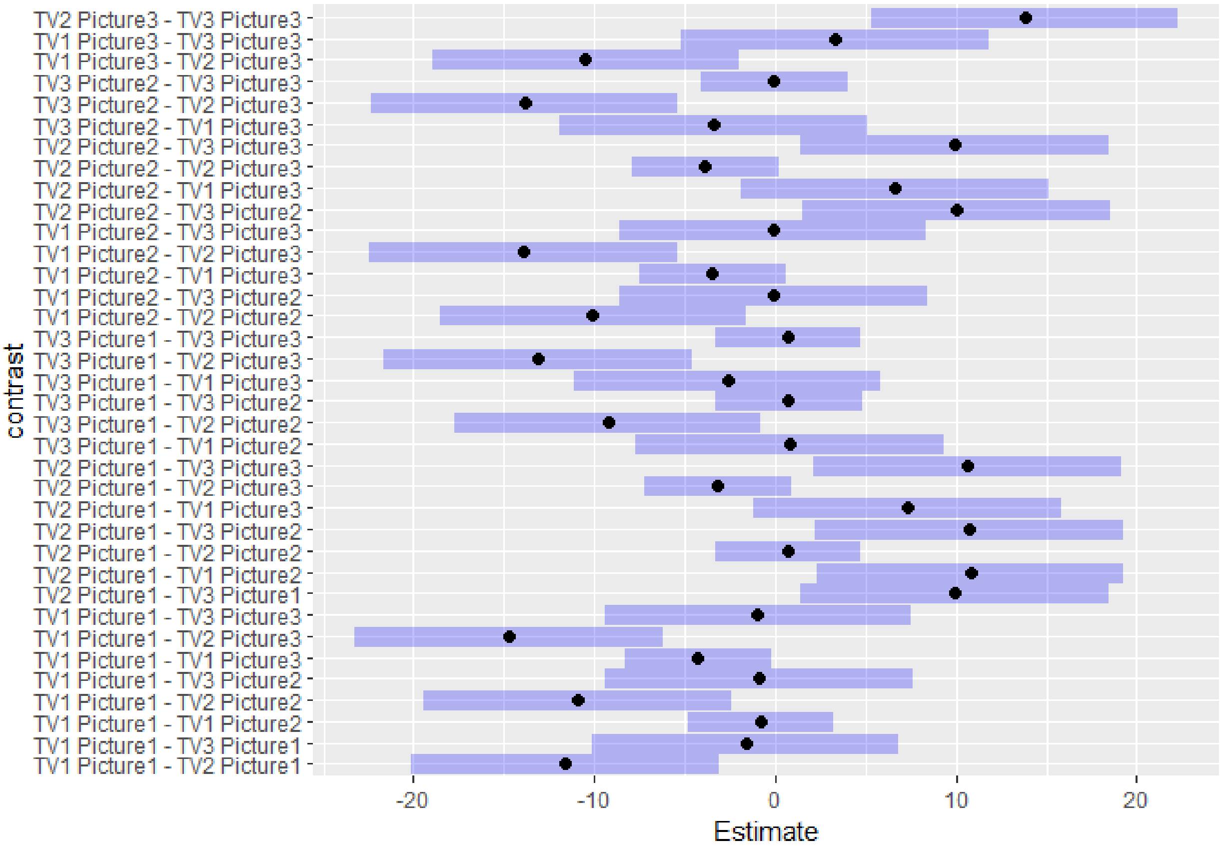

Figure 16: Contrast Plot for TVset:Picture

Tables 10 through 12 and Figures 14 through 16 demonstrate significant differences between TVset2 and TVset3, as well as between TVset1 and TVset2. This is evidenced by confidence intervals that do not cross zero and very low p-values. Similarly, significant differences are observed between Picture2 and Picture3, as well as between Picture1 and Picture3, for the same reasons. In Table 12 the variable with statistically significant p-values and in addition their confidence intervals don't cross zero TV2 Picture3 - TV3 Picture3, TV3 Picture2 - TV2 Picture3, TV3 Picture1 - TV2 Picture3, TV1 Picture2 - TV2 Picture3, TV1 Picture1 - TV2 Picture3 and TV1 Picture1 - TV2 Picture1.

4 Conclusion

According to the results obtained in the Statistical Analysis with Assessor as a random factor, and TVset and Picture as fixed factors, it is evident that TVset, Picture, and the interaction between Assessor and TVset hold statistical significance within the model. From the analysis of the confidence intervals, TV2 surfaces as a dominant level within the TVset category, whereas Picture 3 exerts significant influence within the Picture category. Significant contrasts observed between various levels and interactions indicate a complex interplay of factors influencing the response variable. When Assessor is considered a random factor, the distinct levels of this variable are presumed to exhibit random variations amongst themselves, as each level represents a subset of a more extensive population. This modeling approach effectively encapsulates the variability potentially arising from uncontrolled factors.

List of Figures

List of Tables

5 Appendix A

article listings xcolor

```
#Libraries
library(ggplot2)
library(diagram)
library(emmeans)
library(lmerTest)
library(emmeans)
library(dplyr)
library(MASS)
library(car)
library(multcomp)

#reading in data:
assignment2 <- read.table("assignment2.txt", header = TRUE, sep = "\t
   ")
str(assignment2)
head(assignment2)
assignment2$Assessor <- as.factor(assignment2$Assessor)
assignment2$TVset <- as.factor(assignment2$TVset)
assignment2$Picture <- as.factor(assignment2$Picture)
assignment2$Repeat <- as.factor(assignment2$Repeat)

#Check if Factors are Balanced
assignment2 %>%
  group_by(Assessor, TVset, Picture, Repeat) %>%
  summarise(count = n()) %>%
  ungroup() %>%
  arrange(count)

#---------Diagramms---------#

par(mfrow=c(2,3))
for (var_name in c('Assessor', 'TVset', 'Picture')) {
  k <- length(levels(as.factor(assignment2[,var_name]))) + 1
  boxplot(as.formula(paste("Coloursaturation ~", var_name)),
          col = 2:k, main = paste("Coloursaturation vs.", var_name),
          data = assignment2)
}

# Histogram
f <- function(x) {
  dnorm(x, mean = mean(assignment2$Coloursaturation), sd = sd(
     assignment2$Coloursaturation))
}
```

```
hist(assignment2$Coloursaturation, xlab='Coloursaturation', probability=T, main = "Distribution of Coloursaturation")
curve(f, from = min(assignment2$Coloursaturation), to = max(assignment2$Coloursaturation), lwd=3, col="red", add=T)
rm(f)
par(mfrow=c(1,1))


#Interaction Plot
par(mfrow=c(2,2))
with(assignment2, {
  interaction.plot(TVset, Picture, Coloursaturation, legend=FALSE,
                   bty="n", col=2:4, xtick = TRUE,
                   main = "Interaction Between TVset and Picture")
  interaction.plot(TVset, Assessor, Coloursaturation, legend=FALSE,
                   bty="n", col=2:9, xtick = TRUE,
                   main = "Interaction Between TVset and Assessor")
  interaction.plot(Picture, Assessor, Coloursaturation, legend=FALSE,
                   bty="n", col=2:9, xtick = TRUE,
                   main = "Interaction Between Picture and Assessor")
})
par(mfrow=c(1,1))

#Check the significance of the interaction

analysis.lmer <- lmer(Coloursaturation ~ TVset + Picture + Repeat + TVset:Picture + TVset:Repeat
                      + Picture:Repeat + (1|Assessor) + (1|Assessor:TVset) + (1|Assessor:Picture) + (1|Assessor:Repeat), data = assignment2)
ranova(analysis.lmer)
anova(analysis.lmer)

#Factor Diagram
y.names <- c(expression("[I]" [114]^{144}),
                   expression("[Assessor:TVset]" [14]^{24}),
                   expression("TVset:Picture" [4]^{9}),
                   expression("[Assessor]" [7]^{8}),
                   expression("TVset" [2]^{3}),
                   expression("Picture" [2]^{3}),
                   expression("[0]" [1]^{1}))
M <- matrix(nrow = 7, ncol = 7, byrow = TRUE, data = 0)
M[2,1] <- M[3,1] <- M[4,2] <- M[5,2] <- M[5,3] <- M[6,3] <- M[7,4] <- M[7,5] <- M[7,6] <- ""
plotmat(M, pos = c(1,2,3,1), name = y.names, lwd = 2,
        box.lwd = 2, cex.txt = 1, box.size = 0.12,
```

```
        box.type ="square", box.prop = 0.2, arr.type = "triangle",
           curve = 0)

#---------Fixed model---------#
analysis.lm <- lm(Coloursaturation ~ Assessor + TVset + Picture +
   Assessor:TVset + TVset:Picture, data = assignment2)
summary(analysis.lm)

#---------Mixed model---------#
analysis.lmer <- lmer(Coloursaturation ~ TVset + Picture + TVset:
   Picture + (1|Assessor) + (1|Assessor:TVset), data = assignment2)
summary(analysis.lmer)

#---------Model Diagnostics---------#

par(mfrow=c(2,2))
plot(analysis.lm, which=1:4)
par(mfrow=c(1,1))
par(mfrow=c(2,2))
plot(as.numeric(assignment2$Assessor), rstandard(analysis.lm),
     xlab = 'Assessor', ylab = 'Standardized residuals')
plot(predict(analysis.lm), rstandard(analysis.lm),
     xlab = 'Predicted values', ylab = 'Standardized residuals')
plot(as.numeric(assignment2$Picture), rstandard(analysis.lm),
     xlab = 'Picture', ylab = 'Standardized residuals')
plot(as.numeric(assignment2$TVset), rstandard(analysis.lm),
     xlab = 'TVset', ylab = 'Standardized residuals')
par(mfrow=c(1,1))
studresid = studres(analysis.lm)
par(mfrow = c(2, 2))
plot(studresid ~ fitted(analysis.lm),
     xlab = "Fitted Values",
     ylab = "Studentized Residuals",
     main = "Studentized Residuals vs Fitted Values")
with(assignment2, plot(studresid ~ Assessor,
                       xlab = "Assessor",
                       ylab = "Studentized Residuals",
                       col = heat.colors(length(unique(Assessor))),
                       main = "Studentized Residuals vs Assessor"))
with(assignment2, plot(studresid ~ TVset,
                       xlab = "TVset",
                       ylab = "Studentized Residuals",
                       col = rainbow(length(unique(TVset))),
                       main = "Studentized Residuals vs TVset"))
with(assignment2, plot(studresid ~ Picture,
                       xlab = "Picture",
```

```
                            ylab = "Studentized Residuals",
                            col = rainbow(length(unique(Picture))),
                            main = "Studentized Residuals vs Picture"))
par(mfrow = c(1, 1))

##Check the normality of the random effects
temp<-names(ranef(analysis.lmer))
temp
par(mfrow=c(1,2))
for(i in 1:2){
qqnorm(unlist(ranef(analysis.lmer)[[i]]),main=paste(temp[i]),cex.main
   =2)
lines((-3):3,sd(unlist(ranef(analysis.lmer)[[i]]))*((-3):3),col="red"
   )
}
par(mfrow=c(1,1))

#Box Cox
boxcox(analysis.lm)
par(mfrow = c(1, 1))

#New model for transformed data
analysis.lmer.tr <- lmer((Coloursaturation)^(3/2) ~ TVset + Picture +
     TVset:Picture + (1|Assessor) + (1|Assessor:TVset), data =
   assignment2)
summary(analysis.lmer)

analysis.lm.tr <- lm((Coloursaturation)^(3/2) ~ Assessor + TVset +
   Picture + Assessor:TVset + TVset:Picture, data = assignment2)
boxcox(analysis.lm.tr)

#---------Model Diagnostics for transformed data---------#
par(mfrow=c(2,2))
plot(analysis.lm.tr, which=1:4)
par(mfrow=c(1,1))
par(mfrow=c(2,2))
plot(as.numeric(assignment2$Assessor), rstandard(analysis.lm.tr),
     xlab = 'Assessor', ylab = 'Standardized residuals')
plot(predict(analysis.lm.tr), rstandard(analysis.lm.tr),
     xlab = 'Predicted values', ylab = 'Standardized residuals')
plot(as.numeric(assignment2$Picture), rstandard(analysis.lm.tr),
     xlab = 'Picture', ylab = 'Standardized residuals')
plot(as.numeric(assignment2$TVset), rstandard(analysis.lm.tr),
     xlab = 'TVset', ylab = 'Standardized residuals')
par(mfrow=c(1,1))
studresid = studres(analysis.lm.tr)
```

```
par(mfrow = c(2, 2))
plot(studresid ~ fitted(analysis.lm.tr),
     xlab = "Fitted Values",
     ylab = "Studentized Residuals",
     main = "Studentized Residuals vs Fitted Values")
with(assignment2, plot(studresid ~ Assessor,
                       xlab = "Assessor",
                       ylab = "Studentized Residuals",
                       col = heat.colors(length(unique(Assessor))),
                       main = "Studentized Residuals vs Assessor"))
with(assignment2, plot(studresid ~ TVset,
                       xlab = "TVset",
                       ylab = "Studentized Residuals",
                       col = rainbow(length(unique(TVset))),
                       main = "Studentized Residuals vs TVset"))
with(assignment2, plot(studresid ~ Picture,
                       xlab = "Picture",
                       ylab = "Studentized Residuals",
                       col = rainbow(length(unique(Picture))),
                       main = "Studentized Residuals vs Picture"))
par(mfrow = c(1, 1))

##Check the normality of the random effects
temp<-names(ranef(analysis.lmer.tr))
temp
par(mfrow=c(1,2))
for(i in 1:2){
qqnorm(unlist(ranef(analysis.lmer.tr)[[i]]),main=paste(temp[i]),cex.
   main=2)
lines((-3):3,sd(unlist(ranef(analysis.lmer.tr)[[i]]))*((-3):3),col="
   red")
}
par(mfrow=c(1,1))

#---------Statistical analysis---------#

model <- lmer((Coloursaturation)^(3/2) ~ TVset + Picture + TVset:
   Picture + (1|Assessor) + (1|Assessor:TVset), data = assignment2,
   REML = TRUE)
anova(model, test.statistic = "F", type = 3)
ranova(model)
anova(analysis.lmer.tr, analysis.lm.tr)

#Post-hoc

# Estimation of variance parameters
```

```
VarCorr(model)

# Profile likelihood-based confidence intervals for the variance
   parameters
profile_ci <- profile(model, which=1:2, signames=FALSE)
confint(profile_ci)

# Estimated mean levels and their differences for TVset
emm_tvset <- emmeans(model, pairwise ~ TVset)
emm_tvset
plot(emm_tvset[[2]], xlab = 'Estimate')

# Estimated mean levels and their differences for Picture
emm_picture <- emmeans(model, pairwise ~ Picture)
emm_picture
plot(emm_picture[[2]], xlab = 'Estimate')

# Compact letter displays for TVset
tuke_int_tvset <- glht(model, linfct = mcp(TVset="Tukey"))
tuke_int_tvset_2 <- cld(tuke_int_tvset)
tuke_int_tvset_2
plot(tuke_int_tvset_2, col=2:6, main = '')

# Compact letter displays for Picture
tuke_int_picture <- glht(model, linfct = mcp(Picture="Tukey"))
tuke_int_picture_2 <- cld(tuke_int_picture)
tuke_int_picture_2
plot(tuke_int_picture_2, col=2:6, main = '')

# Estimated mean levels and their differences for TVset:Picture
emm_TVPi <- emmeans(model, pairwise ~ TVset:Picture)
emm_TVPi
plot(emm_TVPi[[2]], xlab = 'Estimate')
```