No Time-of-day Effect on Reaction Time

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Executive Summary

There is no main effect of time of day on the reaction time, but there is interaction effect of time of day with the protocol on the reaction time. Fatigue is a covariate that has a positive effect on the reaction time.

1 Introduction

Reaction time is the shortest time required for a person to react to an environmental change. Reaction time differs for different people due to inborn factors such as genes and neuron-network. It also differs due to the condition of the person during the environmental change, such as his/her fatigue level, hunger level, illness, etc. Reaction time is very important in many situations, such as driving, emergency situations, and even day-to-day work. We investigated in what period of time does a person react the fastest, in order to decide his/her optimal time to perform a task such as driving. We also investigated the key factor that affects the reaction time of a person. This also helps us to analyze the reaction time in the personal condition point of view.

The aim of this report is to analyze the effect of the time in a day on the persons reaction time. There are two types of effect, one in the main effect, which is the reaction time increases or decreases directly due to the changing of the time of day. The other one is the interaction effect, which is the increasing or decreasing of the reaction time due to the changing of the time of day are different depends on the participant's personal condition. The objectives of the study are analyzing both the main effect and the interaction effect in order to fully understand the effect of the time of day. Secondarily, we reveal the personal conditions which also affect his/her reaction time significantly. The remainder of this report is organized as follows. In the Method Section, we described the analysis approaches for the two research questions. We first analyzed the effect of the time of day itself on the reaction time. We then interpreted the personal conditions for the interaction effect. Lastly, in the method section, we analyzed how the personal conditions contribute to the reaction time as covariates. In the result, we found that although the time of day of a person doing the reaction time test has no effect on the reaction time generally, the effect of time of day on the reaction time depends on if he or she follows the protocol. We also found that the level of fatigue of a person when doing the reaction time test has a positive effect on his or her reaction time. In the discussion, we summarized our findings and addressed some limitations of our study.

2 Method

There are eight variables represent eight personal conditions. They are stimulant, busy/-light, illness, sleep, protocol, MEQ, level of hunger and level of fatigue. In the stage of data cleaning, We considered coffee and smoking as stimulants. For the variable busy/light, 1 is busy, 0 is light. For the variable illness, 1 is sick, 0 is not sick. The variable sleep represents the number of sleep in one decimal place. The variable protocol indicated if the person followed the protocol, 1 is followed, 0 is not followed. The variable MEQ(Morning Evening Questionnaire) represents the type of a person. We group it into three levels (Morning, Neither, and Evening). For the variable time of day, we change its format from data to number for further regression.

We noticed that there are many missing values in the data. They are mainly two types. One is missing reaction time and the other is missing time or missing other eight variables. We first deleted all observations that have missing reaction time (n=8). For the second type of missing value, we replaced them by mean values if they are quantitative variables or replaced them by the most common values if they are categorical variables.

2.1 MODEL 1

In the stage of data analysis, We first addressed the research question: Does the time of day have an effect on the reaction time. First, we plotted the reaction time versus the time of day to see if there is any potential main effect that is directly caused by the explanatory variable time of day (Figure 1) (the other variables are not specified). Figure 1 illustrated that the reaction time tested between 15:00 to 20:00 are shorter than reaction time tested between 7:00 to 10:00.

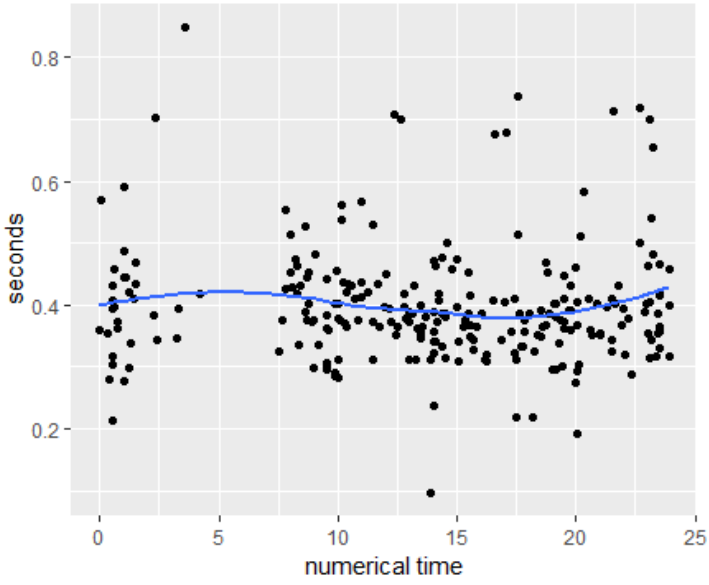


Figure 1: Reaction time versus time of day

Therefore, there are some potential patterns of reaction time during a day. Next, We carried out a regression model to analyze the relationship between the explanatory variable time of day and the response variable log of reaction time. Based on the way we collected the data, every subject has eight dependent observations. Therefore, we chose the linear mixed regression model to analyze the effect of the time of day on the reaction time. That is, each subject has a random intercept differs from others and every subject has a fixed effect the time of day that impact to their reaction time. model 1 is $log(Reaction\ time) = \beta_0 + \beta_1 \times numtime + u_i + \epsilon_{ik}$, where u_i is random effect, ϵ_{ik} is random error.

We also checked three assumptions of model 1, which are the linearity, the normality of the residuals, and the homoscedasticity of the residuals. We identified two outliers and nine influentials points from model 1. We checked the impact of outliers by two approaches in order to decide if to remove them. The first is comparing the beta 0 and beta 1 of pre- and post-outlier removal regression models. Same procedure repeated for influential points. We kept outliers or influential points if the changes of beta are small. Otherwise, we removed outliers or influential points.. The second is to check if removing outliers could meet model assumptions, which are the normality of residuals and the homoscedasticity of the residuals. Same procedures of assumption checking repeated for model 2(the interaction model) and model 3(the final fitted model).

2.2 MODEL 2

The next analysis we did after model 1 was checking the interaction effects between other eight variables with the explanatory variable time of day. In this study, we are interested in if the effect of the explanatory variable time of day varies when the value of another variable changed. For example, if the reaction time increases as the time of day increases for an evening person, but the reaction time decreases as the time of day decreases for a morning person, then we say the explanatory variable time of day has an interaction effect with the explanatory variable MEQ. If the reaction time increases faster for an evening person than a morning person as the time of day increases, then there is also an interaction effect between the explanatory variable time of day and the explanatory variable MEQ.

To test the interaction effect of each variable with the explanatory variable time of day, we built two models to test each variable. One is the additive model and one is the interaction model. We compared the two models using the ANOVA comparison in order to analyze the significant level of the interaction effect of the certain variable with the time of day. If the interaction of a certain variable with the time of day is significant, we add that term into the model 1. Same procedures replicated for all the eight variables(so 16 models in total). We also checked three assumptions of model 2, which are the linearity, the normality of the residuals, and homoscedasticity of the residuals.

2.3 MODEL 3

For the secondary analysis, we were still interested in the personal conditions that affect the reaction time of a person. To reveal the relationship between the personal conditions (which are the eight variables) and the reaction time, we computed the correlation between each variable and the reaction time(table 1). If it is close to 0, then we can include this variable into our full model for further model comparison. If its absolute value close to 1, then this variable has a strong correlation to the explanatory variable time of day, further investigation needs to perform. For the numerical variables, we also plotted the scatter plots of the reaction time versus the numerical variables, which are fatigue, hunger, and sleep.

We included variables that have potential effects and zero collinearity in the model 2. It has the explanatory variable time of day, the interaction term(s), and some or all of the eight variables. We called it the full model. We then reduced the full model to the fitted model (model 3)by the backward process and ANOVA comparisons. The explanatory variables of the fitted model we found would have the time of day, the covariate(s), and the interaction term(s). We also checked three assumptions of model 3, which are the linearity, the normality of the residuals, and homoscedasticity of the residuals.

3 Result Section

3.1 MODEL 1

Model 1 has problems regard to all three assumptions for linear mixed regression. To make model 1 linear meet the three assumptions, we transform the response variable by the log function and removed one outlier. We used the transformed response variable for the following model 2 and model 3 as well. (model 1 $log(Reaction\ time_{ik}) =$

$-0.913185 - 0.002786 \times numtime_k + u_i + \epsilon_{ik}$). We then performed model 1 again and found that the time of day has no significant main effect on the reaction time (p-value is 0.08). As the time increasing from 0:00 to 23:59, reaction time is decreasing very slowly (0.40s at 0:00AM, 0.39 at 12:00PM, 0.38 at 23:59)(Figure 2).

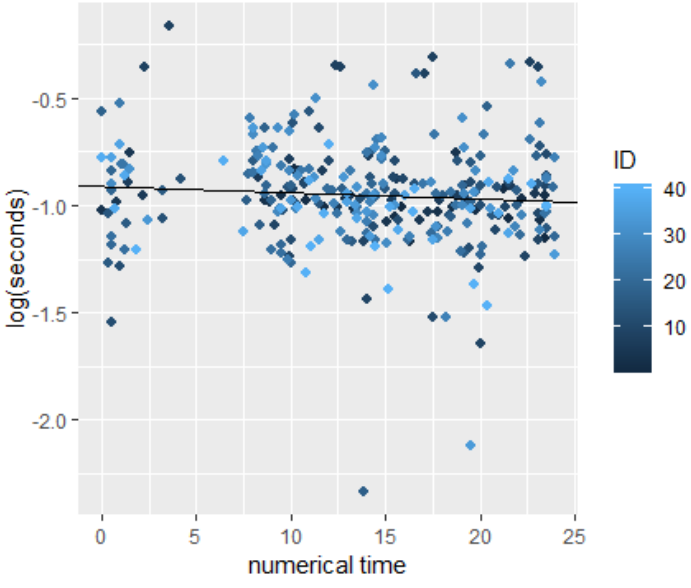


Figure 2: model 1

3.2 MODEL 2

For the interaction analysis, there is a crossover interaction between the time of day and the protocol (p-value is 0.04) (Figure 3). We could see that the reaction time increases substantially as time increases when the protocol is 1, and it decreases slowly as time increases when the protocol is 0. However, the overall slope of the reaction time versus the time of day should still be the later one (which is what we found in Figure 1), because there are only 3 observations for the protocol is 0, but 304 observations for the protocol is 1. Since the variable protocol has a significant effect, we then added the interaction term to model 1. Model 2 is $log(Reaction\ time_{ijk}) = -0.913336 - 0.002899 \times numtime_k + 0.011125 \times numtime \times protocol_j + u_{ij} + \epsilon_{ijk}$. We also removed four outliers to make model 2 valid.

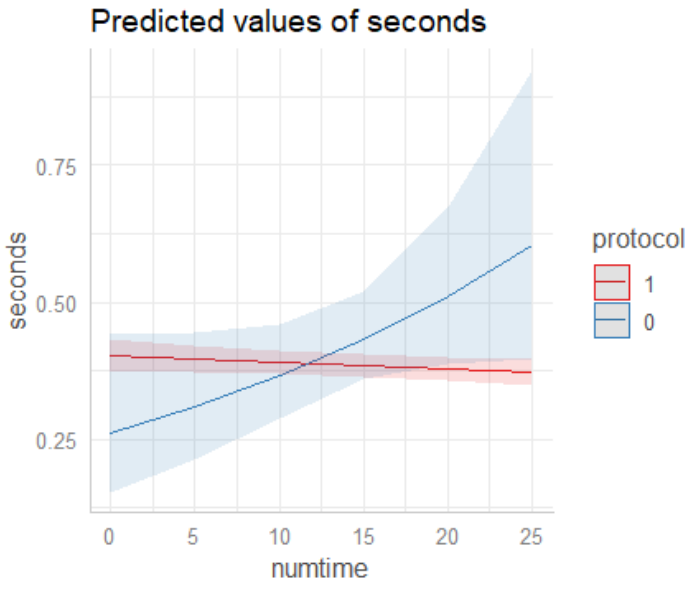


Figure 3: Interaction Analysis

3.3 MODEL 3

There is no collinearity between these seven variables and the explanatory variable time of day because the correlations between each variable and the time of day respectively are close to zero (table 1)(we excluded the variable protocol because it has an interaction effect with the time of day. This made it into seven collinearities).

	Correlation
fatigue	0.20001600
hunger	-0.13329432
sleep	-0.07953758
MEQ	-0.15746238
busy light	-0.06044544
illness	0.09910313
stimulant	0.05865953

From the scatter plots, we found that the variable fatigue has a positive effect with the reaction time (figure 4). We were unable to analyze the potential effect of the other six personal conditions on the reaction time since their relationships are nonlinear (please see Appendix for the other figures).

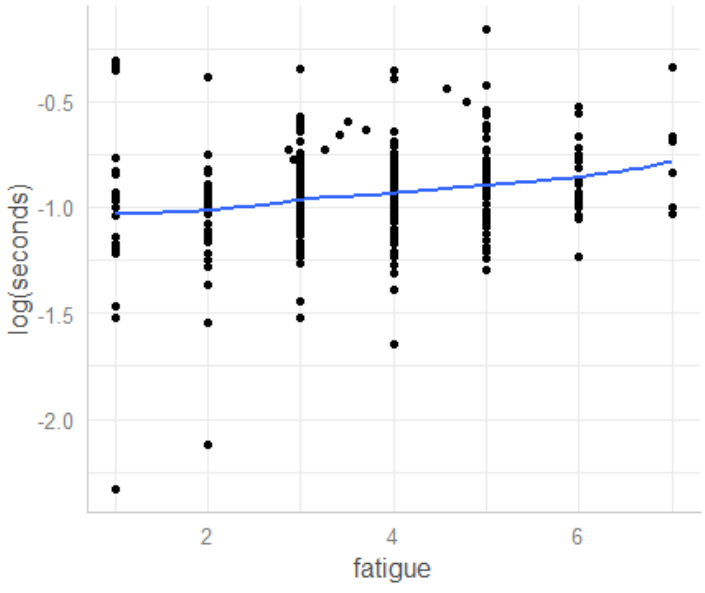


Figure 4: scatter plot of the reaction time versus fatigue

The fitted model we found is $log(Reaction\ time_{ijk}) = -1.089618 - 0.002033 \times numtime_k + 0.045435 \times fatigue_j + 0.008730 \times [numtime \times protocol]_j + u_{ij} + \epsilon_{ijk}$. The explanatory variable fatigue is the covariate that has a positive effect with the response variable reaction time (p-value ¡0.001)(figure 5). As fatigue increases, the reaction time increases. (0.34s when least fatigue, 0.39s when moderate fatigue, 0.45s when most fatigue Figure 8). We also removed four outliers to make model 3 valid.

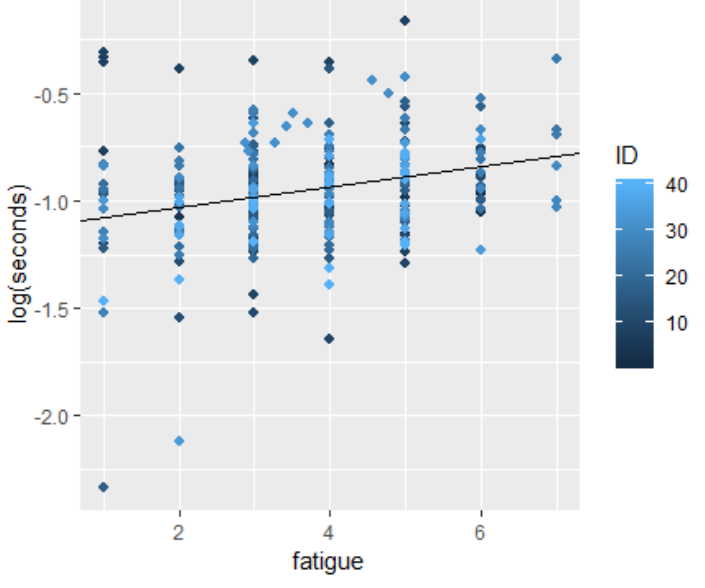


Figure 5: regression of the reaction time against fatigue

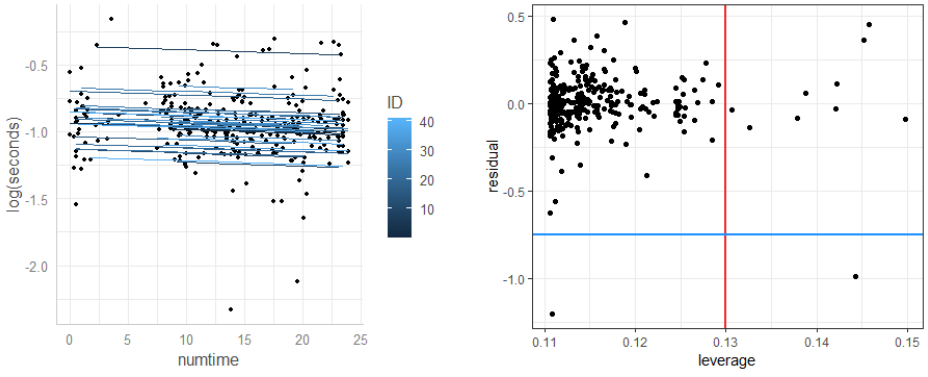
4 Discussion

Although the reaction time decreases (very slowly) as the time of day increases(it decreases 0.02s in total as time change from 0:00 AM to 23:59 PM), we considered there is no relationship between them because the p.value is not small enough (p.value is 0.08). We also found that the reaction time increases as time increases when protocol = 0, and it decreases as time increases when protocol = 1. Although we dont know which specific experiment rule(s) they violate, we could at least know the idea that peoples behavior does interact with their reaction time. Last but not least, the reaction time of a person increases as his/her fatigue level increases. We could interpret this as people find it hard to concentrate or act fast when they are tired. Therefore, we suggest people perform a quick changing task(such as driving) when they are not tired and not feeling guilty.

There are three limitations to our study. The first is the analyzing of the relationship between hunger/sleep and the reaction time was not able to perform due to the non-linearity. The second is the model sensitivity to the imputation of the missing value. The fitted models are different for different imputation of missing values. One possible scenario could be that replacing missing values by different methodology may introduce a different amount of bias to our models. The third limitation is the multicollinearity between variables and the reaction time. We checked the pairwise collinearity because we have a limited sample size. One suggestion to check the multilinearity would be expanding the sample pool, divide the sample into several groups and compare the coefficients of each subgroup.

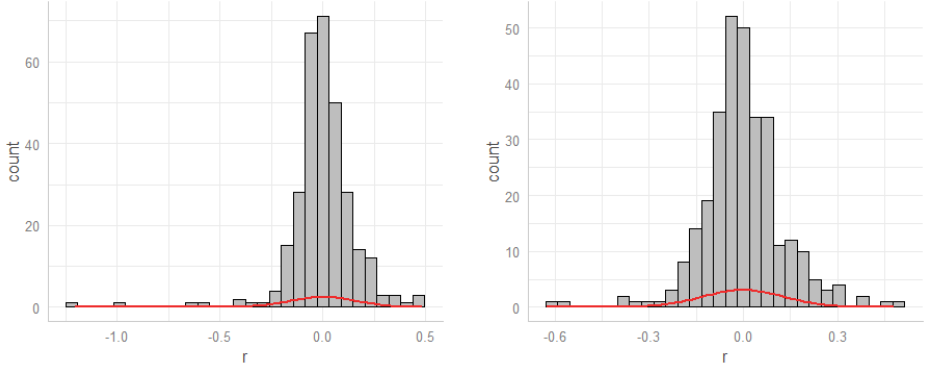
5 Appendix

5.1 Model 1



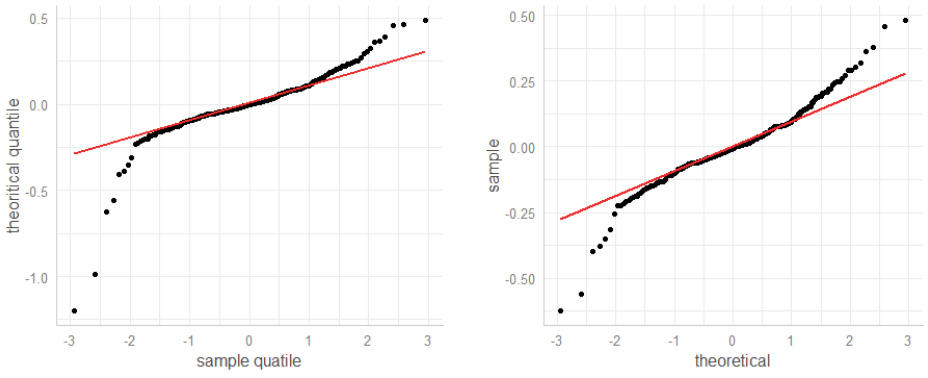
(a) (b)

Figure 6: (a) model 1 regression; (b) outliers and influential points



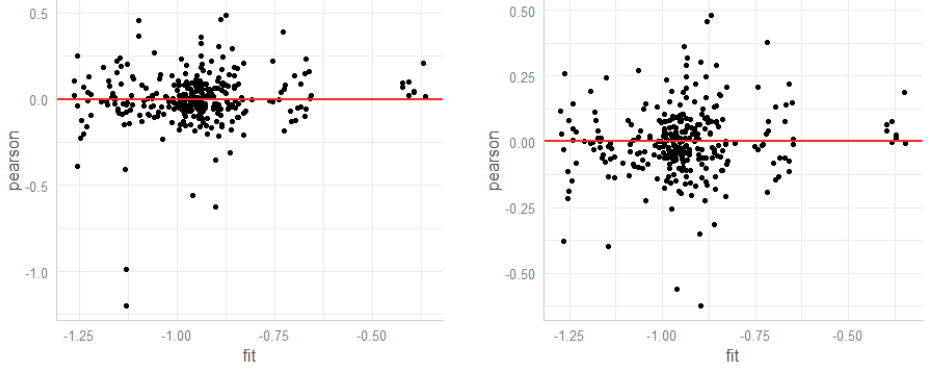
(a) (b)

Figure 7: (a) Distribution of residuals before removing outliers; (b) Distribution of residuals after outliers removed



(a) (b)

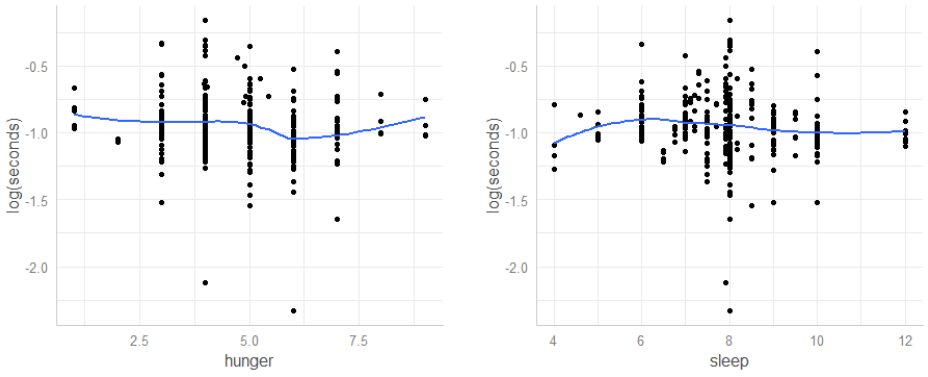
Figure 8: (a) QQ plot of residuals before removing outliers; (b) QQ plot of residuals after outliers removed



(a) (b)

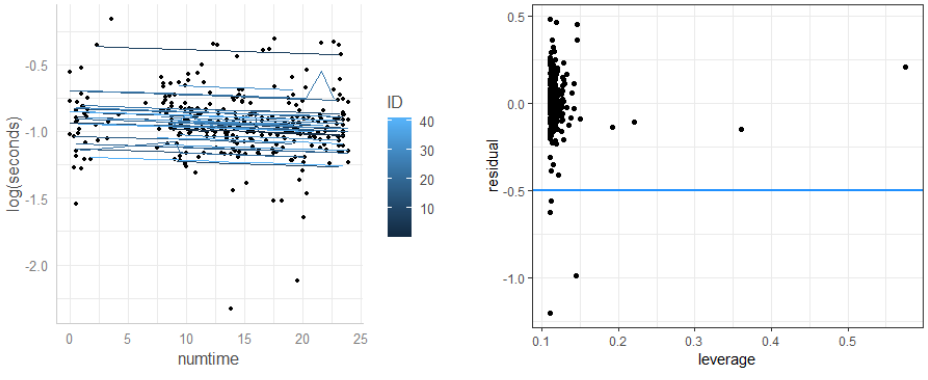
Figure 9: (a) residual vs predicted value before removing outliers (b) residual vs predicted value after outliers removed

5.2 Model 2



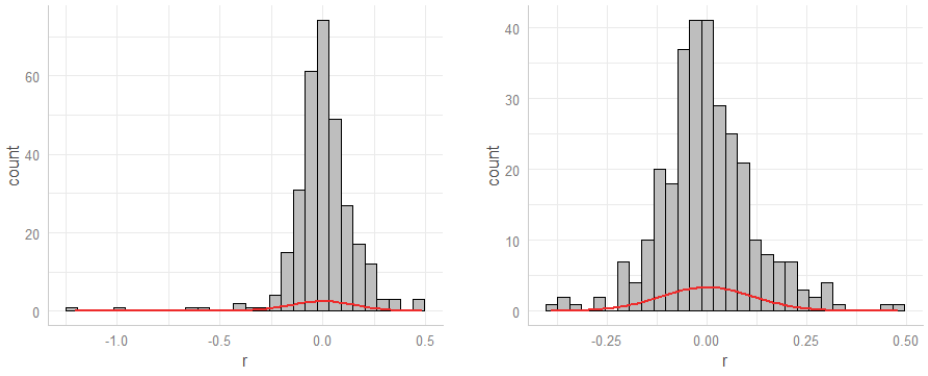
(a) (b)

Figure 10: relationship of log(reaction time) and hunger/sleep



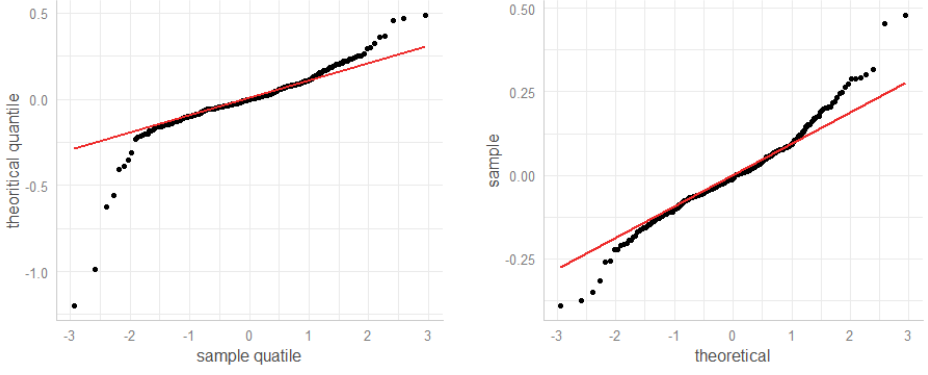
(a) (b)

Figure 11: (a) model 2 regression; (b) model 2 outliers and influential points



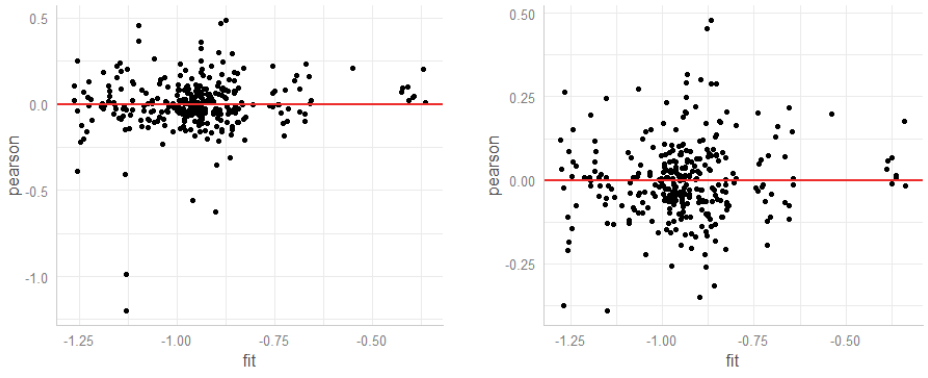
(a) (b)

Figure 12: (a) Distribution of residuals before removing outliers; (b) Distribution of residuals after outliers removed



(a) (b)

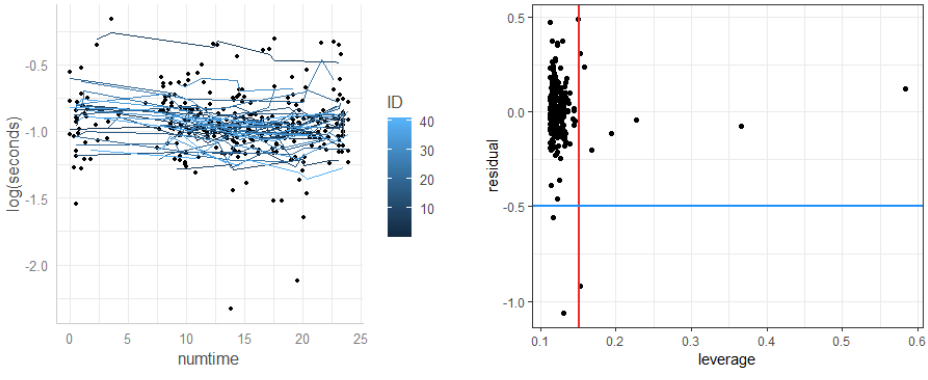
Figure 13: (a) QQ plot of residuals before removing outliers; (b) QQ plot of residuals after outliers removed



(a) (b)

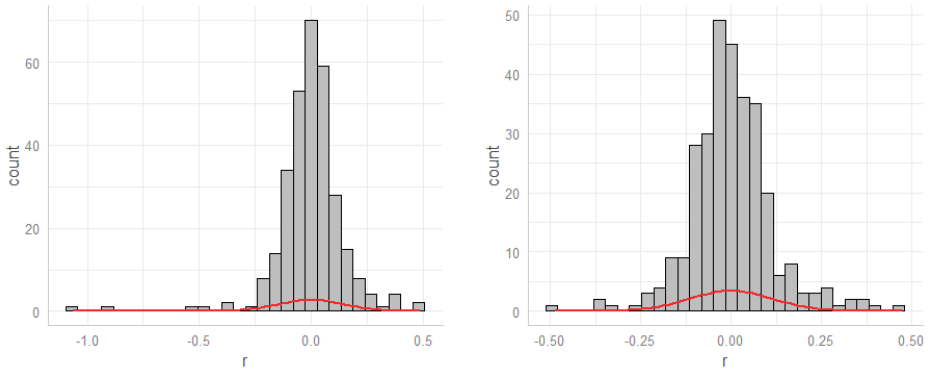
Figure 14: (a) residual vs predicted value before removing outliers (b) residual vs predicted value after outliers removed

5.3 Model 3



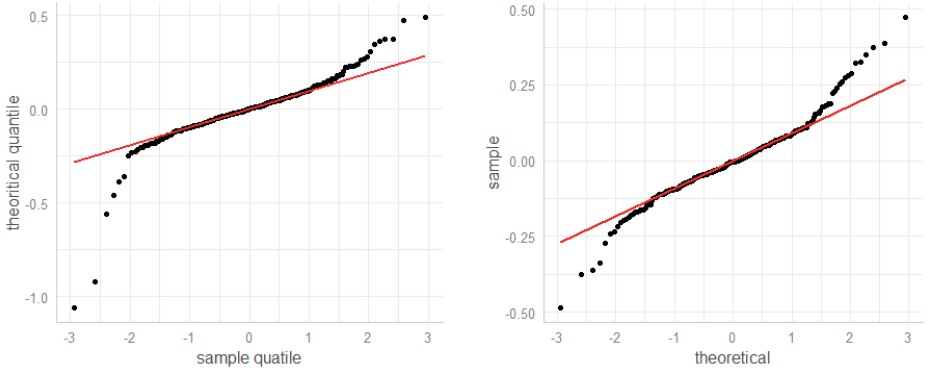
(a) (b)

Figure 15: (a) model 3 regression; (b) model 3 outliers and influential points



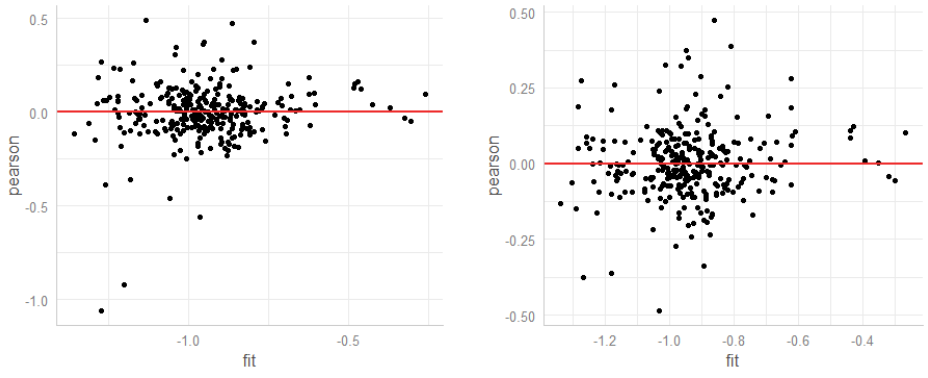
(a) (b)

Figure 16: (a) Distribution of residuals before removing outliers; (b) Distribution of residuals after outliers removed



(a) (b)

Figure 17: (a) QQ plot of residuals before removing outliers; (b) QQ plot of residuals after outliers removed



(a) (b)

Figure 18: (a) residual vs predicted value before removing outliers (b)residual vs predicted value after outliers removed