Candidates shows better cognitive flexibility when listening to music compare to quiet enviroment

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Contents

Introduction

Cognitive flexibility is the ability of the brain to shift between thinking about different concepts or between different tasks (Braem and Egner, 2018). It has been hypothesized that auditory distraction might have an effect on cognitive flexibility. To investigates effect of **auditory distraction** on **cognitive distraction**, 72 candidates were asked to perform stroop tests by Stroop test app on their phone when listening to different music. 8 other measurements were also recorded because they might have potention effect on result of the experiment.

Details about experiment setting and statistical analysis will be discussed in Method section. Answer to the research question is concluded in result section. Future direction and Potential question underlying this analysis are in discussion section

Method

Experiment Setting

In this experiment, different music is regarded as different auditory distraction levels. There are 3 treatment levels in total, which are lyrics, classical and quiet, where quiet enviroment is the reference group. Candidates are required to perform 3 rounds of stroop tests under all 3 distraction levels. For each round of stroop test, candidates are required to successfully complete 5 on runs and 5 off runs. Time spend for on-run, time spend for off-run, difference between on-time and off-time, total runs to complete on-run and total runs to complete off-run are collected.

Since ability of shifting between different tasks is interested, differences between stroop on-time and off-time time is a more appropriate response variabel than on-time and off-time. Smaller the difference, better the cognitive flexibility. Experimetnal data was collected from all 72 students enrolled in sUofT STA490 2019-2020 session.

Besides two main variables mentioned above, some other variables that might have effect on **cognitive distracion** were also collectd. They are types of headphones, order in which the 3 levels of auditory distraction were used, number of years candidate have studied in English language institution, whether or not candidate play video games, hours of sleep before (for each level of auditory distraction), time of day(for each level of distraciton), whether or not the candidate are colour blind, type of device used for Stroop test app.

Statistical Analysis

Brief Data cleaning

No observation was eliminated from analysis for any reason. However, observations from candidate No. 12, 31, 66 are questionable and require manipulation. More specifically, unexpected values for number of runs, which means values are either non-positive or non-integer, are set to 5. Unexpected values for run-time, which means the value are so small that looks like run-time of 1 run rather than 5 successful runs, we multiply the collected value by 5 and use the resultant values for further analysis.

Model

Since the research requestion interested in 'how auditory distraction affects cognitive flexibility', variable represent cognitive flexibility is the response variable, which is difference between on-time and off-time. Variable represents auditory distraction level is the predictor variable of interest, so it is taken into the model as fixed effect.

Since multiple observations were collected from single candidate in this experiment, apparently observations from same subject are not independent; thus a random intercept effect have to be added into the model to accomadate variation due to individual difference among candidates.

In addition, covariate **order** in which the 3 levels of auditory distraction were used, is also very important since mean of reponse collected under same distraction level differ if order of distraction is different(***Appendix Table 4***), so this is also taken into model as fixed effect.

In addition, refer to the non-significant p-value of the interaction term, interaction term between order and distraction was excluded from the model.

Table 1: Model with interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	139	155.359	0.000
distraction	2	139	3.496	0.033
order	1	139	3.403	0.067
distraction:order	2	139	0.165	0.848

Table 2: Model without interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	141	156.887	0.000
distraction	2	141	3.521	0.032
order	1	141	3.426	0.066

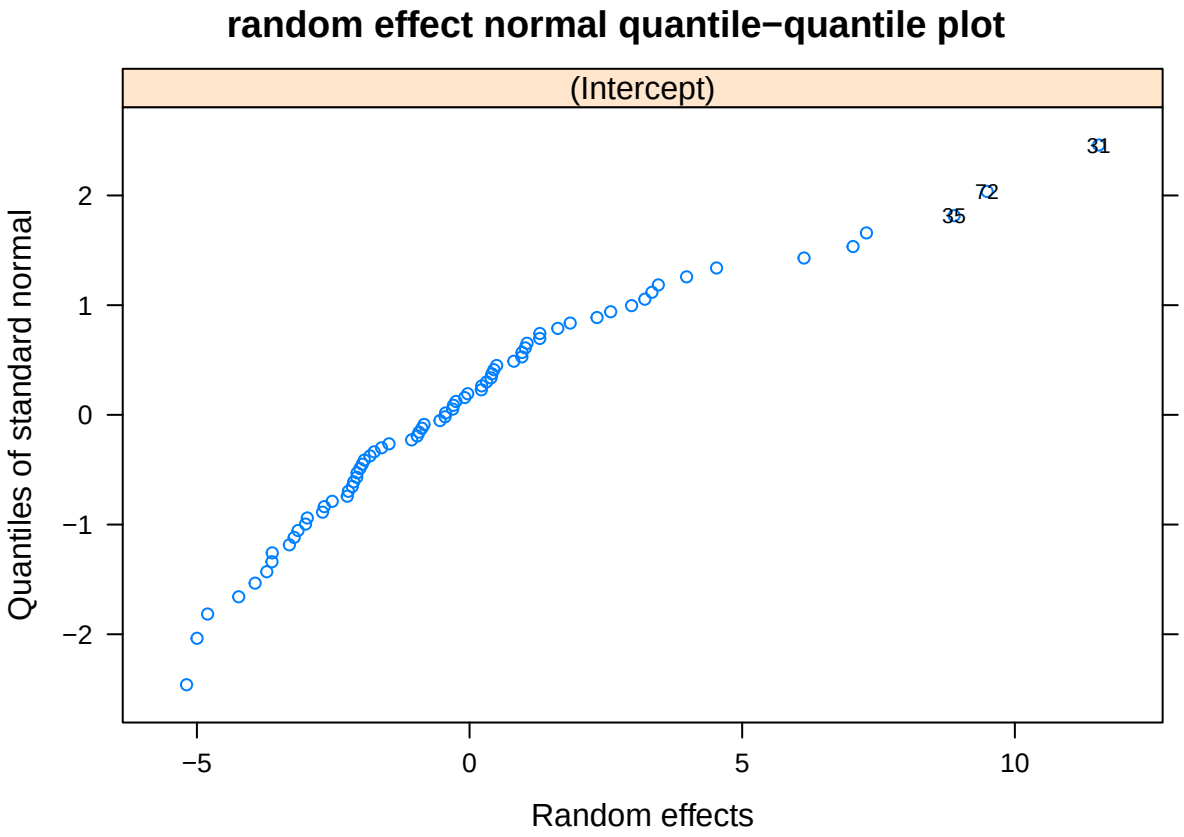
Therefore, in our model, differences between on-time and off-time is the response variable, order and disctraction levels are fixed effect predictor variable, and candidate is the random intercept effect.

Model Verification

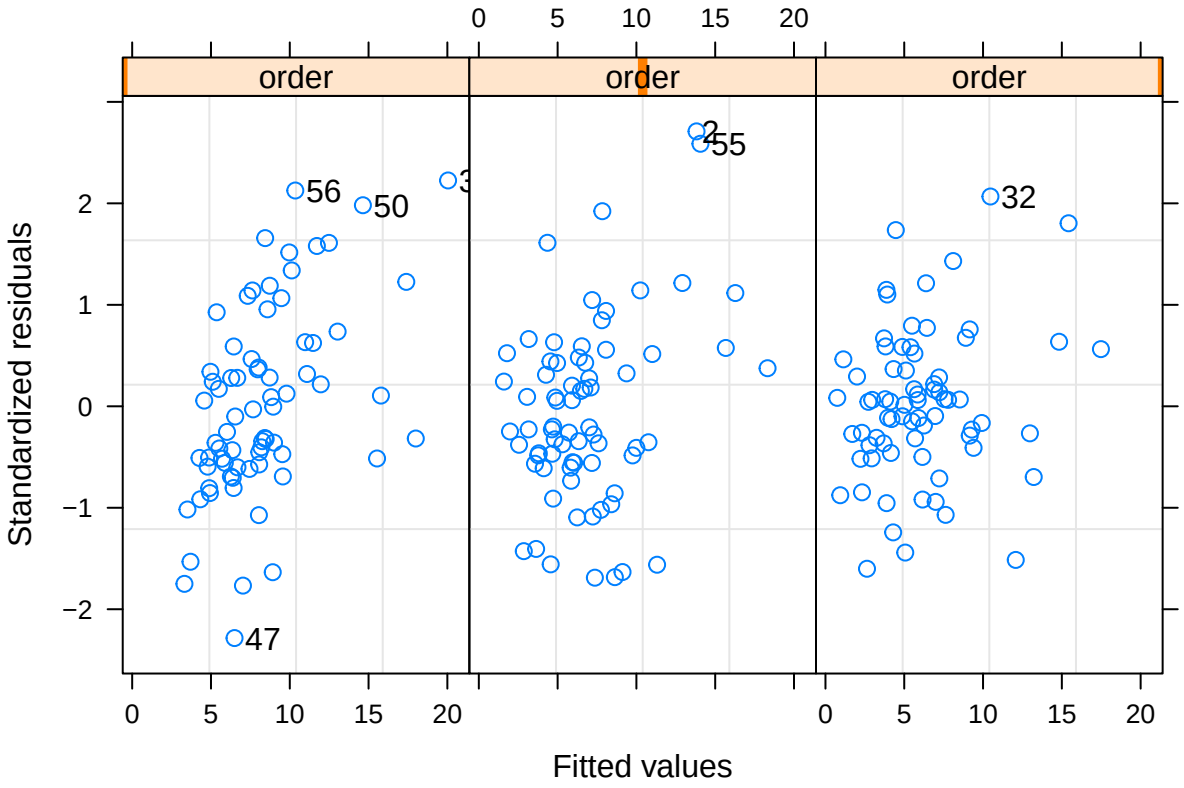
For a linear mixed model, it have to satisify several assumption to be regarded as a valid model.

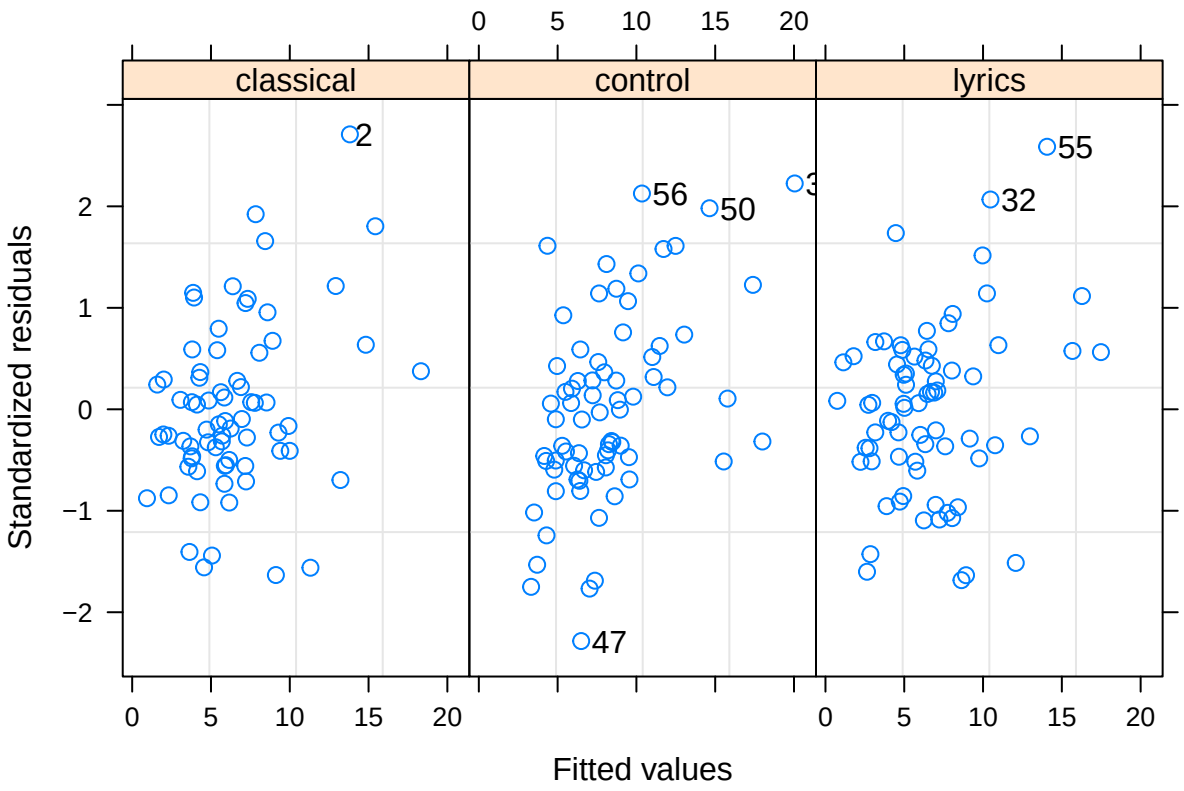
From the residual plot, we can see that the residual is scatter randomly around 0, so no deviation from linear form is detected, assumpition of linearity holds.In addition, relatively constant variance is also shown on this plot.

Then we examine whether allowing the error variance to vary will result in a better fit, result is shown in ***Appendix Table***. Based on the non-significant likelihood ratio, we can conclude that variance is constant across distraction levels and orders.

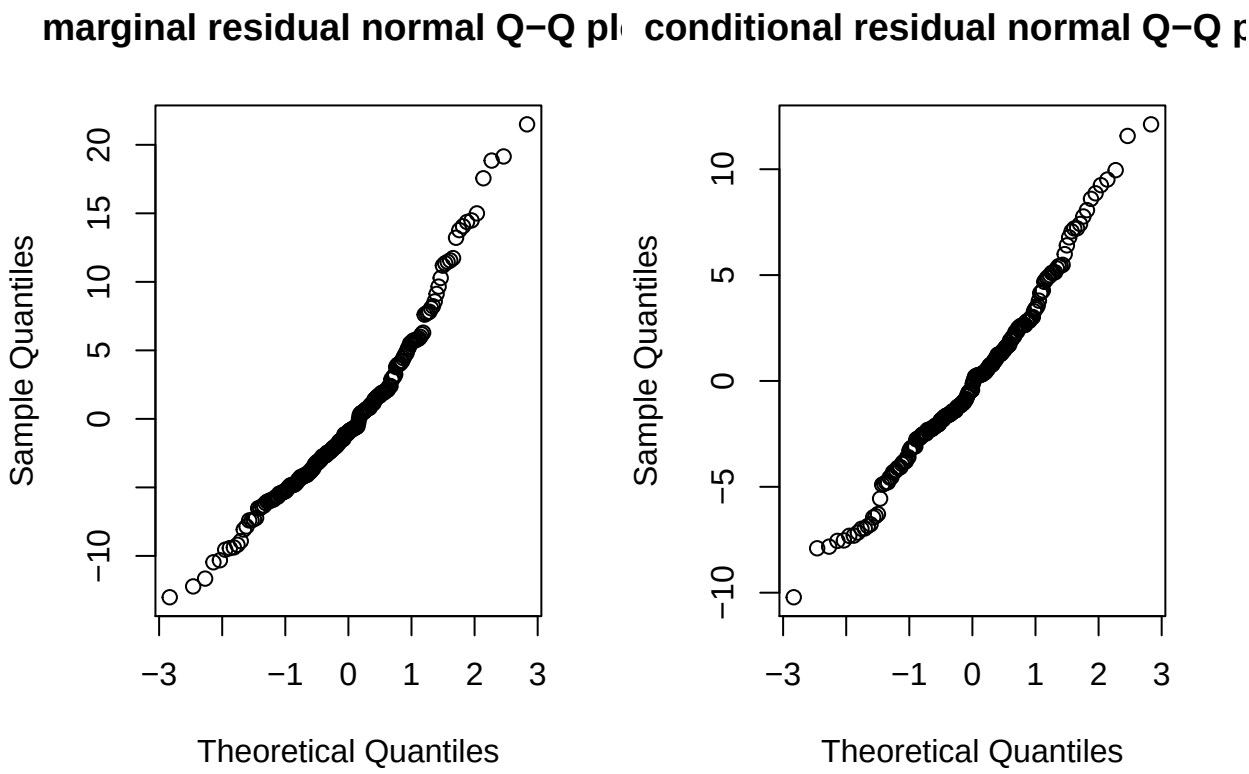


From the Normal q-q plot for random effect, we can see that it is close to the line **x=y** if remove outliers, therefore, normality of random effect holds.


order
order
order
Standardized residuals
Fitted values
56
50
47
2
55
32
0
5
10
15
20
−2
−1
0
1
2



From this two plots, we can see that variance between different orders and distraction levels are roughly equivalent. Moreover, we show correlation are nearly constant in different distraction levels and orders. Then we calculate covariance to show that homoscedasticity assumption of random effect holds. Correponding matrix are shown in Correlation and Variance-Covariance section of Appendix.



From the right plot, we can see that marginal residual is approximately normal distributed since the plot is close to the line **x=y**. From the left plot, we can see that conditional residual is approximately normal distributed since the plot is close to the line **x=y**. Therefore, normality of error term is verified.

In conclusion, model assumpitions hold and the model is valid.

Covariates

Color blindness is excluded from analysis since there is only one color blind participant; thus it's impossible to analyze effect of color blindness.

For the rest of covariates, we built one model with interaction term between covariates and distraction and another model witout interaction then check p-value for corresponding p-value. Tables is shown in appendix.

Result

As estimatied marginal mean table of the model shwon, reference group, which is quiet enviroment, has the greatest estiamted mean. Recall that smaller the response variable, better the cognitive flexibility. So distraction level do affect cognitive flexibility, and people shows worse cognitive flexibility in quiet enviroment. In addition, based on the lmertable, we can conclude approximately $\frac{\sigma^2}{\sigma^2+\tau^2} = 44.9\%$ of variation is due to individual cognitive flexibility difference.

Table 3: lmertable of model

	MLE	Std.Error	DF	t-value	p-value
(Intercept)	8.473	1.323	141	6.405	0.000
distractioncontrol	0.878	0.898	141	0.978	0.330
distractionlyrics	0.003	0.753	141	0.004	0.997
order	-0.845	0.457	141	-1.851	0.066
σ	4.039	NA	NA	NA	NA
τ	4.473	NA	NA	NA	NA

Table 4: Estimated marginal means for distraction

distraction	emmean	SE	df	lower.CL	upper.CL
classical	6.782	0.739	71	5.310	8.255
control	7.661	0.770	71	6.125	9.196
lyrics	6.786	0.717	71	5.357	8.214

As for covariates, only **headphones** and **device** are significant. In addition, the corrsponding interaction terms are not significant. From corresponding table of their marginal mean(***Appendix Table 12 and 15***) we can see that candidates wearing noise-cancelling headphones and candidate who used Apple devices have smaller marginal mean, which means better cognitive flexibility. Since we did not corporate these covariates into a single model, exact values of their coefficients do not contain much informaiton.

Discussion

There are several problem underlying this experiment. First, the reference distraction group, quiet enviroment, is very subjective since we simply label no music as quiet. However, variation due to enviromental noises may affect experiment result largely. Second, all candidates have similar age and education background, which means result obtained from this experiment may not be universal. Future experiment may be conducted on candidates from a wider demographics range. Third, though we have found 2 covariate that may have significant effect on experiment effect, they are not incorporate into a single model, therefore corresponding effects on stroop test result require further investigation. Fourth, imputation for people who had fewer than 5 runs affect the model significantly(***Appendix Tbale 20***), after remove those candidates, the main fixed effect we concerned about become non-significant. Fifth, there are oultiers in residual qq plot, which are participants 31,35,72. Last, there are observations with ontime-Offtime discrepancies, which means values for differences are not equivalent to values obtained by subtracting ontime by offtime. In addition, fixed effect order becomes non-significant in model using value obtained from subtraction.(***Appendix Table 21***)

Appendix

Importance of order effect

Table 5: Mean of response under different distraction levels with respect to different order of distractions

distraction	order	means
classical	1	8.742
classical	2	6.009
classical	3	6.331
control	1	8.695
control	2	6.674
control	3	6.403
lyrics	1	6.721
lyrics	2	7.114
lyrics	3	5.818

Examine whether variance differing with distraction / order gives better fit

	call
simple.model.plus.order.no.ix	lme.formula(fixed = diff ~ distraction + order, data = data, random = ~1 | id, method = “
model.Vdistraction	lme.formula(fixed = diff ~ distraction + order, data = data, random = ~1 | id, weights = va

	call
simple.model.plus.order.no.ix	lme.formula(fixed = diff ~ distraction + order, data = data, random = ~1 | id, method = “
model.Vorder	lme.formula(fixed = diff ~ distraction + order, data = data, random = ~1 | id, weights = va

Correlation and Variance-Covariance

```
print('Correlation and Variance-Covariance matrices by distraction')
```

```
## [1] "Correlation and Variance-Covariance matrices by distraction"
```

```
cor(cbind(data$diff[data$distraction=="control"],
data$diff[data$distraction=="lyrics"],
data$diff[data$distraction=="classical"]))
```

```
##           [,1]      [,2]      [,3]
## [1,] 1.0000000 0.4503484 0.4780272
## [2,] 0.4503484 1.0000000 0.4054406
## [3,] 0.4780272 0.4054406 1.0000000
```

```
var(cbind(data$diff[data$distraction=="control"],
data$diff[data$distraction=="lyrics"],
data$diff[data$distraction=="classical"]))
```

```
##          [,1]     [,2]     [,3]
## [1,] 43.94507 16.93844 18.34075
## [2,] 16.93844 32.19136 13.31393
## [3,] 18.34075 13.31393 33.49798
```

```
print('Correlation and Variance-Covariance matrices by order')
```

```
## [1] "Correlation and Variance-Covariance matrices by order"
```

```
cor(cbind(data$diff[data$order==1],
data$diff[data$order==2],
data$diff[data$order==3]))
```

```
##           [,1]      [,2]      [,3]
## [1,] 1.0000000 0.4372640 0.5343075
## [2,] 0.4372640 1.0000000 0.4012349
## [3,] 0.5343075 0.4012349 1.0000000
```

```
var(cbind(data$diff[data$order==1],
data$diff[data$order==2],
data$diff[data$order==3]))
```

```
##          [,1]     [,2]     [,3]
## [1,] 44.90689 17.77793 18.61137
## [2,] 17.77793 36.80966 12.65349
## [3,] 18.61137 12.65349 27.01851
```

english

Table 8: Model after adding covariate years of English and corresponding interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	139	152.5981316	0.0000000
distraction	2	139	3.3064512	0.0395493
english	1	70	0.1777113	0.6746393
order	1	139	3.7269396	0.0555775
distraction:english	2	139	0.4391713	0.6454616

	numDF	denDF	F-value	p-value

Table 9: Model after adding covariate years of English but no interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	141	152.0220326	0.0000000
distraction	2	141	3.3197730	0.0390083
order	1	141	3.7086813	0.0561428
english	1	70	0.1836022	0.6696113

video games

Table 10: Model after adding covariate videogames and corresponding interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	139	151.6735621	0.0000000
distraction	2	139	3.3379166	0.0383793
vgames	1	70	0.0020418	0.9640876
order	1	139	3.7993887	0.0532849
distraction:vgames	2	139	0.7198683	0.4886222

Table 11: Model after adding covariate videogames but no interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	141	151.7406142	0.0000000
distraction	2	141	3.3235284	0.0388687
order	1	141	3.7047690	0.0562710
vgames	1	70	0.0010089	0.9747511

device

Table 12: Model after adding covariate devices and correpsonding interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	137	164.942413	0.0000000
distraction	2	137	3.203288	0.0436896
device	2	69	3.277484	0.0436736
order	1	137	3.585015	0.0604116
distraction:device	4	137	1.266870	0.2860596

Table 13: Model after adding covariate device but no interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	141	163.159441	0.0000000
distraction	2	141	3.275550	0.0406916
order	1	141	3.678987	0.0571239
device	2	69	3.193007	0.0471804

Table 14: Estimated marginal mean for models with covariate device

device	emmean	SE	df	lower.CL	upper.CL
Android phone	10.104	1.312	71	7.488	12.721
iPad tablet	6.681	1.261	69	4.165	9.196
iPhone / iPod	6.437	0.668	69	5.104	7.769

headphones

Table 15: Model after adding covariate headphones and correpsonding interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	135	164.2809722	0.0000000
distraction	2	135	3.1812971	0.0446632
headphones	3	68	2.6416127	0.0562791
order	1	135	3.5187822	0.0628364
distraction:headphones	6	135	0.1411104	0.9904738

Table 16: Model after adding covariate headphones but no interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	141	164.634598	0.0000000
distraction	2	141	3.330048	0.0386274
headphones	3	68	2.649811	0.0557241
order	1	141	3.682955	0.0569917

Table 17: Estimated marginal means for headphones

headphones	emmean	SE	df	lower.CL	upper.CL
In-ear headphones; noise cancelling	5.144	1.434	71	2.285	8.003
In-ear headphones; not noise cancelling	7.366	0.688	68	5.994	8.739
Over-ear headphones; noise cancelling	4.960	1.511	68	1.944	7.975
Over-ear headphones; not noise cancelling	10.065	1.511	68	7.050	13.080

hours of sleep

Table 18: Model after adding covariate hours of sleep and correpsonding interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	138	152.4336599	0.0000000
distraction	2	138	3.3130569	0.0393218
sleep	1	138	0.4562259	0.5005233
order	1	138	3.6070694	0.0596214
distraction:sleep	2	138	0.2012950	0.8179108

Table 19: Model after adding covariate hours of sleep but no interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	140	152.8964581	0.0000000
distraction	2	140	3.3328462	0.0385447
sleep	1	140	0.4568035	0.5002366
order	1	140	3.6337761	0.0586676

start time

Table 20: Model after adding covariate start time and correpsonding interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	135	154.6643269	0.0000000
distraction	2	135	3.3276828	0.0388419
start	2	135	1.7899003	0.1709165
order	1	135	4.1383354	0.0438808
distraction:start	4	135	0.2868215	0.8861204

Table 21: Model after adding covariate start time but no interaction term

	numDF	denDF	F-value	p-value
(Intercept)	1	139	155.708587	0.0000000
distraction	2	139	3.358746	0.0376241
start	2	139	1.775078	0.1732901
order	1	139	4.149155	0.0435534

Discrepancies

Table 22: anova table for model without id 12,31,66

	numDF	denDF	F-value	p-value
(Intercept)	1	135	167.908291	0.0000000
distraction	2	135	2.200590	0.1146949
order	1	135	3.043462	0.0833387

Table 23: anava table for model using difference obtained from subtraciton as response variable

	numDF	denDF	F-value	p-value
(Intercept)	1	141	156.591686	0.0000000
distraction	2	141	3.912735	0.0221922
order	1	141	2.524690	0.1143166