Relaxation and Memory

An Experimental Study on State of Mind and Memory Recall
Summer 2020 - W241 Final Project

Chitra S. Agastya, chitra.agastya@berkeley.edu
James Gao, jamesygao55@berkeley.edu
Wenqi Liu, wenqiliu@berkeley.edu

August 12, 2020

Abstract

Whether one is managing a job, a business, studies or home life, one is likely to benefit from memory recall and focus. Distractions caused by day to day activities like excessive screen time, stressful multitasking, inadequate sleep, poor sleeping habits etc. cause information overload in our brains and are likely to compromise our ability to stay focused and be productive to our best potential. Does a relaxed mind help one recollect information better? In this project, we attempt to study the impact the state of our mind may have on memory recall by running a simple intervention based experiment that gives people either a calming or a stressful audio treatment and then looks at their short term memory recall scores from a simple memory game.

1 Background

We are in a digital age where our brain is constantly exposed to information from a plethora of media and devices. With this barrage of information, how might one cope with making a mental note of day to day facts? People have become more reliant on technology to stand in for human memory.

Is a calmer mind better suited for cognitive awareness? The answer to this question, substantiated with empirical data, could potentially help us tackle the problem with memory recall. It could help us create learning plans and therapies for people with learning disabilities and some types of dementia, and could aid students with attention deficiencies who are unable to adequately focus on learning activities. A Reuters science news article published in March 2010[1] discussed a neuroscience theory that robust, longer lasting memories are likely to be formed when the mind is relaxed. The neuroscientists suggest that when the brain is relaxed, the memory related neurons fire in synchronization and when these memory related neurons are well

[1] "Scientists find how relaxed minds remember better" Reuters Science News, March 24 2010, https://www.reuters.com/article/us-memory-brainwaves/scientists-find-how-relaxed-minds-remember-better-idUSTRE62N4VJ20100324

coordinated, memories are stronger. Understanding the causal relationship between the state of our mind and the ability to remember could be a crucial step in counterbalancing the brain fog we are subjected to in this age of information overload.

2 Research Question

The primary research question we are trying to answer is: does relaxation of ones mind cause one to remember better? There are several Yoga and mindful breathing workshops that try to tackle the problem of mental stress. One of the benefits of such workshops is said to be the calming impact on the mind and the improvement to memory recall.

3 Hypothesis

Motivated by the general principles of yoga and mindful breathing, our primary hypothesis is that a relaxed mind can remember information better. In addition to our primary research question, we are also interested in seeing if factors like gender, time of day and formal music training have an effect on memory recall. We analyze the experimental data in the light of these control variables to see if they have an effect on memory recall. We additionally hypothesize that: 1. People with significant music training are better at memory recall because their minds are trained to recall music. 2. Time of day affects memory; recall may be higher when a person is relatively free during the day, such as closer to the end of the work day and 3. Gender does not impact memory recall.

4 Experiment

4.1 Overview

To test our hypothesis that addresses the research question at hand, we design a difference in differences experiment with an intervention designed to induce some form of mental relaxation. We use a number game of Digit Span[2] to score and compare a participant's memory recall.

Typically, an intervention in the form of a mini workshop of mindful breathing would be administered in person with the aid of effective tools designed for the very purpose. Given the extraordinary conditions that we are living in, with COVID-19 lock downs prevailing globally, we had to look at alternate mechanisms for providing such an intervention via online medium. Music, similar to Yoga and mindful breathing, is also said to trigger chemicals in the brain that can lead to relaxation. Certain types of music have the ability to lower the level of our body's cortisol, a hormone that can contribute to feelings of stress[3]. We therefore leverage audio clips to deliver the intervention needed for our experiment to relax the mind.

[2] "How Many Numbers Can You Remember?" Science Buddies, 28 July 2017, https://www.sciencebuddies.org/science-fair-projects/project-ideas/HumBehp020/human-behavior/how-many-numbers-can-you-remember

[3] "The Science Behind Relaxing Effects of Music", Audio-Technica, 29 August 2017, https://blog.audio-technica.com/science-behind-relaxing-effects-music/

4.2 Design

Our experimental design involves four steps as illustrated in Figure 1 below:

1. Collecting information on the participant's age, gender, music training and the time of the day they are taking the survey. We use this information for randomization. Appendix C gives an outline of our data schema.

2. Providing a memory exercise in the form of a fun game designed around short term memory recall to establish the baseline score of the participant. We call this the *pre-treatment score*.

3. Providing intervention in the the form of a 90 second long audio clip. All participants hear an audio clip. The treatment group gets a calming audio clip while the control group gets one with loud stressful noises.

4. Providing the memory exercise again to see what impact the treatment has on the memory recall score. We call this the *post-treatment score*.

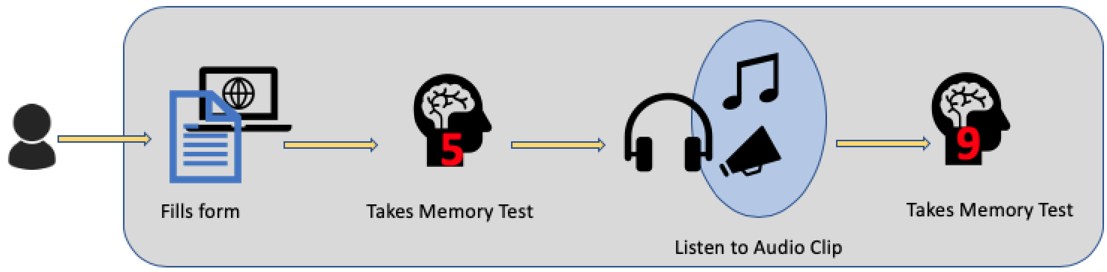


Figure 1: Experimental Design

For the memory exercise, we use an auditory implementation of the Digit Span game. With each game, a series of randomly generated digits from 0 to 9 are read out loud to the participant. The participant then has to recall the digits in the same order that they were read out. We start with a 2 digit number and keep increasing the sequence length by one (i.e. 3 digit, 4 digit etc.) each time the participant gives the correct answer. The game stops when the participant is unable to recall the sequence correctly.

4.3 Intervention

The experiment is designed to have two groups, a treatment group that receives a calming audio and a control group that receives loud stressful noises. We compiled the audio clips that we needed for our experiment using freely available public audio clips on YouTube. Both clips played for a duration of 90 seconds. The loud and stressful audio clip included a combination of noisy sounds like that of a siren, a crying baby, vehicles honking, an alarm clock ringing etc. The calming audio included the white noise of rainfall combined with a soft and soothing Zen music playing in the background. The audio clips were designed to induce a calming or stressful effect on the mind as the case may be.

To ensure that we were not introducing two opposing treatments using the aforesaid method and that we were starting with a common stress level before administering treatment, we ensured that both audio clips started with stressful noises for the first 30 seconds before transitioning into either calming music or loud and noisy sounds for the rest of the clip duration. We also blanked out any video in the clip to not introduce any sort of distraction to the participants while providing the treatment. To make sure that the participants took the treatment fully before they moved on to the post treatment test, we controlled the survey page such that the post treatment test would only load once the audio clip was fully played.

4.4 Survey Implementation and Hosting

The setup for this experiment is minimal for a face to face delivery mechanism. However, since this option was out of question for us, we had to look at an online delivery mechanism instead. Online delivery for this type of survey, which involves implementation of a memory game, was neither easy nor straight forward using the popular survey infrastructures that we had access to. We therefore had to come up with a custom solution with our very own web survey HTML page and render it from a custom web service hosted on the Google Cloud. Behind the scenes we linked the fields in the HTML page to a Google Form so that we could leverage its infrastructure to record participant responses. The responses were saved in a Google Sheet which we downloaded for our data analysis. Figure 2 below shows the custom solution we used to host, render and record our survey. Appendix B gives screenshots of our survey.

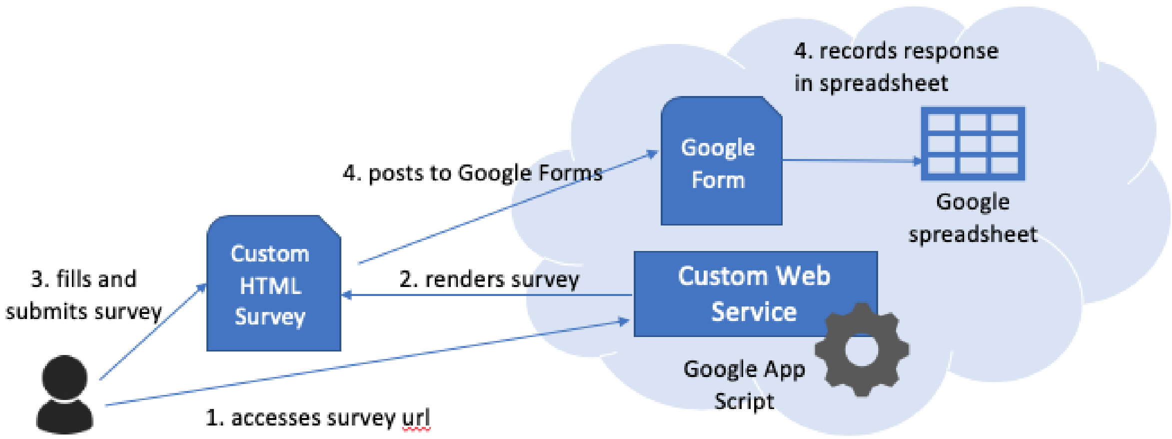


Figure 2: Survey Hosting and Recording

4.5 Measurement Strategy

For our difference in differences experiment, we were interested in measuring the pre-treatment and post-treatment scores of every participant. We were also interested in collecting participant information on age, gender, music training and time of day when they took the survey. As our participants were spread across different countries and geographies, we asked them to choose from a list of local time ranges. We made all these fields mandatory in our survey so that a participant would not be able to submit an incomplete form. Since we primarily relied on our friends and family to participate, we chose to record participant name so that we could reach out to them in case of missing responses.

4.6 Enrollment and Communication Strategy

We did not require any special enrollment to participate in our survey. We used both personal emails and social media postings to request participation in our survey. In our communication we indicated clearly what the experiment was about and what was required to participate without revealing the design. We also used the Berkeley Announcement Channel on Slack to solicit participation. Appendix A gives a snapshot of the communication message we used to encourage participation. We followed up with reminders to ensure we had as many responses as we could gather.

4.7 Randomization

Memory span and working memory is said to improve with age, peak at adulthood and gradually decline after adulthood[4]. It therefore made sense to employ a randomized block design by dividing our subjects into blocks by age and to do a randomized assignment within the blocks to control and treatment groups. This randomized block design would help reduce the noise that might be caused by age on the effect of our treatment and give us better precision on our outcome variable. We used blocks of three age groups: 5 to 21 years, 21 to 55 years and above 55 years. We designed our survey to be accessible to anybody with a link to it. So it was important that we did the block randomization at the web server level using a persistant and centralized store.

4.8 Outcome Variable

We analyze the data using two outcome variables of interest: 1. A dummy variable called *score-improved* which indicates if a participant's score improved or not post treatment. 2. A difference in scores called *score-difference* between pre-treatment and post-treatment scores. Our independent variable is *treatment*, which is a dummy for whether treatment was administered in the form of calming audio. Our covariates include *age*, *music*, *gender* and *time of day*.

5 Data

We received a total of 148 complete responses. A closer inspection of the data showed us that ten of these were duplicated[5]. Eliminating these duplicates landed us with 138 unique responses. Of these responses, 65 were from the control group and 73 from the treatment group. Our experiment randomized based on age blocks. From the responses received, we found that treatment assignment was 50% in the age group 5 to 21 years, 51.8% in the age group 22 to 55 years and 60% in the age group older than 55. It appears that a few participants attrited from the study. We cover more details on the attrition observed in this experiment in section 6.4. Table 1 gives the distribution of participants by the assignment group.

Figure 3 shows the distribution of the scores from the memory tests before and after the treatment and also the difference between the two. The histogram for the *post-treatment-score* shows a small shift in the mean scores to the right for both groups. However, the shift is more

[4]"Memory Span", https://en.wikipedia.org/wiki/Memory_span

[5]https://support.google.com/docs/thread/40862184?hl=en

Participant Characteristic	Treatment	Control
Total count	73	65
Age (5 - 21 years)	15	15
Age(22 - 55 years)	43	40*
Age(> 55 years)	15	10*
Male	32	24
Female	33	49
Music training	19	20
No music training	27	25
		* *attrition observed*

Table 1: Participant numbers by Treatment

pronounced for the treatment group as evidenced in the histogram of *score_difference* where the treatment group shows more positive difference than the control group. This gives us an indication that the treatment has a positive effect on the memory recall score. Table 2 shows the average scores between the treatment and control groups. According to Miller's law[6], the human brain can remember and hold on to seven ± two objects on average[7]. While the mean scores of participants were well within this range for both tests, there were a couple of outliers. It is plausible that a couple of participants relied on external aids to help with their memory recall. We don't correct for these outliers as they are random occurrences and are equally likely in treatment and control groups.

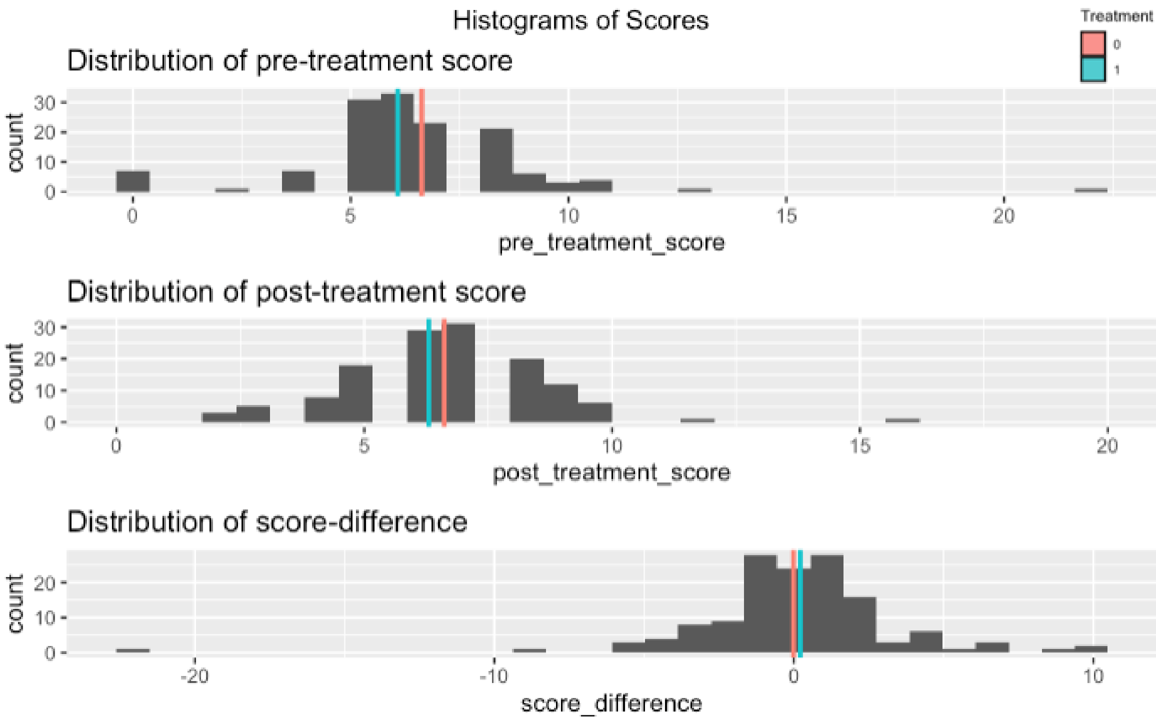


Figure 3: Distribution of Scores

[6]named after the celebrated cognitive psychologist George A Miller from Harvard University

[7]"The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", https://en.wikipedia.org/wiki/The_Magical_Number_Seven,_Plus_or_Minus_Two

Treatment	pre-treatment-score	post-treatment-score	score-difference
0	6.631	6.615	-0.015
1	6.082	6.301	0.219

Table 2: Average Scores by Treatment

Figure 4 shows the box plots of the score differences for all the participants in the experiment and by the three age blocks. The variance of *score-difference* in the treatment group is smaller than in the control group. The score difference is marginally higher in the treatment groups for age blocks 5 - 21 years and older than 55 years. The difference is not discernible in the age block 22 - 55 years .

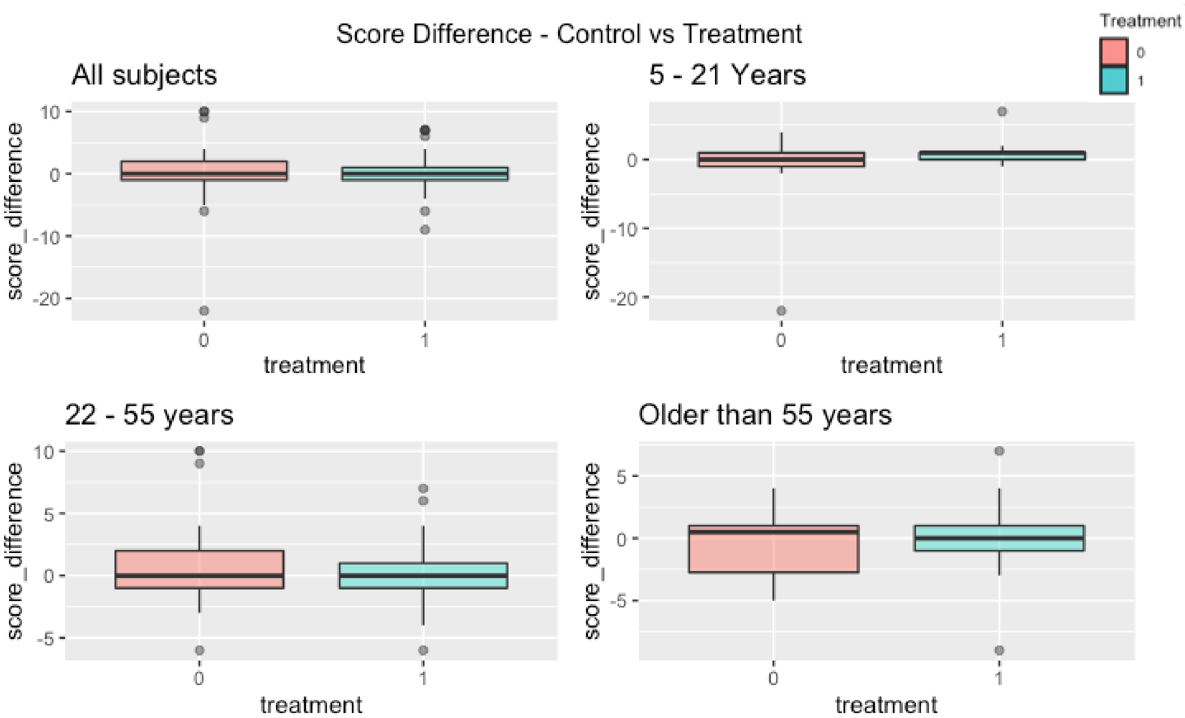


Figure 4: Survey: Box Plots of Score Differences

6 Results

6.1 Validation

Before looking at treatment effects and impact of covariates on the outcome variables, we run validation checks on our data to ensure any regression analysis will give us unbiased estimates.

6.1.1 Covariate Balance Check

To verify if the covariates balance out between the treatment and control groups, we regress the treatment variable on all covariates of interest. Figure 3 shows the results of the covariate balance check. We see that the formal test fails on account of gender. The *Intercept* represents women who are in the age group 22 to 55 years and who have had one to two years of music training. The composition of the *Intercept* is given in Table 4 and Figure 5 shows the distribu-

Covariate Balance Check

	Estimate	Std. Error	t value	Pr(> | t|)
(Intercept)	1.673	0.360	4.653	0.00001***
age5 - 21 years	0.019	0.112	0.169	0.866
ageOlder than 55 years	0.123	0.120	1.021	0.309
music_training3- 5 years of training	-0.138	0.170	-0.809	0.420
music_trainingmore than 5 years of training	-0.189	0.160	-1.187	0.238
music_trainingNo training	-0.112	0.155	-0.720	0.473
genderMale	-0.209	0.093	-2.253	0.026*
time_of_day4 PM - 8 PM	-0.039	0.364	-0.107	0.915
time_of_day8 AM - Noon	0.101	0.370	0.274	0.785
time_of_day8 PM - Midnight	0.075	0.364	0.207	0.836
time_of_dayMidnight - 4 AM	0.111	0.385	0.289	0.773
time_of_dayNoon - 4 PM	0.039	0.362	0.108	0.914

Table 3: Covariate Balance Check

tion of gender between the treatment and control groups. These clearly indicate that the uneven distribution of gender between treatment and control groups is what is causing the imbalance.

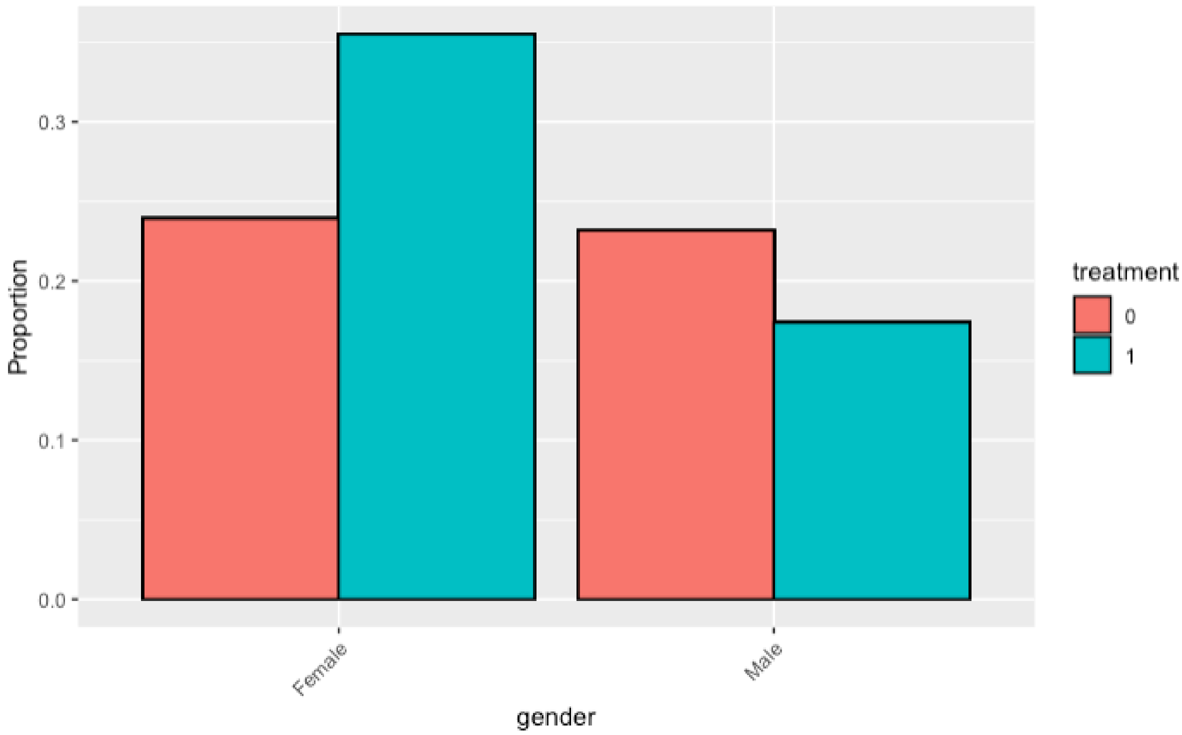


Figure 5: Gender balance between treatment and control groups

To get the ideal balance between the treatment and control groups, we would have had to do block randomization on every covariate making the experimental design complex and the randomization quite difficult to handle. In our experimental design, we chose not to block on gender because we had hoped that the random assignment would automatically take care of this. It is possible that we ended with more women participants because two out of three members in our team are women and we relied on friends and family to be participants in the experiment.

Distribution	Treatment	Control
Women in Age (22 - 55 years)	32	21
Women in Age (22 - 55 years) with 1-2 years of music training	4	4
Men in Age (22 - 55 years)	9	11

Table 4: Distribution of Intercept

6.2 Analysis

This section covers the analysis performed on the data collected from our experiment. We lay out the analysis with respect to both of our outcome variables and then summarize our results.

6.2.1 Score Improvement as Outcome

We first analyze the treatment using an indicator variable called *score-improved*, which is set to one if the memory score improves post treatment. The tally of the score improvement and the mean outcomes among compliers is tabulated in Table 5. We see a CACE or local average treatment effect (LATE) of 0.104.

Effect	Treatment	Control
Participants for whom score improved	48	25
Participants for whom score deteriorated	36	29
Mean Outcome	0.658	0.554

Table 5: Tally - Score Improvement

Score Improvement - Short Model

We run a simple model regressing the outcome variable on the treatment variable. We do this on all three of our age blocks to estimate the effect of our treatment on score improvement.

Short Model - Score Improvement

	Outcome Variable: score-improved			
	All ages	5 - 21 years	22 - 55 years	Older than 55 years
	(1)	(2)	(3)	(4)
treatment1	0.104	0.267	0.055	0.067
	(0.084)	(0.177)	(0.111)	(0.216)
Constant	0.554^{***}	0.533^{***}	0.550^{***}	0.600^{***}
	(0.063)	(0.138)	(0.081)	(0.172)
Age Group:	All	5 - 21 years	22 - 55 years	Older than 55 years
Observations	138	30	83	25
R^2	0.011	0.080	0.003	0.005
Adjusted R^2	0.004	0.047	-0.009	-0.039
Residual Std. Error	0.489 (df = 136)	0.468 (df = 28)	0.499 (df = 81)	0.499 (df = 23)
F Statistic	1.547 (df = 1; 136)	2.435 (df = 1; 28)	0.248 (df = 1; 81)	0.107 (df = 1; 23)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 6: Short Model - Score Improvement

Table 6 shows a positive treatment effect of 0.104 which indicates that for every unit increase in treatment, there is an additional 10.4 percent increase in score improvement compared to the control group and the positive effect is seen across all three age groups. We see a positive effect of 26.7 percent in the age group 5 to 21 years, 5.5 percent in the age group 22 to 55 years and 6.7 percent in the age group above 55 years. However, the p-values of these effects are not statistically significant. The R^2 value of this model is quite low indicating that the model is unable to explain much of the variance in the outcome variable.

Score Improved - treatment and covariates

	Outcome Variable: score-improved			
	All ages	5 - 21 years	22 - 55 years	Older than 55 years
	(1)	(2)	(3)	(4)
treatment1	0.137	0.342^{*}	0.031	0.677^{*}
	(0.110)	(0.202)	(0.147)	(0.407)
music_training3- 5 years of training	0.236	-0.515	0.217	0.410
	(0.155)	(0.381)	(0.187)	(0.576)
music_trainingmore than 5 years of training	0.288^{*}	-0.294	0.368^{**}	0.693
	(0.147)	(0.335)	(0.167)	(0.535)
music_trainingNo training	0.259^{*}	-0.632^{**}	0.329^{**}	0.399
	(0.143)	(0.277)	(0.163)	(0.340)
time_of_day4 AM - 8 AM	0.030		0.234	
	(0.266)		(0.335)	
time_of_day4 PM - 8 PM	0.246^{**}	0.399^{*}	0.350^{**}	0.034
	(0.112)	(0.206)	(0.155)	(0.374)
time_of_day8 PM - Midnight	-0.051	-0.018	0.079	-0.234
	(0.136)	(0.273)	(0.173)	(0.435)
time_of_dayMidnight - 4 AM	-0.179		0.114	-1.424^{**}
	(0.289)		(0.367)	(0.573)
time_of_dayNoon - 4 PM	-0.109	-0.191	0.052	-0.475
	(0.127)	(0.295)	(0.165)	(0.497)
genderMale	0.007	-0.238	0.015	0.248
	(0.128)	(0.253)	(0.169)	(0.540)
treatment1:genderMale	0.024	-0.079	0.228	-0.503
	(0.169)	(0.382)	(0.221)	(0.528)
Constant	0.280^{*}	0.974^{***}	0.134	0.053
	(0.170)	(0.327)	(0.193)	(0.613)
Model:	All ages	5 - 21 years	22 - 55 years	Older than 55 years
Observations	138	30	83	25
R^2	0.131	0.411	0.141	0.330
Adjusted R^2	0.056	0.145	0.007	-0.149
Residual Std. Error	0.476 (df = 126)	0.443 (df = 20)	0.495 (df = 71)	0.525 (df = 14)
F Statistic	1.732^{*} (df = 11; 126)	1.548 (df = 9; 20)	1.055 (df = 11; 71)	0.689 (df = 10; 14)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 7: Score Improvement - Regression Model with treatment variable and covariates

Score Improvement - Long Model

To explain some of the variability observed in the treatment effect, we add all our covariates to our regression model. Since gender is not balanced between the treatment and control groups, we make sure we add gender and the interaction of treatment with gender to our model. Table 7 summarizes the results of this model. The R^2 values of this long model is higher than that of the short model, indicating that we are able to explain some of the variance seen in the treatment variable. The F statistics of this model is significant to the 10% significance level.

The *Constant* here is women with one to two years of music training, who took the test between

8 AM to Noon and who did not receive treatment. The regression output in Table 7 shows that the calming audio treatment has a positive effect of 0.137 on score improvement overall and the effect is positive for all age groups. The effect is statistically significant to the 10% significance level among youngsters and seniors.

We also find that music training shows positive impact on memory. Adults with more than 5 years of music training show 36% increase in score improvement. Youngsters without any music training have a statistically significant negative effect of 63% decrease in score improvement. On the contrary, youngsters with 1 to 2 years of music training see a statistically significant positive effect of 0.974 on their score improvement even when they are not given any treatment. This seemingly suggests that music training does have an impact on memory. We also observe that adults with absolutely no music training also saw a 32% increase in score improvement. It is plausible that there are factors other than music that might be affecting memory. Isolating the causal impact of music would need a different experimental setup. For now, we can only indicate a correlation between memory and music training.

We had hypothesized that gender does not have an effect on memory. The coefficient for males is 0.007 and the for males who received treatment is 0.024. These values are not statistically significant to refute the null hypothesis. This confirms our belief that gender has no impact on memory. The treatment does not seem to affect men and women differently.

Finally, the time of day when the test is taken seems to have an effect on memory. In general, the best impact seems to be between 4 PM to 8 PM when we are close to the end of the work day. Participants who took the test at this time of the day, show a 24.6% increase in score improvement and this is statistically significant. Adult participants who took the test between 4 PM to 8 PM saw a statistically significant effect of 34% increase in score improvement. It is plausible that adults have lesser work related stress closer to the end of a working day and therefore seem to show score improvement when they take the test at this time. Youngsters who took the test between 8 AM and Noon and 4 PM and 8PM saw a statistically significant higher effect on score improvement. Seniors who took the test between midnight and 4 AM saw a negative effect on the score improvement. Based on these results, time of day seems to have an effect on memory and it is possible that its effect is correlated with the level of mental stress and fatigue a person experiences at that time of the day.

Heterogeneous Treatment Effects on Time of Day

To see if the calming audio treatment is more effective at certain times of the day compared to others, we include treatment interaction with time of day in our regression model. The results are summarized in Table 8. Treatment has a negative effect from midnight to 4 AM and from Noon to 4 PM. At all other times, the calming audio treatment has a positive effect on score improvement overall. The treatment seems particularly effective between 4 AM and 8 AM and this effect is statistically significant among adults. The treatment also has statistically significant positive effect on score improvement between 8PM and midnight among seniors. From these results, it appears that the calming audio treatment does have some causal impact on score improvement on this sample based on the time it is administered during the day.

Score Improved - treatment HTES with time of day				
	Outcome Variable: score-improved			
	All ages	5 - 21 years	22 - 55 years	Older than 55 years
	(1)	(2)	(3)	(4)
time_of_day4 AM - 8 AM	-0.354*		-0.152	
	(0.205)		(0.267)	
time_of_day4 PM - 8 PM	0.164	0.565	0.331	-0.284
	(0.180)	(0.387)	(0.265)	(0.578)
time_of_day8 PM - Midnight	-0.241	0.057	-0.008	-0.857***
	(0.218)	(0.527)	(0.315)	(0.323)
time_of_dayMidnight - 4 AM	-0.098		0.074	-1.053
	(0.424)		(0.517)	(0.679)
time_of_dayNoon - 4 PM	-0.075	-0.184	0.230	-1.197**
	(0.193)	(0.490)	(0.259)	(0.554)
treatment1	0.044	0.463	0.098	-0.144
	(0.217)	(0.413)	(0.295)	(0.828)
time_of_day4 AM - 8 AM:treatment1	0.729***		0.738**	
	(0.259)		(0.354)	
time_of_day4 PM - 8 PM:treatment1	0.154	-0.315	0.052	0.732
	(0.228)	(0.437)	(0.328)	(0.790)
time_of_day8 PM - Midnight:treatment1	0.324	-0.065	0.154	1.392**
	(0.282)	(0.556)	(0.389)	(0.677)
time_of_dayMidnight - 4 AM:treatment1	-0.132		0.059	
	(0.577)		(0.777)	
time_of_dayNoon - 4 PM:treatment1	-0.072	0.051	-0.377	1.231
	(0.258)	(0.648)	(0.348)	(0.812)
Constant	0.351*	0.871*	0.101	0.038
	(0.210)	(0.514)	(0.252)	(0.638)
Model:	All ages	5 - 21 years	22 - 55 years	Older than 55 years
Observations	138	30	83	25
R^2	0.161	0.434	0.198	0.502
Adjusted R^2	0.050	0.035	0.004	-0.087
Residual Std. Error	0.477 (df = 121)	0.471 (df = 17)	0.496 (df = 66)	0.511 (df = 11)
F Statistic	1.450 (df = 16; 121)	1.087 (df = 12; 17)	1.021 (df = 16; 66)	0.852 (df = 13; 11)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 8: Score Improvement - Regression Model with treatment heterogeneous effects on time of day

Short Model - Score Difference				
	Outcome Variable: score-improved			
	All ages	5 - 21 years	22 - 55 years	Older than 55 years
	(1)	(2)	(3)	(4)
treatment1	0.235	2.067	-0.503	0.567
	(0.592)	(1.684)	(0.653)	(1.354)
Constant	-0.015	-1.200	0.550	-0.500
	(0.506)	(1.601)	(0.534)	(0.959)
Age Group:	All	5 - 21 years	22 - 55 years	Older than 55 years
Observations	138	30	83	25
R^2	0.001	0.054	0.008	0.008
Adjusted R^2	-0.006	0.021	-0.005	-0.036
Residual Std. Error	3.362 (df = 136)	4.457 (df = 28)	2.906 (df = 81)	3.319 (df = 23)
F Statistic	0.167 (df = 1; 136)	1.613 (df = 1; 28)	0.622 (df = 1; 81)	0.175 (df = 1; 23)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 9: Score Difference - Short Model

6.2.2 Score Difference as Outcome

To get a better understanding of the score difference between the treatment and control groups as an effect of the audio treatment, we perform a similar regression analysis as done in section 6.2.1 using *score-difference* as our outcome variable.

Score Difference - Short Model

We first look at a short model that regresses *score-difference* on the treatment variable. Table 9 summarizes the regression results. There is a positive treatment effect of 0.235 on the score difference which suggests that people who were exposed to the calming audio treatment saw their post treatment score increase by 23.5% on average while people in the control group saw their post treatment score decrease by 1.5% on average. When we look at the effect by age group we see that youngsters see a much bigger positive effect of the treatment followed by seniors. Adults actually see a slightly negative effect of the treatment. However, these results are not statistically significant indicating that there is no causal implication here.

Score Difference - treatment and covariates

	Outcome Variable: score-differnece			
	All ages	5 - 21 years	22 - 55 years	Older than 55 years
	(1)	(2)	(3)	(4)
treatment1	0.351	0.315	0.064	4.876**
	(0.596)	(1.528)	(0.857)	(1.954)
music_training3- 5 years of training	0.567	-11.470**	0.715	6.639***
	(1.173)	(4.579)	(1.254)	(2.414)
music_trainingmore than 5 years of training	0.354	-10.774**	0.763	9.430***
	(1.266)	(4.533)	(1.134)	(2.713)
music_trainingNo training	1.292	-9.002***	1.135	9.243***
	(1.171)	(2.684)	(1.048)	(1.636)
time_of_day4 AM - 8 AM	3.650		2.733	
	(2.841)		(3.335)	
time_of_day4 PM - 8 PM	0.990	3.582	0.267	2.615
	(1.047)	(3.677)	(1.018)	(2.066)
time_of_day8 PM - Midnight	0.270	3.312	0.071	-2.142
	(1.059)	(3.941)	(1.080)	(1.879)
time_of_dayMidnight - 4 AM	-0.236		-0.563	-5.674**
	(1.567)		(1.444)	(2.745)
time_of_dayNoon - 4 PM	-0.144	3.887	-0.645	-0.442
	(1.118)	(4.571)	(1.077)	(2.184)
genderMale	-0.211	-4.688	0.970	2.644
	(1.060)	(3.330)	(1.129)	(2.324)
treatment1:genderMale	-0.110	2.865	-1.286	-4.445*
	(1.135)	(2.763)	(1.289)	(2.300)
Constant	-1.003	8.508***	-0.608	-11.632***
	(1.470)	(1.939)	(1.519)	(2.773)
Model:	All ages	5 - 21 years	22 - 55 years	Older than 55 years
Observations	138	30	83	25
R^2	0.052	0.356	0.081	0.631
Adjusted R^2	-0.030	0.066	-0.061	0.367
Residual Std. Error	3.402 (df = 126)	4.352 (df = 20)	2.987 (df = 71)	2.595 (df = 14)
F Statistic	0.635 (df = 11; 126)	1.228 (df = 9; 20)	0.568 (df = 11; 71)	2.391* (df = 10; 14)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 10: Score Difference - Regression Model with treatment variable and covariates

Score Difference - treatment HTES with time of day

	Outcome Variable: score-differnece			
	All ages	5 - 21 years	22 - 55 years	Older than 55 years
	(1)	(2)	(3)	(4)
time_of_day4 AM - 8 AM	0.253		-2.768	
	(2.670)		(2.415)	
time_of_day4 PM - 8 PM	1.221	10.059	-1.433	1.330
	(2.247)	(10.080)	(2.237)	(2.287)
time_of_day8 PM - Midnight	0.430	9.361	-1.404	-4.934^{***}
	(2.482)	(10.140)	(2.745)	(1.140)
time_of_dayMidnight - 4 AM	1.718		-1.771	-4.188
	(3.135)		(2.849)	(2.847)
time_of_dayNoon - 4 PM	0.832	8.703	-1.173	-5.369^{**}
	(2.497)	(10.140)	(2.364)	(2.369)
treatment1	1.074	7.910	-1.629	0.819
	(2.289)	(10.122)	(2.382)	(3.375)
time_of_day4 AM - 8 AM:treatment1	6.646^{**}		10.363^{***}	
	(2.874)		(2.826)	
time_of_day4 PM - 8 PM:treatment1	-0.282	-10.309	3.066	2.828
	(2.500)	(10.126)	(2.539)	(4.127)
time_of_day8 PM - Midnight:treatment1	-0.264	-8.621	2.373	6.393^{**}
	(2.722)	(10.163)	(3.041)	(2.730)
time_of_dayMidnight - 4 AM:treatment1	-3.345		1.814	
	(3.625)		(3.728)	
time_of_dayNoon - 4 PM:treatment1	-1.706	-7.578	0.504	7.482^{**}
	(2.828)	(10.198)	(2.821)	(3.388)
Constant	-1.119	0.616	0.597	-11.849^{***}
	(2.170)	(10.281)	(2.283)	(2.594)
Model:	All ages	5 - 21 years	22 - 55 years	Older than 55 years
Observations	138	30	83	25
R^2	0.084	0.502	0.176	0.740
Adjusted R^2	-0.037	0.151	-0.024	0.434
Residual Std. Error	3.414 (df = 121)	4.150 (df = 17)	2.933 (df = 66)	2.455 (df = 11)
F Statistic	0.693 (df = 16; 121)	1.430 (df = 12; 17)	0.882 (df = 16; 66)	2.414^{*} (df = 13; 11)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 11: Score Difference - Regression Model with treatment interaction with time of day

Score Difference - Long Model

We now look at the regression model using treatment variable and other covariates but with score difference as the outcome variable. Table 10 shows that the treatment has a positive effect on score difference across all age groups including adults between 22 and 55 years of age and this effect is statistically significant among seniors.

Youngsters see a decrease in score difference without any music training but youngsters with one to two years of music training see a huge positive effect on the score difference. This suggests that music training affects the way youngsters recall information. The effects of music are statistically significant among seniors. Adults and seniors with more than three years of music training see a positive effect on score difference. Lack of music training also shows positive effect on score difference indicating that people that lack music training might have possibly something else that is helping them with memory recall.

Gender's impact on score difference is similar to what we observe in section 6.2.1. Men perform better than women in both treatment and control groups among adults and seniors but worse among youngsters. But these effects are not statistically significant at the 5% significance level.

The time of day has an effect on score difference. Midnight to 4 AM has a statistically significant negative effect on score difference for seniors. Table 11 shows that treatment has a positive effect on score difference between 4AM to 8AM among adults. This effect appears to be statistically significant. For seniors, treatment also has a statistically significant positive effect on score difference between 8 PM to midnight and noon to 4 PM. In general treatment's interaction with time of day seems to have a positive effect for adults and seniors but a negative effect for youngsters.

6.3 Power

6.3.1 Power - Score Improvement

With a sample size of 138, we were only able to achieve a power of 23.6% with outcome variable *score-improved*. To increase the power to 80% with the same sample size, we would either need to reduce the variance to 0.217 or increase the treatment effect by 2.25 times to 0.234 as shown in Figure 6.

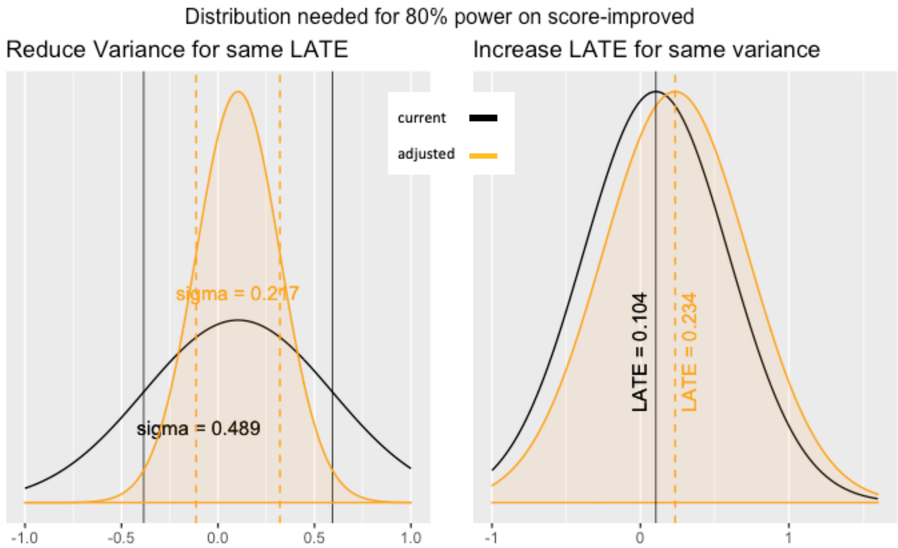


Figure 6: Power adjustments for score-improved

6.3.2 Power - Score Difference

For the treatment effect and variance we observed on *score-difference*, we were only able to achieve 6% power in our experiment . To increase the power to 80% with the same sample size, we would need to either reduce our sample variance or increase the treatment effect by 6 times as show in Figure 7.

Another way to increase power would be to increase the sample size. For the same treatment effect and variance, we would need a much larger sample size to get an experiment with 80% power. Table 12 gives an idea of how big a sample size we would need to get 80% power out of our experiment for the same treatment effect and variance. With additional time, we might

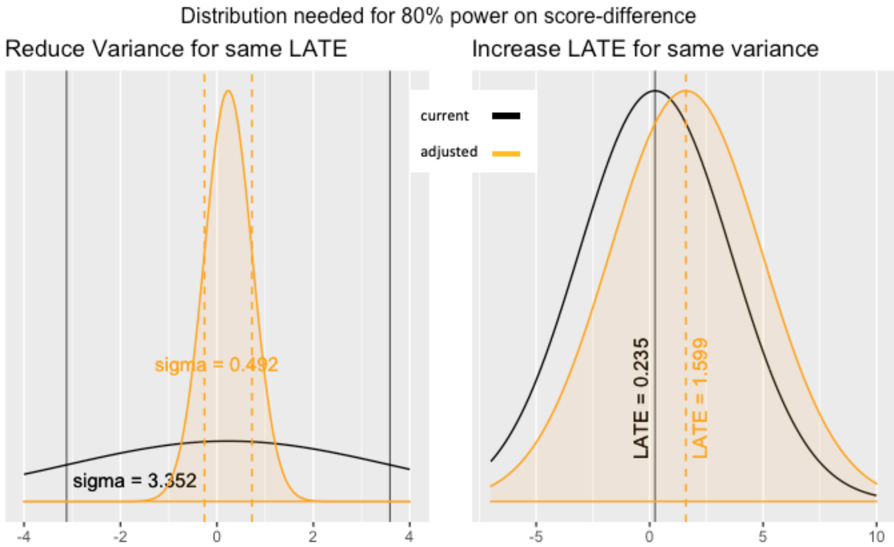


Figure 7: Power adjustments for score-difference

have managed to get the additional forty responses needed for a well powered experiment with *score-improvement*. However, to be able get to 80% power with *score-difference*, we could not have relied on friends and family to get to the sample size required.

Outcome Variable	LATE	Sigma	Sample Size
score-improved	0.104	0.489	175
score-difference	0.235	3.352	1603

Table 12: Sample Size Required for 80% Power

6.4 Attrition

Based on the number of responses we see in each age block for the treatment and control groups, we know that there has been some level of attrition. We find 7 to 8 missing records indicating that we have overall attrition of around 5.5 percent. The attrition seems to be systemic to the control group as we see that all missing records belong to the control group. The control group in our experiment received an audio clip in the form of loud and stressful noises. It is possible that some of the participants in the experiment found the noise unpleasant and stressful and quit the experiment midway.

7 Conclusion

In this study we designed an experiment to answer the research question: does a relaxed mind cause one to remember information better? We designed an experiment based on difference in differences approach to help answer our research question. We hypothesized that a relaxed mind remembers better, music training and time of day impact memory and that gender does not affect memory.

7.1 Summary

Through the results of our experiment, we observe that a calming audio treatment has a positive effect on memory recall. Based on our results, we can say that calming audio treatment caused improved memory recall among participants older than 55 years of age in our sample. While we see statistically significant effects of the treatment on one age group, our experiment lacked enough power to detect a statistically significant causal result across the entire population.

Per our hypothesis we did observe that music training had a positive effect on memory recall. We also observed that the calming audio treatment had a statistically significant positive effect on memory when administered: (1) between 4 AM to 8AM for adults and (2) between 8 PM to midnight and noon to 4 PM for seniors. Taking the test between 4PM to 8PM had a statistically significant positive effect on memory score improvement. Based on these observation we can say that the time of day plays a role in memory recall. We also see no significant effects of treatment between men and women to say that gender affects memory.

While the treatment may have been effective, the treatment effects we observed were small and the variance was quite high giving us an under-powered experiment. While we are thrilled that we were able to see some statistically significant results, we cannot generalize our results with such a small sample. We would need a much larger sample size to generalize the results.

7.2 Limitations

We used an online experimental setup to administer treatment and gather the data required for our causation analysis. Effectiveness of the treatment is harder to gauge when not administered in person, as participants may mute the audio clip if they find it loud and stressful. In some cases there were more than one participant from the same household. The exclusion restriction is hard to enforce in an online setup. We mitigated spill over effects by giving explicit instructions asking participants to wear headsets or be alone in a quiet room. But these are hard to enforce when the setup is remote. We trust the participants followed the instructions correctly and did not violate the exclusion restriction.

We relied on our friends and family to respond to the experiment. We learnt that it is not easy to come by responses quickly.

7.3 Future Work

It would be worthwhile to conduct further experimental study with a larger sample size and larger treatment effect to ensure the model has enough power to detect a statistically significant causal effect of the calming treatment on memory recall. Researchers could potentially collaborate with K-12 schools and colleges to enroll more participants in age group 5 to 21 years. The possible benefit of better memory from the calming treatment could help students achieve academic success.

It would also be meaningful to further investigate the effects of the time of day on memory as suggested by our analysis. A different selection of categories for time of day could possibly lead to different results that may reduce the heterogeneous effects of the treatment. Additionally, we received qualitative feedback that the control audio clip seemingly increased memory due to the fact that subjects felt like they were "woken up" by the noise. We would need to conduct a new experiment testing this hypothesis.

8 References

1. “Scientists find how relaxed minds remember better” Reuters Science News, March 24 2010
https://www.reuters.com/article/us-memory-brainwaves/scientists-find-how-relaxed-minds-remember-better-idUSTRE62N4VJ20100324

2. “How Many Numbers Can You Remember?” Science Buddies, 28 July 2017
https://www.sciencebuddies.org/science-fair-projects/project-ideas/HumBehp020/human-behavior/how-many-numbers-can-you-remember

3. ”The Science Behind Relaxing Effects of Music”, Audio-Technica, 29 August 2017
https://blog.audio-technica.com/science-behind-relaxing-effects-music/

4. ”The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information”
https://en.wikipedia.org/wiki/The_Magical_Number_Seven,_Plus_or_Minus_Two

5. ”Memory Span”, https://en.wikipedia.org/wiki/Memory_span

A Appendix: Communication

1. Email Communication

Thank you for participating in our experimental study on memory! We're excited to learn about how our minds remember things and share these learnings with you too.

When you're ready and in front of a computer, click the link to begin (it will only work through Chrome, Safari, or Firefox). You'll be asked to review your google permissions and login to your google account to allow access to CustomHTML. This is the tool we used to build our survey so that you'd be able to take the test appropriately. This is a one-time permission (no permanent changes will be made to your account) and will only allow us to record your survey responses.

Further instructions will be on the webpage when you open it up. Have fun and thank you again!

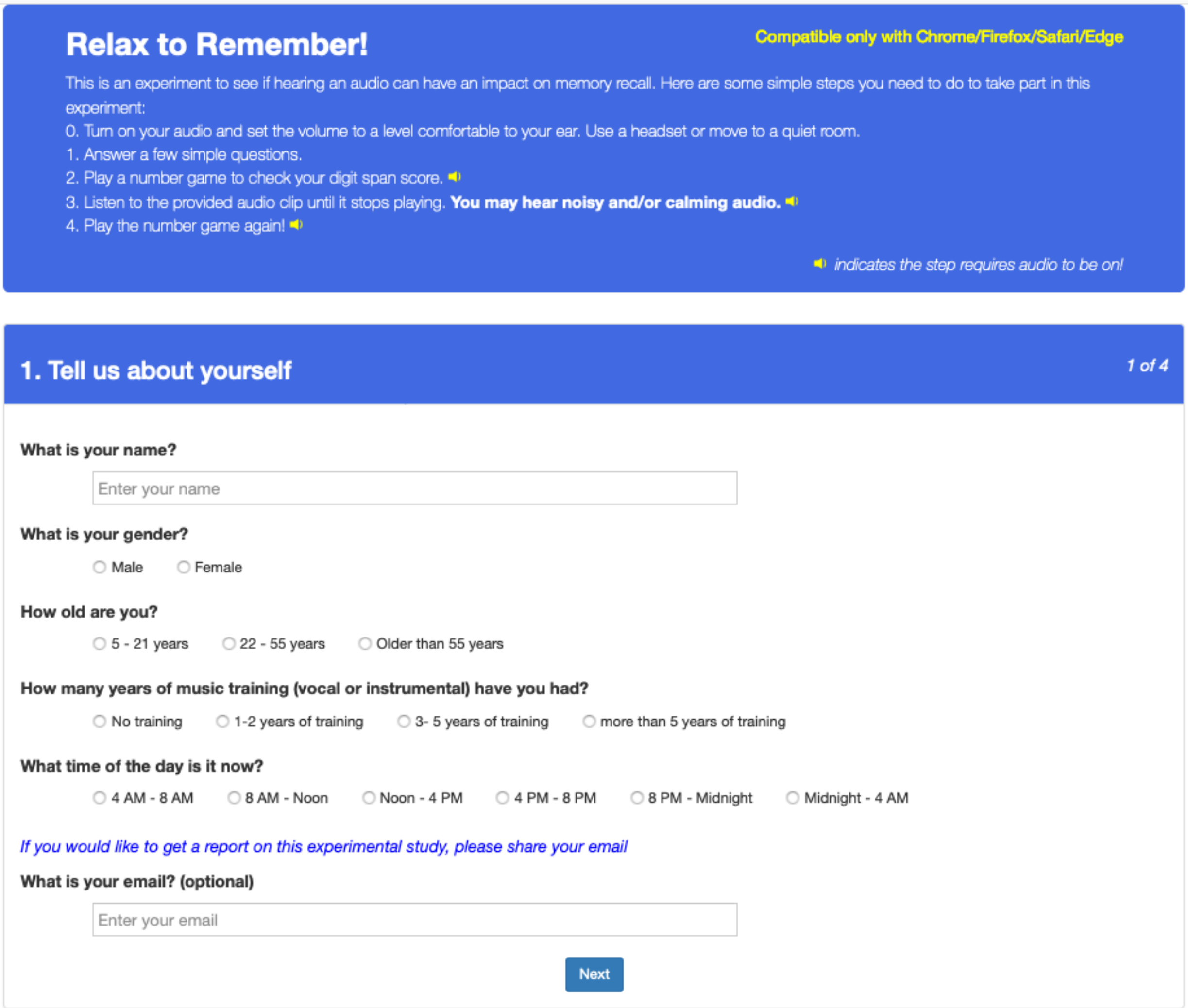
Figure 8: Communication message sent out to participants

B Appendix: Survey Data Schema

Variable	Type	Values
age	categorical	5 - 21 years 22 - 55 years Older than 55 years
gender	categorical	Male Female
music training	categorical	No training 1-2 years of training 3-5 years of training more than 5 years of training
post-treatment-score	continuous	numeric > 0
pre-treatment-score	continuous	numeric > 0
time of day	categorical	Midnight - 4 AM 4 AM - 8 AM 8 AM - Noon Noon - 4 PM 4 PM - 8 PM 8 PM - Midnight

Table 13: Schema of data collected from Survey

C Appendix: Survey Pages



Relax to Remember!

Compatible only with Chrome/Firefox/Safari/Edge

This is an experiment to see if hearing an audio can have an impact on memory recall. Here are some simple steps you need to do to take part in this experiment:

0. Turn on your audio and set the volume to a level comfortable to your ear. Use a headset or move to a quiet room.
1. Answer a few simple questions.
2. Play a number game to check your digit span score.
3. Listen to the provided audio clip until it stops playing. **You may hear noisy and/or calming audio.**
4. Play the number game again!

indicates the step requires audio to be on!

1. Tell us about yourself

1 of 4

What is your name?

Enter your name

What is your gender?

Male Female

How old are you?

5 - 21 years 22 - 55 years Older than 55 years

How many years of music training (vocal or instrumental) have you had?

No training 1-2 years of training 3- 5 years of training more than 5 years of training

What time of the day is it now?

4 AM - 8 AM 8 AM - Noon Noon - 4 PM 4 PM - 8 PM 8 PM - Midnight Midnight - 4 AM

If you would like to get a report on this experimental study, please share your email

What is your email? (optional)

Enter your email

Next

Figure 9: Survey Page 1 - Informational Data which is used for block randomization

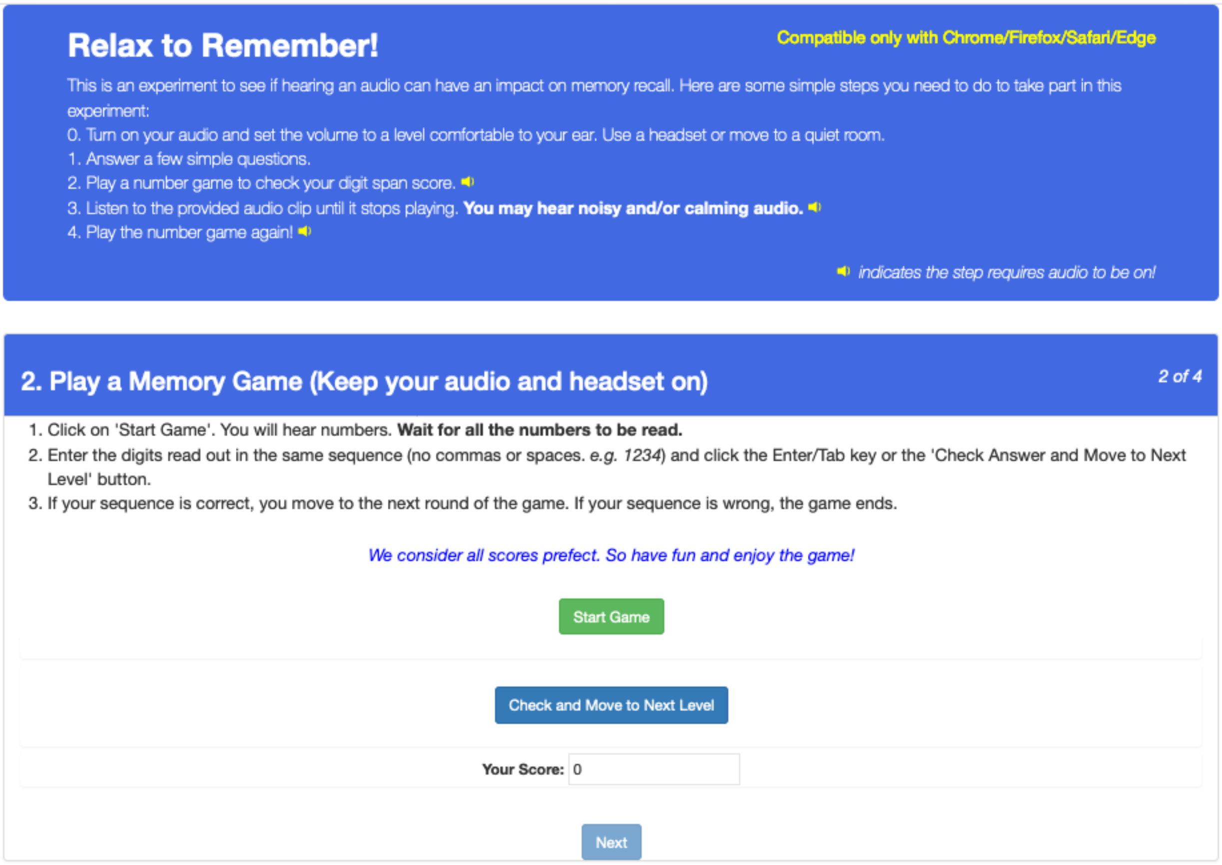


Figure 10: Survey Page 2 - Pre-treatment Memory Test

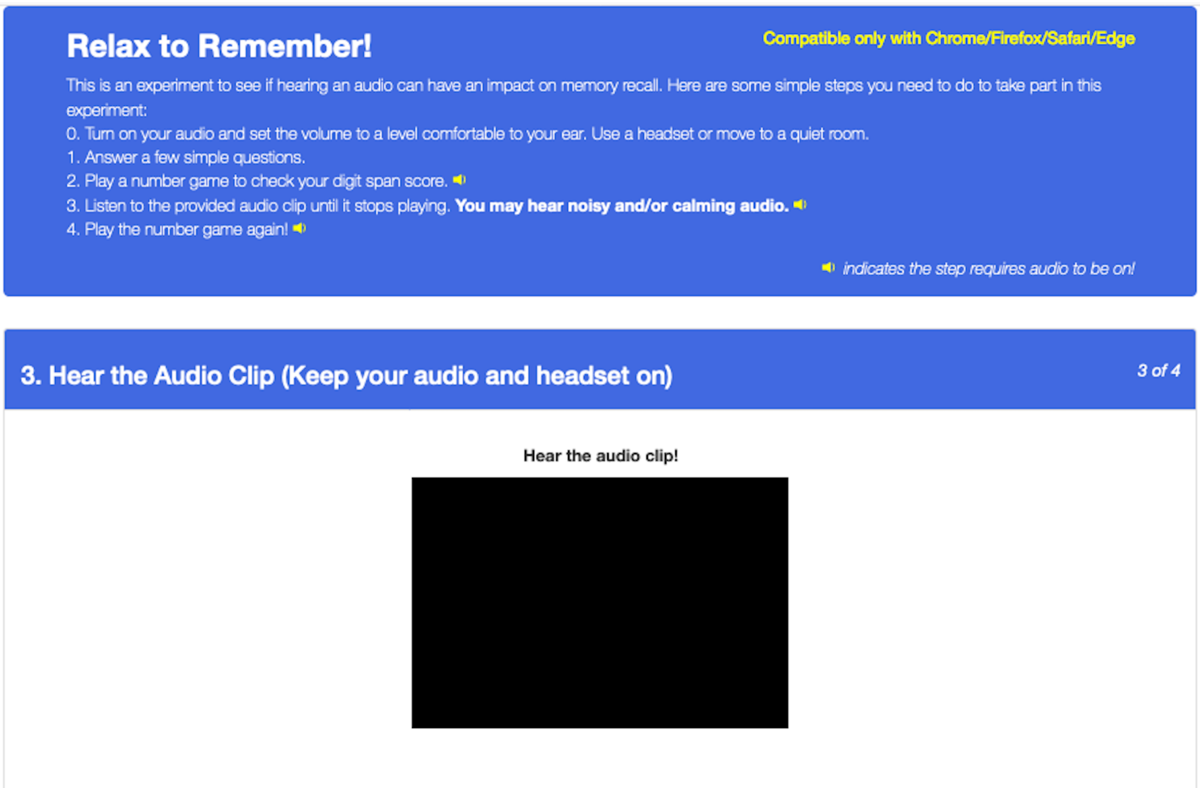


Figure 11: Survey Page 3 - Treatment

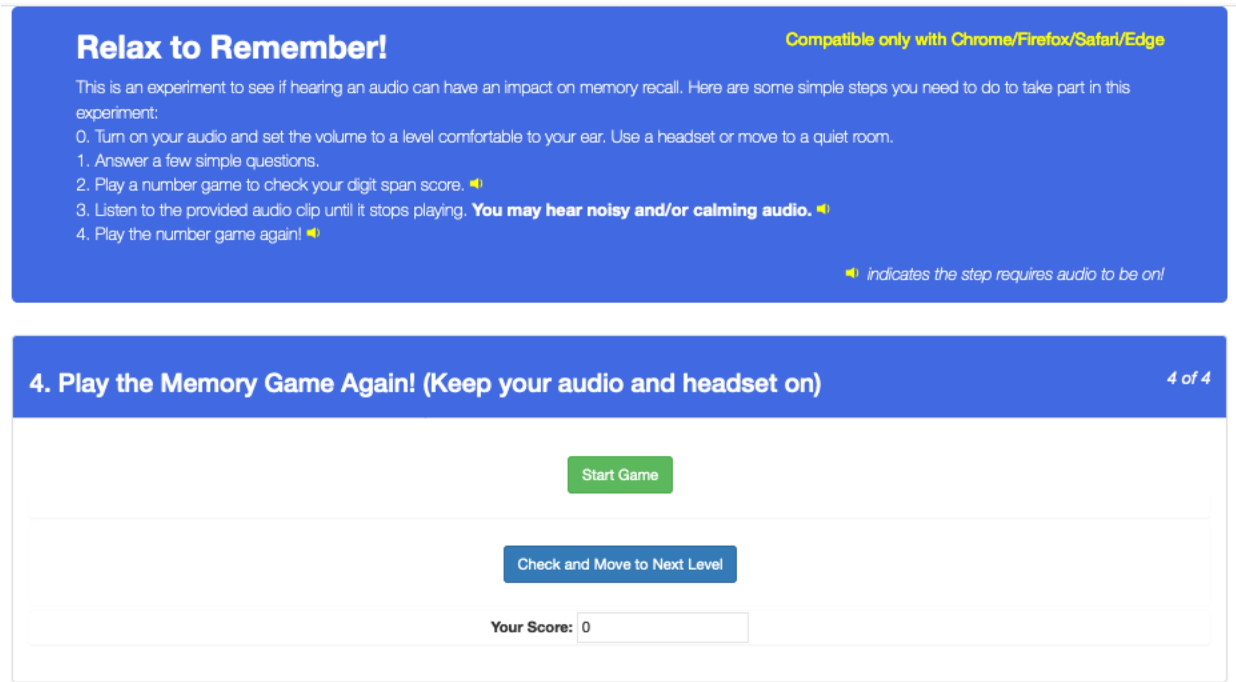


Figure 12: Survey Page 4 - Post treatment memory test

D Appendix: Additional Plots

1. Covariate Balance Plots for all covariates

```
Balance Measures
                                               Type Diff.Un
age_22 - 55 years                            Binary -0.0538
age_5 - 21 years                             Binary -0.0613
age_Older than 55 years                      Binary  0.1348
music_training_1-2 years of training         Binary  0.1406
music_training_3- 5 years of training        Binary  0.0420
music_training_more than 5 years of training Binary -0.1053
music_training_No training                   Binary -0.0304
time_of_day_4 AM - 8 AM                      Binary -0.0141
time_of_day_4 PM - 8 PM                      Binary -0.2020
time_of_day_8 AM - Noon                      Binary  0.0862
time_of_day_8 PM - Midnight                  Binary  0.0862
time_of_day_Midnight - 4 AM                  Binary  0.0555
time_of_day_Noon - 4 PM                      Binary  0.0239
gender_Male                                  Binary -0.3371

Sample sizes
    Control Treated
All      65      73
```

Figure 13: Covariate balance measures of each covariate

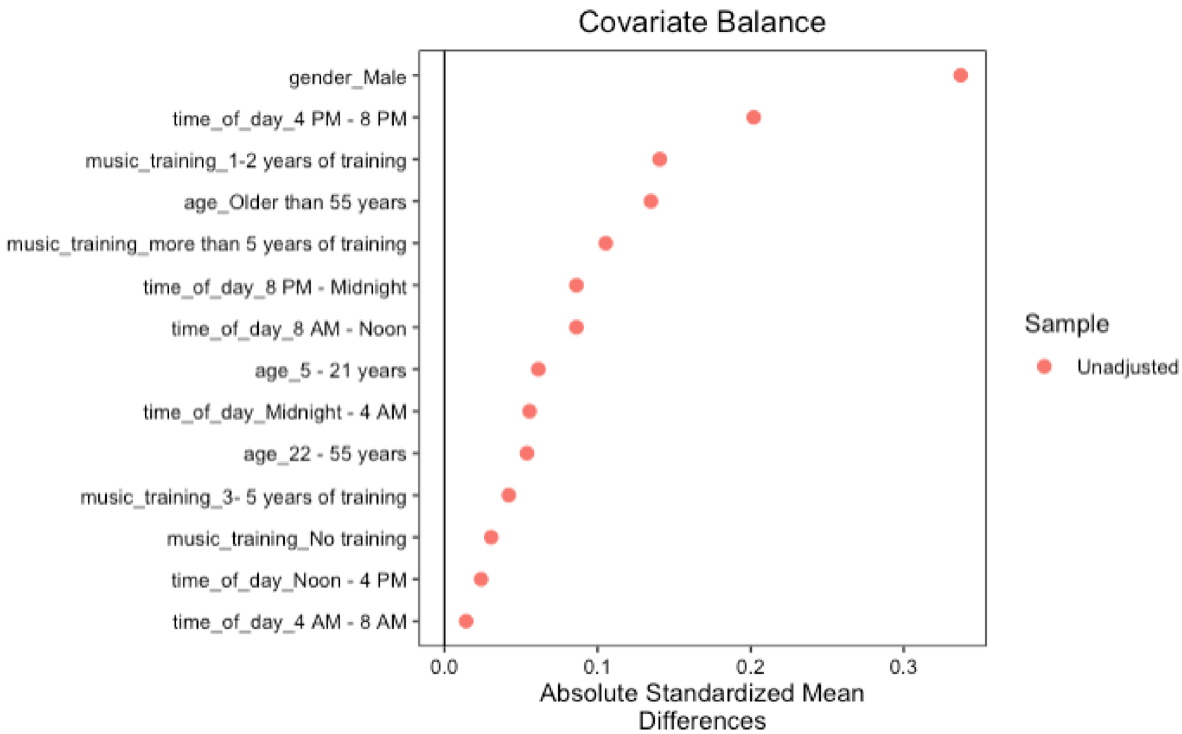


Figure 14: Diff. in means between treatment and control groups

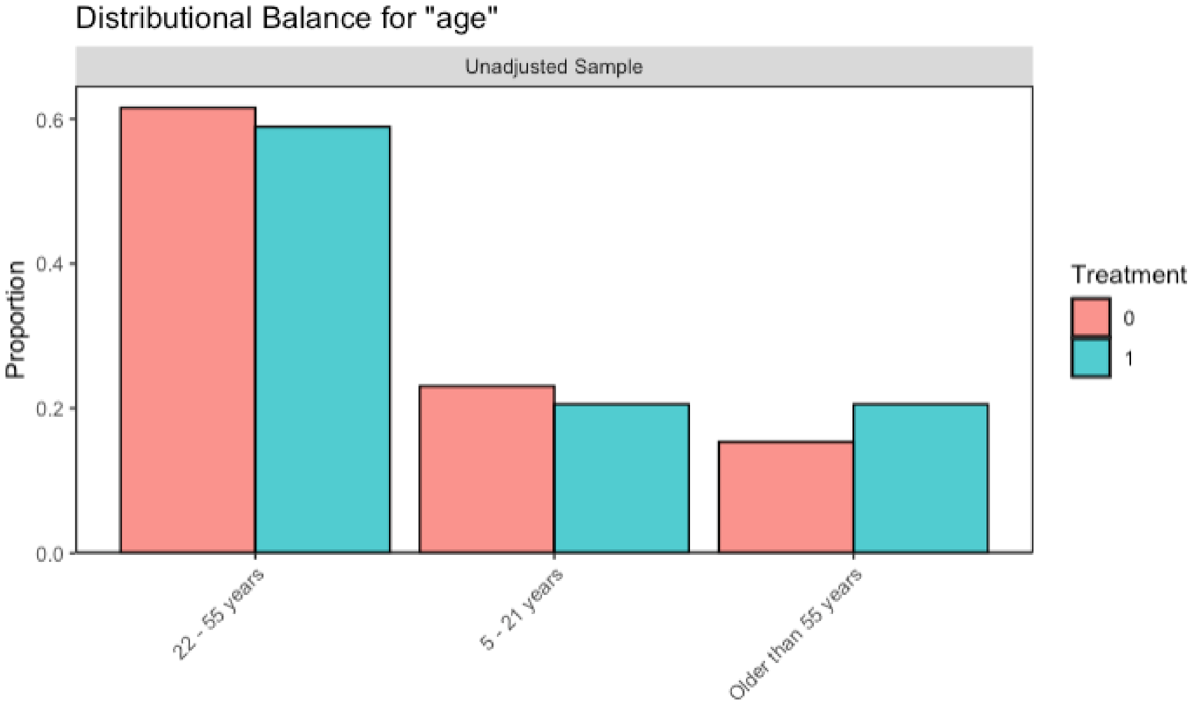


Figure 15: Covariate balance for all covariates

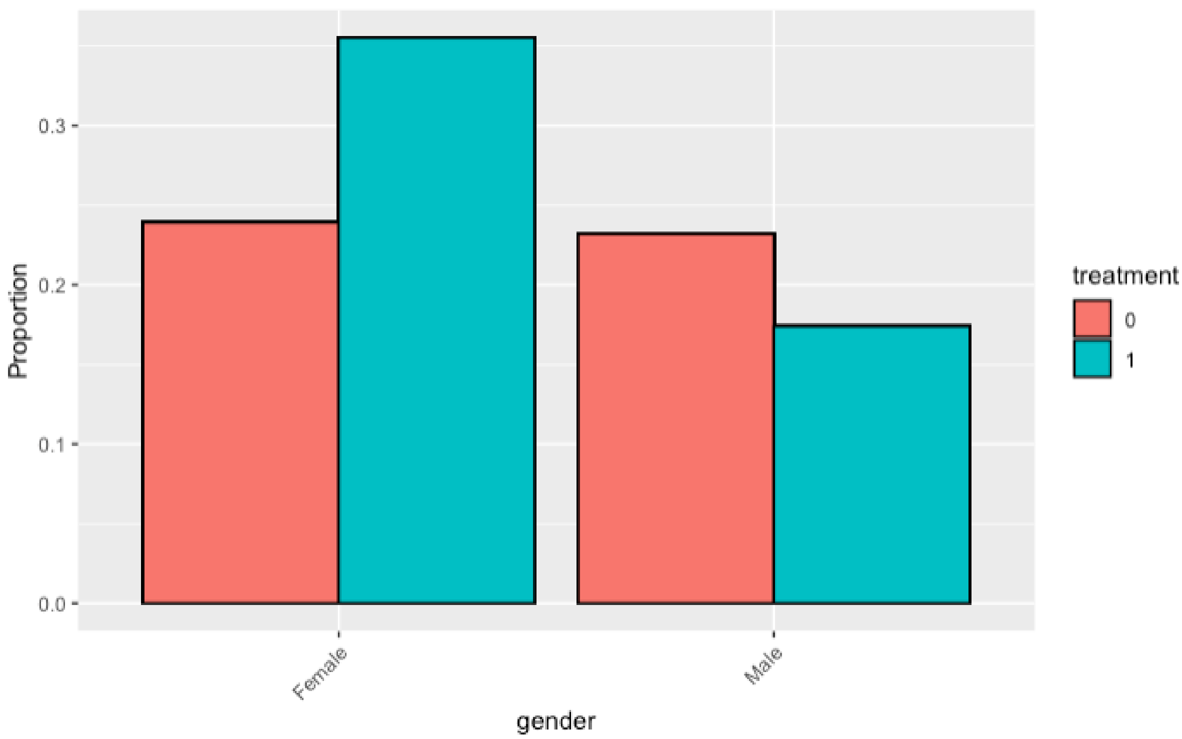


Figure 16: Covariate balance measures of each covariate

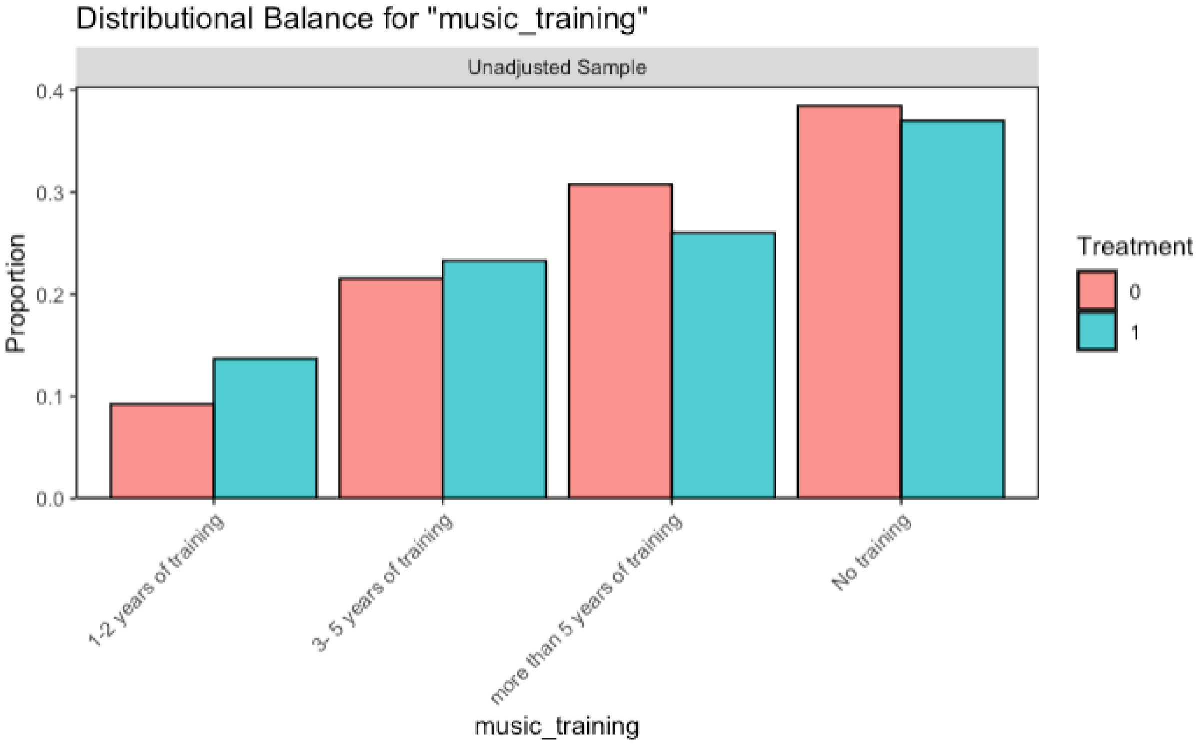


Figure 17: Covariate balance measures of each covariate

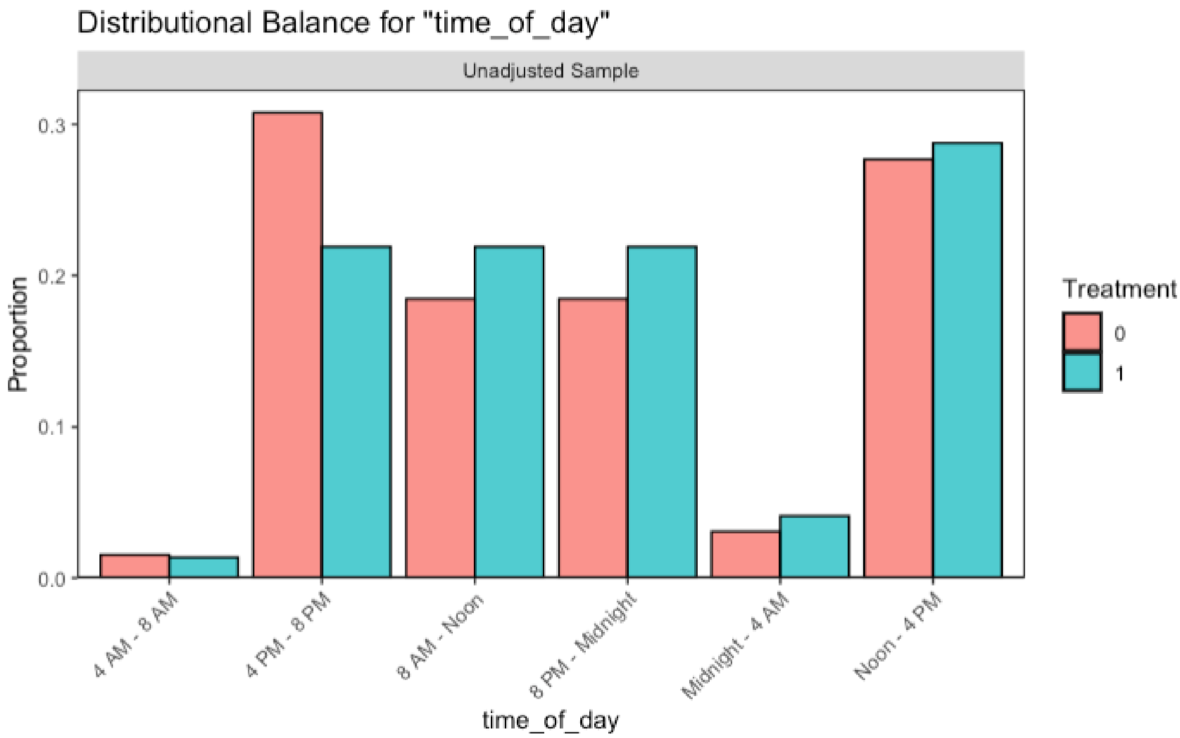


Figure 18: Covariate balance measures of each covariate