Investigation of the Impact of Lighting on Cognitive Task Performance and Subjective Mood in Virtual Environments

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With Virtual Reality becoming more popular throughout recent years, the question of how does an environment's lighting and color affect the stress levels produced by the environment. Our study looks into how to find a specific lighting and color of an environment that does not induce stress in individuals using virtual reality. We conducted a user survey with twenty-two people, concluding that color and lighting alone do not contribute to stress levels within a virtual environment. In addition, we found that there may be other factors that contribute to an individual's stress level within a virtual environment. Finally, we propose possible ways to further this study with other factors involved in the environments.

Additional Key Words and Phrases: lighting, color, virtual reality, emotion, surveys

1 INTRODUCTION

With the introduction and promotion of spatial computing devices as the next innovation in computing, questions arise around the impact that virtual environment design has on human emotion and performance of digital tasks. The challenge of creating stress-relieving virtual environments has been assessed in several studies, such as that conducted by researchers at the School of Architecture and Design at Beijing Jiaotong University [15]. An important aspect of virtual environments is lighting, which is divided into two categories: color and brightness [1]. This study dives into both categories. In particular, we aimed to learn if it is possible to create a stress-relieving environment using color and brightness of lighting [1, 24, 30].

2 RELATED WORK

Lighting plays an important role in the emotions of others, and there have been previous studies involving lighting in particular [19, 26]. Most of these previous results have mixed results on whether lighting can affect the emotions of participants [4]. With lighting there are different categories such as brightness and hue. Colors were explored in other studies and have shown to make people be more depressed, happy, etc as well [29]. By swapping the order that the participants experience the change in lighting and color, we can determine if a specific color combination can invoke an emotional response more than the other [5]. Colors play an important role in lighting due to specific colors or color combinations being able to invoke certain emotions within participants even if brightness does not. We used a similar method to Naz Kaya, in which we collected college students to go through our study and asked them to indicate their emotional responses (on a scale of one to five) to specific colors and brightness of lighting [11, 12]. With the use of Virtual Reality, we were able to insert the participant within the colors and brightness of the virtual environments we created. Virtual Reality played a role in our own work where the VR will be how the participant can experience the virtual environments to invoke emotional responses [14, 25]. Depending on the level of immersion of the participant within the Virtual Reality headset will determine whether the individual will be emotionally aroused during the experiment [7, 18, 23]. We created a sense of immersion by making the mood surveys be answered within the Virtual Reality to not break the immersion of the participants. If we had made the participants take the surveys outside of the headset each time the condition changed, the immersion could be lost and affect the results of the study. The virtual

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environments can also change in perception due to the emotions of the participants [8]. Virtual environments can be perceived differently just like within the real world depending on how the individual is feeling within the environment.

3 METHODOLOGY

Unity was used to build two different virtual environments within Virtual Reality (VR). These two environments contained three different lighting conditions. The participants—in a fixed seated position—were given a mood survey within the environment on the headset's screen. The participants would then be directed to the next screen to perform an adaption of The Stroop Color and Word Test (SCWT). SCWT gets the participants to look at names of colors, but the color of the text is sometimes different than what the name is. They then have to answer what the color of the text is [21]. Stroop found that completion time increased when the word and color were incongruent, a result we were able to reproduce (ANOVA $p<0.0001$). The software would automatically record the speed and accuracy of completing these tasks, as well as the mood survey that would be displayed before being transitioned into the next testing condition. Participants would complete these tasks and surveys a total of six times, not including the initial mood survey before the conditions were presented. The study design was within-subjects with two counterbalancing groups. The method used was the survey method [10].

3.1 Design of the Virtual Environments

Two virtual environments were created using Unity, and were designed for the viewer to be in a fixed seated position in the center of the scene. The two distinct environments that were created are: a realistic forest scene and a video game-styled office scene [27, 28]. The forest scene was based around a green "key modulation" and the office a tan "key modulation" [2]. The scenes were created with specific static elements in mind to better resemble their real-life equivalents. The environments contained no dynamic entities in order to not create any distractions. For each of the environments, the three lighting conditions that were implemented were: bright yellow lighting, dark red lighting, and bright green lighting as seen in Figure 1.

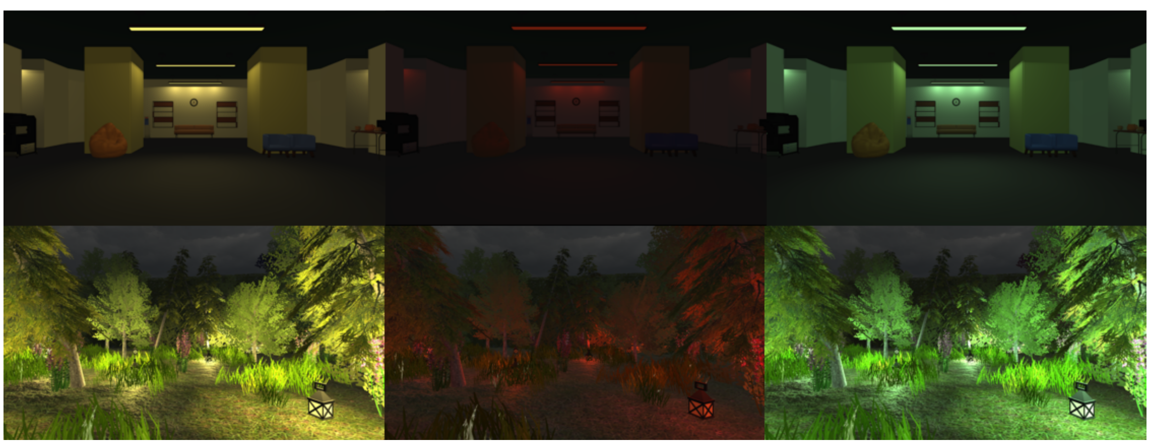

Fig. 1. Both environments containing all three of the lighting conditions: bright yellow, dark red, and bright green, respectively.

3.2 Experimental Equipment

In order to increase the rate of data collection, we each used our own equipment to conduct the experiment. The Valve Index and Meta Quest 2 virtual reality headsets were used for this experiment. There were no notable differences in testing quality between the two headsets that we could observe. The participants stayed in a seated position for the entirety of the experiment, therefore the full features of the headsets were not utilized. The only potential concern that came from the equipment was the need of base stations for the Valve Index as seen in Figure 2. The Valve Index did not allow for movement across the room due to the placement of these base stations as the Meta Quest 2 did, but due to the participants staying seated the entire experiment, this feature was not needed. Both headsets were wired directly to Windows computers that were capable to run the testing application. The headsets' standard controllers were used as the input devices for the experiment. Some problems that did arise was the controllers not registering the pressure being put on the index finger triggers, causing some speed results to be skewed in the Stroop Color and Word Tests questions.

Fig. 2. Experimental setup with a participant using the Valve Index

3.3 Participants

Twenty-five participants conducted the experiment, but four had to be discarded in the results due to the ages not being between the ages of eighteen to thirty. These participants were recruited from the Colorado State University student body, along with friends and family. Participants initially completed an online survey, and then at a different point in time would be asked to complete the experiment. The contents of the survey included the participant's age, gender, experience with VR, and whether the participant was colorblind. Only participants with normal color vision could participate in the final experimentation. This is due to the experiment revolving around lighting and color, and participants who are colorblind would not get genuine results due to them not being able to see the color change [32]. The participants were then divided into two groups after receiving all surveys for the purpose of order counterbalancing. Groups were assigned following minimization techniques [22] such that both groups had a similar mean of participants' levels of experience with virtual reality, with age and gender as second and third priorities respectively (see table 1). These levels were measured by the online survey in which the experience was ranked on a scale of zero to five. Zero would mean that the participant had absolutely no experience with virtual reality, and five would mean that they would be considered a "veteran" in terms of virtual reality. The amount of participants per level of VR experience can be seen in Figure 3. Virtual reality experience was the priority in the grouping process, followed by the group member count, age (number of participants per age group can be seen in Figure 4), and lastly gender. The first group would first start in the office scene and proceed through each lighting condition starting with light yellow, dark red, and light green, and then go through the same lighting within the forest scene. The second group would start in the forest scene, but the lighting would instead go bright green, dark red, and then bright yellow, and then proceed within the office scene.

Table 1. Demographics Between Assigned Groups

	VR Experience							Age				Gender		
Group	0	1	2	3	4	5	Mean	18–21	22-25	26–30	Mean	Male	Female	Non-Binary
Group 1	0	2	2	3	1	3	3.09	6	4	1	21.36	6	3	2
Group 2	1	3	0	2	5	0	2.64	5	4	2	22.63	6	4	1

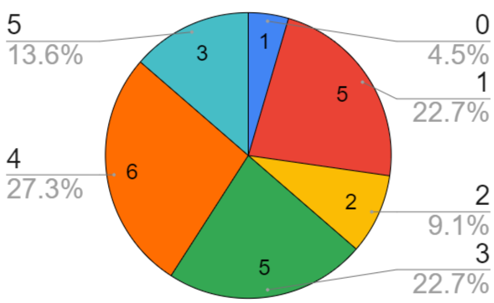

Fig. 3. Number of participants per level of VR experience

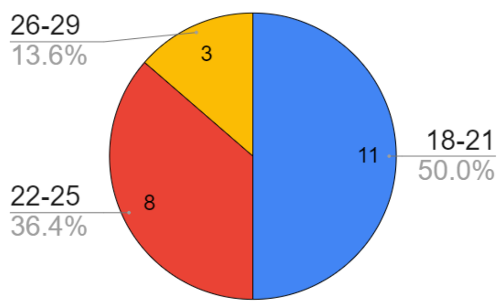

Fig. 4. Number of participants per age group

3.4 Experimental Procedure

Participants would first read the consent form, and then verbally consented to continue with the study. The participants would be quickly briefed on what to expect and then assisted with putting on the virtual reality headset. Within the virtual environment, the participant would be placed into a waiting room and be presented with a virtual instruction screen. The virtual screen we designed to be more appealing by using a simplistic design for participants [9, 20]. The instruction screen explained how the environments would cycle, how to use the controllers, and let them have time to get comfortable with the headset. The input was performed by using VR controllers—one controller per hand—as pointing devices. The controllers had a visual representation within the environment for spatial awareness, and a ray going from the controller to the screen. The participant was able to point at the virtual screen, and by holding down the index finger triggers, participants would be able to interact with the graphical controls. Participants would then be prompted with a starting mood survey to gauge their mood starting out. The participants were presented with six emotions, and a rating of one to five in each. One is that the participant does not really feel this emotion, and five is that the participant really feels this emotion. The emotions presented were: Tired, Excited, Anxious, Comfortable, Uneasy, and Frustrated [13]. The participants were able to easily select their emotions and this allowed us to successfully see if there were any emotional changes while participants were within the scenes without needing an automatic emotion sensor [6]. The participants, after completing this first survey, would be transported into their assigned first testing environment. They would then be prompted to complete four practice Stroop Color and Word Tests questions, for which no data was collected. After the completion of the practice questions (pictured in figure 5), participants were given sixteen SCWT questions in which their responses would record the speed it took for the participant to answer the question after it was presented, and the accuracy of each question. Once all sixteen of the SCWT questions were answered, the participant was then prompted with the mood survey again, (also pictured in figure 5). Then the participant would transition into the next lighting condition and follow the same tasks until after all three conditions are completed within the starting scene. Finally, the participant is transitioned into the next scene following the same three lighting conditions, and the same tasks through each lighting condition. Those starting in the office scene would have these lighting conditions in this order for both scenes: yellow with bright lighting, red with dark lighting, and green with bright lighting. Those starting in the forest scene would have the lighting conditions in the opposite order: green with bright lighting, red with dark lighting, and yellow with bright lighting [17].

Fig. 5. The mood survey and SCWT questions respectively as seen by participants in Virtual Reality

4 RESULTS

Our core null hypothesis to test against was as follows: For each emotion listed in our mood survey, the virtual environment will not have an effect on that emotion. The secondary null hypothesis we tested against was related to the Stroop tests; the means across both environment and congruence will not be significantly different, and environment has no effect on test congruence. In order to challenge these hypotheses, we needed to process the data we collected in a way that was meaningful in reaching a conclusion. Data collected from the mood surveys was processed through a Friedman analysis (Table 3) in an attempt to find a correlation between user responses and their current environment, whereas Stroop tests results were run through two-way ANOVA tests (Table 2) in an effort to see if altering an individual's virtual environment would impact their completion time in the Stroop tasks.

Table 2. Two-Way ANOVA - Stroop Completion Time

	Sum Squares	df	Mean Square	F	p
Congruence	44.98976	1	44.98976	79.67407	<.0001
Environment Number	1.23686	5	0.24737	0.43808	0.8222
Congruence × Environment Number	2.25752	5	0.45150	0.79959	0.5499

The overall results provided statistical significance in two emotional categories: comfort and frustration. As shown in table 3, subjects' changes in comfort across environments has a p-value of 0.0108, while their frustration is associated with a p-value of 0.0406. This finding therefore disproves the null hypothesis for two of the six emotions within the study, implying that the shift in coloration and environments does in fact have an impact on subjects' emotional responses. This statistical significance led us to perform Durbin Pairwise Comparisons on both comfort and frustration datasets, as shown in figures 4 and 5 below. The results obtained from the "comfortable" table suggest that pairs including environments 2 and 5 (dark red) were the most influential in changes of comfort. Notably pairs 1-3, 2-5, 2-6 have statistically significant p-values, all of which contain shifts to and from the dark red environments. Similarly, in the "frustration" table, pairs 1-4, 1-5, 2-4, and 2-5 contain statistically significant p-values for the same reason.

Table 3. Friedman analysis of mood survey data

	Anxious	Comfortable	Excited	Frustrated	Tired	Uneasy
χ^2	4.03315	14.90196	9.95298	11.60714	2.34657	3.84259
p-value	0.5447	0.0108	0.0766	0.0406	0.7994	0.5723
df	5	5	5	5	5	5

Table 4. Durbin Pairwise Comparisons (Comfortable)

Environment Pair	Statistic	p
1,2	0.06716	0.9466
1,3	1.81329	0.0726
1,4	1.54465	0.1254
1,5	2.55204	0.0121
1,6	3.02215	0.0032
2,3	1.88045	0.0628
2,4	1.61181	0.1100
2,5	2.61919	0.0101
2,6	3.08931	0.0026
3,4	0.26864	0.7887
3,5	0.73875	0.4617
3,6	1.20886	0.2294
4,5	1.00738	0.3161
4,6	1.47749	0.1425
5,6	0.47011	0.6393

Table 5. Durbin Pairwise Comparisons (Frustrated)

Environment Pair	Statistic	p
1,2	0.53464	0.5940
1,3	0.98018	0.3293
1,4	2.04947	0.0429
1,5	2.13857	0.0348
1,6	0.17821	0.8589
2,3	1.51482	0.1328
2,4	2.58411	0.0111
2,5	2.67322	0.0087
2,6	0.71286	0.4775
3,4	1.06929	0.2874
3,5	1.15839	0.2493
3,6	0.80197	0.4244
4,5	0.08911	0.9292
4,6	1.87125	0.0641
5,6	1.96036	0.0526

However, it's important to consider that the Stroop tests themselves were the root cause of the resulting frustration statistics, as subjects reported getting increasingly upset with the tasks presented to them. The comfort statistics are a bit more viable considering that subjects reported feeling "more relaxed" in environments where the dark red coloration was absent.

What is interesting, however, is that our VR Stroop test functioned the same as it would in a traditional setting; by performing an ANOVA test on both congruence and completion time, we observed that there was in fact a statistically significant p-value. This was to be expected, as Stroop tests are designed to produce such a result. However, it's worth considering that these tests are normally conducted on traditional technologies such as paper or a computer monitor and not in virtual reality. Given more time to research, a study could be conducted to observe if differing environments have any effect on Stroop test performance, and the time it takes to complete such a test. A boxplot of our Stroop test findings across both groups is shown below in Figure 6.

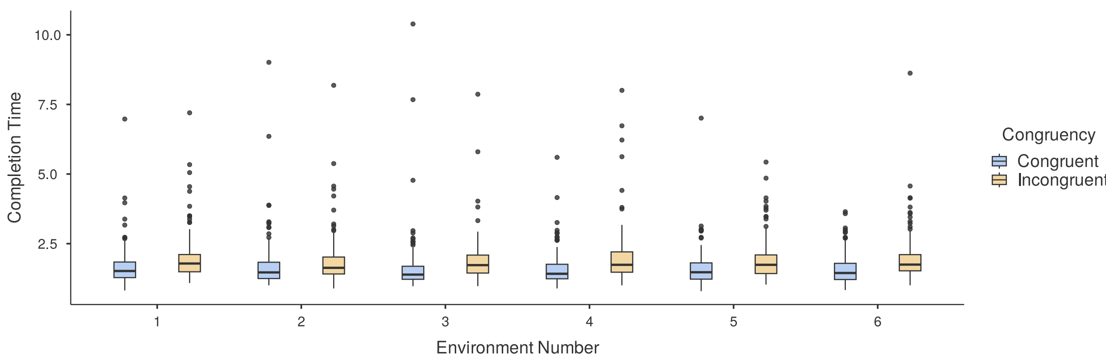

Fig. 6. Box Plot - Stroop Test Completion Time

5 DISCUSSIONS

One of the limitations we experienced was the restricted time frame to complete this study. We could have done more with this study if we had a month or two more. Another limitation was the access to a singular lab with no outside disturbances. The controllers did seem to sometimes not register the pressure on the index finger triggers, as mentioned above, with no extra controllers to be able to use instead. The scenes would also sometimes lag or completely shut down if we had inputted the info of the participant before they passed the instruction virtual screen. We also excluded four of the participants due to the participants being older than thirty. However, this did not affect our results due to the speed and accuracy of these participants lining up with those we kept within the study. We learned that our study could have been better and included more static variables that may have invoked more emotional arousal than what our results were. We found out that a majority of the participants preferred to observe their surroundings before continuing onto the next condition, as well as that most found the study to be boring and lacking complete immersion.

6 CONCLUSION AND FUTURE WORK

In conclusion, we did not find a correlation between color and brightness of lighting of our virtual environment and stress-levels or emotions. A majority of participants did not have worse or better accuracy throughout the different conditions, and participants emotions did not change throughout the different lighting conditions. Participants did express that their emotions were non-changing due to the fact that there was not enough immersion, by which they said that the use of sound or specific items within the virtual environments could have caused their emotions to fluctuate throughout the different conditions. There could be more work to be added to this study that may change the overall results that we observed. The future work of this study can include a multitude of adaptations to this study all of which would not change the independent factors, but rather enhance the study. One of these adaptations would be to include sound within the environments. Participants mentioned that without the use of sound, it seemed like they were just watching an environment change colors. The sound for the office scene could be nature sounds that does not change throughout, and the office could have a typical office sound also not changing throughout. Another adaptation could be to have an item in both environments that could be fear-inducing in certain lighting conditions, but not in others. An example of such an item could be a mannequin. In certain lighting conditions this could induce uneasiness and anxiety, whereas different conditions could have no change in a participants emotions [16, 31]. The use of a specific lab area could also be used in future work, where all participants experienced this experiment in the same area [3]. The use of a heart rate monitor can also enhance this study in the future by allowing us to observe if heart rate increases with emotional arousal within the specific lighting conditions. All of these adaptations could result in differentiating results from those that we gathered and observed with our current study.

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