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

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With the promotion of spatial computing devices as the next computing paradigm, questions arise around the impact that the design of virtual environments has on performance of computing tasks. Our study examines how lighting and color of an environment, as well as environment design impact cognitive task performance and emotion. We conducted a study with twenty-two participants. We did not find a significant impact on speed of task completion between any of our virtual environments. We did find a slight, but statistically significant impact on some emotions between environment designs, but color and lighting were not significant on their own. 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 [14]. 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, 23, 29].

2 RELATED WORK

We were influenced by similar works which examined the impact of environment color on cognitive task performance.[16] Lighting plays an important role in the emotions of others, and there have been previous studies involving lighting in particular [18, 25]. Most of these previous results have mixed results on whether lighting can effect 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 [28]. 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 from 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 [13, 24]. 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, 17, 22]. 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

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of the headset each time the condition changed, the immersion could be lost and effect the results of the study. The virtual 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.[26, 27]

3 METHODOLOGY

Unity was used to build two different virtual environments within Virtual Reality (VR). These two environments each 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) [20]. 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. In his original study, Stroop found that completion time increased when the word and text color were incongruent, a result we were able to reproduce. Speed and accuracy of task completion were automatically recorded by the software. After completing each battery of tests, participants answered the subjective mood questionnaire again before transitioning to the next testing condition. Participants did this six times; once for each lighting condition in both environments. The study design opted for was within-subjects with two counterbalancing groups. Survey methodology was used to collect emotional data [10].

3.1 Design of the Virtual Environments

Two virtual environments were built using the Unity game engine. Environments were designed for a fixed seating position with the viewer at the center. Two distinct environments were created: a facsimile of a typical office lounge and a realistic forest setting. The forest scene was based around a green "key modulation" and the office a tan "key modulation" [2]. The scenes were decorated with various static visual elements to adequately resemble their real-life equivalents. Environments were completely static and contained no dynamic entities which could serve as a distraction. For each environment, three lighting conditions were implemented: warm lighting, dark red lighting, and green lighting.

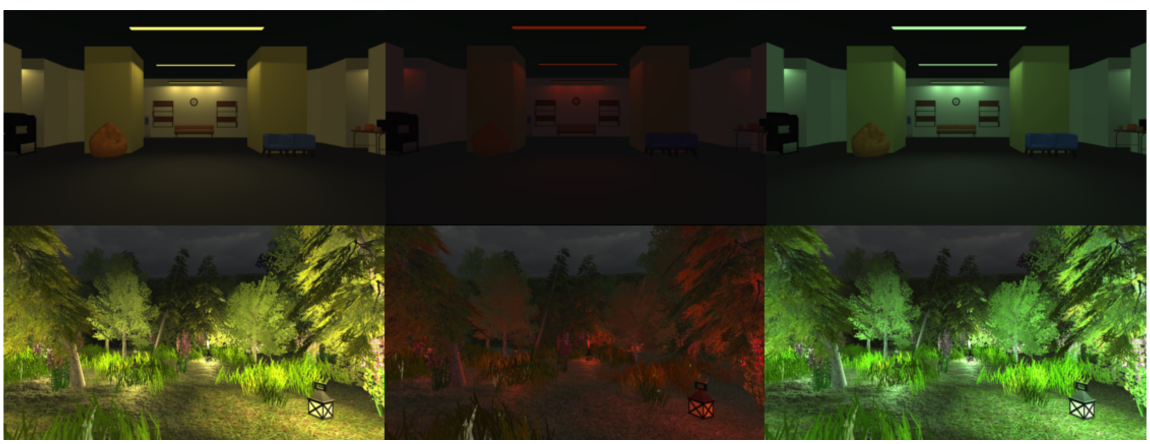

Fig. 1. Both environments containing all three of the lighting conditions: bright yellow, dark red, and bright green, respectively.

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.

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

3.3 Participants

Twenty-five participants conducted the experiment, but four were discarded from the results due to age substantially impacting performance. The remaining participants were all between the ages of eighteen and thirty. These participants were recruited from the Colorado State University student body, along with friends and family. Participants completed an online survey at the time of recruitment, and participated in the experiment at a later date. 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 [31]. After receiving all survey results, the participants were divided into two groups for the purpose of order counterbalancing. Groups were assigned following minimization techniques as described by Taves[21] such that both groups had similar mean levels of experience with VR, with age and gender as second and third priorities respectively (see table 1). This metric was obtained through the online survey completed prior to the experiment and were ranked on a scale of zero to five. Zero meaning that the participant had absolutely no experience with virtual reality, and five meaning that they had extensive VR experience. The number 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 started in the office scene and proceeded through each lighting condition before proceeding to the forest scene to do it again. The second group experienced conditions in the exact reverse order as that of the first group, starting in the forest scene on the last lighting condition.

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

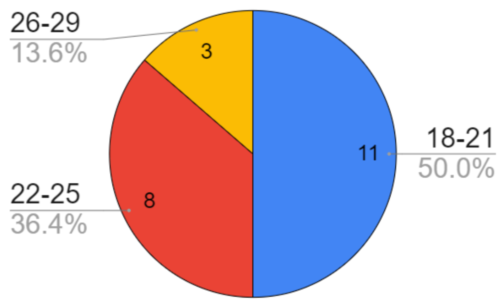

Fig. 4. Number of participants per age group

3.4 Experimental Procedure

Participants first read the consent form, and then verbally consented to continue with the study. The participants were quickly briefed on what to expect and then assisted with putting on the virtual reality headset. Within the virtual environment, the participant was placed into a waiting room and presented with a virtual instruction screen. The virtual screen was given a simplistic design to be more appealing to participants [9, 19]. The instruction screen explained how the environments would cycle, how to use the controllers, and directed them to take as much time as they needed to get comfortable being in VR. Participants were then prompted with a starting mood survey to gauge their mood starting out. The participants were presented with six emotions, and asked to rate their current mood on a scale from 1–5. The emotions presented were: Tired, Excited, Anxious, Comfortable, Uneasy, and Frustrated. The participants were able to easily select their emotions, allowing us to assess if there were any emotional changes while participants were within the scenes without needing an automatic emotion sensor [6]. Input was performed using VR controllers—one controller per hand—as pointing devices. A virtual representation of the controllers' spatial position and a ray originating from each of their ends was visible to the participant; By pointing at a screen element and holding down the index finger trigger, participants were able to interact with graphical controls. The participants, after completing this first survey, were transported into their assigned first testing environment. They were then prompted to complete four practice SCWT questions, for which no data was collected. Subsequent to the completion of the practice questions, participants were given a battery of sixteen SCWT questions. Time elapsed between the presentation of each prompt and the participant choosing a response, as well as response correctness were automatically collected and recorded by the application. Upon completion of the requisite number of tasks (sixteen), the participant was prompted to complete another mood survey (as previously described), then transitioned into the next testing condition to start the next battery of sixteen SCWT tasks. The experiment proceeded in this manner through all six conditions: yellow, dark-red, and green lighting conditions in the office, followed by those conditions again in the forest. The counterbalancing group experienced these conditions in the exact opposite order.

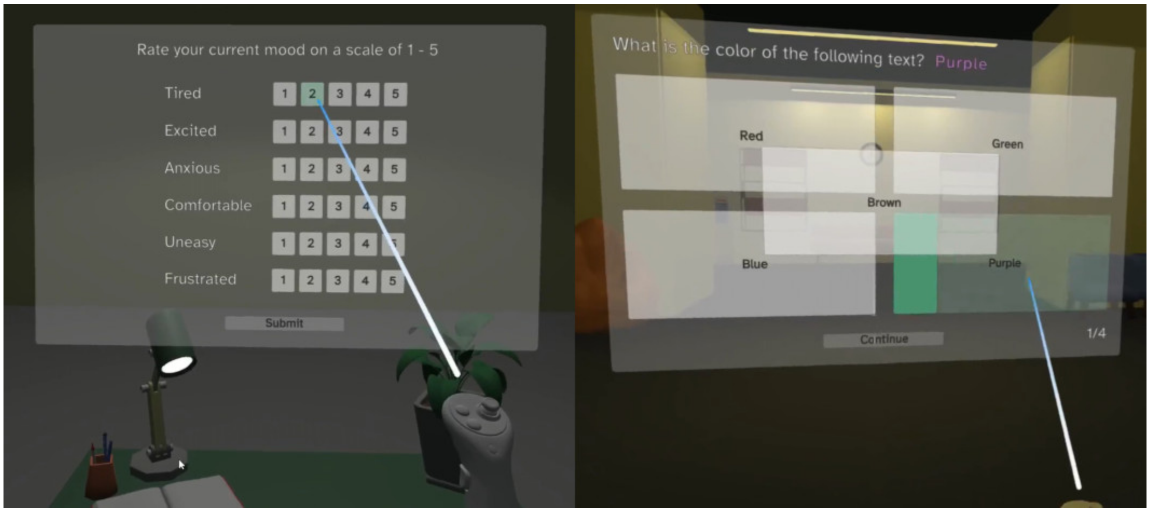

Fig. 5. The mood survey and SCWT questions respectively as seen by participants in Virtual Reality

4 RESULTS

We found that that our VR implementation of the Stroop Test reproduced the results of conventional Stroop Tests; by performing an ANOVA test on both congruence and completion time, we observed that there was a statistically significant correlation (see table 2) between congruence and completion time. This was important to test, as conventional stroop tests are performed verbally, whereas our implementation used selection via buttons. We did not find a significant correlation between environment and completion time, nor was the interaction between congruence and environment significant. We speculate that a longer testing period or a more substantial environmental difference may have produced significant results. A boxplot of our Stroop test findings across both groups is shown below in Figure 6.

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

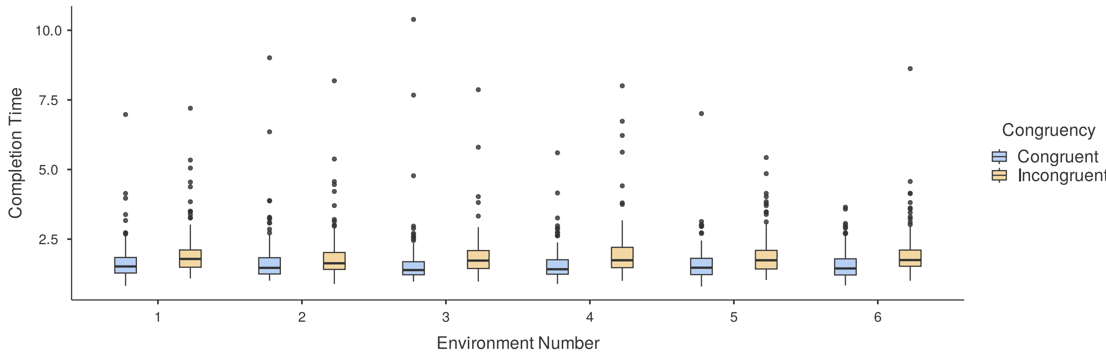

Fig. 6. Box Plot - Stroop Test Completion Time

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. The overall results showed 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.

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

This statistical significance led us to perform Durbin Pairwise Comparisons on both comfort and frustration datasets, as shown in tables 4 and 5 below. Pairwise analysis of comfort ratings (table 4) suggest that the pairs (1,5), (1,6), (2,5), and (2,6) differed significantly. Recall that conditions 1–3 are warm, red, green, in the office scene, and 4–6 are the same in the forest scene. No significant pairs appear within scenes, so lighting changes within scenes did not significantly impact comfort; All pairs are between scenes. The pair (2,5) represents the dim red lighting condition between both scenes; Cross-referencing with table 6, we see that participants were approximately 0.31 points more comfortable in the forest under the same lighting condition. The relationships represented by the other pairs are less clear, as they occur in both different scenes and lighting conditions, but they consistently show that participants were more comfortable in the forest than the office. The most significant pair was (2,6) with a delta of approximately 0.45 points. Another observation we can make is that significant pairs don't occur at the center, rather they appear at the beginning and end conditions; This may suggest an insufficient number of counter-balancing groups, as the extremes of this table represent the starting conditions of the two groups. Comfort was universally high to begin with and slowly decreased over time, which in turn effected our results.

Similar results occur for frustration. As shown in table 5, the significant pairs were (1,4), (1,5), (2,4), (2,5). Again, significant differences only occur between scenes and not between lighting conditions. We can therefore determine that

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

Table 6. Rating - Comfort

	Environment					
	1	2	3	4	5	6
Mean	3.54545	3.50000	3.81818	3.77273	3.81818	3.95455
Standard deviation	1.22386	1.30018	0.95799	0.97257	0.95799	0.84387

Table 7. Rating - Frustration

	Environment					
	1	2	3	4	5	6
Mean	1.59091	1.68182	1.50000	1.40909	1.40909	1.59091
Standard deviation	1.05375	1.08612	1.14434	1.00755	0.85407	1.14056

lighting conditions did not have a significant effect on frustration, but the physical environment that the subject was placed in did. The most significant difference was (2,5) with a delta of approximately 0.28 points (table 7). Participants were less frustrated in the forest than they were in the office.

5 DISCUSSION

The primary limitations we experienced was the restricted time frame to complete this study, as we were given roughly 14 weeks and could have benefited from an extra month or two more. Another limitation was out lack of access to a lab with no outside disturbances, as we had to conduct our studies in our family homes and the university's computer labs. The controllers of the Valve Index occasionally failed to register when the subject held the trigger to select an answer, which could not be remedied as we did not have replacement controllers immediately accessible. We observed that the majority of participants preferred to immerse themselves with their surroundings before continuing onto the next condition. Subjects had mixed reactions to the experiment, with some praising it for its environment design while others critiqued its lack of activity and immersive capabilities.

6 CONCLUSION AND FUTURE WORK

In conclusion, our study revealed a correlation between virtual environments and user emotion as well as the effectiveness of Stroop tests within virtual reality. Color variations proved to have a non-existent effect on subject emotional responses, given our limted subject counts. The majority of participants did not experience a change in Stroop test accuracy between environments. Participants reported that a lack of immersion was what led their emotions to remain unchanged, which may have been remedied using sound sources or various thematic items scattered within the virtual environments. There is potential for more progress to be added to this study that would produce results better than our own. These changes may include a multitude of adaptations that would not alter the independent factors, but rather enhance the study. Participants mentioned that without the presence of sound, it seemed like they were just observing as an environment change colors. Ambient nature audio could be utilized in the forest scene, while the slow hum of ceiling lights and the typing of a keyboard could be implemented into the office scene. Another adaptation could be to have an item in both environments that could induce fear within certain lighting conditions (such as the dark red scene, but not in others), such as a mannequin. In darker lighting conditions this could induce uneasiness and anxiety where the participants would have no change in emotion otherwise [15, 30]. A designated lab could also benefit the study, where all participants would participate in a uniform, controlled environment [3]. The use of a heart rate monitor can also enhance this study by allowing us to observe if heart rate increases with emotional arousal within the specific lighting conditions. All these adaptations could result in results differentiating from those that we gathered and observed in our own study.

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