Cognitive Distraction to Improve Cybersickness in Virtual Reality Environment

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***Abstract*—Immersion into a virtual environment (VE) often results in adverse symptoms including nausea, dizziness, and disorientation. These symptoms are an indicator of cybersickness, which is a condition similar to motion sickness experienced in VEs. In this paper, we hypothesized that administered cognitive distraction can accelerate the rate of habituation to a VE. This acceleration, therefore, can lower severity of cybersickness in fewer amount of immersions. To evaluate the impact of cognitive distraction on reducing the effects of cybersickness, we designed a VE and carried out a human subject study with control and experimental groups created through stratified random sampling. Subjects were immersed in our VE on four separate sessions, and our experimental group received cognitive distraction throughout the immersions. Cybersickness was measured using the Simulator Sickness Questionnaire (SSQ) and Presence Questionnaire (PQ). Upon comparing the average SSQ subgroups nausea, oculomotor, and disorientation scores reported by participants for each immersion session, we observed that our experimental group exhibited decrease in cybersickness to a greater extent than that of our control group. We completed t-tests for each of these comparisons, to find that these results are statistically insignificant. We plan to continue with this work by incorporating up to 30 total participants to clarify these findings.**

***Index Terms*—cybersickness, cognitive distraction, habituation, presence, virtual reality**

I. Introduction

In 2019, virtual reality (VR) technology is ubiquitous. Aside from the awe evoking, trendy VR pop up bars along the streets of New York and Los Angeles, VR has applications spanning an array of industries. It has been effectively used for virtual exposure therapy [1]; mental stress reduction [2]; new, experimental, artistic mediums [3]; and of course, video games. However, a large percentage of users experience cybersickness, and interestingly enough, women are significantly more prone to cybersickness than men [4]. Cybersickness is the motion sickness that occurs when stationary users view virtual environments, particularly through a head mounted display [5]. Symptoms include nausea, disorientation, headaches, sweating, dizziness, vertigo, and lack of coordination [4]. These symptoms can become severe while users are immersed in a VE, and often linger for about an hour after exiting a VE. Users experiencing symptoms of cybersickness often discontinue using VR. As VR technology increases in popularity and applicable potential, research regarding cybersickness is necessary, and seemingly omnipresent.

The complex, contrasting interaction between vection, or in other words, the illusion of self motion, and the physical stillness of the user, are likely the cause of cybersickness [6]. There are a plethora of proposed visual and auditory solutions to mediating cybersickness [7]–[9]. Some visual examples include employing a dynamic field of view during perceived rotational movement [7], and implementing vignetting during head rotations [8]. As for an auditory example, it was found that *pleasant* music in a virtual environment reduces a user's cybersickness [9]. Keshavarz and Hecththen suggested that pleasant music only mitigated users' cybersickness because it distracted them from their symptoms. Therefore, we plan to incorporate distraction as a method of decreasing cybersickness in our research.

Our work focuses on the potential of cognitive distraction for cybersickness reduction. In particular, we hypothesize that cognitive distraction will speed up a users habituation to virtual reality environment, reducing their cybersickness at a faster rate than habituation without cognitive distraction. Habituation has already been proven effective in reducing cybersickness [5], [10]. Simultaneously, cognitive distraction has been effective in mitigating nausea for regular motion sickness [11], for reducing nausea due to chemotherapy in both adult [12] and pediatric [13] cancer patients. Because of the similarities between motion sickness and cybersickness symptoms, we see potential in the combination of habituation and cognitive distraction for mitigating cybersickness.

To explore this new potential for cybersickness reduction, we created a virtual environment in Unity [14] and conducted an experiment by immersing our participants in this environment. Participants used the Oculus Rift head mounted display and hand controllers to undergo four sessions of immersion. Our experimental group received cognitive distraction in the middle two sessions, in the form of yes or no questions that they had to answer using our user interface. All participants took questionnaires regarding their cybersickness symptoms [15] and level of presence [16] following each immersion so that we could compare the rate of habituation between our control and experimental group, investigating the effect of cognitive distraction on habituation.

The remainder of this paper is organized as follows. Section II provides the background information and discusses related works. Section III presents our proposed experimental design and procedures. Section IV presents the preliminary findings. Section V concludes the paper.

II. Related Works

A. Presence

What aspects of the real world cause a person to feel *fully there*, which aspects of a virtual environment (VE)

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can encapsulate this, and to what extent? Presence, a user phenomenon within a VE, is a topic of interest within virtual reality research. It has been defined as the sense of *being there*, demonstrated by a user behaving and interacting intuitively with the VE [17]. It is also defined as the *sensation of being there*, in a certain environment, when one is physically situated elsewhere [16]. Both involvement, the state of focusing ones energy on a VE's coherent stimuli, and immersion, the psychological state of perceiving ones self to be actually in and surrounded by the VE [18], are required sensations for experiencing presence [16]. Witmer and Singer's findings indicate a weak yet consistent positive correlation between presence and task performance [16]. Moreover, their results from the questionnaires displayed a negative correlation between levels of cybersickness and levels of presence. Presence is important because the objective of virtual reality technology is to give the user an experience more realistic than a regular display monitor, but without the limitations of the real world [17].

B. Habituation

Habituation is defined as the decreased response to a reoccurring stimulus [19]. It is synonymous with *getting used to* a certain stimulus over time. Habituation to motion sickness has long been proven effective, but habituation to the appearance of motion in a VE has more recently been studied to find that the more sessions participants had immersed in a VE, the less nausea they experienced each time. It was also found that if users were repeatedly immersed for longer immersion sessions, their rate of habituation increased [10]. Similarly, the more sessions one immersed in a VE, the longer one can remain in the environment, due to the desensitization to nausea, and delaying of its escalation [5].

C. Cognitive Distraction

The vast majority of people are unable to effectively focus on two tasks at once. Strayer, Watson, and Drew's framework of distraction categorizes sources of distraction as visual, manual, and cognitive. Cognitive distraction occurs when ones attention is removed from the processing of certain information [20]. Cognitive distraction has been effective in significantly reducing nausea resulting from motion sickness [11]. In this particular study, participants self-defined levels of nausea lowered after being instructed to memorize a sequence of letters. Furthermore, cognitive distraction has effectively lessened nausea for both adult and pediatric chemotherapy patients [12], [13]. Music has also been utilized as a means of mitigating cybersickness [9]. In this study, participants who categorized the music they heard in a VE as pleasant reported significantly lower scores on the Simulator Sickness Questionnaire. Keshavarz and Hecht then speculated that this may have been due to the fact that the music was distracting the participants from their cybersickness. To the best of our knowledge, cognitive distraction as a means of mitigating cybersickness has not been studied before.

III. Methods

In this section, we describe our methodology for conducting the experiment, including the equipment, the designed virtual environment, the participants, and our test procedures.

A. Equipment

The virtual reality environment was tested using the Oculus Rift and the Oculus Touch controllers [21]. The virtual reality environment was engineered using the Unity Gaming Engine [14]. It was tested on a computer with and Intel Core i7-7700K CPU and a GTX 1080 GPU.

B. Virtual Environment

We created a suburban neighborhood virtual environment in Unity for participants to explore using assets from Unity Asset Store. Our neighborhood consisted of four intersecting streets, which formed nine total blocks. These blocks contained a variety of two-story residential houses, city buildings, storefronts, and public parks. Some of the houses could be entered. The neighborhood was surrounded by hilly terrain filled with trees. Fig. 2 displays an example of what participants see while exploring our VE. Within this environment, there were 30 bouncing balls hidden in different locations for subjects to find. Subjects were instructed to *collect* as many balls as possible by using artificial locomotion via the joystick on the controller to collide with them. Once collected, the ball disappears from view. The purpose of this task was to keep the subjects engaged in the environment, similar to S. Nichols et al.'s [17] task performance's purpose. We implemented the cognitive distractions by writing a user interface (UI) script in C#. The UI allowed users to point to and select answers for our questions that would pop up every two minutes, as displayed in Fig. 3. Subjects interacted with the UI while in the VE using the Oculus Touch controllers.

Nausea (N)	Oculomotor (O)	Disorientation (D)
General Discomfort	General discomfort	Difficulty focusing
Increased Salivation	Fatigue	Nausea
Sweating	Headache	Fullness of head
Nausea	Eye strain	Blurred vision
Fullness of head	Difficulty focusing	Dizzy (eyes closed)
Stomach awareness	Difficulty concentrating	Dizzy (eyes opened)
Burping	Blurred vision	Vertigo

Fig. 1. NOD Symptoms

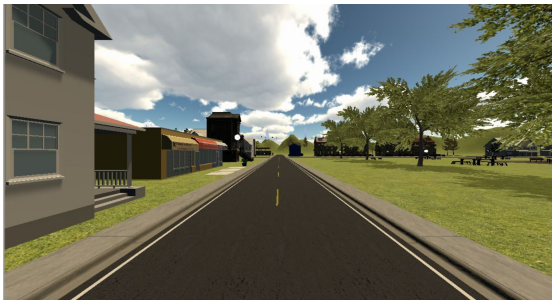

Fig. 2. VE From User Perspective

C. Participants

Participants were recruited on a voluntary basis by responding to flyers posted around New York Institute of Technology's campus. All participants were 18 years of age or older. The control and experimental group were created through stratified random sampling, with gender (specifically males and females)

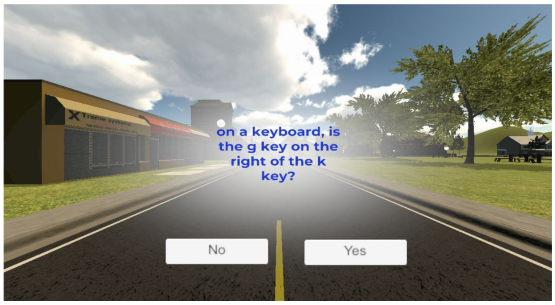

Fig. 3. VE From User Perspective With UI Pop-Up Question

representing the strata. The protocol is reviewed and approved by the New York Institute of Technology Institutional Review Board (Protocol No. BHS-1476).

D. Procedure

Our procedure consisted of a total of four immersion sessions, twenty minutes each, on four separate days. Participants were allowed to terminate the session at any time if they felt too cybersick. Before the first immersion session, all 14 participants completed an orientation session to practice using the controllers, answering the questions that pop up on the screen, and retrieving a bouncing ball. We randomly selected participants to be in our control and experimental group, evenly dividing the male and female participants between each group. The experimental and control groups differed in the middle two sessions, in which the experimental group received cognitive distraction in the form of yes or no questions that popped up every 2 minutes that they needed to answer, while the control group did not. An example of the questions used is "Are all even numbers divided by other even numbers even?" This is predominantly a cognitive distraction, but would also be considered manual and visual distraction as well, due to the nature of the user interface and the text on the screen [20]. After each immersion session, all participants filled out the Presence Questionnaire (PQ) [16] and Simulator Sickness Questionnaire (SSQ) [15]. Hence, we were able to compare questionnaire results to see if the rate of habituation was faster for the experimental group due to the administered cognitive distraction in the middle two habituation sessions.

IV. Results

A. Evaluation Metrics

Of the sixteen symptoms listed in the SSQ, seven correspond to the nausea subcategory of cybersickness, seven to the oculomotor subcategory of cybersickness, and seven to the disorientation subcategory of cybersickness; each symptom corresponds to either one or two different subcategories. For example, "headache" contributes only to the oculomotor aspect of the SSQ, while "difficulty focusing" contributes both to the oculomotor and disorientation aspects of the SSQ. Hence, each participant has a nausea (N), oculomotor (O), and disorientation (D) score that is found by adding the scores of corresponding symptoms. Fig. 1 shows the SSQ symptoms corresponding to each NOD category. For each question in the SSQ, participants were asked to rate the severeness of the symptom from a scale of 0 (none) to 3 (severe). Summing up the scores for each column will give the score for each NOD category with a range from 0 to 21. To assess the changes in the levels of cybersickness, we compared the average NOD scores across the 4 trials for the experimental and control groups. To address the differences between control and experimental results, we compared the average NOD scores, split up by male and female participants, in both experimental and control groups.

We calculated each participant's PQ score by averaging all of their responses [22].

Subject #	S1 M		S2 F		S4 F		S6 M		S7 M		S8 M		S17 F	
Trial #	1	4	1	4	1	4	1	4	1	4	1	4	1	4
N	7	3	5	12	1	2	6	7	10	4	4	1	6	6
O	5	2	6	11	2	2	9	12	7	5	5	1	10	8
D	3	1	9	13	1	1	5	10	9	6	2	1	7	6
TOTAL	56.1	22.4	74.8	135	15	18.7	74.8	108	97.2	56.1	41.1	11.2	86	74.8

Fig. 4. SSQ Questionnaire NOD Data: Control Group

Subject #	S3 M		S9 M		S10 M		S12 M		S13 F		S15 F		S16 F	
Trial #	1	4	1	4	1	4	1	4	1	4	1	4	1	4
N	12	4	0	2	2	0	1	1	3	3	7	2	9	8
O	11	7	0	7	6	2	1	3	9	4	2	0	9	12
D	15	7	0	3	6	3	0	1	6	1	5	2	10	11
TOTAL	142	67.3	0	44.9	52.4	18.7	7.48	18.7	67.3	29.9	52.4	15	105	116

Fig. 5. SSQ Questionnaire NOD Data: Experimental Group

To determine the statistical significance of our results, p-values are calculated by using the t-values obtained from performing one- and two-tailed Welch's t-tests. Instead of using the more common Student's t-test, we used Welch's t-test because it provides more accurate results for groups with unequal sample sizes and variances. In the case of groups having equal sample sizes or variances, the Welch's t-test produces the same results as the Student's t-test. The t-values were calculated using the following formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}, \tag{1}$$

where $\overline{X}_1$, s_1, n_1 represent the average, standard deviation and sample size of group 1 and $\overline{X}_2$, s_2, n_2 represent the average, standard deviation and sample size of group 2.

B. Control vs. Experimental

Figs. 4 and 5 show each participant's N, O, and D scores for their first and fourth immersion session for control and experimental groups, respectively. Fig. 6 shows control group's averaged NOD scores across the 4 trials. Here, we see an increase throughout trials 1 and 3, and then a slight decrease in trial 4 in each NOD score. Fig. 7 shows the experimental group's averaged NOD scores across the 4 trials, and here there is a decrease in all three categories across the 4 trials. Specifically, the average decrease in N scores between trial 1 and 4 for control was 0.57, while that of experimental group was 2. For O scores, both control and experimental had an average decrease of 0.43. As for D scores, control averaged an increase of 0.29 while experimental averaged a decrease of 2. The p-value for the difference in control and experimental N scores is p=0.25, for the difference in O scores p=0.5, and for D scores p=0.12. Hence, although there is generally a greater decrease in NOD scores for experimental group, this difference is statistically insignificant.

C. Female vs. Male Control

Within the control group, we compared female and male participants' NOD scores. Figs. 8-10 show the respective N, O, D scores between control male and female. On average, male control group participants' N score decreased by 3 while female's increased by 2.67. Male group's O score decreased by 1.5 while female group's increased by 1. Male D score decreased by 0.25 while female scores increased by 1. Hence, for NOD categories, women in control group tended to report an increase in symptoms from trial 1 to trial 4 while men reported a decrease in symptoms. The p-score for the difference in N scores between male and female control participants is p=0.12 for O it is p=0.39, for D p=0.62. Hence, these difference are statistically insignificant.

D. Female vs. Male Experimental

For the experimental group, we compared female and male participants' NOD scores as shown in Figs. 11-13, respectively. We observe that on average both male and female experimental group participants' N, O, D scores decreased. For N score, male's decreased by 1 while female's decreased by 2. Male group's O score decreased by 0.25 while female group's decreased by 1.33. Male group's D score decreased by 2.5 while female group's decreased by 2.33. The p-score for the difference in N scores between male and female experimental participants is p=0.74, for O it is p=0.79, for D p=0.96. Hence, these difference are statistically insignificant.

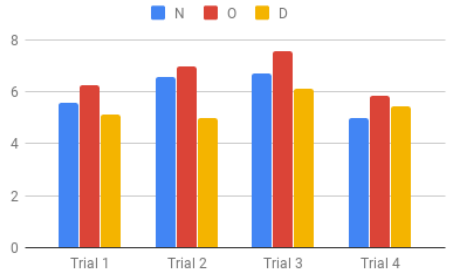

Fig. 6. Average NOD Subscores: Control Group

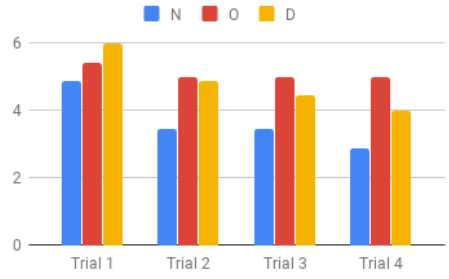

Fig. 7. Average NOD Subscores: Experimental Group

E. Discussion

The limitation of this study is the small sample size of 14 participants due to time constraints. We initially had 16 participants, but two participants had withdrew from participating in the following experiments after the first trial due

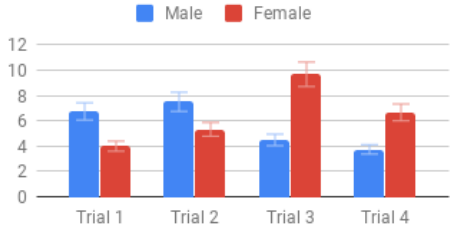

Fig. 8. Average N Scores: Control Group

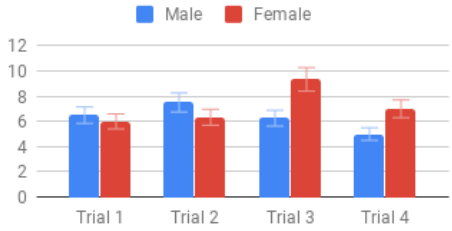

Fig. 9. Average O Scores: Control Group

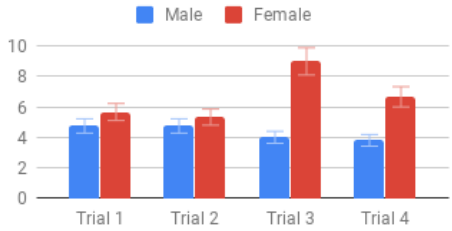

Fig. 10. Average D Scores: Control Group

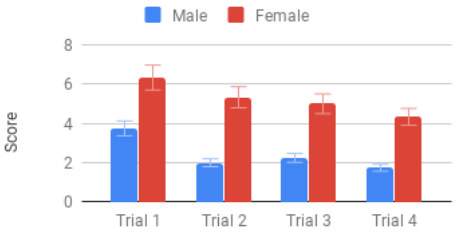

Fig. 11. Average N Scores: Experimental Group

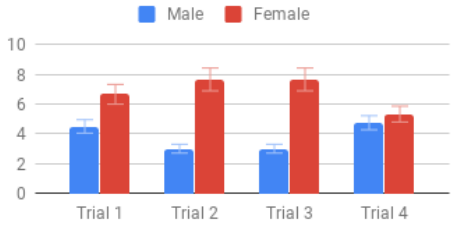

Fig. 12. Average O Scores: Experimental Group

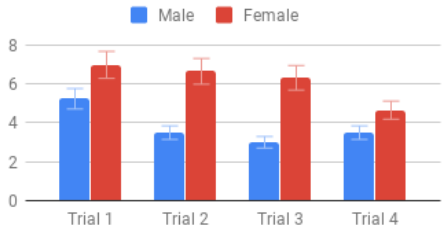

Fig. 13. Average D Scores: Experimental Group

to their experience of extreme levels of discomfort caused by cybersickness. We did not use these participants' data in our analysis. Both of these participants were female, which is a predictable outcome according to previous research regarding the intersection of gender, VR, and cybersickness [4]. In the future, we plan on continuing to conduct our experiment with more participants.

There were some confounding variables within this study. First, participants varied in their level of external distraction. Some participants talked during the experiment, while some remained silent. This could have contributed to the unexpected increase of cybersickness of control participants between the first three sessions. Moreover, we didn't regulate the path on how our participants walked around in our VE. In particular, some explored indoor components of our environment while others spent more time on our hilly terrain. Overall, participants were engaged in our task of collecting all bouncing balls, which in a way standardized each participant's experience and behavior within our VE. Thanks to this standardization, we can attribute most of the differences in cybersickness to the cognitive distraction, and not to the individual user experience.

While these findings were all statistically insignificant, we see this as an exploratory study, and further research could clarify, strengthen, and expand upon our results.

V. Conclusions

Cognitive distraction may improve cybersickness in virtual reality environments and we designed an experiment to test this hypothesis. We hypothesized that cognitive distraction, in the form of pop up questions administered every two minutes in our VE, will speed up a user's habituation to VR, and reduce their cybersickness faster. To test this, we immersed participants in our VE for 20 minutes on 4 separate days. The control group did not receive any pop up questions, while the experimental group did for the middle 2 sessions. Each participant completed the SSQ and the PQ after each immersion session. We compared and analyzed participants' levels of cybersickness using their questionnaire scores. Overall, we observed a greater decrease in cybersickness in our experimental group than that in our control group. This is represented by a greater decrease in experimental group's NOD scores. While habituation seems to improve cybersickness in male subjects for both control and experimental groups, the effect of that on female only happens in experimental group. We test the results through Welch's t-test and found that the results between control and experimental groups are not statistically significant. Our future work will include more subjects to expand the sample size to validate the hypothesis.

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