Effects of Environmental Clutter and Motion on User Performance in Virtual Reality Games

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Abstract
With the increasing prevalence of virtual reality, games for this medium have also been increasing in number lately. Several factors affect the balancing of video games. However, effects of environmental clutter and motion on game design for virtual reality have not been well explored yet. Environmental clutter and motion are important in making virtual environments more interesting and closer to real life since real world environments usually include some form of clutter or motion. Total exclusion of clutter and motion may make the virtual environment drab and dull. On the other hand, these components may affect the user performance, making the tasks and the game in general more difficult. This study aims at exploring the effects of clutter and motion on task performance in a virtual reality searching game. A user study was performed with 15 participants. Results indicated that clutter effected user performance negatively, made the users feel more restricted inside the virtual environment and made it more difficult to concentrate. No effect of motion on user performance was observed.

Author Keywords
Virtual reality; game design; clutter; motion; virtual environments.

ACM Classification Keywords
H.5.1. Information interfaces and presentation (e.g., HCI): Multimedia Information Systems—Artificial, augmented, and virtual realities.

Introduction

Video games intend to provide entertaining, fulfilling and meaningful experiences for the users. Several components effect user experience such as game mechanics, narrative and interface [10]. Balancing of challenge and pace is crucial to keeping the users in flow zone; giving them enough challenge so that they do not feel bored yet over-challenged at the same time. Besides the goals, obstacles and the rules of the game; several factors may affect the perceived difficulty of a task such as the environmental properties.

In the last few years, with the release of the second generation virtual reality headsets such as Oculus [9] and HTC Vive [11], number of games that are designed for this medium have also increased in number. Virtual reality (VR) have been attracting attention for both entertainment and serious games. Serious games can be described as video games with an aim of teaching new skills or training the users on the already learned ones [7]. Since VR offers several advantages such as safety, easy customization, automated data collection and no severe real life consequences of mistakes, it has been a popular choice for training in various areas [2, 3, 6]. Training in VR is usually achieved via serious games. However, since VR is relatively new, video game design for this medium have not been well studied yet. Virtual environments are anticipated to have prevalent use in our daily lives in the future in many areas such as gaming, education, training, sports, entertainment events and communication. Thus, effective and well-designed virtual environments may leverage these applications and provide more user friendly everyday experiences. As an endeavor in this area, in this study, we explored the effects of clutter and motion on user performance in a VR searching game. The goal of the game was to find as many boxes as the user could within a short timeframe. Effects of clutter and motion on user performance and user experience was evaluated in a user study with 15 participants.

Effects of clutter and movement on task performance in VR games has not been well studied yet. It might be thought that less clutter and movement may simplify the task and lead to better user performance. However, it may also make the games too simple and boring, and degrade the quality of training offered by serious games. The motivation behind this study is to give insight into future VR games for better balancing (entertainment games) and more effective training (serious games). This study tries to emphasize the importance of environmental elements in game design since these elements may have a direct impact on the perceived difficulty of the task, hence the game balancing.

Related Work

There have been very few studies that explored the effects of clutter and movement on user performance or experience in VR games. Ragan et al. studied the effects of visual complexity and field of view on training effectiveness for visual scanning tasks in virtual reality systems [8]. The authors included clutter, dynamism and textural fidelity in their visual complexity component so that the increased visual complexity included more realistic graphics and more static objects

such as vehicles, people, plants and street lights. The users were requested to find the targets around an urban environment while automatically moved under different conditions. Results indicated that higher visual complexity worsened the performance. However, the definition of visual complexity in the study included many elements and the effects of separate elements were not examined. Bacim et al. explored the effects of visual display fidelity, visual complexity and task scope on spatial understanding of graphs in virtual reality [1]. The study included abstract visuals such as lines, numbers and geometric shapes. The cluttered case included more of these visuals than the non-cluttered case. The users were requested to perform four tasks using 3D graphs: intersection search, path following, connection identification and length comparison. Results indicated that higher clutter led to slower performance in terms of time. However, clutter did not affect the correctness of the results. Since the study did not include realistic visual elements but only abstract ones, the results may not be applicable to games and applications having realistic visual elements. Ferrer et al. studied the effects of background motion and visual clutter on perception of virtual object motion in augmented reality [4]. Although augmented reality is different than virtual reality, the study is related in terms of implications of clutter and motion on user performance on a perception task. The users were requested to track the velocity changes in moving virtual particles on a black background and a cluttered/high motion background. Results indicated that the presence of clutter and motion degraded user performance and made it more difficult for the users to perceive the velocity of the tracked particles. The authors interpreted that clutter and motion caused perceptual illusions in tracking the moving particles and made it more difficult for the users to track them since there were no consistent reference points. As the participants were interviewed, twenty-five out of the thirty stated that the motion made the task more difficult rather than the clutter. Since the study examined the clutter and motion in a single condition, effects of separate components on user performance were excluded from the study's scope.

The Searching Game

A virtual reality searching game was designed and implemented to evaluate the effects of clutter and motion on user performance. The goal of the user was to find and mark the boxes with the matching labels with the one that was shown on the virtual display. The boxes were positioned on six virtual shelves surrounding the user (Figure 1). As the user touched a box with their hands, the color of the box changed and got highlighted in pink to provide real time feedback. The users could walk on the tracked area to select the virtual boxes (Figure 2). The virtual shelves were placed to fit inside the tracked area so that the users didn't need to step out of the tracked area. If the users selected a box unintentionally, they could deselect it by touching again. When deselected, the boxes returned to their original color. The labels of the boxes were always facing the user so that they did not need to move around the shelves to see the other faces of the boxes. There was a time limit of 25 seconds that was imposed to be able to explore the effects of different conditions on user performance. Each shelf had three levels. Each level of each shelf had three boxes and each shelf had twelve boxes in total. For clutter, there were two conditions: no-clutter and clutter (Figure 3). For motion, there were also two conditions: no-motion and motion. Moving objects were as follows: a forklift, five

small fans on the shelves, a big fan on the ceiling, flowing text on six displays attached to shelves, three blinking reflectors, two smoking bins and two swinging machine arms. Clutter and motion were not only in the background, but also in the workspace.

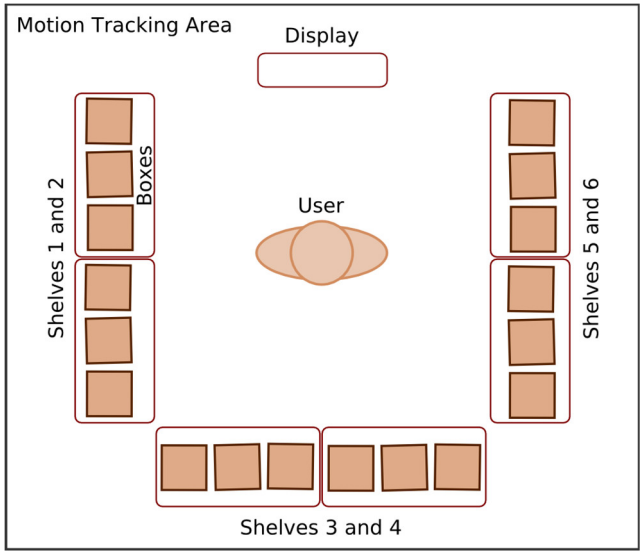

Figure 1: A layout sketch of the virtual reality searching game.

Hardware

12 Opti Track V100R2 FLEX cameras were used for real time motion tracking. The size of the tracked area was 8ft by 8ft. A VR2200 head mounted display (HMD) was used for viewing [12]. HMD was tracked by the system in real time via markers attached on top. The game was implemented using the Unity game engine and worked around 60 frames per second. Users also wore hand bands that were equipped with reflective markers for real time hand tracking.

Figure 2: Four conditions of the VR searching game. From top to bottom: (1) No clutter - no motion. (2) Clutter - no motion. (3) No clutter - motion. (4) Clutter - motion.

Experiment Design

Two by two within subjects experiment was performed with the independent variables of clutter and motion. Both independent variables had two levels: no clutter - clutter and no motion - motion, making four levels in total. The level of these two variables were varied within subjects in four conditions: no clutter-no motion, clutter-no motion, no clutter-motion, and clutter-motion. Each participant completed three instances with each condition. The configurations were assigned to each user in a random order with counterbalancing. In each instance, a different box label was presented to the users so that no two instances of the total twelve had the same two labels. The users needed to find as many boxes with the requested label as they could within 25 seconds. This duration was found by in-house testing as the duration in which a user familiar with VR could select all of the boxes. We avoided giving the users too much time to be able to detect the differences between different conditions. Each trial contained 10 boxes with the requested label that were distributed roughly evenly among the six shelves. The users were not informed on the number of boxes in the scene with the requested labels to make them keep searching. Box distributions and the labels were assigned randomly to the instances to eliminate any possible learning effect. The score was calculated as follows: Number of hits - number of misses + (0.5)*number of corrections. Hits were the boxes that were correctly selected (matching with the requested label). Misses were the boxes that were incorrectly selected (not matching with the requested label). Corrections were the deselections of the misses.

Research Questions and Hypothesis

Our study aims to answer the following research question: What are the effects of clutter and motion on user performance in virtual reality games? We developed the following two hypotheses: (H1) Clutter will effect user performance negatively. (H2) Motion will effect user performance negatively.

Data Collection

Automated data was collected for the following: box distribution, number of hits, misses, unintentional touches and corrections with their time logs. After the users completed three repetitions of a condition, a survey was given to them that had questions on the perceived difficulty of the task, frustration, ease of finding the boxes, distraction, feeling of being restricted, ease of concentration, presence and motion sickness as well as user comments.

Participants

15 adult individuals participated in the study (N = 15) who were recruited via e-mail announcements and word of mouth. All participants were undergraduate or graduate university students from several different majors. Participants were aged between 21 and 33 (μ = 25.80, SD = 3.05). Gender distribution was 5 female and 10 male. 13 participants had no prior virtual reality experience, 2 participants had minimal prior virtual reality experience. The user study was conducted under the IRB Pro00013008.

Procedure

Participants arrived at the laboratory, read and signed the consent form and filled out the demographics questionnaire. The research staff briefly explained the VR equipment and the user’s objective in the game.

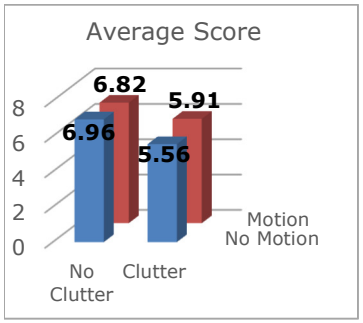

Figure 4: Bar charts of the scores for different conditions.

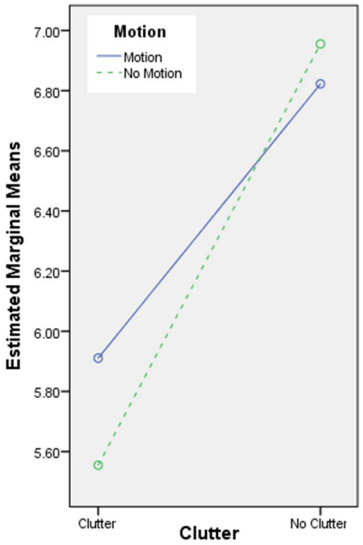

Figure 5: Plot of the means of scores for the clutter and the motion variables.

The research staff helped the users to wear the head mounted display and the hand bands, and a familiarization session began. The aim of the familiarization session was to make the users comfortable with the VR system and the game mechanics. The familiarization session included one display and one shelf with the no clutter - no motion condition. The familiarization session ended when the user stated that they were comfortable with the VR system, which took 53 seconds on average. The experiment then began. The users were randomly assigned with a condition and then presented with three instances of that condition. After the users completed one condition's three instances, they were given a survey. Then, they were assigned with another condition and completed three instances with that condition that was followed by a survey. After the users completed the four condition's three instances (12 instances in total), the experiment ended and the research staff helped the users to take off the worn equipment. The labels, the boxes in the scene and the distribution of the boxes on the shelves were assigned randomly for each instance to eliminate any bias and learning effect.

Results

Performance Data

Average scores for the four conditions are presented in Figure 4. As we analyzed the data for the effects of conditions on score using two way ANOVA with repeated measures with $\alpha = 0.05$ and Bonferroni correction; for clutter/no-clutter variable there was statistically significant difference ($F(1, 14) = 14.259$, $p = 0.002$), for motion/no-motion variable there was no statistically significant difference ($F(1, 14) = 0.177$, $p = 0.680$). As paired t-tests were performed, the results presented in Table 1 were obtained. Effect of clutter on user performance was statistically significant when there was no motion. Plot of the means of scores for the clutter and the motion variables are presented in Figure 5. As it can be observed in Figure 5, change in the clutter variable creates a significant change in the mean score. Presence of clutter worsens the score. However, no significant effect of motion on the score was observed.

Condition	N	df	t-stat	p
Clutter - Motion, No Clutter - Motion	15	14	-2.027	0.062
Clutter - No Motion, No Clutter - No Motion	15	14	-3.883	**0.002**
Clutter - Motion, Clutter - No Motion	15	14	0.898	0.384
No Clutter - Motion, No Clutter - No Motion	15	14	-0.370	0.717

Table 1: Paired sample t-tests for the score data.

Survey Data

At the end of each condition's trial of three instances, we asked each user to give a score for the following variables: the perceived difficulty of the task, level of frustration, ease of finding the boxes, level of distraction, feeling of being limited (restricted), ease of concentration, presence and motion sickness, within a Likert scale of 5 to 1 (5: very much, 1: not at all). The presence questions were from the Witmer and Singer's questionnaire [13] and the motion sickness questions were from the questionnaire of Gianaros et al. [5]. Results of these survey variables are presented in Figure 6. Error bars represent the standard error of the mean. Two way ANOVA with repeated measures with α

= 0.05 and Bonferroni correction resulted in statistical significance only for the following variables: clutter variable for feeling of being limited ($F(1, 14) = 7.977$, $p = 0.014$) and clutter variable for ease of concentration ($F(1, 14) = 5.091$, $p = 0.041$). As paired t-tests were performed, results in Table 2 and Table 3 were obtained respectively. For the limitation, effect of clutter was statistically significant in both the presence and the absence of motion. For the ease of concentration, effect of clutter was statistically significant only for the absence of motion.

Condition	N	df	t-stat	p
Clutter - Motion, No Clutter - Motion	15	14	2.168	**0.048**
Clutter - No Motion, No Clutter - No Motion	15	14	2.168	**0.048**
Clutter - Motion, Clutter - No Motion	15	14	0.619	0.546
No Clutter - Motion, No Clutter - No Motion	15	14	0.695	0.499

Table 2: Paired sample t-tests for the limitation.

Condition	N	df	t-stat	p
Clutter - Motion, No Clutter - Motion	15	14	-1.323	0.207
Clutter - No Motion, No Clutter - No Motion	15	14	-2.168	**0.048**
Clutter - Motion, Clutter - No Motion	15	14	-0.323	0.751
No Clutter - Motion, No Clutter - No Motion	15	14	-1.000	0.334

Table 3: Paired sample t-tests for the ease of concentration.

Qualitative Survey Results

In the surveys, there were open ended questions about what the users liked the most and the least about the game, and if they had any additional comments or suggestions. There were a lot of positive comments about how fun and realistic the VR game was. User 1: "Very realistic. Boxes seemed like they were there." User 13: "It is fun and interactive. Also going against the time makes it challenging." User 18: "Overall, I thought this was a lot of fun. I liked how real it felt and the difficulty of it."

A lot of users stated positive comments about the clutter. For the clutter - no motion condition, the following comments were made: User 5: "I think this one has more decorations on the shelf. I feel this makes it look more real." User 10: "I liked the mess." User 17: "I liked the extra materials added." User 18: "I liked how there were other things around the room making it more difficult to find the boxes." For the clutter - motion condition, the following comments were made: User 2: "I liked all the detail." User 5: "The scene looks very real." User 20: "The boxes were usually easy to spot and the environment seemed like one I would find in the real world."

A few users stated negative comments about the distraction caused by the clutter: User 1: "Clutter (tools etc.) made the task difficult to focus on the boxes. The distractions made the task significantly more difficult." User 13: "The mess was the most distracting thing.

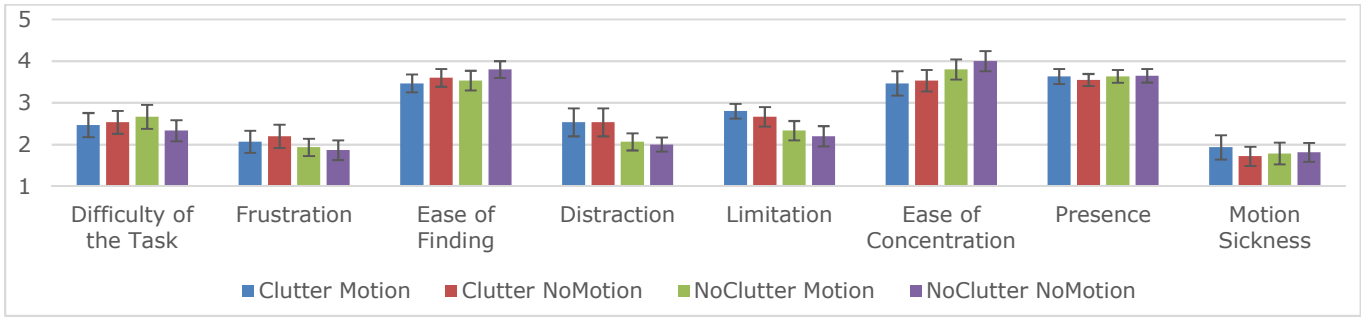

Figure 6: Bar charts for the average scores of the survey variables for different conditions.

Discussion

The user study results and the statistical analysis indicated that clutter effected user performance negatively, supporting H1. This aligns with the findings in [8] and [1]. Clutter also made it significantly difficult for the users to concentrate. Although clutter worsened the user performance, a lot of users stated that the presence of clutter made the game seem more real and interesting. Hence, the addition of clutter may increase the level of difficulty in VR games whereas contributing to the naturalness and richness of the virtual environment. Clutter made the users feel more limited inside the virtual world. In VR games where a feeling of restriction/limitation is desired such as confined places, clutter may be utilized. No significant effect of motion on user performance were observed, rejecting H2. This does not align with the results found in [4]. However, the task in [4] was tracking the particles by constantly watching and estimating their velocity changes. The task in our study was searching, which may be the reason behind this difference. Also, medium of [4] was augmented reality, which may be another contributing factor for the difference in the results.

A few users stated that they perceived that the shelves were farther away in the conditions with no-clutter. Although the layout was the same between all four conditions, lack of clutter made the virtual environment seem larger. This might be incorporated into game design when the scene is desired to look spacious.

On a different note, some users stated that when the label to search for was a brand they liked or they were familiar with, the task was more fun to perform.

In light of these results, when task performance isn't important in the designed game, extra elements may be added in the scene to give the users a more realistic and more interesting game environment. However, in serious games where the task performance is important, it might be a better practice to keep the virtual environment empty at first, eliminating any distractions and then gradually inducing clutter and

dynamism as the user gets trained. This way, the users would be better prepared for real world conditions without getting overwhelmed.

Limitations

This study focuses on virtual reality games. The results may or may not be applicable for games for other mediums such as computer or console. It should also be noted that this study was based on a searching task, which shaped the results and their interpretation. Age of the participants may be another limiting factor in applying the conclusions of the study for the children or elderly population groups.

Conclusions and Future Work

In this study, effects of clutter and motion on user performance in a virtual reality searching game was examined in the search of more effective virtual environment design. A two by two user study was performed with 15 college aged participants. Results indicated that clutter effected user performance negatively, made the users feel more limited and made it more difficult to concentrate. No effect of motion on user performance was observed. We believe these results will provide insight into the design of future virtual environments that will lead to more user friendly everyday VR experiences.

Future work may include evaluating different levels of clutter and dynamism, or other environmental properties on user experience in virtual environments.

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