Assessing the Effects of a Full-body Motion-based Exergame in Virtual Reality

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ABSTRACT

There is a growing number of commercial exergames tailored for virtual reality (VR) head-mounted displays (HMDs). However, empirical evaluations of the feasibility and effects of such games, especially those requiring full body motions, are still limited. This research investigates the effects of playing a full-body motion VR exergame. We have conducted a study with a game that has two modes, single- and multi-tasking, and with two types of displays, a VR HMD and a 50-inch Large Display, to collect data about users' game experience, simulator sickness, and brainwave responses. Our results indicate that (1) Participants have the same level of game experience and simulator sickness when playing the exergame in VR and Large Display; (2) VR has increased participants' Theta wave; (3) Participants believe multi-tasking is more challenging and show a higher level of simulator sickness than single-tasking; and (4) Participants have a worse game performance in multi-tasking than single-tasking.

Author Keywords

Virtual Reality; Exergame; Game Experience; EEG; Head-Mounted Display; Large Display.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous; I.3.7. [Three-Dimensional Graphics and Realism]: virtual reality; K.8.0 [Personal Computing]: General – Games.

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INTRODUCTION AND RELATED WORK

Physical inactivity has been identified as the fourth leading cause of death worldwide [16]. In recent years, the idea of using exergames (i.e., video games that are also a form of exercise) to enhance people's health has been promoted by researchers and medical practitioners. Prior studies [2,3,9,17,24] have shown that exergames can increase enjoyment and intrinsic motivation compared to conventional exercises and as such, they can be effective in promoting physical and mental health [21,22].

People are often challenged when attempting to simultaneously accomplish multiple tasks (multitasking) due to limitations of how we process information [8]. In the context of games, this challenge can promote users to play them. Since exergames are often used to enhance people's health, researchers have looked at the use of multi-task physical activities as a way to achieve this in different population groups (e.g., elderly [1,7]).

Recently, more and more researchers have assessed the use of Electroencephalography (EEG) to analyze players' physiology feelings and cognitive activities during the gameplay to help to provide a better gaming experience. One of the first studies to deal with games and EEG is [23], their research defines events during gameplay and analyzed the Event-Related Potential (ERP) of the brain when those events are performed. More recently, Monteiro et al. [19] investigated the effect of viewing perspective on players' Arousal-Valence and Focus level. Nacke [20] studied how the use of different kinds of controllers influences the brain during gameplay.

Researchers have also investigated full-body motion-based exergames (e.g., [10,11]). This research has been primarily conducted with common flat displays such as large-screen TV that are placed at some distance for the gamers. Virtual reality (VR) allows a greater degree of immersions and there is a recent trend to use VR for exergames—for example for athletic training [25], fitness training [27], and

High-intensity interval training [4]. Although there are a growing number of VR exergames in the market, there is limited research on the feasibility and effect of such games. The advantage of VR is its ability to immerse users in the environment and afford full-body motions. Most of the exergames explored in the recent literature are based on a stationary setting (e.g., on a cycling bike [4]) and to our best knowledge, no study has been done on investigating full-body motion-based exergames in VR, especially focusing on their feasibility and cognitive effects elicited during gameplay.

In this research, we have developed a multi-tasking motion-based video game called KIMove. The game combines the advantages of multitasking [1,5] and exercises [6,26] to understand the feasibility of playing full-body motion-based exergames in VR, the effect of multi-tasking on the gamers and the type of responses elicited in players' brains using EEG data collected during the experiment.

KIMOVE

To study the effect and gameplay experience of single- and multi-tasks involving hands and feet in VR, we implemented KIMove, a game that was inspired by Beat Saber and Fruit Ninja. The game was implemented in Unity3D and written in C#. It uses Microsoft's Kinect to capture full body motions. We had two versions, one for VR and the other for Large Display, which served as the baseline condition.

The gameplay consisted of performing hand motions in midair and foot movements in the form of stepping on the ground through 3 minutes of game time. There were two types of game objects. Fruits would appear in midair for users' hands to hit them, while rectangular prims or cubes would show up on the floor for their feet to step on them.

Objects would appear close to the player and move in a straight line, passing in front (like apples and pears) or going towards (yellow prims) the player. The player's hand and feet had colored balloons attached to them (red, green for each arm and yellow for the legs). The different colors were used to allow fast differentiation of the limbs and also to link the objects to the limbs that should be used to catch and destroy them. The score was given when players successfully eliminate (i.e., catch) the game objects.

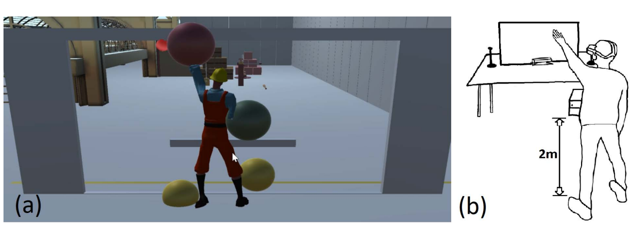

Figure 1. A user is trying to kill the arm object (apple) by using the left hand. (a) In a virtual view. (b) In a real-life view. Fruits are passing in front (x-direction) the user during the game.

We used the Kinect for motion capture and designed the game to be playable at about 2 meters away from the device which was required for tracking user's limb movements. A door frame was designed as a reminder for the users to be aware of the playing area in the virtual world. Figure 1 shows that a player is lifting the left arm to catch the apple while Figure 2 presents an example of the player stepping left-wards to stop the foot game object.

The game has two different game modes: Single-tasking and Multi-tasking. For single-tasking, the game spawns one object in every 5 seconds so that only one object moving at a time during the game. For multi-tasking, it would present to players multiple concurrent objects to be destroyed by both feet and arms in every 5 seconds. This means that players were required to perform two tasks in rapid succession and sometimes in parallel. All game objects have the same speed which was 0.2 m/s. These values were chosen after a preliminary study.

EXPERIMENT

Participants and Apparatus

12 participants (3 females) between the ages of 19-29 (M = 22.42) were recruited from a local university campus to take part in this experiment. 5 of them had experience on VR but were all infrequent VR users. We used an Oculus Rift CV1 as our VR device and a 50-inch 4K TV as our Large Display device. Both devices were connected to a standard computer with an i7 CPU, 16GB RAM, and a GeForce GTX 1080Ti GPU. The brainwave signals Alpha (8-14 Hz), Beta (14-30 Hz), Theta (4-8 Hz), Delta (1-4 Hz), and gamma (30-50 Hz) were measured and collected by the MUSE headset edition 1. A Kinect was used to capture the players' movements.

Experiment Design, Task, and Procedure

To understand the feasibility of playing the exergame in VR HMDs, we conducted an experiment using 2 × 2 within-subjects design. There were two independent variables: (1) Game Mode—Single-tasking and Multi-tasking, and (2) Display (or Device) Type—VR and TV. The order of Game Mode × Display Type combinations was counterbalanced in the experiment. Nacke [20] have shown that playing games with different types of controllers could affect brain activity differently. We were interested in whether Game Mode and Display Type have a similar effect on brain activity.

Figure 2. A user is trying to destroy the foot object (cubes) by stepping the left foot on it. (a) In a virtual view. (b) In a real-life view. Cubes moving towards the user in the z-direction during the game. The red line indicates the movement area (3m long) that required throughout the game.

Before the experiment started, the participants were asked to complete a pre-experiment questionnaire to gather demographic information and were informed of the purpose of the study. Before each session, the participants were taught the game rules and were asked to calibrate the position in the game, and then they were asked to play a 1-min warm-up round to familiarize themselves with the game. Once the warm-up round finished, participants were asked to wear and calibrate the EEG device with the help from a researcher. We only started to record the EEG data when the actual experiment round began and stopped recording once each experiment round had finished. After each session, participants were asked to completed two questionnaires: Game Experience Questionnaire (GEQ) [12], Simulator Sickness Questionnaire (SSQ) [14]. Between sessions, they could rest as much as they want. The whole experiment lasted about 35 minutes for each participant.

Results

We analyzed the data using a two-way repeated measures ANOVA with two independent variables, Display Type (VR and Large Display) and Game Mode (Single-tasking and Multi-tasking). Bonferroni correction was used for pairwise comparisons, and Greenhouse-Geisser adjustment was used for degrees of freedom for violations to sphericity. We reported effect size η_p^2 whenever possible.

The gameplay performance data were recorded in the background during gameplay. We evaluated the data using the Missing Target Rate (MRT) which was the percentage of the objects missed by the users among all objects generated by the system. MRT for foot and arm objects was analyzed separately. For EEG data, we excluded the Delta and Gamma data in the analysis because Delta waves could be affected by blinking and Gamma waves by muscle movements. Therefore, we only analysis the Alpha, Beta, and Theta waves in this study. In details, Alpha power increases have been associated with cortical inactivity and mental idleness. Beta activity is most evident in the frontal cortex and has been connected to cognitive processes, decision making, problem-solving, and information processing. Theta activity seems to be related to creativity, intuition, memory recall, emotions and sensations [20].

Gameplay Performance. Figure 3 shows the mean MRT for each condition for foot game objects. ANOVA tests yielded a significant effect of Game Mode ($F_{1,11} = 37.864$, $p < 0.001$, $\eta_p^2 = 0.775$), but not for Display Type ($F_{1,11} = 2.628$, $p = 0.133$, $\eta_p^2 = 0.193$). There was also a significant interaction effect on Display Type × Game Mode ($F_{1,11} = 7.918$, $p < .05$, $\eta_p^2 = .419$). Post-hoc pairwise comparison showed that participants missed more foot game objects ($p < 0.001$) in multi-tasking mode (M = 23.5%, s.e. = 2.0%) than single-tasking mode (M = 9.8%, s.e. = 1.8%). No main and interaction effects were found for hand game objects.

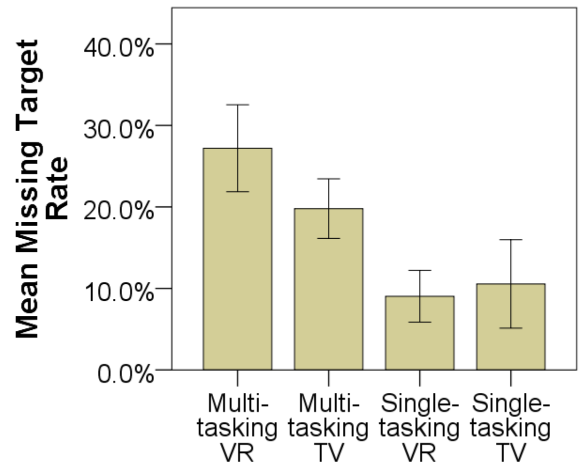

Figure 3. Mean missing target rate on foot game object. Error bars indicate ± 2 standard errors.

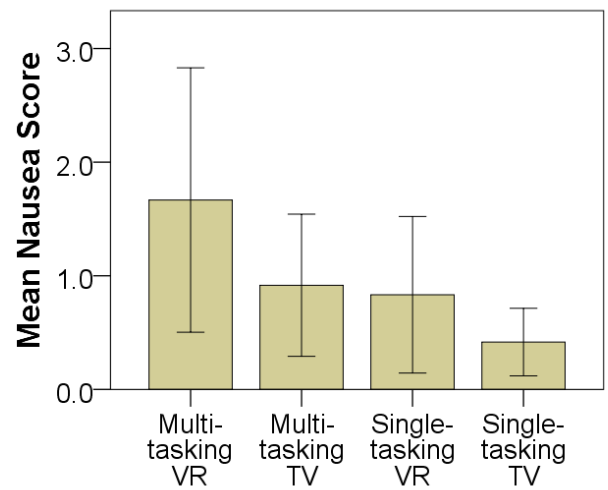

Figure 4. Mean nausea score from SSQ. Error bars indicate ± 2 standard errors.

Simulator Sickness Questionnaire. Regarding the participants' perceived level of simulator sickness (Nausea, Oculomotor), there was a significant main effect of Game Mode on Nausea ($F_{1,11} = 5.333$, $p < 0.05$, $\eta_p^2 = 0.356$), but not for Display Type ($F_{1,11} = 4.115$, $p = 0.067$, $\eta_p^2 = 0.272$) and Display Type × Game Mode ($F_{1,11} = 0.169$, $p = 0.689$, $\eta_p^2 = 0.015$). Post-hoc pairwise comparison indicated that participants felt sicker ($p < 0.05$) when playing in the multi-tasking mode (M = 1.29, s.e. = 0.35) than single-tasking mode (M = 0.63, s.e. = 0.21). Figure 4 shows the mean nausea score from SSQ for each condition. No main and interaction effects were found on Oculomotor.

Game Experience Questionnaire. The core GEQ module consists of seven components (Competence, Tension, Sensory and Imaginative Immersion, Flow, Negative Affect, Positive Affect, Challenge). ANOVA tests yielded a significant effect for Game Mode ($F_{1,11} = 7.957$, $p < 0.05$, $\eta_p^2 = 0.420$) on Challenge, but not for Display Type ($F_{1,11} = 0.166$, $p = 0.691$, $\eta_p^2 = 0.015$) and Display Type × Game

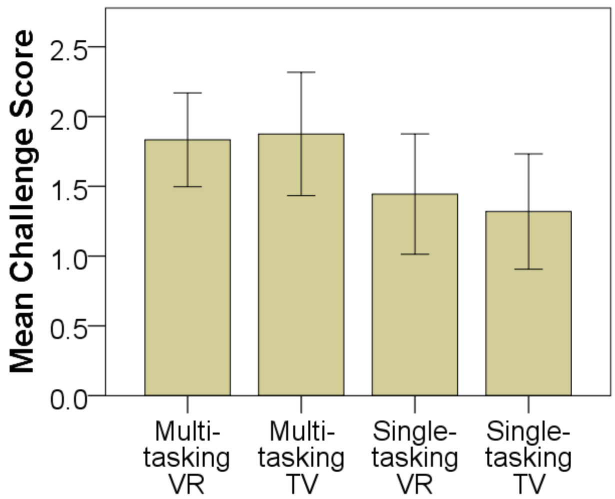

Figure 5. Mean challenge score from GEQ. Error bars indicate ± 2 standard errors.

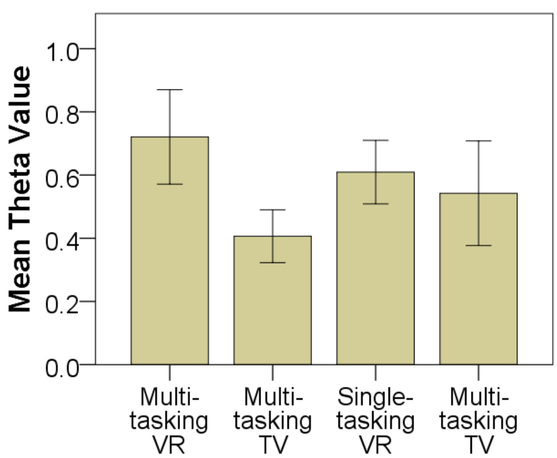

Figure 6. Mean Theta power during the gameplay. Error bars indicate ± 2 standard errors.

Mode ($F_{1,11}$ = 0.617, p = 0.449, η_p^2 = 0.053). Post-hoc pairwise comparison revealed that users felt multi-tasking (M = 1.85, s.e. = 0.18) was more challenge ($p < 0.05$) than single-tasking (M = 1.38, s.e. = 0.20). Figure 5 shows the mean challenge score from GEQ for each condition. However, no other main and interaction effects were found on Competence, Tension, Sensory and Imaginative Immersion, Flow, Negative Affect, Positive Affect.

EEG. We calculate the mean value of each brainwave signal. Figure 6 presents the mean Theta value during the gameplay among the 4 conditions. ANOVA tests showed there was a main effect of Display Type for Theta ($F_{1,11}$ = 7.415, $p < 0.05$, η_p^2 = 0.403), but not of Game Mode ($F_{1,11}$ = 0.031, p = 0.864, η_p^2 = 0.003) and Display Type × Game Mode ($F_{1,11}$ = 3.604, p = 0.084, η_p^2 = 0.247). Figure 6 shows the mean Theta power for each condition. No other main and interaction effect were found for both Alpha and Beta waves.

DISCUSSION

Gameplay Performance

We found that multi-tasking affects the way how participants would decide to eliminate the game objects. From our observation and comments from the participants, they prefer to eliminate the easy option (hand game object) when in a complicated situation (hand and foot game object come in one time).

Simulator Sickness

We found that VR did not generate a higher level of simulator sickness than Large Display. This shows that VR exergames are as feasible as those shown in Large Display for sickness and Oculo-motor. Meanwhile, we found that participants felt sicker when played in multi-tasking mode than single-tasking, suggesting multi-tasking may cause a higher sickness than single-tasking in a full-body motion-based exergame. Therefore, we suggest the future designer should carefully design a game that may consist of a series of multi-tasking tasks, as it may cause a higher sickness.

Game Experience

We found that multi-tasking mode is more challenging than the single-tasking mode, but VR and Large Display share the same level of challenge for participants. Regarding the other GEQ components (Competence, Tension, Sensory and Imaginative Immersion, Flow, Negative Affect, Positive Affect), VR and Large Display have brought similar game experience to participants while single-tasking and multitasking also have no effect on their game experience.

EEG

We found a higher mean Theta value for the users when they played the game in VR than Large Display. One possible explanation is that VR might at some point affect the ways participants calculate the spatial position of the game objects. Early studies [13,15] have shown that Theta power increases during spatial navigation, especially during processing of spatial cues and landmarks, which was also required in our game. We have not found any significant effect of Display Type and Game mode on Alpha and Beta waves.

Limitations and Future Work

The experiment has one issue where each game session only last 3 minutes, which is a relatively short time period and may lead to a different result. Future work will increase the time for each session, test different game elements (i.e., game object's moving speed). We will also seek an opportunity to examine how feasible for elderly to play VR Exergame. Moreover, we have recorded the gameplay video for each condition, and the next step will focus on the analysis of Event-Related Potential (ERP), which analyses brain waves as an event is happening, helping us to have a deeper understanding of what is happening during gameplay [19]. Also, we will investigate how the EEG metrics related to the subjective questionnaires [18].

CONCLUSION

This paper has explored the effects of display/device type (virtual reality and large display) and game mode (single-task and multi-talk) for exergames. Our experiment with 12 young adults indicates that (1) Players have the same level of game experience and motion sickness when playing the exergame in either VR and large display; (2) VR has led to increasing Theta power in players' brain; (3) Players believe multi-tasking is more challenging and brings a higher of motion sickness than single-tasking; and (4) Players have a worse game performance in multi-tasking than single-tasking.

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