Directional Motion-based Interfaces for Virtual and Augmented Reality Head-mounted Displays

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***Abstract*—This research, conducts an experiment to investigate whether there is a difference in user performance and preference for two types of head-mounted displays (HMDs) when users need to perform directional motion movements such as moving one foot forward and backward (or leftward or rightward). The two types of HMDs we have considered are virtual reality (VR) and augmented reality (AR), which represent the two most commonly marketed HMDs. The AR device chosen for this research is the Meta 2 while the chosen VR device is the Oculus RIFT CV1. The results of our experiment show that there is a close significant difference on task completion time between AR and VR condition when users perform motion direction tasks. Also, no significant effect has been found on the accuracy of making these motion movements between the AR and VR conditions. In terms of user preference, the results show that there is no significant effect on workload, motion sickness, immersion, and user experience. These results suggest that both AR and VR HMDs are suitable for interfaces that can rely on body motions like tapping on the floor using one foot in any of the directions around the user.**

Keywords—Augemented Reality, Virtual Reality, Motion direction interface, user study; task performance, user preference

I. Introduction and Background

Virtual Reality (VR) and Augmented Reality (AR) are both emergent technologies and represent the two most common types of commercial head-mounted displays (HMDs). VR provides users the sense of immersion within virtual environments and emphasizes their 3D nature, while AR combines real and virtual world into one by overlaying the virtual on the physical world. Commonly, VR users use controllers to interact with the virtual menu, and AR users use their hand to interact a menu. However, when using VR HMDs, controllers may not be around, or users may be able to use them because their hands are occupied with other activities. Similarly, when using an AR HMD, users need to put their hands in front of the AR headset's camera and often hold it for long periods of time to interact with virtual objects, which can often cause physical tiredness but also it may not work if the lighting conditions are not ideal.

Recently, Qian et al. [1] have argued that using directional movements can be useful for interfaces in Exergames; they can also be used for simple interactions like selecting an item in a menu. We believe that motion direction can be used to create a better VR/AR Exergame and as a way to allow users to make menu selections. For instance, letting players play a VR dance game will not only entertain themselves but also gain cognitive and physical benefits; they need to practice their focus and also exercise their body even if they play just for ten minutes [2]. A motion direction exergame is not only suitable for the general population but also for the elderly (and even children). A carefully designed motion direction Exergame for the elderly or children can be used to let them do physical activity in a fun way regularly at home so that they can gain physical strength [3], [4].

Besides exergames, motion direction as an interface (for example, for menu item selection) can be useful in AR and VR HMDs. This can be useful for instance where the VR controller is not around. A motion direction interface is a hands-free interface, so it will be helpful for users who cannot manipulate a VR controller at all or who have difficulty in using their hands to interact with the virtual objects when using the AR (e.g., elderly or children).

This research investigates the effect of the most common types of HMDs (AR vs. VR) on user performance and user preference when performing motion direction movements—e.g., movements using users' feet around their body. This study act as a preliminary study to explore the potential usefulness and practicality of motion direction interfaces in AR and VR. In this paper, we present one study that assesses motion direction movements in AR and VR. The contributions of this paper include (1) an examination of the difference in user performance between AR and VR HMDs on directional motion movements; and (2) an examination of users' perceived level of workload, motion sickness, immersion, user experience between these two types of HMDs. The results of our study can help inform the design of motion-based interfaces for both AR and VR devices.

II. Experiment

A. Objective

Our primary objective of this study was to evaluate whether there would be any difference in user performance and user preference when participants perform motion direction movements in AR and VR as a way to interact with these systems.

B. Participant and Apparatus

Eight participants (one female) between the ages of 17 to 27 (M = 22.13) were recruited from a local university campus to take part in this study. Participants had normal or corrected-to-normal vision and reported an average of 4.75 for balance skill in daily life on a scale from 1 ('No Skill') to

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7 ('Expert'). Six participants had previous experience with AR HMDs before, and seven participants had some previous experience with VR HMDs—they had either seen and/or interacted with them.

The experiment was conducted on an Intel Core i7 processor PC equipped with an NVIDIA GTX 1070 dedicated graphics card and 16 GB of RAM. The program was developed in C#.NET and was run within the Unity3D platform. Meta 2 [5] was employed as the AR HMD, which had a 90-degree field of view and offered a projected display with a 2560 × 1440 resolution. The Oculus Rift CV1 was employed as the VR HMD, which had a 110-degree field of view and a display resolution of 2160 × 1200. The experiment was held at a university lab. An example of the devices and users wearing them can be seen in Fig. 1.

Fig. 1. Experiment setup with a user wearing the Oculus RIFT CV1 (left) and the user wearing the Meta 2 (right).

C. Task, Procedure, and Experiment Design

We developed an application where participants were positioned in the middle of a circle with 8 blocks and had to move one of their feet to tap a highlighted block. The application would randomly change the color of one block (as a way to highlight it) and participants were required to perform motion direction movements to hit that block (Fig. 2 (b)). Each block was located 0.3 meters away from the participants. A white circle is provided which represented a participant's current location (Fig. 2). Once the target was hit successfully, the central plane would change the color to inform the participant to return to the central position (Fig. 2 (c)). A sound was also provided when the participant successfully hit the target. After 1.5 seconds of wait time in the central position, the next target will show up. The task would continue until all each block appeared ten times.

Fig. 2 shows an example of completing a task and Fig. 3 presents an example of a user movement to hit the target located on the East side. When a wrong move was executed, participants were asked to return to the central plane immediately, and then re-perform the motion direction movement.

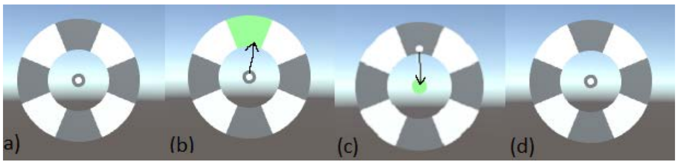

Fig. 2. Example of a user head position movement to hit the front target.

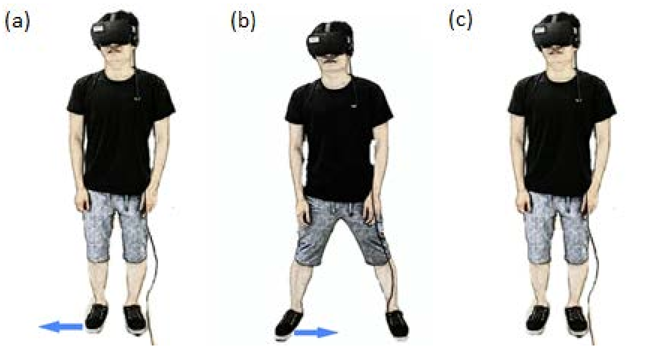

Fig. 3. Example of a user movement: (a) the user is required to do the motion direction movement towards his right; (b) when the user hits the target, the user should be ready to return the starting position; and (c) the user has returned to the starting position.

The study used a one-way within-subjects design with one independent variable: Platform (VR and AR). We counterbalanced the order of the Platform. Participants would need to go each direction ten times. Before the experiment started, we described to the participants the goal of the experiment and the devices that were to be tested. Then participants were asked to fill in a pre-experiment questionnaire to collect their demographic information and experience with VR/AR devices. Since the pre-experiment training may cause some motion sickness and tiredness, we did not allow training time but instead included it within the actual experiment. Once participants finished the pre-questionnaire, they would proceed to carry out the motion-direction movement tasks in VR and AR (counterbalanced). We instructed them to complete the task as fast and accurate as possible. After finishing each platform, they were given a post-questionnaire to complete so that we could collect information about their perceived level of workload, motion sickness, immersion, and user experience. Between the two sessions, participants could take an extra 1-minute break if they needed. The whole experiment lasted approximately 20-30 minutes per participant.

D. Evaluation Metrics

Task performance was measured by objective data (overall task completion time, correct task completion time, accuracy) and subjective feedback—that is, workload, motion sickness, immersion, user experience.

1) Task Performance

For each trial, since we required the participants to go back to the center if there was a mistake, we used two measurements. One was the correct task completion time, which would be the best-case scenario where there had been no errors during the task completion; the other was the overall task completion time, which represented the overall task completion performance and would include the time spent to correct any prior error(s). A correct task completion time was measured for the correct movement only; it measured from the time the block switched color to the time when the user entered (or tap on) the block without entered any other blocks. The overall task completion time estimated the time from the time the system switched the block's color to when the user eventually entered the current block to switch it back to its original color.

Accuracy is measured by the number of correct movements among the total number of movements.

2) User Preference

NASA-TLX. The NASA-TLX [6] is used to evaluate the workload for participants. It measures workload on six factors (mental, physical and temporal demand, effort, performance, and frustration). For the NASA-TLX, lower scores meant that participants' felt that their workload level was also low. We were interested in whether participants would experience different workload levels when performing motion direction movements in AR and VR condition.

Motion Sickness Assessment Questionnaire (MSAQ). Motion sickness is commonly argued in the VR condition [7], [8], and in the AR condition [9], [10]. The MSAQ [11] was selected since it could cover four dimensions of motion sickness, including gastrointestinal, central, peripheral, and sopite-related. Same as the NASA-TLX, the lower the rating the participants would give, the better (e.g., the lower the workload felt by them). We want to explore whether the player may suffer more motion sickness in VR condition than AR condition.

Slater-Usoh-Steed Questionnaire (SUS). SUS was selected to measure the participants' perceived level of immersion and presence in a virtual environment. Immersion and presence have been the main features in VR, and studies have shown that participants would experience a higher level of immersion in VR than large displays and small camera monitors [12] as well as flat screens [13]. Thus, we wanted to investigate whether there would be a difference in immersion and presence when participants would be doing motion direction movements in either AR or VR.

User Experience Questionnaire (UEQ). UEQ [14] is designed to evaluate interactive products. The questionnaire covered classical usability factors (such as efficiency, perspicuity, and dependability) and user experience aspects (like attractiveness, novelty, stimulation). Unlike NASA-TLX and SUS, high the ratings given to UEQ would mean a better experience for participants. Before filling out this questionnaire, participants are informed to imagine this was a menu selection task using motion direction as an interface to select menu items (that is, a tap with their foot would mean a selection of an item).

E. Results

1) User Performance

Fig. 4 shows the overall and the correct task completion time for all participants. The average task completion time for AR is 1.18 (SD = 0.11) and for VR is 1.15 (SD = 0.12). A one-way repeated ANOVA yielded a close significant effect of Platform ($F_{1,7}$ = 5.245, p = 0.056) on the average task completion time. Average task completion time for correct movement on AR is 1.16 (SD = 0.11) and on VR is 1.13 (SD = 0.13). A one-way repeated ANOVA also yielded a close to significant effect of Platform ($F_{1,7}$ = 3.855, p = 0.090).

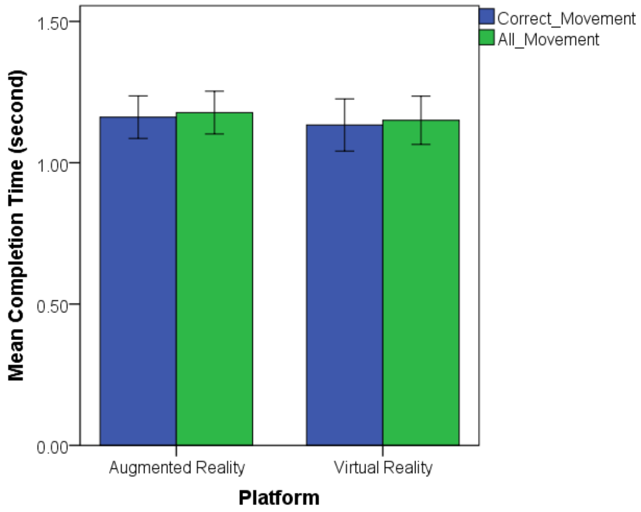

Fig. 4. Mean task completion time for correct movements and all movements under AR and VR conditions. Error bars indicate ±2 standard errors.

In terms of accuracy, a one-way repeated ANOVA found no significant effects of Platform ($F_{1,7}$ = .069, p = 0.800). The accuracy for AR is 98.6% (SD = 1.36%) and for VR is 98.5% (SD = 1.78%).

2) User Preference

NASA-TLX. The weighted overall workload for VR (M = 42.67, SD = 19.35) was higher than AR (M = 37.33, SD = 20.04). However, a one-way repeated ANOVA yielded no significant effects of Platform ($F_{1,7}$ = 0.997, p = 0.351) on overall NASA-workload. A multivariate ANOVA with all six NASA-TLX subscales (Mental, Physical, Temporal, Effort, Frustration, Performance) as dependent variables and Platform as the factor was conducted. Fig. 5 shows the resuts of each subscale. It showed that there were no significant differences between the Platform regarding the NASA-TLX factors (Mental: p = 0.334; Physical: p = 0.743; Temporal: p = 0.844; Effort: p = 0.807; Frustration: p = 0.879; Performance: p = 0.777).

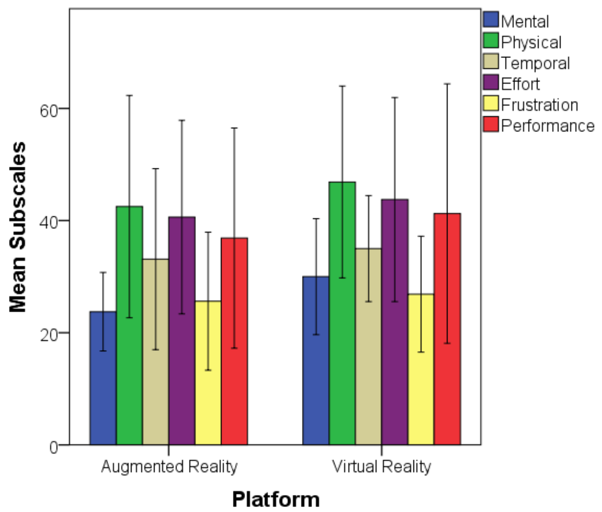

Fig. 5. Mean NASA-TLX subscales for each platform. Error bars indicate ±2 standard errors.

Motion-sickness. The motion sickness average score for AR was 0.21 (SD = 0.22) while for VR was 0.24 (SD = 0.28). A one-way repeated ANOVA found no significant effect of Platform ($F_{1,7}$ = 0.833, p = 0.392) on overall motion sickness. A multivariate ANOVA also showed no significant effect of Platform on all four MSAQ factors (Gastrointestinal: p = 0.906; Central: p = 0.830; Peripheral: p = 0.805; Sopite-related: p = 0.842). Fig. 6 shows the results of each subscale.

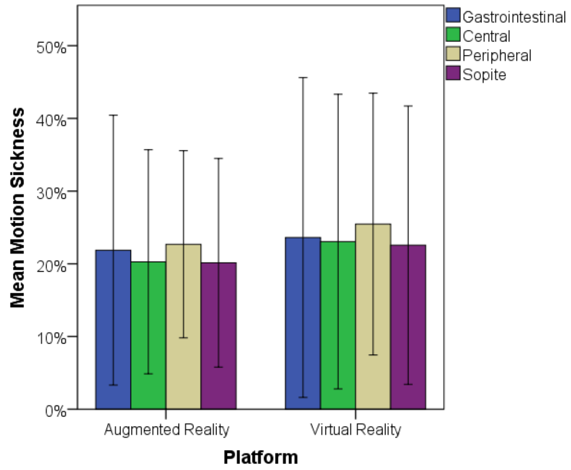

Fig. 6. Mean motion sickness subscales under AR and VR conditions. Error bars indicate ±2 standard errors.

SUS. The SUS means for AR (M = 4.42, SD = 1.41) was slightly higher than VR (M = 4.38, SD = 1.20). A one-way repeated ANOVA found no significant effect of Platform ($F_{1,7}$ = 0.046, p = 0.836) on immersion and presence. The SUS counts for AR and VR were the same, both having an average count of 1.25 (SD = 1.28).

UEQ. The average user experience score for AR was 1.07 (SD = 0.59) and for VR was 1.06 (SD = 0.59). A one-way repeated ANOVA found no significant effect of Platform ($F_{1,7}$ = 0.046, p = 0.836) on averaged user experience. A multivariate ANOVA also showed no significant effect of Platform on all UEQ subscales (Attractiveness: p = 0.707; Perspicuity: p = 0.827; Efficiency: p = 0.884; Dependability: p = 0.514; Stimulation: p = 0.662; Novelty: p = 0.909). Fig. 7 shows the results of each subscale.

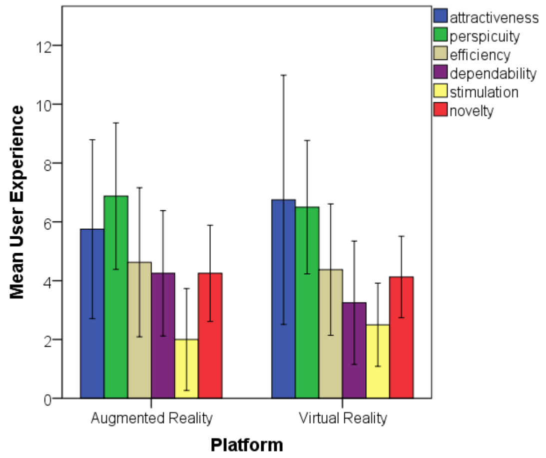

Fig. 7. Mean user experience subscales under AR and VR conditions. Error bars indicate ±2 standard errors.

III. Discussion and Future Work

In terms of task performance, no significant effect of Platform has been found on both task completion times and accuracy. This indicates that participants can achieve equal task completion time and accuracy in both AR and VR when using motion direction as an interface.

Regarding user preference, the following points can be extrapolated from our results.

- Participants using the VR HMD cannot see the background of the physical environment (in contrast to the AR device that allows them to see the background) but this has not increased the workloads. We had expected a heavier workload for the VR condition. One reason that participants have not felt that the VR HMD is more demanding is that they have had some prior experience already.
- Doing motion direction under VR condition have not resulted in a higher immersion than under AR condition. One reason for this might be the tasks are simple. Unlike some other studies like [12], [13], our participants only are required to move the body towards eight directions. Another reason might be because the AR HMD also has provided immersion and presence for participants that have made them felt comparable to the VR HMD. Similarly, the virtual test environment has been simple and does not emphasize 3D elements, which may have given an extra advantage to the VR HMD.
- Participants have reported the same motion sickness level in AR and VR when doing the motion direction movements. This means that both can be used for interfaces that rely on body movements.
- No significant differences between AR and VR are found on the user experience and such as we can assume motion direction interface could result in the same level user experience in AR as VR.

This research only focused on two types of HMDs, but motion-based interfaces could be used for non-HMDs, like those based on tracking devices such as the Kinect. In the future, we want to explore whether there is a difference in levels of immersion and presence as well as workload and user experience between non-wearable devices (e.g., using a Kinect) and wearable devices (e.g., AR/VR/MR HMD).

IV. Conclusions

This research focuses on investigating user performance (in terms of time) and user preference for motion direction tasks using two of the most common types of head-mounted displays (HMDs), augmented reality (AR) and virtual reality (VR). One experiment is conducted to explore whether doing directional motion movements under AR and VR conditions may result in different user performance and user preference (in terms of workload, immersion, presence, and motion sickness). The results show that the type of HMDs (AR and VR) does not affect user performance for both task completion time and accuracy. In terms of user preference, our results show that the participants experience the same level of workloads, motion sickness, immersion, and user experience under AR and VR conditions. That is, both these two types of HMDs can potentially be used for interfaces that are based on directional body motions (for example, as a way to select menu items).

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