Effect of virtual reality usage on postural stability

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Abstract. Virtual reality (VR) is a technology that has been widely used for various industrial purposes in recent days. Despite the potential benefits, VR usage may impose adverse effects that can prevent users from reaching their goals of using VR safely and comfortably. One potential adverse effect is the disruption of postural stability during VR usage. This study aimed to evaluate the effect of using VR on postural stability. Fourteen participants involved in the experimental set up playing a simulated game with Samsung Gear 3 Head Mounted Display (HMD) for 30 minutes with standing posture. During the experiment, the center of pressure data was obtained every 10 minutes using a force plate to calculate postural stability using three parameters including mean distance (MD), mean velocity (MV), and sway area (SA). The results showed that a longer duration of VR usage significantly increased MD and SA. Meanwhile, MV remained constant throughout the experiment. It means the use of VR may worsen users’ postural stability. Thus, caution should be used to develop a future guideline to increase VR safety.

1. Introduction
With the development of digitalization, one advanced technology has arisen, named virtual reality. Virtual reality (VR) is the process of encouraging the formation of targeted behaviors from organisms by using artificial sensory stimulation [1]. Artificial stimuli are created by replacing the original stimuli of the real environment with artificial stimuli that decreases the user's awareness. Reduced awareness causes a sense of presence in a virtual environment. The ability of VR to present humans in a virtual environment is then widely used in the entertainment industry such as making video games [1].

Along with the development of technology, VR has also begun to be used in other fields, such as tools for surgery training in health [2] [3] [4] and safety or work method training in the industry [5] [6] [7]. VR was known to have an ability to improve technical skills in orthopedic [2] and laparoscopic surgery [3]. Training using VR was also known to be able to improve practical skills in cataract surgery [4]. In the aviation industry, the use of VR mobile apps can improve passenger ability to perform safety procedures [5], while VR head-mounted display (HMD) was able to increase knowledge and self-efficacy to carry-out safety procedures [6]. In the manufacturing industry, it is known that the workers who participate in maintenance & assembly training using VR were able to work well [7]. VR was also used to evaluate product concepts by developing a virtual prototype [8]. This virtual prototype requires a lower cost compared to a physical prototype.

Despite the potential benefits, VR usage may impose adverse effects that can prevent users from reaching their goals of using VR safely and comfortably. One potential adverse effect is the disruption of postural stability during VR usage. Sinitzki et al. (2019), found sway on the user body after VR immersion exposure, which indicates a postural stability disturbance [9]. Postural instability induced by VR usage can increase accident risk on human activity that needs body balance such as driving and walking [10]. This postural disturbance may vary due to gender differences and human adaptability to
repeated VR exposure [11]. Murata conducted a study to investigate postural stability in prolonged VR immersion [12]. The results showed that the longer VR immersion exposes humans, the greater postural instability. However, technological developments have resulted in more sophisticated VR technology, with a higher level of immersion and realism. This study aimed to evaluate the effect of using Samsung Gear 3 VR HMD with more advanced technology and a higher field of view on postural stability.

2. Methods

2.1. Participants
Fourteen male participants were involved in this study. The participants are engineering undergraduate students with an average (standard deviation) age of 21.56 (0.81) years. Prior to the experiment, participants were confirmed to be in good health and had experiences in playing a game in a console/PC/smartphone. As many as 44% of the participants were often (almost every day) playing a game and 56% of the participants were rarely (2-3 times a week) playing game.

2.2. Instruments
The experiment was conducted using a Samsung Gear 3 VR HMD from South Korea. This VR HMD had a 101° field of view and using a gyro sensor to detect user movement. Samsung Gear 3 was operated using Samsung S8 Galaxy smartphone with specification: 148.9 x 68.1 x 8 mm dimension; 5.8-inch screen, 3 GB RAM; Android OS. A VR application named MISSION: ISS form Oculus was used in this study. This application is a game simulator where the user had a role as an astronaut and get information about astronaut life and international space station (ISS). The user learns to walk, touch the virtual object, operate tools, and surf in the application. VR user interacts with a virtual environment using a controller provided by Samsung Gear. The controller is completed with buttons with several functions as an input to the game.

2.3. Procedures
Participants were asked to use VR HMD and played simulator game for 30 minutes. There was no specific instruction to the participants for the simulation. They were free to do anything as long as they remain in the simulator for those 30 minutes. The participant was standing on a force plate (AMTI 400600 V1.00) during the simulation and the center of pressure (COP) data was measured every 10 minutes. The COP was sampled at 1000 Hz and obtained in anterior-posterior (A-P) and medial-lateral (M-L) direction. During the data recording, participants were instructed to stand upright for 20 seconds with shoulder-width apart, hands beside the waist, and eyes closed. Measurement was conducted with eyes closed to avoid the effect of visual signals from VR HMD. In other to compare postural stability with and without VR, control data was collected. In the control experiment, participants were instructed to maintain their stability while standing for 30 minutes. Participants were free to do any activity except activities that can tire the eyes such as playing mobile phones/laptops.

2.4. Data Processing and Analysis
There was a total of 20,000 COP data for 20 seconds of duration of measurement. COP data for each axis then were converted into three postural stability parameters (i.e., mean distance (MD), mean velocity (MV), and sway area (SA)). All parameters were calculated for each measurement time: baseline; 10th minute; 20th minute; and 30th minute.

3. Result

3.1. Mean Distance (MD)
This parameter shows the average distance of the COP as it shifts from its average. The MD value was divided into three parameters (i.e., MD on the A-P axis, MD on the M-L axis, and MD for the resultant
of the two axes). Figure 1 shows the average trend of MD values for the resultant axis, A-P axis, and M-L axis for the treatments using VR and control.

![Graph showing MD values for treatments using VR and control](image_url)

**Figure 1.** The average of mean distance

The data showed that the trend of MD values while using VR tends to increase every 10 minutes. There was an average 21% increase in MD, a 24% increase in mean AP distance, and a 22% increase in mean ML. Nevertheless, the AP axis in 20 minutes to 30 minutes was decreased by 9%. The MD in control experiments tends to be constant for all parameters even though there was an increase in the 20 minutes by 26%. However, the slope returned to a decrease between 20-30 minutes. The results of Friedman's statistical test showed that there was a significant difference in MD indicator value (p-value = 0.007) and ML axis MD value (p-value = 0.005), but there was not a significant difference found in mean axis AP distance (p-value = 0.103). Further post-hoc tests of the MD and mean axis distance of the ML axis using the Wilcoxon test showed a significant difference SA level (p <0.05) in baseline condition - 20 minutes, baseline - 30 minutes, 10 minutes - 20 minutes, and 10 minutes - 30 minutes. There was no significant difference between the SA in baseline-10 minute, and between 20-30 minutes.

### 3.2. Mean Velocity (MV)

This parameter showed the average speed of the COP movement from the average COP. The COP parameters were obtained from data collection in initial conditions (0-minute trial), 10 minutes, 20 minutes, and 30 minutes experiments. COP data was then converted to an MV parameter. The MV score was also divided into three parameters: MV for the A-P axis, MV for the M-L axis, and resultant of both axes. Figure 2 shows the average trend of the average velocity of all respondents in experiments in two conditions, during VR usage and without VR usage in control experiments. The data showed that the average MV resultant for the main experiments tends to increase. Every 10 minutes there was an average of 2% increase observed. However, the increase was relatively low. Starting from the baseline conditions up to 30 minutes of VR usage, the average increase was only 7.25%. For the AP and ML axes, the MV also experienced a slight increase with an average of 10% and 1% every 10 minutes. For control experiments, the MV of the three axes also tends to be constant. The average change of the MV every 10 minutes was only around 0-3%. The results of the Friedman statistical test showed that there was no significant difference in MV indicator (p-value = 1.80), mean AP axis velocity (p-value = 0.359), or ML axis MV (p-value = 0.093) due to the duration of VR usage.
This parameter is one of the postural stability parameters that shows the average area of the COP shifting. COP parameters will be obtained at data collection in 4 measurement points: baseline conditions (0 minutes of the experiment); 10 minutes; 20 minutes; and 30 minutes of VR usage. COP data obtained were then converted into the Sway Area (SA) parameter. Figure 3 shows the average trend in SA values in two conditions, during VR usage and without VR usage in control experiments.

Based on the data, known that SA value during VR usage tends to increase with an average of 23% increase every 10 minutes. The difference between SA on the baseline (0 minutes VR usage) and 30 minutes VR usage reached 82%. In the control experiment, obtained the SA was relatively constant, with an average increase of only 1.2% every 10 minutes. Friedman statistical test showed a significant difference in SA value in all four measurement points during VR usage (p-value = 0.018). Further post-hoc tests using the Wilcoxon test showed significant differences in the level of swaying area (p <0.05) between the baseline conditions - 20 minutes; baseline - 30 minutes; 10 minutes - 20 minutes; and 10 minutes - 30 minutes. There was no significant difference between the SA at the 10-minute baseline, and between 20-30 minutes.
The statistical correlation test leads to the conclusion that the SA parameter was correlated with all postural stability parameters with 0.000 p-values. However, no strong correlation was found between the MD and MV. Strong correlations were only found between the MV resultant and AP axis with an MD of the AP axis with p-values of 0.012 and 0.022. In general, the correlation test results showed that all postural stability parameters are highly correlated with each parameter used.

4. Discussion
The result showed that all three postural stability parameters of HMD VR users were increased during the experiment. In other words, there was an increase in postural instability with a longer duration of VR usage. Increased MD and SA parameters reached more than 75% after 30 minutes of use. This indicates that the use of advanced VR HMD with a duration of less than one hour has a significant impact on the level of postural instability of its users. The results of this study were in line with the previous study using a less advance monaural HMD with a 60° field of view where the use of VR HMD for 3 hours was known to increase postural instability [12]. The longer the immersion of the VR environment, the higher the postural instability. This study showed that more advanced technology could not eliminate the impact of VR immersion on postural instability. However, further study is needed to investigate whether more advance technology can reduce this side effect or not.

The increased level of postural instability itself possibly is related to the symptoms of physical fatigue due to the experimental process that was done in standing posture and a fairly long duration. For this reason, a control experiment was carried out in which the participants did not play VR for 30 minutes to observe whether the increased postural stability was caused by VR immersion or due to fatigue. The results obtained from control experiments showed that postural stability values for all parameters tend to be stable, while the value of all parameters only changed around 1–4%. This indicated that the effect of physical fatigue due to standing does not significantly influence the level of postural stability.

The three parameters of postural stability indicated different things. The MD was related to the effectiveness of the level of stability produced by the posture stability system [13]. The higher the MD, the higher the level of postural instability. The MV indicates the activity level of postural stability control to achieve a stability state [13]. Moreover, the SA parameter quantifies the relationship between the body's stability control system and the level of stability achieved [14]. The correlation test showed that those three parameters were correlated with each other. It showed that the overall effort of the body in controlling postural stability resulted in three interrelated phenomena, the distance of the COP movement from the average COP, the speed of the COP movement, and the area of COP movement.

The MV and SA show a tendency to increase as the VR HMD usage duration increase. For every 10 minutes of VR usage, there was an average increase of 20-25% each parameter. However, differences in parameter values every 10 minutes of use did not always occur. The statistical tests showed that there were no significant differences MD and SA in the first 10 minutes of VR usage. There was an increase, but it was very slight. This might occur because, in the initial period of using VR, the user's body was in the warming up phase so that the level of body awareness was high. This high awareness supported the VR user body to maintain a level of postural stability [9].

The MV is a parameter that indicates the level of activity of the postural control system in the body to achieve a level of stability [13]. Based on experiments it was found that the MV parameters for the three sub-values (resultant, AP axis, and ML axis) tended to be constant, with an average change 2 to 3 percent every 10 minutes. When compared to baseline conditions, the use of 30 minutes VR only results in a change of 7% means velocity. However, the previous study using narrower VFR HMD stated that all seven COP measurement including MV sensitively reacted to VR exposure [12]. This different result might be due to the difference in VR apparatus that was used or the difference in VR immersion duration. In the previous study, VR was used for a longer time which is 3 hours. Knowledge about the impact of VR on postural stability can be utilized to manage the procedures of VR usage. With postural stability caused by VR immersion, it is recommended that users avoid activity that requires stability such as driving or walking. This will improve safety in VR usage. In addition, in this study, it was known that a more advanced VR with a wider field of view can still cause postural instability. However, there was
one indicator that tended to be constant, MV. Nevertheless, this research had not directly compared VR HMD with different technological advances. For that reason, further research can be conducted to compare the effects of different technological specifications on postural stability.

5. References

[1] S. M. LaValle, Virtual Reality, Cambridge University Press, 2019.
[2] F. Aim, G. Lonjon, D. Hannouche and R. Nizard, "Effectiveness of Virtual Reality Training in Orthopaedic Surgery," Arthroscopy: The Journal of Arthroscopic & Related Surgery Vol 32 Issue 1, pp. 224-232, 2016.
[3] M. Alaker, G. R. Wynn and T. Arulampalam, "Virtual reality training in laparoscopic surgery: A systematic review & meta-analysis," International Journal of Surgery Vol 29, pp. 85-94, 2016.
[4] A. S. S. Thomsen, D. Bach-Holm, H. Kjærbo, K. Højgaard-Olsen, Y. Subhi, G. M. Saleh, Y. S. Park, M. Cour and L. Konge, "Operating Room Performance Improves after Proficiency-Based Virtual Reality Cataract Surgery Training," Ophthalmology Vol 124 Issue 4, pp. 524-531, 2017.
[5] L. Chittaro, C. L. Corbett, G. McLean and N. Zangrando, "Safety knowledge transfer through mobile virtual reality: A study of aviation life preserver donning," Safety Science, pp. 159-168, 2018.
[6] F. Buttussi and L. Chittaro, "Effects of Different Types of Virtual Reality Display on Presence and Learning in a Safety Training Scenario," IEEE Transactions on Visualization and Computer Graphics, pp. 1063 - 1076, 2018.
[7] N. Gavish, T. Gutiérrez, S. Webel, J. Rodríguez, M. Peveri, U. Bockholt and F. Tecchia, "Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks," Interactive Learning Environments Vol 23 No 6, pp. 778-798, 2015.
[8] PWC, "). Virtual and augmented reality and the factory of the future is here.," [Online]. Available: http://www.pwc.com/us/en/industrial-products/nextmanufacturing/Augmented-virtual-reality-manufacturing.html.
[9] E. Sinitski, A. A. Thompson, P. C. Godsell, J. L. Honey and M. Besemann, "Postural stability and simulator sickness after walking on a treadmill in a virtual environment with a curved display," Displays, vol. 52, p. 1–7, 2019.
[10] R. Kennedy and M. Lilienthal, "Postural Instability Induced by Virtual reality exposure: Development of a certification protocol," International Journal of Human-Computer Interaction, vol. 8, no. 1, pp. 25-47, 1996.
[11] P.-A. Fransson, M. Patel, H. Jensen, M. Lundberg, F. Tjernström, M. Magnusson and E. E. Hansson, "Postural instability in an immersive Virtual Reality adapts with repetition and includes directional and gender specific effect," Scientific reports, vol. 9(1), p. 3168, 2019.
[12] M. A, "Effects of Duration of Immersion in a Virtual Reality Environment on Postural Stability," International Journal of Human Computer Interaction, vol. 17, no. 4, pp. 463-477, 2004.
[13] T. E. Prieto, J. B. Myklebust, R. G. Hoffmann, E. G. Lovett and B. M. Myklebust, "Measures of postural steadiness: Differences between healthy young and elderly adults," IEEE Transactions on Biomedical Engineering, vol. 43, no. 9, p. 956–966, 1996.
[14] A. Hufschmidt, J. Dichgans, K. H. Mauritz and M. Hufschmidt, "Some methods and parameters of body sway quantification and their neurological applications," Arch Psychiatr Nervenk, vol. 150, no. 228, p. 135–150, 1980.