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The Effects of Viewing Smart Devices on Static Balance, Oculomotor Function, and Dizziness in Healthy Adults

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Background: The number of people using smart devices such as smartphones (SPs) or virtual reality head-mounted displays (HMDs) is rapidly increasing. This study aimed to investigate the effects of viewing smart devices, including SPs and HMDs, on postural balance and the development of dizziness in healthy individuals.

Material/Methods: Twenty-six healthy adults underwent static balance measurements at baseline, and after 5, 10, and 20 minutes of viewing the SP and HMD display. Measurements were taken using a force plate and Wii Balance Board (WBB) and included the parameters of postural sway velocity, path length, and postural sway area. A modified Simulator Sickness Questionnaire (SSQ) evaluated oculomotor function and dizziness twice for each device, after 5 and 20 minutes of use.

Results: Compared with baseline, the use of smart devices for 20 minutes had significantly increased effects on balance, oculomotor function, and dizziness than shorter use for 10 minutes or 5 minutes in healthy adults. Postural sway velocity and path length were significantly increased after 20 minutes of use of the HMD and SP when compared 5-minute use and baseline measurements ($p < 0.05$). Postural sway area after 20-minute use of the HMD was significantly increased compared with the baseline and 5-minute and 10-minute use of the SP and 5-minute use of the HMD ($p < 0.05$). The SSQ showed that dizziness was significantly increased after 20-minute use compared with 5-minute use of the HMD and SP ($p < 0.05$).

Conclusions: Longer use of smart devices affected static balance, oculomotor function, and dizziness in healthy adults.

MeSH Keywords: Cellular Phone • Dizziness • Postural Balance

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Background

With advances in communication and information technology, increasing numbers of people are using smart devices, such as smartphones (SPs) and virtual reality head-mounted displays (HMDs). In June 2019, according to the Pew Research Center (www.pewinternet.org/fact-sheet/mobile/), 81% of the population of United States own SPs, and the average use time has been shown to increase with increased SP ownership [1]. However, increased screen time when interacting with smart devices can have a negative effect [1]. Increased use of smart devices is significantly associated with increased levels of depression and stress [2]. Also, given the small screen size of smart devices, and the use of augmented reality or virtual reality devices, attention of the user is distracted, which may increase the risk of falls or accidents [3].

The development of computer-based media and entertainment is moving towards augmented reality and virtual reality by expanding existing temporal and spatial concepts with the convergence of visual media [4]. Augmented reality enables people to perceive the world within a combined reality, or real space overlaid with virtual sensory information [5]. However, due to restrictions of mass production and supply, production of augmented reality devices are limited by miniaturization of the optical systems [6]. For this reason, augmented reality is used less often as the virtual world is displayed within a limited frame [4]. Therefore, there has been a growing demand for new media that retain the characteristic of miniaturization but are free from the limitations of display frames, which is the output surface and mode of viewing images. In response to this demand, the development of HMDs is accelerating rapidly [6]. Technologies enabling the implementation of a virtual environment using low-cost smart devices are being developed and used in a range of fields, and can be realized in several ways, from two-dimensional to three-dimensional (3D) HMDs, using a lightweight helmet or an HMD that enables people to concentrate on a 360-degree viewing angle and 3D virtual reality. While this virtual environment is not real, smart devices allow people to be immersed in the virtual environment as though it were real [7]. For the past few years, many HMDs have made it easier to access virtual environments [8–10].

The virtual environment system may lead to sensory conflict when information from visual perception differs from that of the vestibular system [11]. A recent study reported that dynamic and static balance could be affected while using smart devices [9], and these symptoms may also occur after using an HMD [12]. However, little is known about how balance and oculomotor function may be affected after using smart devices, including HMDs, and how this may increase the risk of dizziness, falls, or accidents. Also, a previous study showed a negative effect of smart devices on balance [6], but few studies

Table 1. Characteristics of the study participants.

Variables	Mean $\pm$ SD
Gender (M/F)	13/13
Age (years)	22.57 $\pm$ 2.2
Height (cm)	167 $\pm$ 7.53
Weight (kg)	63.29 $\pm$ 15.23
BMI (kg/m ²)	22.27 $\pm$ 2.98

M – Male; F – Female; BMI – body mass index; SD – standard deviation.

have investigated the effects of increasing SP and HMD use on balance and dizziness.

With virtual reality simulation now requiring just an SP and paper box, for example, Google Cardboard version 2.0 (Google Inc., Mountain View, California, USA), which produces images similar to those produced by professional equipment, the health issues associated with the use of smart devices are likely to increase. However, the increased use of these devices may lead to different risks compared with watching a simple SP screen. Therefore, the aim of this study was to investigate the effects of short and prolonged use of SPs and HMDs on balance and dizziness in healthy adults.

Material and Methods

Study participants

The study participants were recruited by posting an announcement about the purpose and methods of this study on a bulletin board. Healthy adults aged between 20–29 years who were interested in volunteering were screened. The exclusion criteria were musculoskeletal or neurological conditions, congenital deformity, injury, or inflammatory conditions involving the extremities, cognitive impairment, and a history of alcohol or drug abuse. A total of 30 volunteers responded to the advert, and 26 participants were included after screening. Demographic characteristics of the participants in the study are shown in Table 1.

Participants were thoroughly informed about the purpose of the study and the study procedures before providing informed consent. The Kyungnam University Institutional Review Board approved this study.

Study procedures and use of smartphones (SPs) and virtual reality head-mounted displays (HMDs)

The study was conducted in a quiet and spacious physical therapy practice room. After providing consent, demographic

Figure 1. A smartphone (SP) and a head-mounted display (HMD).

and clinical characteristics were recorded including, gender, age, height, weight, and body mass index (BMI), and baseline measurements were taken. The smart devices used in this experiment were the LG V10 Smartphone (LG-F600L) (LG Electronics Inc., Seoul, Republic of Korea) with length (L)×width (W)×height (H) of 159.6×79.3×8.6 mm (Figure 1) and the VR Box (HMD Korea, Seoul, Republic of Korea) with a 70° viewing angle, 42-mm lens diameter, L×W of 83×163 mm, and a weight of 330 g (Figure 1).

Participants were asked to use an SP and HMD in the order of their choice, using the device to watch eight video clips while seated in a comfortable position. Video clips consisted of eight K-Pop music videos lasting at least 5 minutes, played in random order. Viewing ceased after 5 or 20 minutes depending on the conditions. After watching the videos for the set duration, participants were asked to stand on a force plate to measure their balance. Balance ability was measured at baseline or time 0 (before using the smart device), and at 5, 10, and 20 minutes and after using both the SP and HMD. Dizziness and oculomotor symptoms were assessed using the Simulator Sickness Questionnaire (SSQ) at 5 and 20 minutes. Participants were given 5 minutes of rest (non-screen time) before using the same smart device for the next experiment in a different time condition. This break did not include measurement or preparation time, and additional rest was provided if participants did not feel as though their vision had returned to normal. A 10-minute rest was allocated between device trials to avoid eye strain [13].

Outcome measurement of static balance

A Nintendo Wii Balance Board (WBB) (Nintendo, Kyoto, Japan) was used to measure static balance. Similar to a force plate,

WBBs are widely used because of their portability [14]. The WBB sequentially collected center of pressure (COP) information through load cells located on its four corners, which was then transmitted to a computer connected via Bluetooth. Participants were asked to step on the force plate with their bare feet and place their feet in the most comfortable position with their arms by their sides. Each participant's foot position was marked so that the same position was used when measurements were repeated. Data were extracted using Balancia software version 2.0 (Mintosys Inc., Seoul, Republic of Korea) at a sampling rate of 50 Hz and low-pass filter frequency of 10 Hz. The inter-observer reliability of this method had an intraclass correlation (ICC) of 0.89–0.79, the intra-observer reliability had an ICC of 0.70–0.92, and the validity had an ICC of 0.73–0.87 [14].

Evaluation of dizziness and oculomotor symptoms using the SSQ

Dizziness and oculomotor symptoms were investigated using the SSQ self-reporting tool that was originally designed for the assessment of dizziness, motion sickness, and oculomotor function [15]. The original SSQ consisted of 30 questions related to the individual's experience of nausea, oculomotor function, and dizziness [30]. For this study, the questionnaire was reduced to 16 questions, including questions about dizziness (9 items), and oculomotor symptoms that included eye strain, blurred vision, and difficulty concentrating (6 items) [16]. The highest possible score for the 9 questions related to dizziness was 27, while that for the 7 questions on oculomotor function was 21 (total possible score=48). Higher SSQ scores indicated an increase in dizziness, blurred vision, and eye strain.

Table 2. Comparison of the effects on static balance from using a smartphone (SP) and a head-mounted display (HMD).

	Baseline condition	5 minutes of use of SP	10 minutes of use of SP	20 minutes of use of SP	5 minutes of use of HMD	10 minutes of use of HMD	20 minutes of use of HMD
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Sway velocity (cm/s)	2.34 $\pm$ 0.37 (100%)	2.45 $\pm$ 0.43 (105%)	2.53 $\pm$ 0.45 (108%)	2.58 $\pm$ 0.45 (110%)	2.48 $\pm$ 0.35 (106%)	2.63 $\pm$ 0.47 (112%)	2.96 $\pm$ 0.70 ^{*,**,***,##} (126%)
Path length (cm)	69.94 $\pm$ 11.47 (100%)	73.40 $\pm$ 13.01 (105%)	75.58 $\pm$ 13.82 (108%)	77.08 $\pm$ 13.84 (110%)	74.19 $\pm$ 10.88 (106%)	78.65 $\pm$ 14.28 (112%)	88.88 $\pm$ 21.71 ^{*,**,***,##} (127%)
Area of postural sway (cm ²)	2.57 $\pm$ 2.08 (100%)	3.20 $\pm$ 2.29 (125%)	3.66 $\pm$ 3.11 [*] (142%)	4.68 $\pm$ 4.39 ^{*,**} (182%)	3.61 $\pm$ 2.10 [*] (140%)	5.77 $\pm$ 5.87 ^{*,**,***,##} (225%)	10.13 $\pm$ 9.45 ^{*,**,***,##} (394%)

SP – smartphone; HMD – head-mounted display. * Significant differences when compared to baseline condition ($p < 0.05$); ** significant differences when compared to condition after 5 minutes of use of an SP ($p < 0.05$); *** significant differences when compared to condition after 10 minutes of use of an SP ($p < 0.05$); # significant differences when compared to condition after 20 minutes of use of an SP ($p < 0.05$); ## significant differences when compared to condition after 5 minutes of use of an HMD ($p < 0.05$).

Table 3. Comparison of the results from the Simulator Sickness Questionnaire (SSQ) from using a smartphone (SP) and a head-mounted display (HMD).

	5 minutes of use of SP	20 minutes of use of SP	5 minutes of use of HMD	20 minutes of use of HMD
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Oculomotor function	3.73 $\pm$ 4.09	6.35 $\pm$ 3.54 [*]	6.699 $\pm$ 4.68 [*]	9.929 $\pm$ 4.77 ^{*, **,***}
Dizziness	2.27 $\pm$ 2.97	2.73 $\pm$ 2.22)	3.42 $\pm$ 3.19	5.38 $\pm$ 4.30 ^{*, **,***}

SP – smartphone; HMD – head-mounted display. * Significant differences compared to condition after 5 minutes of use of an SP ($p < 0.05$); ** significant differences compared to condition after 20 minutes of use of an SP ($p < 0.05$); *** significant differences compared to condition after 5 minutes of use of an HMD ($p < 0.05$).

Statistical analysis

Statistical analysis was performed using SPSS version 18.0 software (IBM, Chicago, IL, USA). The demographic and clinical characteristics of the study participants were expressed as the frequency or the mean $\pm$ standard deviation (SD). One-way analysis of variance (ANOVA) and the Kruskal-Wallis test were used to compare outcomes across test conditions. The Mann-Whitney U test with Bonferroni correction was used for post hoc analysis. A P-value < 0.05 was considered to be statistically significant.

Results

The results of this study are presented in Table 2. Sway velocity and path length were significantly increased after 20 minutes of virtual reality head-mounted display (HMD) use compared with baseline ($p < 0.05$), after 5-minute and 10-minute

smartphone (SP) use ($p < 0.05$), and after 10-minute HMD use ($p < 0.05$).

Postural sway area was significantly increased after 10 minutes of SP use and after 5 minutes of HMD use when compared with baseline ($p < 0.05$). Also, the postural sway area was significantly increased after 20 minutes of SP use compared with baseline and after 5 minutes of SP use ($p < 0.05$). Using an HMD for both 10 minutes and 20 minutes significantly increased the postural sway area compared with that at baseline, after 5-minute use and 10-minute use of SP, and after 5-minute use of HMD ($p < 0.05$).

Also, 20 minutes of HMD use, dizziness and oculomotor symptoms were significantly increased compared with 20 minutes of SP use ($p < 0.05$). The results for dizziness and oculomotor function with each smart device are presented in Table 3. Oculomotor impairment was significantly increased after 20 minutes of SP use and after 5 minutes of HMD use compared

with 5 minutes of SP use. The SSQ score was significantly increased after 20 minutes of HMD use compared with that after all other conditions ($p < 0.05$).

Discussion

The present study investigated the effects of 5, 10, and 20 minutes of the use of a smartphone (SP) and virtual reality head-mounted display (HMD) devices on balance, dizziness, and oculomotor function. The results showed negative effects of both SP and HMD use, although those caused by HMD use were more pronounced, occurring after a shorter period of time. These results add to those from a previous study that investigated the effect of using an SP on balance in 36 healthy adults, which reported that postural sway was significantly worse when using an SP [17]. The authors of this previous study concluded that there was a reduction in balance when playing games, sending a text message, surfing the web, or listening to music after using an SP [17]. Another study assessed balance while using an SP in 30 healthy adults [18], and showed that sending a text message and social network chat messaging activity significantly reduced dynamic balance. Therefore, recent studies support that staring at a smart device negatively affects balance [17,18].

Robert et al. conducted a study on 14 healthy adults and examined the effects of using an HMD for 3 minutes on static and dynamic balance [9]. In this previously published study, static balance was measured using a force plate, while dynamic balance was measured using the short-form of the Berg Balance Scale (BBS) [9]. Static and dynamic balance were measured by comparing standing posture with the eyes open and then closed [9]. The effect of using an HMD was examined by comparing the measurements of static and dynamic balance while using an HMD and control conditions [9]. The study reported that although there was no significant difference in static balance caused by using an HMD, there was a significant difference in dynamic balance [9]. However, in the current study, a significant difference in static balance was observed. This difference could be attributed to the duration of HMD use. In a previous study [11], the HMD was used for 3 minutes, which is comparable to the 5-minute condition of this study where no effect on balance was observed. In contrast, after 10 minutes of use, there was a significant effect on static balance [11]. Cobb and Nichols also found that more prolonged visual exposure to virtual reality in an immobile posture may lead to postural instability [19].

The results from these previous studies support those of the present study. The sensory information required for maintaining balance is derived from the visual, proprioceptive, and vestibular systems [9]. The input of this sensory information is

important in maintaining balance [20]. Since the relative level of contribution of input from visual information is far greater than that of the proprioceptive and vestibular systems, it has been suggested that the righting reaction can sufficiently control postural imbalance caused by postural sway together with visual, vestibular, and proprioceptive input [20,21]. This finding could explain the results from the present study that also indicated that HMD use has a more negative effect on maintaining balance than SP use, thus supporting the theory that visual input has the largest effect on balance. Also, it has previously been reported that HMDs inherently limit movement of the head, perhaps causing sensory conflict between the visual and vestibular sensory systems [20,21]. Such sensory conflict can reduce information processing required for maintaining balance, and in serious cases, this can lead to headache and nausea [9]. Also, longer duration of sensory conflict may lead to the disturbance of balance and safety of users [9]. Similarly, the present study found that dizziness and oculomotor function were most significantly affected after the 20-minute use of an HMD. However, in contrast to previously reported findings, the present study showed that there was a significant difference in postural imbalance among participants who used an HMD for more than 20 minutes compared to those who used an SP for 5 and 20 minutes and those who used an HMD for 5 minutes. Also, the use of an HMD for 20 minutes increased dizziness and oculomotor symptoms of the user more than the use of an SP for 20 minutes.

In the present study, balance was measured immediately after the virtual reality HMD was removed, which meant that the measurements were taken as an adaptation to light began, and balance may have been affected because of this change. Therefore, it is recommended that more caution be used when experiencing virtual reality using an HMD. This study adds to the findings from previous studies that have focused on HMD-specific equipment, as opposed to SP-compatible technology. The problem of dizziness after playing computer games or using an HMD is relatively well established, but this was not observed in the current study using smartphone HMD technology. Also, conventional computers and HMDs are not portable devices and can be used only in a limited space. The equipment used in this study is usable anywhere, so the risk of falling is potentially greater. Therefore, the findings from this study have more real-world relevance and application. This study of the effect of smartphone-compatible HMDs will be a useful consideration in the development of this technology when considering how to prevent dizziness and balance disturbances.

Previous studies have reported on the effect of SP use on balance and walking. However, to the best of our knowledge, there has been no previous study on the impact of SP use on dizziness. Also, although there have been studies on the effects of using HMD on dizziness, there are few studies on the

effects of HMDs on balance. This study brings these results together by measuring the effect of different durations of SP and HMD use on both dizziness and balance. As the technology of SPs continues to evolve, it has become possible to use HMDs with SPs. The increase in HMD accessibility as a result of this development in technology increases the risk of balance disturbances and dizziness to the public. The findings from this study add to those from previous studies by reporting the use of SPs and HMDs. Comparison of the difference between the SP screen view and the HMD screen view shows that dedicated HMD equipment produces a more realistic virtual world, it is heavier, more expensive, and more complex than SP-compatible devices. In contrast, SP-compatible HMDs, such as Google Cardboard version 2.0 (Google Inc., Mountain View, California, USA), the LG V10 Smartphone (LG Electronics, Seoul, Republic of Korea), and the Samsung Gear VR (Samsung Electronics Co. Ltd., Suwon, Republic of Korea) can be used with limited space. This technology should be accompanied by a guideline that states that use of an HMD for 10 minutes and an SP for 20 minutes may increase oculomotor symptoms, dizziness, and balance disturbances of users and that the risk of falls and other injuries may increase as the usage times increase. Therefore, after using these devices for longer than 10 minutes, the user should allow enough time to rest before standing and walking.

This study had several limitations. Because the study sample size was small, it is difficult to generalize the findings.

Also, the study participants were healthy young adults, and little is known of the combined effects of age or comorbidities on the effects of the use of smart devices on balance and dizziness. A 5-minute break was provided between device time trials, and a 10-minute break was provided before using the other smart device, but this might not have been sufficient time to reduce eye fatigue. Therefore, future studies should address these limitations and include increased numbers of study participants with a wider age range and differing rest periods between assessments.

Conclusions

The results of this study showed that when compared with baseline, longer use for 20 minutes of smart devices has adverse effects on static balance, oculomotor function, and dizziness than shorter use for 5 minutes in healthy adults. These results have implications for those using smart devices for more than 20 minutes, as this could increase the risk of falls or accidents. Virtual reality head-mounted display (HMD) devices that use smartphones (SPs) are likely to increase with the development of 5G wireless communication technology. The findings from this study, although preliminary in nature, should encourage further studies to support the use of improved user information that limits excessive periods of use of smart devices to prevent falls and accidents associated with the adverse effects on balance and oculomotor function.

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