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Original Article

# Effects of virtual reality programs on balance in functional ankle instability

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**Abstract.** [Purpose] The aim of present study was to identify the impact that recent virtual reality training programs used in a variety of fields have had on the ankle's static and dynamic senses of balance among subjects with functional ankle instability. [Subjects and Methods] This study randomly divided research subjects into two groups, a strengthening exercise group (Group I) and a balance exercise group (Group II), with each group consisting of 10 people. A virtual reality program was performed three times a week for four weeks. Exercises from the Nintendo Wii Fit Plus program were applied to each group for twenty minutes along with ten minutes of warming up and wrap-up exercises. [Results] Group II showed a significant decrease of post-intervention static and dynamic balance overall in the anterior-posterior, and mediolateral directions, compared with the pre-intervention test results. In comparison of post-intervention static and dynamic balance between Group I and Group II, a significant decrease was observed overall. [Conclusion] Virtual reality programs improved the static balance and dynamic balance of subjects with functional ankle instability. Virtual reality programs can be used more safely and efficiently if they are implemented under appropriate monitoring by a physiotherapist.
**Key words:** Virtual reality, Balance, Functional ankle instability

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## INTRODUCTION

In a virtual reality (VR) program, human beings interact with a virtual space; this has the advantage of allowing the movements of an experiment's subjects to be perfectly observed, evaluated, and controlled, which makes it a good candidate for new intervention methods for neurological rehabilitation[1)]. Despite such advantages, however, the use of VR programs has been limited due to restrictive usefulness and the high cost of VR systems[2)]. Although the effects of traditional training programs on enhancement of the sense of balance has been proven, the programs have a disadvantage in that they are somewhat boring and unable to arouse participants' interest[3)]. VR programs are especially useful in the field of physiotherapy because they enable repetitive exercise learning and provide a mechanism for providing proper incentives to patients who need feedback[4)]. Through this direct feedback, VR programs can not only provoke excitement but also enable users to develop a good sense of balance[5)].

Ankle sprains make up a large proportion of injuries in several different areas of activity, especially sports. For example, according to a study that investigated injuries incurred in a total of fifteen sports, including baseball, basketball, hockey, and soccer, for approximately 16 years, ankle sprain accounted for the highest proportion of injuries, representing 15% of the total[6)]. Another study reported that 25% of the injuries relevant to sports involved ankle sprains[7)]. Moreover, 40–70% of those who suffer an ankle sprain have the potential risk of chronic ankle instability if the sprain goes untreated[8)]. College students who actively participate in sports activities therefore should pay special attention to physiotherapy for ankle sprains. Functional ankle instability (FAI) refers to a subjective condition in which the subject has the feeling of his or her ankle giving way as a result of repetitive ankle sprain[9)]. FAI is a major cause of lack of muscle strength and sense of balance. In particular, the sense of balance plays a fundamental role in many activities, and it is a critical factor for successful exercise performance[5, 10)].

Balance refers to the neuromuscular activity process that occurs when individual tries to maintain his/her posture in a smooth and coordinated manner when the body is about to deviate from the gravitational center line of the basal plane. Some of the factors essential for balancing include the visual system, vestibular system, and proprioceptive sense[11)]. Balance can be classified into static balance and dynamic balance. Static balance refers to sense of balance when maintaining a stand-still posture on one or both legs without movement. Dynamic balance refers to the sense of balance when standing without collapse during movement. According to study results concerning the difference in balance between subjects with FAI and a stable ankle, deficiency

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of balance turned out to be related to ankle instability, which can subsequently cause ankle sprain[12, 13]. Thus, balance and coordinated training is frequently used for preventing the reoccurrence of ankle sprain[14, 15].

This study therefore investigated the impact that recent VR training programs used in a variety of fields have had on the ankle's static and dynamic senses of balance among subjects with FAI; it further attempts to complement previous physiotherapeutic intervention methods applied to the ankles.

## SUBJECTS AND METHODS

### *Subjects*

There were 20 participants (16 female and 4 male) aged 21–27 years (mean 23.3 years, SD = 2.4 years). They ranged in height from 155 to 177 cm (mean = 163.1 cm, SD = 7.4 cm) and in weight from 42 to 73 kg (mean = 55 kg, SD = 10.2 kg). Their Cumberland ankle instability tool (CAIT) scores ranged from 7 to 26 (mean = 18.3 score, SD = 5.4 score).

The research subjects were gathered by public invitation for students enrolled in universities located in Gwangju and Suncheon in South Korea. The sample consists of 20 university students in their twenties. This study randomly divided research subjects into two groups, a strengthening exercise group (Group I) and a balance exercise group (Group II), with each group consisting of 10 people. The CAIT was used to measure FAI. The selection criteria were as follows: (1) previous experience of an ankle sprain that made weight support impossible, (2) previous experience of a feeling of the ankle joint giving way as a result of an ankle sprain, (3) a CAIT score lower than 24, (4) capability to perform the intervention or daily activities without an increase in pain, (5) not currently participating in other rehabilitation exercise programs, and (6) no history of ankle surgery. This study proceeded after receiving approval through a preliminary review by the Committee of Clinical Tests at Gwangju Oriental Hospital of Dongshin University (IRB No. DSGOH-019), and all participants provided informed consent.

### *Methods*

A VR program was performed three times a week for four weeks. It required a total of 30 minutes for daily exercise, including 10 minutes for warming up and wrap-up exercises. VR exercises from the Nintendo Wii Fit Plus (Nintendo Inc., Kyoto, Japan) program were applied to each group for twenty minutes; the intensity of the exercise program was properly controlled by the physiotherapist according to the participants' needs. In the event of unforeseen circumstances in which a subject could not participate, he or she performed the exercise program on a different day. The experiment participants were told of the purpose and objective of this study, and they were asked for consent before participation, which was voluntary.

The Nintendo Wii Fit Plus contains programs that aim to enhance muscle strength as well as those that aim to enhance the sense of balance. For muscle strengthening exercise, lunges, single-leg extensions, sideways leg lifts, single leg twists, and rowing squats were performed. For exercise that enhances balancing sense, the soccer heading, ski slalom, tight rope walk, table tilt, and snowboard slalom games were used (Fig. 1).

A Biodex Balance System (Biodex Medical Systems, Shirley, NY, USA) was used as a tool for measuring ankle balance. The Biodex Balance System consists of a display and a platform, and it contains twelve strain gauges that measure the angle of the platform. The platform can freely move in any direction up to 20°, and information for balance overall and for and anterior-posterior and medial-lateral directions can be obtained using the system[3, 16].

Measurements were performed while the subjects supported their weight with their legs straight on the center of the support plate and with eyes open while maintaining 90° flexion on the other side's knee joint (Fig. 2). The weight-bearing foot was entered following the program directions for measurement. The support plate stability can be adjusted between 1 and 8 degrees, with a lower value indicating better balance sense. Measurements were conducted for 30 seconds, followed by a 10 second break; the average of three measurements was calculated and used as the experiment value. After static balance measurement, dynamic balance was measured, and the level of dynamic balance was set at level 2, which indicates low stability[17, 18].

Descriptive statistics (average and standard deviation) were calculated for all the data measured in this study using the PASW statistics 18.0 software. The one-sample Kolmogorov-Smirnov test was performed to determine if each measurement variable had a normal distribution. The paired-samples t-test was performed to determine if there were significant differences before and after VR training

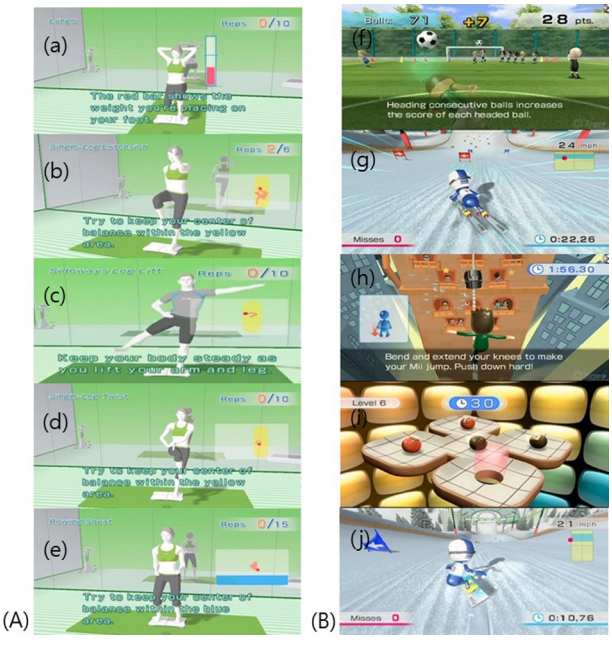


**Fig. 1.** Virtual reality training
(A) Strength training group. (B) Balance training group. (a) Lunge. (b) Single leg extension. (c) Sideways leg lift. (d) Single leg twist. (e) Rowing squat. (f) Soccer heading. (g) Ski slalom. (h) Tight rope walk. (i) Table tilt. (j) Snowboard slalom

programs. Moreover, an independent-samples t-test was performed to examine the difference according to the type of VR training program. In testing the significance of the statistical analysis results, the significance level α was set at 0.05 for all tests.

## RESULTS

Group I showed a significant decrease in post-intervention static balance in the medial-lateral direction compared with the pre-intervention test results ($p<0.05$) (Table 1), with no significant difference overall or in the anterior-posterior direction. Group II showed a significant decrease in post-intervention static balance overall and in the anterior-posterior and medial-lateral directions compared with the pre-intervention test results ($p<0.05$) (Table 1). In comparison of the post-intervention static balance between Group I and Group II, a significant decrease was observed overall direction ($p<0.05$) (Table 1), with no significant difference in the anterior-posterior and medial-lateral directions.

Group I showed a significant decrease in post-intervention dynamic balance overall compared with the pre-intervention test results ($p<0.05$) (Table 1), while no significant difference was observed in the anterior-posterior and medial-lateral directions. Group II showed a significant decrease in post-intervention dynamic balance overall and in the anterior-posterior and medial-lateral directions compared with the pre-intervention test results ($p<0.05$) (Table 1). In comparison of post-intervention dynamic balance between Group I and Group II, a significant decrease was observed overall and in the anterior-posterior direction ($p<0.05$) (Table 1), with no significant difference in the medial-lateral direction.

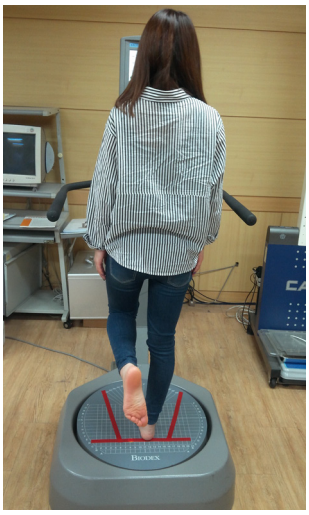

**Fig. 2.** Measure of ankle balance

## DISCUSSION

Group I showed a significant decrease in post-intervention static balance in the medial-lateral direction compared with the pre-intervention test results while no significant difference was observed overall or in the anterior-posterior direction. This can be attributed to the fact that among the five muscle strength exercises in this study, the sideways leg lift, the single leg extension, and the single-leg twist exercise were designed with the purpose of enhancing muscle strength in the medial-lateral direction while maintaining balance. Pessoa et al.[19] pointed out that even though the muscle strength exercises of Nintendo Wii Fit Plus can be used for physiotherapeutic intervention, they were originally designed for entertainment, rather than for professional intervention, which supports the results of this study.

Group II showed a significant decrease in post-intervention static balance overall and in the anterior-posterior and medial-lateral directions compared with the pre-intervention test results. Considering this, balance training using VR is effective in enhancing static balance in all directions among subjects with FAI. These results can be attributed to the fact that the ski slalom and snowboard slalom games used in this study not only spur anterior-posterior directional movement but also enable medial-lateral directional movement. Moreover, the tight rope walk game stimulates movement in the medial-lateral direction, and the table tilt game involves movement in all directions (overall)[20]. Moreover, in the comparison of post-intervention static balance between Group I and Group II, a significant decrease was observed overall, which implies that balance training is more effective than strength training.

Group I showed a significant decrease in post-intervention dynamic balance overall compared with the pre-intervention test results, with no significant difference in the anterior-

**Table 1.** Within-group and between-group comparisons of balance

| | Direction | Group I | | Group II | |
|---|---|---|---|---|---|
| | | Pre | Post | Pre | Post |
| Static balance (°) | Overall | 1.2±0.7 | 1.1±0.4 | 1.2±0.3 | 0.7±0.2*† |
| | Anterior-posterior | 0.8±0.6 | 0.6±0.2 | 0.7±0.3 | 0.5±0.1* |
| | Medial-lateral | 0.8±0.3 | 0.5±0.2* | 0.6±0.2 | 0.4±0.2* |
| Dynamic balance (°) | Overall | 3.4±1.3 | 2.5±0.8* | 2.8±0.8 | 1.5±0.7*† |
| | Anterior-posterior | 2.4±1.5 | 1.9±0.7 | 1.8±0.8 | 1.0±0.5*† |
| | Medial-lateral | 1.3±0.7 | 1.2±0.7 | 1.2±0.6 | 0.8±0.3* |

All values are shown as mean±SD. *Within-group comparison ($p<0.05$). †Between-group comparison ($p<0.05$). Group I: strengthening training group; Group II: balance training group; pre: before intervention; post: after intervention

posterior and medial-lateral direction. This result can be interpreted as indicating that an increase in ankle muscle strength was linked to pain reduction, which subsequently affected ankle balance. Son et al.[21] reported a correlation between ankle strengthening exercise and balance, which is consistent with this study's results.

Group II showed a significant decrease in post-intervention dynamic balance overall and in the anterior-posterior and medial-lateral directions compared with the pre-intervention test results. These results are consistent with the static balance results in this study, which can be attributed to the fact that more interesting and exciting factors were added compared with traditional physiotherapy exercise programs[22]. Moreover, it is believed that the application of VR training programs enables participants to be immersed in repetitive practice with controlled movement[23]. A VR program using Nintendo Wii Fit Plus can thus be thought of as a useful tool for improving the balance of those with FAI. In comparison of post-intervention dynamic balance between Group I and Group II, there was a significant decrease overall and in the anterior-posterior direction but no significant difference in the medial-lateral direction. This implies that balance exercises were more effective on dynamic balance than strengthening exercises in this study. However, the balance training did not show as many effects as the strength training in the medial-lateral direction. This can be attributed to the limited time of four weeks for the intervention.

The body receives ground reaction forces (GRFs) in every type of gait; vertical GRFs, in particular, which have two peaks for each step, have a magnitude as large as 120% of a person's weight. These GRFs thus have a considerable impact on the foot, and they can also incur plantar flexion, as the line of action is located in the rear of the ankle. Considering these points, maintaining a sense of balance overall is important in preventing ankle sprain. In the gait cycle, GRFs are located toward the posterior direction during heel strike, and toward the anterior direction during the late stance and early swing phases. Anterior-posterior GRFs have a magnitude of approximately 20% of one's weight, and they can affect the body's center of gravity and walking speed. Without proper balance in the anterior-posterior direction, people can slip forward or slip backward or can be unable to move the body forward. The magnitude of GRFs in the medial-lateral direction is as small as approximately 5% of body weight, and hence it is not easily felt during normal gait. It can be felt, however, in cases of a very long gait or when jumping sideways. Moreover, in cases of walking on snow-covered roads or on ice, people minimize medial-lateral GRFs by minimizing their step width[24]. Considering this, balance in the medial-lateral direction is apparently very important for preventing ankle sprain in situations such as rough sports activities or when walking on slippery ground, e.g., over snow or on uneven ground.

In this study, the application of VR programs showed significant effects on static and dynamic balance among subjects with FAI. There have been some reports of damage or injury in shoulder and knee joints, however, as well as fractures of cervical vertebrae in cases of VR application. It is important to implement exercise programs under appropriate monitoring of a physiotherapist in order to avoid such potential risks[25–28]. As for the limitations of this study, the intervention period was rather short (four weeks), and the subjects included were all in their twenties. We expect that the physiotherapeutic area can be further expanded if the effects of VR programs are investigated not only in terms of ankle balance but also in terms of more diverse areas such as strength and proprioceptivity in future studies.

To sum up, virtual reality programs improved the static balance and dynamic balance of subjects with functional ankle instability. Moreover, we believe that virtual reality programs can be used more safely and efficiently, as long as they are implemented under appropriate monitoring by a physiotherapist.

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