# The effect of lower extremity exercise on gait, balance and proprioceptive sensation with or without AR

**Jong-min Kim[1], Hong-ju Moon[2], Bo-hwan Shin[3], Dong-Yeop Lee[4], Ji-Heon Hong[5], Jin-Seop Kim[6], Jae-Ho Yu[*7]**

[1,2,3,4,5,6,*7] *Department of physical therapy, Sunmoon University, Asan-SI, Chungnam, Korea*

skdiwhdals@naver.com[1], 11honda@naver.com[2], tlsqhghks200@naver.com[3], kan717@hanmail.net[4], hgh1020@sunmoon.ac.kr[5], skylove3373@hanmail.net[6], naresa@sunmoon.ac.kr[*7]

*Corresponding author[*]: mobile Phone: +82-010-8701-0597*

**Abstract**

**Background/Objectives:** The purpose of this study is to compare the effect of lower extremity muscle strength exercise on gait, balance and proprioception depending on presence and absence of the augmented reality.

**Methods/Statistical analysis:** After the preliminary investigation, 52 healthy male and female university students agreed to participate in this study and were physically disease free. The subjects were divided into randomized Augmented Reality Exercise group (AREG) and Non-Augmented Reality Exercise group (NAREG). We did not provide the augmented reality to the control group. The subjects have conducted the lower extremity strength exercise three times a week for a total of four weeks. The results were measured before and after 4 weeks. For data analysis, we used matching sample t-test for comparison between groups and the independent-sample t-test for comparison of changes in groups.

**Findings:** There were no significant differences between the groups in knee angle while walking, but there were no significant differences between the groups in balance and proprioception. Also In the experimental group(AREG), the balance and proprioception were activated, showing a statistically significant difference. In the control group (NAREG), the balance and angle of knee flexion during walking showed a statistically significant difference.

**Improvements/Applications:** As a result of this study, the group with AR exercise showed more changes in proprioception and sagittal plane of legs than the group without AR when they both exercise for strengthening lower body.

***Keywords*: Augmented Reality, Knee angle, Balance, Proprioception, Lower extremity, Center of pressure

## 1. Introduction

The virtual and augmented reality have been used for rehabilitation purpose, which has been attracted by scientific journals. Numerous studies have demonstrated that Virtual Reality(VR) and Augmented Reality(AR) are the future of rehabilitation for balance and gait training. Therefore, this study aims the effectiveness of using augmented reality for gait training, balance and proprioception[1].

AR, which is a sort of VR, is a computer technology providing users with additional information about the observed situations. Therefore, patients can easily understand and act in the real environment[2]. AR can make interactions with virtual objects on the screen when the user executes augmented reality games with hands and feet in front of the camera[3].

Balance is essential for the mobility and daily activities. Lower limb stability is the ability to maintain the center of gravity and balance the body within the base of support[4]. Lower limb strength has been considered an important component of exercise programs for knee disease. The weakness of quadriceps has been frequently found in people with knee disease and related to the cause of the disease which affects severity pain and deterioration of physical function such as balance ability[5]. Quadriceps can help patients to improve balance.

People with knee disease have impaired sense of proprioception in the knee joint[6]. According to Susan Hillier, the concept of self-awareness means that the torso and limb movements feel body sensation and position. Therefore, it is reported that the proprioception which is interchangeably used with self-awareness is the sense of joint position, space position, motion and power[7]. And it is important to improve lower leg flexion/knee angles in gait for the treatment of numerous pathologies, which is based on visual assessment and oral guidance. If patients walk with a lower/bend angle of the lower limb by modifying them, kinematics on sagittal plane of lower limb can be changed[5].

The AR is a factor in visual transformation which is more natural than VR and does not require additional devices for interaction. We also learned that there is sufficient space to study and find the effects of the AR in rehabilitation and clinical settings[8]. In addition, it can place the foot directly in the augmented object reflected on the gait surface, therefore, AR also has been used in the training of gait adaptation in stroke patients, as a result, it shortened time to complete timed up to go and improved scores of Berg balance scale. And the VR and AR systems have demonstrated that it can improve motor control of stroke patients after proprioceptive training[2,9]. In this way, training of virtual environments has been introduced in rehabilitation in recent years. However, no studies have demonstrated about the effect and relationship between AR and proprioception. Therefore, we will demonstrate the effects through this study. Patients get opportunities to train their gait and balance skills by realizing their limitations in a challenging and safe environment[10]. It is proposed that AR can be used in fields related to rehabilitation and exercise function of experimenters[11].

The AR system is often regarded as a fun training tool that can help motivate patients to continue rehabilitation. However, the main limitation of this system is the difference in distance perception. Compared to the actual situation, it is underestimated in the AR[12]. And the AR has been still considered a new technology, but there are limitations to the implementation. Since it has not been examined to a large extent, data on the AR and the identification of user requirements for the AR applications have been limited. However, further studies should be conducted because the AR has the potential[8, 13].

AR has been closely related to our lives. Various posture exercises and many types of exercises have been highlighted through AR. However, there has been no studies on the effect about posture with AR and posture without AR on gait. Therefore, this study will demonstrate the effect of exercise with AR by focusing on the change of short-term gait pattern, which will be the basis for future studies and treatments. Therefore, this study has been conducted to find the change of gait, balance, and proprioception according to posture and leg strengthening exercise for a short period.

## 2. Materials and Methods

This study examined the effects of visual and auditory stimulation of the AR system on the lower strength exercise depending on the presence or absence of AR through 'squat exercise, side to side' exercise and compared the knee angle, balance and proprioception.

### 2.1. *Subjects*

This study recruited 52 adults from S university located in A city who had not been treated or under surgery for ankle, knee, hip joint and musculoskeletal disorders in the last 6 months. The subjects have come to the hospital for the pain in the lower extremities (ankle, knee, hip), or have no pain or discomfort about the movement of the lower extremities, have not had surgical operations on the lower extremities have been excluded. In addition, those who had no inflammatory or degenerative joints connective tissue disease, or no previous or current skin diseases, scars, burns, skin sensitization and neurological deficiencies have been excluded. As a total, 52 subjects have been targeted for the study. All subjects have been fully listened to the explanation of the study and signed on a consent form to participate in the study so as not to violate the research ethics. This study has been conducted with approval of human subject research from Sun Moon University Institutional Ethics Committee (Approval No. SM-201904-032-1).

The subjects who have had a disease in the lower extremities (ankle, knee, hip) and pain during the experiment are excluded and took rest in the middle of the experiment. And those with visual impairments have been excluded from this study. Before the intervention, all the subjects have been listened about the exercise. The general characteristics of the participants are shown in [Table 1]. The overall research process is shown in [figure 1].

**Table 1: Subject characteristics** **(n=52)**

| | AREG(n=26) | NAREG(n=26) |
|---|---|---|
| Age(year) | 22.7 ± 0.70 | 21.7 ± 0.70 |
| Height(cm) | 168.9 ± 3.90 | 167.9 ± 0.43 |
| Weight(kg) | 64.9 ± 5.40 | 63.85 ± 5.03 |

Values indicate mean ± stand deviation, AREG: Augmented reality exercise group, NAREG: Non augmented reality exercise group.

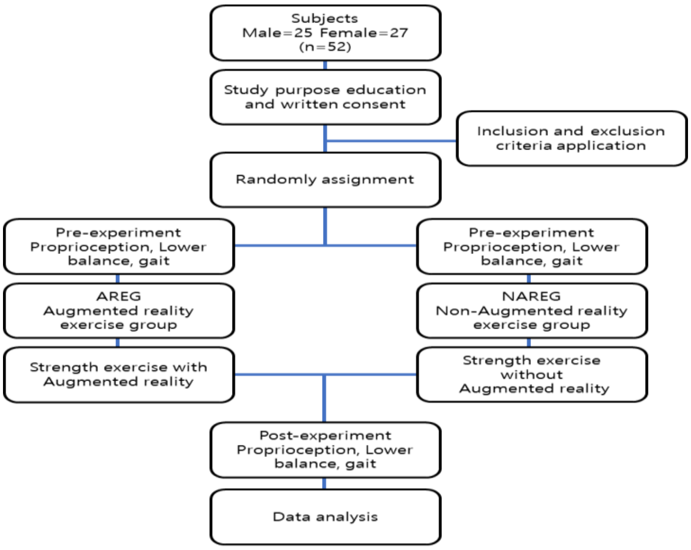



**Figure 1. Experiment protocol flow chart**

### 2.2. *Intervention method and measurement methods*

#### *2.2.1. Intervention method*

The subjects have been randomly divided into the Augmented Reality Exercise Group(AREG) and the Non-Augmented Reality Exercise Group(NAREG). The above groups performed four weeks of exercise, and the reinforcement training program was conducted three times a week and three sets of two exercises each day[14], [figure 1]. The participants' reinforcement training and AR training programs are shown in [figure 2, figure 3, figure 4, figure 5].

(1) Reinforcement Training Program[14]

① side-to-side steps

This exercise activates muscles attached to both sides of the thigh, which are known as adductor muscle and abductor muscle. Wrap the theraband in your hand and step on the band with both soles. Move your left foot to the side and hold it for 3 seconds. Cross your arms from side to side, make the band "X" and bring your right foot with the resistance increased. Take 15 steps of right and left alternately and breathe slowly from start to finish.

② squat exercise

Make your hands horizontally and flex your knees as if you are sitting on a chair. Hold it for 3 seconds and keep your knees inside your toes. After that, repeat six sets of five times. Do a total of 30 sessions, including 1 minute break. Breathe slowly from start to finish.

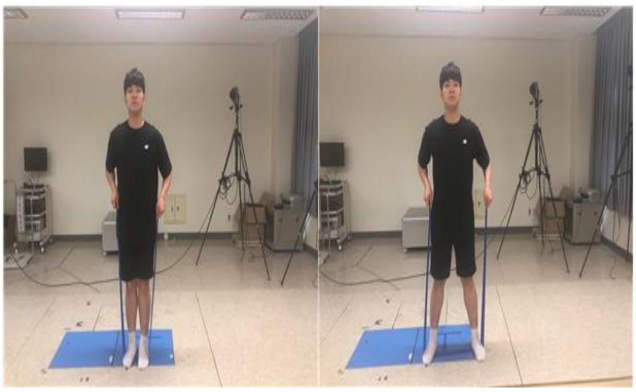


**Figure 2. Side to side steps**

**Figure 3. Squat exercise**

(2) AR training program

① Stand and walk sideways with theraband

Keep your back straight and step the theraband with both soles. Follow the instructions of the AR program and wa lk on both sides as you stretch the theraband. Make sure that your feet are facing forward. Go back to the starting position and repeat the 15 steps left and right in the same way. Keep your back straight and in an upright position, step on the theraband with both soles. Follow the instructions of the AR program and walk side by side, while stretching the theraband. Make sure that your feet are facing forward. Go back to the starting position and repeat 15 steps left and right in the same way.

**Figure 4. Stand and walk sideways with theraband**

② Stand and knee flexion

Keep your back straight and in a right position, then abduct your legs to shoulder width. Flex your knees with your arms crossed following the instruction of the AR program. After holding for 5 seconds, return to the starting position, do 6 sets of 5 times, and apply 30 minutes of repetitive exercise with 1 minute of break time.

**Figure 5. Standing and knee flexion**

***2.2.2 Measurement tools and methods***

(1) Measurement of range of motion

Observe the bending, angle and motion of the knee joint through the 3D motion analyzer system. Marker attachment points are shown in [Table 2].

**Table 2: The attached location of Landmarker**

| lower limb | Location |
|---|---|
| Pelvis | Anterior superior iliac spine, Posterior superior iliac spine |
| Femur | Right, Left greater trochanter |
| | Lateral thigh shaft |
| | Lateral, medial epicondyle |
| Tibia | Lateral, medial condyle |
| | Lateral shank shaft |
| | Lateral, medial malleolus |

(2) Balance measurement

Before applying it on the experiment, a series of motions and calibrations will be performed to determine the value from the relationship between the meter, scale, and standard values of the measurement system. Two force plates have been used to determine the balance of the COG. Analyze the data using the average value of the X and Y axes.

(3) Measurement of proprioception

Use voluntary contraction and relaxation and the AR, then keep your knee at an angle of 30°, 60°, and 90° with the eyes open. Then close your eyes and bend and stretch them at the same angle.

***2.2.3 Data analysis***

Data analysis has been carried out by SPSS ver. Using 22.0, all the measurements and general characteristics of the subjects have been proposed as average and standard deviation using descriptive statistics. Pre-post variables in group exercise program used Paired t-test, and the test of homogeneity for intergroup measurement variables used independent t-test. Independent t-test was used to verify the effects of each exercise type program on a group basis. All statistical significance levels were set below 0.05.

## 3. Results

We measured the changes in gait pattern, balance and proprioception between the group with strength of lower extremity and the group without AR, and analyzed its significant difference with matching sample t-test and independent t-test. AREG and NAREG showed no significant difference in the gait pattern ($p$>.05) however, there was a significant difference in balance and proprioceptive ($p$ <.05).

Comparing to the difference in gait pattern variation of the two groups, the flexion angle of the gait pattern in the experimental group (AREG) did not show a significant increase in the pre-intervention value (64.75 ± 7.14), neither in the post-intervention value (68.90 ± 6.52) ($p$>.05). And there was no significant increase in extension angle in the pre-intervention (3.76 ± 5.47) and the post-intervention (3.70 ± 5.67) ($p$>.05). In the control group (NAREG), the flexion angle of the gait pattern has been increased significantly in the pre-intervention (68.71 ± 9.58) and the post-intervention (70.08 ± 8.22) ($p$<.05). And there was no significant increase in the post-intervention value (3.75 ± 6.56) and the post-intervention (4.94 ± 7.92) ($p$>.05). Comparing between groups, AREG showed no significant difference in flexion and extension and NAREG showed no significant difference in extension angle of gait ($p$>.05) However, there was significant difference in flexion angle of gait ($p$<.05)[Table 3].

As a comparison of the balance measurements within the group, it showed a significant increase in the pre-intervention value (-.27 ± 0.001) and the post-intervention value (-.29 ± 0.0006) of X-axis(Mediolateral) and the pre-intervention value (.35 ± 0.002) and the post-intervention value(.33 ± 0.002 of Y-axis (Anteroposterior)($p$<.05). In addition, we observed a significant increase between the pre-intervention value (-.29 ± 0.001) and post-intervention value (-.28 ± 0.03) of X-axis of the control group (NAREG) ($p$<.05). And a significant increase has been found in the pre-intervention value (.34 ± 0.003) and the post-intervention value of Y-axis (.32 ± 0.001) ($p$ <.05). When comparing between groups, there has been a significant difference in the balance ability between the experimental group (AREG) and the control group (NAREG), and the experimental group (AREG) showed a little shaking. The results measured in the study [Table 4] and [Figure 6] reflect the fields of physical function and activity of the International Classification of Functioning(ICF) and consist of laboratory measurements and clinical trials. Balance assessments included Center of Pressure(CoP) measurements(CoP shake and speed, etc.) during static conditions[18].

In proprioception, AREG showed a significant difference in the pre-intervention value (49.85 ± 3.48) and the post-intervention value (44.26 ± 3.78) at 30 degree(*p*<.05). Also significant differences have been found in the pre-intervention (79.75 ± 4.78) and the post-intervention (73.35 ± 5.40) at 60 degree(*p*<.05). At the 90˚ degree, the significant difference has been found in the pre-intervention value (111.74 ± 9.11) and the post-intervention value (110.73 ± 6.07) (*p*<.05). On the other hand, no significant difference has been found between in the pre-intervention value (44.20 ± 4.56) and the post-intervention value (44.73 ± 5.90) at 30˚ in the control group (NAREG) (*p*>.05). And there was no significant difference between the measured values (74.43 ± 6.79) and the post-intervention measured values (73.27 ± 9.15) (*p*>.05). In addition, no significant difference has been found in the pre-intervention value (105.45 ± 10.37) and the post-intervention value (104.83 ± 9.69) at 90˚ degree (*p*>.05). When compared the groups, the experimental group (AREG) corrected the angles with significant differences at all angles (*p*<.05), and the control group (NAREG) did not show any significant differences at all angles (*p*>.05). [Table 5], [Figure 7, Figure 8]

**Table 3: Comparison of the knee flexion angle between AR and non AR lower limb exercise according to lower Limb exercise. (n=52)**

| | | | AREG | NAREG | t |
|---|---|---|---|---|---|
| KFA | Flexion | Before | 64.75±7.14 | 68.71±9.58 | -1.875 |
| | | After | 68.90±6.52 | 70.08±8.22 | |
| | | t | -4.991 | -1.123* | |
| | Extension | Before | 3.76±5.47 | 4.94±7.92 | -1.306 |
| | | After | 3.70±5.67 | 3.75±6.56 | |
| | | t | .104 | 1.772 | |

KFA: Knee flexion angle, AREG: Augmented reality exercise group, NAREG: Non augmented reality exercise group

**Table 4: Comparison of balance according to axis between AR and non AR lower limb exercise. (n=52)**

| | Axis | | AREG | NAREG | t |
|---|---|---|---|---|---|
| Balance | X | Before | -.27±.001 | -.29±.001 | 2.152* |
| | | After | -.29±.0006 | -.28±.03 | |
| | | t | 87.379* | -2.997* | |
| | Y | Before | .35±.002 | .34±.003 | 4.481* |
| | | After | .33±.002 | .32±.001 | |
| | | t | 31.302* | 35.772* | |

AREG: Augmented reality exercise group, NAREG: Non augmented reality exercise group

**Table 5: Comparison of proprioception between AR and non AR according to lower limb exercise. (n=52)**

| | | Angle | | AREG | NAREG | t |
|---|---|---|---|---|---|---|
| Proprioception | KFA | 30 | Before | 49.85±3.48 | 44.20±4.56 | -6.790* |
| | | | After | 44.26±3.78 | 44.73±5.90 | |
| | | | t | 12.603* | -.696 | |
| | | 60 | Before | 79.75±4.78 | 74.43±6.79 | -3.396* |
| | | | After | 73.35±5.40 | 73.27±9.15 | |
| | | | t | 7.200* | 1.196 | |
| | | 90 | Before | 117.74±9.11 | 105.45±10.37 | -3.910* |
| | | | After | 110.73±6.07 | 104.83±9.69 | |
| | | | t | 5.301* | .655 | |

KFA: Knee flexion angle, AREG: Augmented reality exercise group, NAREG: Non augmented reality exercise group

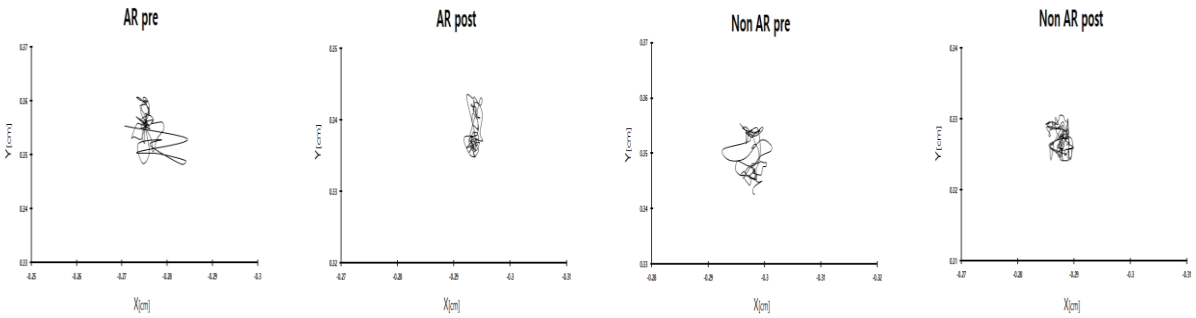
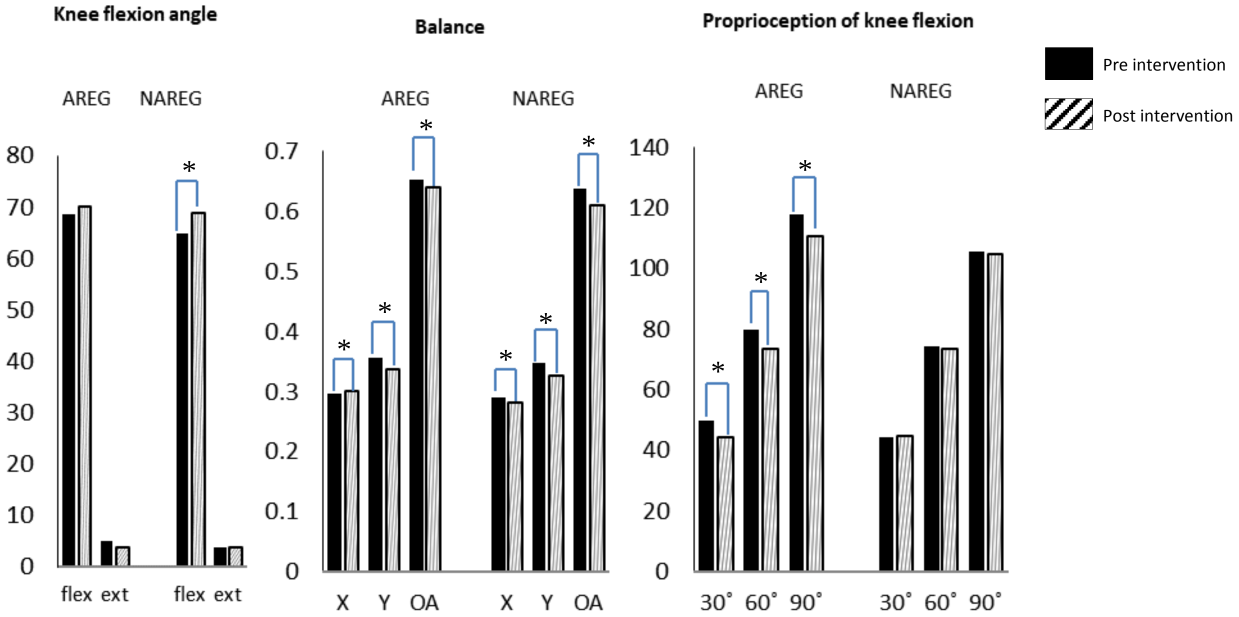
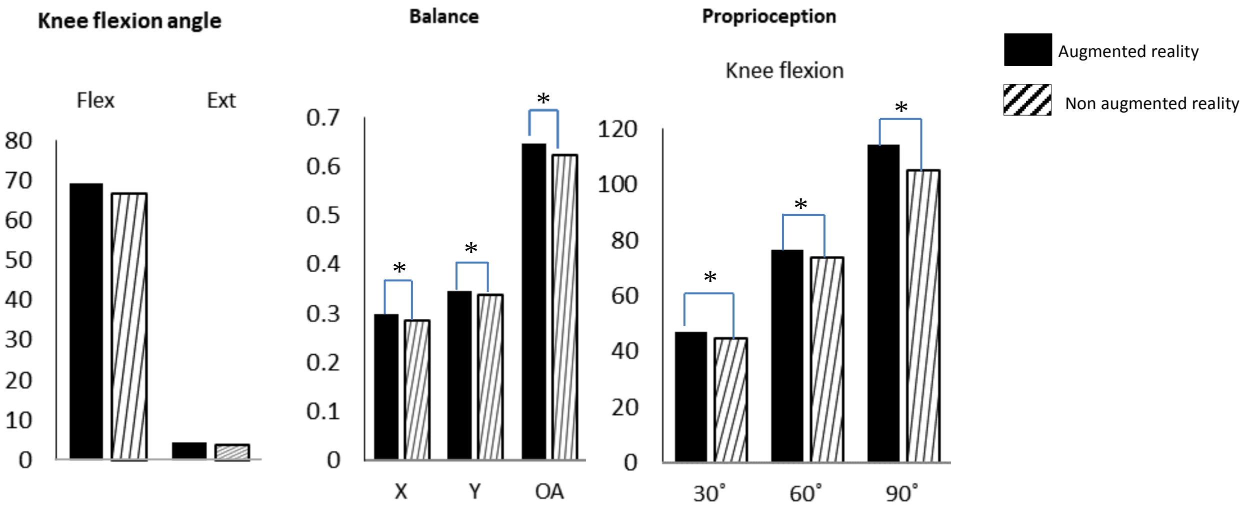



**Figure 6. AR and Non AR CoP pre-post comparison**




AREG: Augmented reality exercise group, NAREG: Non augmented reality ex ercise group, flex: flexion, ext: extension, OA: Over all

**Figure 7. Comparison within groups**




Flex: Flexion, Ext: Extension, OA: Over all

**Figure 8. Comparison between groups**

## 4. Discussion

The main purpose of this study is to investigate the changes in gait, balance, and proprioception by conducting lower extremity strength exercises with or without AR system. It indicated that it is intuitive for the participants to perform any action when the participant's perception is reflected into the AR environment. In this situation, there was no need to recreate unique perceptions and visions. However, the intensity and frequency could be modified, therefore, no special learning was needed to adapt to the AR quickly and easily[16]. According to our hypothesis, the experimental group (AREG) was expected to be more effective in gait pattern, balance, and proprioceptive improvement compared to the control group (NAREG). But as a result of the experiment, there was no significant difference in gait pattern, but a significant difference in improving balance and proprioceptive.

As a result of the before and after comparison in the group of the experimental group (AREG), it was difficult to find a significant change in the gait pattern. According to Myer et al., Studies have shown that squat exercise on plyometric and unstable ground is effective in increasing knee flexion angle, improving neuromuscular control and stimulating proprioception during initial contact[17]. However, in this study, it was difficult to find the change of knee angle because exercise was performed slowly over time for safety. On the other hand, there was a significant difference in balance ability. We found a research that showed the AR-based fall prevention programs have significantly improved balance[15,18]. AREG group showed improvement in post-intervention balance and mobility scores, which were statistically significant improvements in Berg balance scale, timed up to go, Fugl-Meyer Assessment-Lower Extremity and Fugl-Meyer Assessment-Balance scores[19]. The proprioception has also increased which is known that the AR involves not only immersing ability for a completely artificial environment, but also a screen to project virtual images into the physical world and provide visual, auditory, and kinematic feedback[20]. Based on the conclusions of these previous studies, this study focused on the visual and vestibular system through AR in order to stimulate visual acceptability by receiving visual feedback. As a result, body sense and position sense on the angle of knee were well assessed more accurately, which led to a significant difference before and after exercise.

As a result of the comparison between before and after group in the control group (NAREG), the knee flexion angle only showed significant difference in the initial contact while gait. The exercise has done faster than AREG due to the lack of experimental control compared to AREG, such as mechanical time and intensity control. For this reason, the knee flexion angle has been increased during initial contact due to the inclusion of high intensity-high speed movement such as plyometric compared to AREG[17]. In addition, there was a significant improvement in balance ability as a result of comparing the balance ability before and after. According to a previous study, the balance training including squat exercise had the effect of preventing the fall of the elderly, balance ability, muscle hypertrophy, and strengthening of muscle strength[21,22]. However, the proprioception showed no significant difference. DiLuca et al. has demonstrated that visual feedback causes excessive movement due to a discrepancy between the amount of visually perceived displacement and the amount of body sensationally perceived displacement[23]. For this reason, participants could not accurately perceive the angle of the body without visual feedback, therefore we could not make a significant difference before and after exercise.

The comparison between the groups of the experimental group (AREG) and the control group (NAREG) showed no significant gait pattern, and the balance and proprioception showed significant results. Based on the findings that training and gait with modifying the flexion/extension angle of the lower limb may change the lower limb sagittal kinematics with visual assessment and oral guidance provided by the AR system, we expected a significant change on the lower muscle[5]. However, the experimental group (AREG) lacked the characteristics of high intensity-high speed motion such as plyometric, and it was difficult to find the change of knee angle while gait because we did not consider environmental factors such as unstable ground. On the contrary, in the control group (NAREG), the knee flexion angle was improved while gait because the exercise was performed at free speed and intensity without the experimenter's control. Compared to the balance of the two groups, we confirmed that the AREG group was more balanced than the NAREG group. Human balance is generally assessed through CoP (displacement center) displacements measured by force plates in order to produce a 2D time series representing CoP trajectories in the anteroposterior and mediolateral directions[18]. Recent AR studies showed that instructions pointing to the external focus may call attention to a given environment and affect movement ("squats to the box") and lead to better motor learning. The AR in such an external focus leads the patient's attention to the virtual world. Therefore, one of researches has shown that it may promote the concentration of external focus and improve the outcome of treatment[5]. In the balance measure, the external focus group showed better learning compared to the groups of Internal focus or non-focus[24]. Similarly, in this study, the lower extremity strength exercise for balance has been conducted by receiving external focus through AR, therefore the CoP movement curve was measured before and after the intervention. As a result, it showed smaller movement width when compared with the group without AR. Among the factors necessary to maintain balance, ownership of the lower limbs takes 58%, visual information takes 22%, and the vestibular system takes 20%. In this way, self-acceptance is very important, therefore it requires training focusing on the visual and vestibular system[25]. Antonio et al. proposed that intrinsic receptive training programs are associated with significant improvements in static posture and functional stability of the lower extremities and reduce the risk of falls. 30-minute sessions (two days a week) with a 12-week training program had a positive effect on external and post-mortem stability[26]. In another study, Pincivero et al. measured self-acceptance using joint position detection tests and applied the same method to subjects at various knee joint angles, such as 15°, 30°, 45°, and 60°. They reported that self-acceptance sensations may affect the ability to perceive angles[27]. As a result of many studies related to proprioception, visual feedback with the AR affects not only balance but also knee joint angle. This study was a short-term experiment compared to previous studies, but showed a significant improvement in unique recognition.

The limitations of this study can be divided into three categories. First, previous studies showed that the knee joint motion values are often misaligned due to the wrong axis where the rotation occurs and axial misalignment may have a substantial effect on the shape and size of knee joint moments[28]. As a result of these previous researches, we could not find the significant change of knee angle while gait between the exercise group using AR and the group without AR. Second, in the case of plyometric exercise, the experiment has been conducted for more than 8 weeks, but in this study, we had difficulties to find the change of knee angle while gait due to the relatively short study period of 4 weeks. Thus, further research should cover these limitations. Third, this study is conducted on healthy young adults and is difficult to apply to people of all ages. In addition, this study has been conducted on people who do not have a specific disease, therefore the pathological improvement could not be demonstrated.

## 5. Conclusion

In conclusion, this study applied the AR method to find gait patterns, balance, and proprioception. The subjects were quickly adapted to the AR system and showed that they could correct the gait pattern and the unique acceptability accurately. The group with AR showed a change in proprioception and leg sagittal kinematics compared to the group without AR, which supports the method for retraining gait. In order to design and evaluate specific rehabilitation protocols, further research should be conducted focused on specific pathologies.

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## 6. References

1. Selma P, Floris M, Frans S. Virtual and augmented reality based balance and gait training. Motek: white paper; 2017. p. 2-8.
2. Lee CH, Kim YM, Lee BH. Augmented reality-based postural control training improves gait function in patients with stroke: randomised controlled trial. Hong kong physiotherapy journal. 2014 Dec;32(2):51-57. DOI: 10.1016/j.hkpj.2014.04.002
3. Zhihan L, Alaa H, Shengzhong F, Shafiq R, Haibo L. Touch-less interactive augmented reality game on vision-based wearable device. Personal and ubiquitous computing. 2015 Jan;19(3-4):551-67. DOI: 10.1007/s00779-015-0844-1
4. Amico AP, Nisi M, Covelli I, Polito AM, Damiani S, Ianieri G, et al. Efficacy of proprioceptive training with prokin system in balance disorders from multiple sclerosis. J mult scler. 2014 Jul;1:110. DOI:10.4172/2376-0389.1000110.
5. Bennour S, Ulrich B, Legrand T, Jolles BM, Favre J. A gait retraining system using augmented-reality to modify footprint parameters: effects on lower-limb sagittal-plane kinematics. Journal of biomechanics. 2018 Jan;66(3):26-35. DOI: 10.1016/j.jbiomech.2017.10.030.
6. Nafiseh K, Noor AAO, Abdul HM, Mahboobeh M, Wan ABWA. Balance and risk of fall in individuals with bilateral mild and moderate knee osteoarthritis. Plos one. 2014 Mar;9(3): e92270. DOI: 10.1371/journal.pone.0092270.
7. Hillier S, Immink M, Thewlis D. Assessing proprioception: A systematic review of possibilities. Neurorehabil neural repair. 2015 Nov;29(10):933-49. DOI: 10.1177/1545968315573055
8. John S. Cognitive-motor rehabilitation through low-cost mobile augmented reality technology. Diss. 2017 Sep. p. 1-38.
9. Cho S, Ku J, Cho YK, Kim IY, Kang YJ, Jang DP. et al. Development of virtual reality proprioceptive rehabilitation system for stroke patients. Computer methods and programs in biomedicine. 2014 Jan;113(1):258-65. DOI: 10.1016/j.cmpb.2013.09.006
10. Van DRB, De Jong LA, Groen BE, Vos-van der Hulst M, Geurts ACH, Keijsers NLW. et al. Gait stability training in a virtual environment improves gait and dynamic balance capacity in incomplete spinal cord injury patients. Front neurol. 2018 Nov;20(9):963. DOI:10.3389/fneur.2018.00963.
11. Brown IE, Stephen HS. System and method for integrating gaze tracking with virtual reality or augmented reality. U.S. Patent and trademark office. 2014 May; Patent No. 8,730,266.
12. Morel M, Bideau B, Lardy J, Kulpa R. Advantages and limitations of virtual reality for balance assessment

and rehabilitation. Neurophysiologie clinique/clinical neurophysilogy. 2015 Nov;45(4-5):315-26. DOI: 10.1016/j.neucli.2015.09.007.

13. Han D, Jung T, Gibson A. Dublin AR: Implementing augmented reality in tourism. information and communication technologies in tourism. Springer. 2014 Jan. p.511-23. DOI: 10.1007/978-3-319-03973-2_37.

14. Sharma V, Kaur J. Effect of core strengthening with pelvic proprioceptive neuromuscular facilitation on trunk, balance, gait, and function in chronic stroke. Journal of exercise rehabilitation. 2017 Apr;13(2):200-5. DOI: 10.12965/jer.1734892.446.

15. Luis M, Rossana C, Leandro P. Selection of entropy-measure parameters for force plate-based human balance evaluation. In world congress on medical physics and biomedical engineering. Springer 2018 May;68(2):315-19. DOI: 10.1007/978-981-10-9038-7_59

16. Haarman JAM, Choi JT, Buurke JH, Rietman JS, Reenalda J. Performance of a visuomotor walking task in an augmented reality training setting. Human movement science. 2017 Dec;56(B):11-19. DOI: 10.1016/j.humov.2017.10.005.

17. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. The american journal of sports medicine. 2016 Mar;34(3):445-55. DOI: 10.1177/0363546505281241

18. Cano Porras D, Sharon H, Inzelberg R, Ziv-Ner Y, Zeilig G, Plotnik M. Advanced virtual reality-based rehabilitation of balance and gait in clinical practice. Therapeutic advances in chronic disease. 2019 Aug;10:1-16. DOI: 10.1177/2040622319868379

19. Ku J, Kim YJ, Cho S, Lim T, Lee HS, Kang YJ. et al. Three-dimensional augmented reality system for balance and mobility rehabilitation in the elderly: a randomized controlled trial. Cyberpsychology, behavior, and social networking. 2019 Feb;22(2):132-41. DOI: 10.1089/cyber.2018.0261.

20. Mouraux D, Brassinne E, Sobczak S, Nonclercq A, Warzée N, Sizer PS. et al. 3D augmented reality mirror visual feedback therapy applied to the treatment of persistent, unilateral upper extremity neuropathic pain: a preliminary study. Journal of manual & manipulative therapy, 2017 Jul;25(3):137-43. DOI: 10.1080/10669817.2016.1176726

21. Eiji F, Nobuo T, Daisuke K, Yoshiji K. Effects of body-weight squat training on muscular size, strength and balance ability in physically frail older adults. Sport and health science. 2016 May;14:21-30. DOI: 10.5432/ijshs.201504

22. Adriano PS, Núbia CA, Rosalina TG, Camila DN, Vanessa AM, Aline SM. et al. Functional performance and inflammatory cytokines after squat exercises and whole-body vibration in elderly individuals with knee osteoarthritis. Archives of physical medicine and rehabilitation. 2012 Oct;93(10):1692-1700.

23. Stephanie H, Raz L, Ilana N. The effect of dissociation between proprioception and vision on perception and grip force control in a stiffness judgment task. 2018 IEEE haptics symposium. 2016 May. DOI: 10.1109/HAPTICS.2018.8357166

24. Gabriele W. Attentional focus and motor learning: a review of 15 years. Intentional review of sport and exercise psychology. 2012 Aug;6(1):77-104. DOI: 10.1080/1750984X.2012.723728

25. Oh HT, Hwangbo G. The effects of proprioception exercise with and without visual feedback on the pain and balance in patients after total knee arthroplasty. Journal of physical therapy science. 2018 Jan;30(1):124–6. DOI: 10.1589/jpts.30.124

26. Antonio MA, Fidel HC, Rafael LV, Isabel CM, Alvarez PJ, Emilio ML. Effects of 12-week proprioception training program on postural stability, gait, and balance in older adults: a controlled clinical trial. Journal of strength and conditioning research. 2013 Aug; 27(8);2180-88. DOI:10.1519/jsc.0b013e31827da35f.

27. Pincivero DM, Bachmeier B, Coelho AJ. The effects of joint angle and reliability on knee proprioception. Journal of physical therapy science, 2001 Oct;33(10):1708-12.

28. Almosnino S, Kingston D, Graham RB. Three-dimensional knee joint moments during performance of the bodyweight squat: effects of stance width and foot rotation. Journal of applied biomechanics. 2013 Feb;29(1):33-43. DOI: 10.1123/jab.29.1.33