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# Effects of Robot-Mediated Gait Training Combined with Virtual Reality System on Muscle Activity: A Case Series Research

Background: Previous robot-mediated gait training has been proven several limitations such as pointless repeated motion training, decreased presence, etc. In this research, adult stroke patients were participated in robot-mediated gait training accompanied with or without virtual reality program.

Objectives: Exploring whether the results indicated virtual reality system has contribution to muscle strength and balance ability.

Design: A case series research, cross-over trial.

Methods: Eleven participants (male 4, female 7) with adults diagnosed as stroke from medical doctor ware engaged. The participants received 2 treatment sessions of identical duration, robot-assisted gait training with virtual reality and robot-assisted gait training with screen-off randomly crossed over include 1-day for each person of wash-out period. The parameter was muscle activity, the researchers assessed sEMG (surface electromyography).

Results: The result showed less muscle activities during training in robot-assisted gait training with virtual reality circumstances, and these indicated muscles were gluteus medius muscle, vastus medialis muscle, vastus intermedius and vastus lateralis muscle, semimembranosus muscle, gastrocnemius-lateral head, and soleus muscle ($P<.05$).

Conclusion: In this study, we analyzed the outcome of muscle activity for clinical inference of robot-assisted gait training with virtual reality (VR). Less muscle activity was measured in the treatment accompanied by VR, therefore, a more systematic, in-depth and well-founded level of follow-up research is needed.

Keywords: *Virtual reality; Stroke; End-effector; Robot-mediated ambulation training*

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## INTRODUCTION

Robotic rehabilitation intervention system and training have been used for ambulation training which commonly is intervening for patients like stroke, spinal cord injury, and other neurological disorders,[1] despite the short history. Rehabilitation therapy using robots has been reported to have the benefits of improving recovery or function in areas such as functional independence, spasticity, cognitive impairment degree, and balance as with many existing treatment methods and treatments.[2]

The exoskeleton or wearable is mainly used for rehabilitation training accompanied by these robots, including the multi-degree of the freedom robot system, optimal adaptive robust control design is emphasized. These modules has been considered more comfortable, safer, and active for the patient.[3]

There are various types of wearable robots, but end-effector types have been widely used for rehabilitation of patients in recent years. The term first used in robotics when a tool or device is attached to the robot's mechanical arm, the robot can be a production machine; robot tools are called by several names. The most frequently used term is end-effector, but the term end-of-arm-tooling is also commonly used. If the end device is a mechanically open and closed device, it is called a gripper. If the end device is a tool or special attachment, it is called process tooling.[4] With this principle, a robot for the purpose of rehabilitation could also adopt a method of end-effector that exerts a dynamic motion and exerts a force on the distal end of a limb such as a person's limb.

Previous studies have emphasized that the combined types of treatments of robots and virtual reality (VR) are effective in treating stroke patients, multiple sclerosis, children, and the general public, and that they are widely applied to categories such as gait availability, body balance, motor function, efficient function, and cognition.[5-8] These indicators have been the basic and common goal of general rehabilitation over the past decades, these studies focused on the motor skills of the upper and lower limbs, especially in the rehabilitation area, concerning the functional movement of the hands with arms, and walking of the lower limbs.[9,10] However, there have been many papers produced on individual treatments for each robot and VR, but there are still relatively few studies tested to meet the two appropriate and ideal common goals.

The basic concept of VR means 'an artificial environment similar to reality, but not real'. Therefore, in a broad sense, visual media such as simulations such as flight simulators and games can also be included in virtual reality. In general, however, VR refers to a technology that enables spatial and temporal experiences close to reality by directly acting on the five senses of the user, rather than simply implementing a virtual space. The sub-concept is 'Simulated Reality', which is a simulation of VR as close as possible to reality. VR can distinguish between "reality" and "virtual," but there is a difference that simulated reality is so realistic that it cannot be distinguished. In physics, it is impossible to completely reproduce reality 100%, but it is possible to simulate enough to deceive people. VR has been mainly used in the field of rehabilitation to improve cognitive function, but is gradually used for physical exercise, strengthening motivation, and providing fun.[11] As people can see the television point installed in front of the treadmill exercise at the gym, monitors began to appear in gait training during rehabilitation using robots at some point.

Since conventional gait training arranged by physical therapists or other rehabilitation specialists have been reported several limitations such as pointless repeated motion training, decreased presence, etc.[12] In the early stage of robot-assisted rehabilitation novel approach, it is in the almost like circumstances as non-purposeful repeated motion training and decreased motivation.[13] VR system has been introduced alternative newer intervention methods in this field, robot-mediated gait training combined with VR system could be started to be proposed as promising future rehabilitation program.[14] However, there were still few tries to find out clinical meaning and effects of robot with VR training in the topic of recovery. There are many papers that induce curiosity, motivation, and fundamental interest,[7] but since the fact that the combined form of the intrinsic VR and Robot has been commonly used, various research methods and many additional studies are needed for the true validity of this treatment form. This clinical trial is aimed to figure out the effects of robot-mediated gait training combined with VR program.

## SUBJECTS AND METHODS

### Research design

This research is corresponding case series research including cross-over trial; design to test the effect of the independent variable by applying each treatment condition of the independent variable in turn to the same subject. All the experimental procedure was fully explained for researchers and written informed consent was provided for the participants. This cross-sequential design made the participants experience robot-assisted gait training without VR (RGT) or robot-assisted gait training with VR (RGT-VR). All the subjects provided informed consent before participating in the present study according to the Declaration of Helsinki and public health.[15] This research project had been approved for registration through Thai Clinical Trials Registry (Identification number: TCTR 20200520003).

### Subjects

Eleven participants (male 4, female 7) with adults diagnosed as stroke from medical doctor, within 10 months of their onset, were engaged. Participants were excluded if they had (1) positive neurologic symptoms on their own foot; (2) need orthosis or assistive devices; (3) previous history of leg surgery; (4) previous history of fractures and significant traumas on lower body; (5) similar level of upper extremity in stages of stroke recovery: the Brunnstrom stage 4-5. It was recruited to fall within the scope within stage 4-5; the participant's recovery level of lower extremity of Brunnstrom stage.

### Intervention Procedures

Eleven adults diagnosed as stroke from medical doctor were participated in this study. They were recruited from community health care center in Seoul, Korea. All the participants allocated to two types of robotic system as a rehabilitative approach; (1) conventional robot-mediated gait training: robot-assisted gait training without VR (RGT), (2) VR-combined robot-mediated gait training: robot-assisted gait training with VR (RGT-VR) (Figure 1). In the RGT session, the screen was set to off.

To allow patients to adapt themselves to the concept of gait therapy, a general gait therapy by a physical therapist was run for 30 minutes duration, once a day for a week as a run-in period. Since there is possibility for increased muscle strength in the initial session, the researchers provided a sufficient adaptation period. After the one finished the conventional robot training (RGT), the one used robot with VR program (RGT-VR) very next day (a wash-out period). The order of these process was randomly allocated using Excel (Microsoft) random macro function. Each robot treatment per session was performed intensively for 4 months (30 minutes duration, once a day, 3 times for a week). All treatments were conducted under the supervision of an occupational therapists or physical therapists.

Robotic system and VR program were used only from Morning Work by Hyundai Heavy Industries and this is equipped with a semi-exoskeleton with end effector-type driving system, that is operated by the robot's driving force transmitted from the sole of each foot plate (MW-V150 (K), 3,900 (L) X 1,540 (W) X 1,950 (H) mm, 900 Kg (Net), 135 Kg (patient capacity), 200-240 V, 2,000 VA). In RGT-VR, the trail walking mode (3 km/h, 0% gradient) provided by the program was implemented, and the center of the patient's gaze was arranged at the point where the diagonal of the 40-inch screen meets. Visual aids such as eyeglasses were provided to patients with difficulty in recognizing the screen due to vision problems, and sufficient sound was provided through the speakers.


**Figure 1.** VR-combined robot-mediated gait training

## Outcome Measures

### Surface Electromyography (sEMG)

The authors assessed muscle activities (%MVIC; maximum voluntary isometric contraction) during each section to indicate person's physical status and changes. sEMG was measured to see if there was a real-time difference between walking while looking at the screen and training when the screen was off. These wireless sEMG nodes were attached to participant's affected and non-affected side, but we only collected data from the affected side only; due to prevent node-conscious movement phenomenon. The target sEMG single node was attached to key lower extremity muscles; gluteus maximus muscle, gluteus medius muscle, vastus medialis muscle, vastus intermedius muscle, vastus lateralis muscle, semitendinosus muscle, semimembranosus muscle, biceps femoris muscle, head of medial gastrocnemius, head of gastrocnemius-lateral, and soleus muscle. It was collected during the cycle of ambulation, onto mean values. Every sEMG data was measured from Desktop DTS and MR 3.8.30 software (Noraxon, USA) was attached, basic raw EMG signals were sampled at 1000 Hz and were handled into a root mean square (RMS) with a window of 50 m/s. A band pass filter of 20-450 Hz was used together with notch filters at 60 Hz. Every muscle was measured by RMS of a 5s for normalization of sEMG data collected from the %MVIC for each muscle at the manual muscle test-position, described by Kendall and McCreary.[16]

## Statistics and Analysis

All the data was statistically analyzed using IBM SPSS 20 software and for assessing each session, we examined descriptive statistics and Wilcoxon signed rank test and the patients' general information of disorder was reported (Table 1).

# RESULTS

Patients profile and general characteristics were reported via Table 1. The differences were reported in Table 2. It showed less muscle activities during training in RGT-VR session and the indicated muscle were gluteus medius muscle, vastus medialis muscle, vastus intermedius and vastus lateralis muscle, semimembranosus muscle, gastrocnemius-lateral head, and soleus muscle. This clinical assessment differences were statistically significant ($P<.05$). The rest

**Table 1.** Demographic information of the participants (n=11)

| Categories | | Values (Mean ± SD or %) |
|---|---|---|
| Sex | Male | 36.3% (n=4) |
| | Female | 63.6% (n=7) |
| Age (year) | | 54.51 ± 2.72 |
| Stroke Type | MCA | 11 (100%) |
| | Hemiplegic side-Rt. | 6 (54.5%) |
| | Hemiplegic side-Lt. | 5 (45.5%) |
| | Gait Disturbance | 11 (100%) |

SD: Standard Deviation

**Table 2.** Comparison between two types of trainings-Muscle activities (%MVIC) during sEMG measurement (n=11)

| | RGT (M ± SD) | RGT-VR (M ± SD) | Z | *P* |
|---|---|---|---|---|
| Gluteus maximus muscle | 11.01 ± 3.87 | 13.01 ± .41 | -.2221 | .231 |
| Gluteus medius muscle | 14.06 ± 1.35 | 12.01 ± 1.33 | .321 | .036* |
| Vastus medialis muscle | 24.85 ± 4.93 | 21.06 ± 1.46 | .110 | .007*. |
| Vastus intermedius muscle | 15.00 ± 1.17 | 12.07 ± .64 | 2.21 | .032* |
| Vastus lateralis muscle | 12.62 ± .53 | 14.06 ± 1.46 | -1.3 | .006* |
| Semitendinosus muscle | 14.06 ± 1.46 | 13.50 ± .51 | .231 | .334 |
| Semimembranosus muscle | 15.00 ± 1.17 | 13.62 ± .58 | .32 | .015* |
| Biceps femoris muscle | 17.03 ± 1.11 | 16.06 ± 1.31 | .1001 | .171 |
| Gastrocnemius-medial head | 15.00 ± 2.31 | 14.06 ± .16 | .673 | .616 |
| Gastrocnemius-lateral head | 22.33 ± .44 | 19.72 ± 2.14 | .132 | .005* |
| Soleus muscle | 11.06 ± 1.41 | 16.13 ± .55 | -1.18 | .017* |

VR: Virtual Reality, M: Mean, SD: Standard Deviation, sEMG: Surface Electromyography, MVIC: Maximum Voluntary Isometric Contraction, RGT: Robot-assisted gait training, RGT-VR: Robot-assisted gait training with VR, *$P$<.05

of the muscles, on the contrary, required greater muscle activity in the RGT, but did not show statistically confirmed results.

## DISCUSSION

The therapeutic concept of robot-mediated gait training combined with VR program was started not many years ago, there are still needs of basic methodologies and clinical trials. Configuring out factors of VR with robot rehabilitation is most crucial prior task for regular clinical field usage. This study could contribute to building evidence and future randomized controlled trials or even case-control studies.

Cross-over design is a research design that allows each patient to serve as his or her control. The shape of the cross design can also be determined in various ways depending on the specific purpose of the study and the content of the study.[17] The first design is the simplest form of a two-period cross-over design, and half of the patients selected for study are randomly selected to apply RGT or RGT-VR, and after a certain period of time, RGT-VR and treatment respectively. It is changed to RGT and assigned. The second design is a design of a typical two-period cross-design, and the effect of the training that was first administered from the patient's body before the treatment was changed after randomly assigning treatments to patients in the first study and performing treatment for a certain period of time. After a certain washout period has elapsed until complete disappearance, the rehabilitation was cross–linked. Allowing this period before crossing the treatment is a method to prevent the effect of the other treatment to be administered next due to the carry–over effect by the previously administered therapeutic method. It is a device that prevents the occurrence of interaction effects due to residue. By applying this basic form, it is a four–period cross–design form that crosses two drug groups, or a four–period cross–design and cross–treatment method.[18,19]

A design can be designed to have a fixed period of a break for each time point, and a design of observing by extending the second treatment period more than twice as well as in the form of cross–design for two periods. Since this cross–design compares the conditions before and after treatment in the same patient, it shows the effect of less variation in the observed treatment effect compared to the parallel design, which is a study design that compares treatment results observed from completely different patients. Expressed in statistical terms, the size of the variance decreases when evaluating treatment results, so it has the advantage of reducing the number of study subjects required for the study compared to parallel design when planning clinical trials to identify differences in the same treatment effect.[20] There was applied to this study.

The result presented less muscle activities during training in RGT–VR session and the indicated muscle were gluteus medius muscle, vastus medialis muscle, vastus intermedius and vastus lateralis muscle, semimembranosus muscle, gastrocnemius–lateral head, and soleus muscle; in the remaining muscles involved in walking, gluteus maximus muscle, vastus lateralis muscle, soleus muscle, the average value of near–activity measured in real time during RGT–VR was measured higher than that of the data group that only RGT performed.

We deduced there would be many controversial in the interpretation of result's phenomenon. If less muscle strength was used at the phase of RGT–VR implementation, a number of situations can be inferred; it could be predicted that the occurrence of a compensational or abnormal movement has resulted in muscle intervention[21] which is difficult to occur in normal motion;[22-24] rather, it may be thought that more efficient movement in operating the muscle has taken place, and this means less effort concerned for the same movement;[25-27] there is also a possibility that increased automation or motility of motion may affect;[28,29] RGT–VR can be a task–oriented activity, so this is also a possible variable which is get involved. Therefore, it is difficult to control everything because many of these variables may exist, and a thorough examination of the aforementioned issues is necessary to accurately identify them. Walking has little to do with the enhancement of muscle strength,[30,31] but there is room for muscle strength to increase in early sessions, so this study provided a sufficient duration of adaptation for run–in time.

Stroke patients are concerned that they can behavior passively because the walking robot moves along a predefined trajectory during VR walking training.[32] Nevertheless, it is believed that the patient's activeness and the therapist's motivation contributed to the decrease in muscle activity.[33] and that the muscle activity decreased more than the screen turned off gait could be considered to have increased muscle efficiency. During this training, VR continuously induces patient engagement,[34] and this active contribution appears to be the crucible of motor learning.[35] Researchers and clinicians of this study found that the size of the screen, the distance or location between the eyes and the screen could be greatly involved in forming the sense of clinical and concentration when performing VR. It was difficult to control factors such as height, weight, or body size during the experiment, the height and size of the screen were adjusted relatively and indirectly to provide the most unified experimental conditions. However, the patient's request after the experiment (client's inner drive), resulted in a different sense of immersion and performance of motor skills when the screen was nearer to the additional session regardless of the conditions of the experiment. Perhaps the results would have been different if there had been enough environmental settings to create an illusion as if they were actually in the place.

## CONCLUSION

In this study, we analyzed with a parameter called muscle activity for clinical inference of robot–assisted gait training with or without VR, which is currently being performed mainly in Korea. As a result, less muscle activity was measured in the treatment accompanied by VR. A more systematic, in–depth and well–founded level of follow–up research is needed to grasp the true meaning of this.

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