Gait Training with Wearable Hip-assist Robot Reduce Trunk and Leg Muscle Efforts and Metabolic Energy Consumption in Community Dwelling Elderly Adults: A Randomized Controlled Trial

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Abstract

Background: Wearable types of gait-assist robots have been developed to provide additional advantages such as being easily transportable, producing a more natural gait pattern, and being simple to control. The purpose of this study was to investigate the effect of intensive gait training with a newly developed wearable hip-assist robot on gait function and cardiopulmonary metabolic energy efficiency in community-dwelling elderly adults. Methods: Total of 27 community-dwelling elderly adults with age-related problems completed in this intervention study (15 experimental group and 12 control group) . The experimental participants received an intensive gait training program with a total of 10 sessions involving five sessions of treadmill and five sessions of over-ground gait training with the wearable hip-assist robot. The control group received gait training without a wearable-hip assist robot. The primary outcomes were gait functions (spatio-temporal parameters and muscle effort). The secondary outcome was cardiopulmonary metabolic energy consumption. Results: Compared to the control group, the experimental group had significantly greater improvements after intervention in spatio-temporal parameters (gait speed, cadence, and stride length) and reduced muscle efforts (trunk and lower extremity) with gait ($p < 0.05$). In addition, the reduction in oxygen consumption (ml/min/kg) was about 16.31% in the experimental group after intervention. Furthermore, the reduction in the aerobic energy expenditure measurement (Kcal/min) was about 17.36% in the experimental group after intensive gait training with wearable hip-assist robot. All cardiopulmonary metabolic energy consumption parameters in the experimental group were reduced significantly more than in the control group ($p < 0.01$). Conclusion: The intensive gait training with a wearable hip-assist robot was effective in improving gait function and cardiopulmonary metabolic energy efficiency in community-dwelling elderly adults with age-related problems. Trial registration: NCT02843828, registration date: 07/14/2016 - retrospectively registered

Background

Aging causes changes in the neuromuscular system such as strength loss and the alteration of muscle activation, which may result in reduced walking function [1]. Walking is a major activity during which a large proportion of falls in elderly adults occur, and an impaired gait is associated with an increased risk of falling [2]. Elderly adults' gait is characterized by slow speed, a reduced joint angle, short steps, and mechanical plasticity, reflecting the age-related changes in the neuromuscular system [3]. Furthermore, the cardiopulmonary metabolic energy cost of walking has been shown to be 23% higher in elderly adults than in healthy young adults [4]. An increased metabolic energy cost in elderly adults could be clinically significant because it can increase the sense of effort, fatigue, and the potential for accidents and reduce the ability for physical activity [5, 6]. Consequently, walking therapy for elderly adults has been promoted as a method for improving both physical and cognitive functions, assisting with the recovery of independence, and preventing disability.

As a solution to these problems, many gait training efforts for elderly adults with limited walking abilities have attempted dual-task therapy [7, 8], Tai Chi training [9], group exercise [10], use of treadmills [11], over-ground gait training [12] and robot-assisted gait training [13]. In particular, over-ground gait training performed under natural conditions could provide an alternative type of training, closer to normal ambulatory activities. Furthermore, treadmill training is increasingly being used as a method for increasing gait velocity and distance in elderly adults. Therefore, both over-ground and treadmill training are recommended as a good exercise program for elderly adults [12, 14].

In recent years, gait training robots have increasingly been used to provide highly repetitive and intensive training sessions for various gait disorders [15-17]. These robots are designed to be worn by the user and provide force to move the user's lower extremity and they are designed for automated gait training on a treadmill. However, these robots are not widely available because they are large and not portable. More recently, wearable types of gait-assist robots have been developed to provide additional advantages such as being easily transportable, producing a more natural gait pattern, and being simple to control. These wearable gait-assist robots could also be used in a community dwelling setting as a therapeutic technology to assist with performing activities of daily living [18, 19].

This study investigated a newly developed wearable hip-assist robot, which uses an active assist algorithm. The Gait Enhancing and Motivating System (GEMS, Samsung Electronics Co., Ltd., Suwon, Korea) was newly developed at the Samsung Advanced Institute of Technology on elderly. The GEMS is a wearable robot that can provide part of the joint torque and power around the bilateral hip joints in the direction of extension and flexion during walking. In our previous study using GEMS, it has been proposed that providing external power to the hip joint via a wearable gait-assist robot could provide more improvement in gait functions and reduction of about 7% in cardiopulmonary metabolic energy cost than in free gait condition without wearable gait-assist robot [20]. The purpose of this study was to investigate the effect of intensive gait training of 10-sessions intervention program with a newly developed wearable hip-assist robot on gait function and cardiopulmonary metabolic energy efficiency in community-dwelling elderly adults. We hypothesized that intensive gait training with the wearable hip-assist robot would improve the gait function and reduce metabolic energy consumption in elderly adults.

Methods

Participants

Participants were recruited from community-dwelling elderly people in Seoul, Korea. All participants were eligible for inclusion if they met the following requirements: they were over the age of 65, they had sufficient cognition to follow simple instructions and to understand the content and purpose of the study (based on the Korean version of the Montreal Cognitive Assessment of ≥ 23 points), and they did not have a musculoskeletal condition that could potentially affect the ability to walk safely. Participants were excluded if they had severe heart disease or uncontrolled hypertension and pain or if they had any neurological disease that might interfere with the study. Ethics approval was granted from Samsung Medical Center institutional Ethics Committee, and written informed consent was obtained from all participants prior to the study.

Design of the GEMS as a wearable hip-assist robot

The GEMS is developed to enhance gait function and to increase the community locomotor interaction in patients with gait disorders and elderly people. The GEMS is a lightweight (2.8 kg), slim, comfortable, and powerful active assist robot. As shown in Figure 1., the GEMS consist of a pair of actuators for transmit assistance torque of the both hip joints, a hip brace that fits around the waist, a pair of thigh carbon frames that carry on assistance torque from the actuators to the thighs. It also had fabric belts at the ends of the thigh frames. The assist torque element in GEMS consist of angular sensors and actuators on both hip joints. The hip joint angle is given to the controller, then PSAO (Particularly Shaped Adaptive Oscillator) estimates the gait phase or percent gait cycle. The output torque is then calculated from the torque look-up table based on the actual gait phase. The details information of the GEMS's assistant algorithm are described in our previous paper [21, 22]. In addition, a research administrator used a tablet PC (Galaxy Tab 3 8.0 from Samsung Electronics Co., Ltd., Korea with the Android 4.2 OS) to users' weights and assistance levels for experiments and to log the data from GEMS at the rate of 100 Hz.

Experimental design

A randomized, controlled trial was performed to test the effectiveness of a gait training using a newly developed wearable hip-assist robot with community-dwelling elderly adults. All participants were recruited by way of an advertising poster with information about enrollment, study objectives, and exclusion criteria. The eligible participants were randomly placed in either the experimental group (gait training with wearable hip-assist robot) or the control group (gait training without wearable hip-assist robot) by a research administrator using a random number table after baseline assessment. All participants were assigned a code number. The intervention was administered by two physiotherapists. The study flow diagram is outlined in Figure 2.

Intervention protocol

Experimental participants received an intensive gait training program with a total of 10 sessions during three sessions per week for four weeks involving five sessions of treadmill gait training with GEMS and five sessions of over-ground gait training with GEMS. The goal of the gait training was to facilitate improvements in gait functions (walking speed, muscle efforts of trunk and lower extremity) and cardiopulmonary metabolic energy consumption. All participants were randomly assigned to treadmill or over-ground gait training by a random number table. For treadmill gait training, the participants wore a harness without any body weight support and used handrails to prevent falls. In addition, the first treadmill training session was used to adjust the device properly to the individual participant and allow the participants to get comfortable with GEMS. In contrast, the control group received treadmill gait training at their most comfortable speed without GEMS. We gradually increased treadmill speed (normally up to 3 km/h) in order to challenge the participant to walk as actively as possible with GEMS during five treadmill gait training sessions. At the final session, the experimental group reported a faster comfortable speed on the treadmill than the control group. Also, during the five sessions of over-ground gait training, participants performed training at their most comfortable speed with (experimental group) or without (control group) GEMS in the corridor in front of our laboratory.

According to previous research based, similar to our study, in the training protocol, the average time per session was 45 min, divided into a 5 min warm-up, 35 min intensive gait training (including 5 min resting time) and 5 min cool-down [23, 24]. The structure of the intervention was customized to each participant's physical function level.

Outcome measures

Gait function as a spatio-temporal parameter and muscle effort while walking were the primary outcomes of this study. Spatio-temporal parameters (gait velocity, cadence, stride length and step width) were measured using a 3D motion capture system with six infrared cameras (Motion Analysis Corporation, Santa Rosa, CA, USA). In addition, muscle efforts while walking were measured using a 12-channel wireless surface electromyography (sEMG, Noraxon Inc., Scottsdale, AZ, USA). sEMG signals were registered via 12-channel wireless electromyography using 10 mm 3M^{TM} Ag/AgCl surface electrodes. The electrodes were positioned on the participants' right sides on the rectus abdominis (RA), external oblique (EO), erector spinae of the lower back (ES), hip flexor (HF), gluteus maximus (GMAX), gluteus medius (GMED), rectus femoris (RF), vastus medialis (VM), adductor longus (AL), biceps femoris (BF), tibialis anterior (TA), and the medial of gastrocnemius (GCM) muscles in accordance with the recommendations of the sEMG for the Non-Invasive Assessment of Muscles Project (SENIAM) [25]. Besides, foot-switch sensors were placed on participant plantar surface of the right toe and heel. The signals from the foot-switch sensors recorded data on the stance and swing phases during gait. The maximum voluntary contraction (MVC) data of all muscles for each subject was measured according to method of the SENIAM before performing the gait assessment [25]. After measuring the MVC, the EMG data of each muscle collected while the subject walked was normalized based on the walking cycle (%MVC), combined with the MVC data. The EMG signals were amplified and filtered (sampled at 1000 Hz with bandpass filtered between 10 Hz and 350 Hz) and full-wave rectified with Noraxon software (MyoResearch XP Master Edition).

Cardiopulmonary metabolic energy consumption was the secondary outcome. This assessment was performed using a portable cardiopulmonary metabolic system (Cosmed K4B^2, Rome, Italy). This system was worn on the back, to measure breath-by-breath metabolic cost. The flow meter was calibrated using a 3-L syringe. Energy consumption variables collected included oxygen consumption (ml/min/kg) and an aerobic energy expenditure measurement (EEm; Kcal/min). Cardiopulmonary metabolic energy consumption measurements consisted of a resting and gait test on a treadmill. The resting condition was obtained during a standing position for three minutes prior to the gait trial. Following this, participants walked continuously for six minutes on the treadmill at their most comfortable speed without GEMS assist. The participants were given specific instructions not to talk or laugh during measure. Particular care was taken that each participant walked on the treadmill while wearing a safety harness and that each participant walked comfortably without using handrails. All participants were performed clinical measurements without GEMS at before the intervention and immediately after the ten sessions intervention.

Statistical Analysis

All statistical analysis were undertaken using SPSS version 22.0 (IBM, Armonk, N.Y., USA) and the level of significance was set at 0.05. The Shapiro-Wilk test was used to confirm that all outcome variables were normally distributed. The independent *t*-test for continuous parameters, Mann-Whitney *U* test for ordinal parameters, and x^2 test for categorical parameters were used to compare the baseline characteristics of the participants in both groups. For measures of dependent parameters, a repeated measures analysis of variance with mixed design (within-subjects factor = time, between subjects factor = group) was used to compare each outcome variable between two time points (pre- and post-test). Means, SDs and 95% CIs were provided to depict the change within each group during the course of the study and the training effect.

Results

Flow of participants through the trial

Forty-six community-dwelling elderly adults expressed an interest in participating in this study during the recruitment period, and thirty participants were included. 27 participants were completed except to three participants in the control group (Figure 2). General characteristics of the 27 participants are shown in Table 1. No significant differences in the general characteristics and dependent variables were observed between the experimental and control group.

Effects of intervention

Group data for the spatio-temporal parameters are presented in Table 2. There were statistically significant mean between-group differences for the spatio-temporal parameters. Gait speed, cadence and stride length improved more in the experimental group participants after the intensive gait training with GEMS than in the control group participants after the intensive gait training without GEMS.

Groups data for muscle efforts while walking are presented in Table 3. After 10 sessions of intervention, there were statistically significant between-group differences in stance and swing phase muscle efforts during walking. In the stance phase, the muscle efforts of ES, GMAX, AL, BF, RF, VM and GCM in the experimental group were significantly lower than in the control group ($p < 0.05$). In the swing phase, the muscle efforts of ES, HF, GMAX, BF, RF and VM in the experimental group were significantly lower than in the control group. Interestingly, in the stance and swing phases, the RA muscle effort in the experimental group was significantly higher than in the control group ($p < 0.05$).

Fig 3. shows the analysis of the changes in cardiopulmonary metabolic consumption in terms of oxygen consumption (ml/min/kg) and EEm (kcal/min). After 10 sessions of intervention, there were statistically significant mean between-group differences ($p < 0.01$). For the oxygen consumption parameter, the experimental group was significantly lower than the control group. The reduction in oxygen consumption was about 16.31% after intensive gait training with GEMS in the experimental group. For the EEm parameter, the experimental group was significantly lower than the control group. The reduction in EEm was about 17.36% after intensive gait training with GEMS in the experimental group.

Discussion

The current study was conducted to examine the effect of an intensive gait training program with GEMS on gait function and cardiopulmonary metabolic energy efficiency in community-dwelling elderly adults with age-related walking problems. The findings from this study suggest that intensive gait training with GEMS has some key benefits in terms of walking quality compared with conventional intensive gait training. The main findings were that the intensive gait training with GEMS in elderly adults improved gait speed, cadence and stride length and reduced muscle efforts in the erector spine muscle and lower extremity while walking. In contrast, trunk muscle effort increased when walking. Additionally, the reduction in oxygen consumption was 16.31% and EEm was reduced by 17.36% after intensive gait training with GEMS.

Elderly adults used the muscles of their back (trunk extension, ES muscle) and lower extremities more than younger adults when walking at a comfortable speed. The walking characteristics of these elderly people expend 18.4% more physical energy than young adults during walking, and this increased physical energy is associated with the magnitude of muscle activation in the back and lower extremities of elderly walkers [26, 27]. More specifically, extensor muscle activity is contributed to elderly adults during the stance phase of gait cycle, which could administrate to the increased extensor power and postural stability during the stance phase commonly observed in the gait of elderly adults [3]. Therefore, greater activation of back and lower extremity stabilizer muscles is related to the increased costs of walking for elderly adults. Based on these evidences, our results demonstrated that the effort required for forward progression in the standing extremities is effectively reduced in elderly adults due to intensive gait training with GEMS. Interestingly, Back muscle effort was significantly reduced in participants of experimental group after the intervention program. Back muscles are important for postural stabilize the trunk above a relatively small base of support [3, 27]. This stability function of the back muscle is most important for balance in elderly adults given their kyphotic posture. Kyphotic changes of the spine due to aging have been associated with imbalance during walking in elderly adults [28]. Mian et al. [29]

demonstrated that elderly adults use 21% more energy than younger adults for the activation of body stabilizer muscles when walking. Consequently, intensive gait training with GEMS has the potential to improve stabilization of the trunk while walking in elderly adults with kyphotic posture. It may be possible to predict which of our intervention programs with GEMS will improve the balance function for elderly adults when walking. As another interesting result, our intervention program with GEMS as a hip-assist robot also indirectly decreased the knee and ankle muscle efforts, and directly decreased flexor and extensor muscle efforts of the hip. Previous study result similar to GEMS reported that GCM significantly decreased their muscle effort when walking with a wearable hip-assist robot [30]. These findings demonstrate that the action of an external assistant, such as the external torque provided by a wearable hip-assist robot, can modify the physical balance by altering the muscle effort of the normal gait pattern of the hip, knee and ankle strategies.

The inefficient gait function of elderly people is induced by age-related gait impairments such as a reduction in gait speed, stride length and cadence. Gait speed is the most important factor in gait function [26, 31] Shimada et al. [32] reported that gait speed significantly improved after long-term gait training with a wearable hip-assist robot in community-dwelling elderly adults. In the present study, despite the decrease in muscle efforts, intensive gait training with GEMS significantly improved gait speed, stride length and cadence. In fact, all participants in the experimental group gradually increased their comfortable gait speed during the intervention program period. Therefore, our intervention program with a wearable hip-assist robot may have a greater impact on improving gait functions than an intervention program without a hip-assist robot in community-dwelling elderly adults with age-related gait problems.

Cardiopulmonary metabolic energy consumption is an accurate indicator of another walking efficiency. Most elderly people experience an increase in cardiopulmonary metabolic energy consumption when performing the activities of daily living. Moreover, elderly people have reported a strong association between cardiopulmonary metabolic cost and muscle effort [33]. Based on various subjects in previous studies, the cardiopulmonary metabolic energy efficiency of gait assist devices has been investigated for walking. However, only one previous study with a wearable hip-assist robot reported that the hip-assist robot reduced cardiopulmonary metabolic consumption by about 7% in healthy young adults [34]. Although the present study differed from the previous one in that we focused on community-dwelling elderly adults, the GEMS was found to greatly reduce oxygen consumption and EEm by approximately 17% after intensive gait training. Consequently, The GEMS as a our newly developed wearable hip-assist robot has the potential to provide fundamental advantage with respect to cardiopulmonary metabolic efficiency due to its ability to reduce locomotor-related muscle efforts in community-dwelling elderly adults.

There are several limitations to this study. First, the statistical power was low because of the small number of participants. Therefore, these results cannot be generalized to all community-dwelling elderly adults. Second, long-term follow-up of the training program was not considered. We suggest that further research includes long-term follow-up to examine the long-term effects of gait training with GEMS.

Conclusions

The results of this study demonstrate important benefits of intensive gait training with a newly developed wearable hip-assist robot. We recommend the intensive gait training with the wearable hip-assist robotic system for improving the gait function and metabolic energy efficiency of elderly adults.

Abbreviations

GEMS, Gait Enhancing and Motivating System; PSAO, Particularly Shaped Adaptive Oscillator; PC, Personal Computer; OS, Operating System; sEMG, surface Electromyography; RA, Rectus Abdominis; EO, External Oblique; ES, Erector Spinae of the lower back; HF, Hip Flexor; GMAX, Gluteus Maximus; GMED, Gluteus Medius; RF, Rectus femoris; VM, Vastus Medialis; AL, Adductor Longus; BF, Biceps Femoris; TA, Tibialis Anterior; GCM, the medial part of Gastrocnemius; SENIAM, Non-Invasive Assessment of Muscles Project; MVC, Maximum Voluntary Contraction; EEm, Energy Expenditure measurement.

Declarations

Ethics approval and consent to participate

All participants were briefed on the experimental procedure, and written consents were collected from all participants before the experiment. This study protocol was approved by the ethics committee of the Samsung Medical Center Institutional Review Board (Reference 2015-05-013).

Consent for publication

Not applicable.

Availability of data and material

The data sets supporting the conclusions of this article are included within the manuscript.

Competing interests

The authors declare that there are no conflicts of interest, financial or otherwise, related to the submitted manuscript or any associated with this research.

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Authors’ contributions

YHK and HJL contributed to experimental design, experimental progress, data analysis and drafting the manuscript. SHL contributed to setting up the experiment and collecting data. WHC and BOC contributed to experimental design, data analysis and data interpretation. KHS and JSL contributed to developing the device and the algorithm, and providing device maintenance and repairs. GHR contributed to setting up the experiment and revising the manuscript. YHK gave conceptual advice and edited the manuscript. Finally, GEMS developed by Samsung Advanced Institute of Technology was provided for this study. All authors read and approved the final manuscript.

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Conflicts of interest

The authors declare that there are no conflicts of interest, financial or otherwise, related to the submitted manuscript or any associated with this research.

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Tables

able 1. General characteristics of participants.

Characteristic	Experimental group (n = 15)	Control group (n = 12)
Gender (male / female)	8 / 7	7 / 5
Age *(yr)*	74.23 (4.87)	74.25 (3.36)
Height (*cm*)	160.07 (6.01)	162.41 (9.72)
Weight (*cm*)	61.00 (9.56)	64.25 (8.95)
SPPB (point)	9.60 (1.45)	10.00 (1.81)
Self-selected treadmill speed (m/s)	1.73 (0.58)	1.68 (0.50)

alues are expressed as means (SD).
PPB = Short Physical Performance Battery.

Table 2. Mean (SD) of groups, mean (SD) difference within groups, and mean (95% CI) difference between groups.

Outcome	Groups				Difference within groups		Difference between groups
	Pre-training		Post-training		Post- minus pre-training		Post- minus pre-training
	Exp (n = 15)	Con (n = 12)	Exp (n = 15)	Con (n = 12)	Exp	Con	Exp minus Con (95% CI)
Gait speed *(cm/s)*	91.42 (10.76)	91.35 (11.75)	114.97 (13.02)	99.88 (9.69)	23.55** (9.55)	8.53** (6.28)	15.01** (8.41 to 21.61)
Cadence *(step/min)*	107.38 (8.94)	105.66 (7.92)	120.13 (8.42)	109.22 (7.72)	12.75** (9.01)	3.55** (2.55)	9.20* (4.05 to 14.36)
Stride length (cm)	100.14 (11.29)	104.80 (x)	116.52 (9.27)	112.65 (11.12)	16.38** (7.62)	7.85** (6.32)	8.53* (3.00 to 14.06)
Step width (cm)	14.94 (1.91)	13.77 (4.83)	13.13 (3.47)	11.16 (4.83)	-1.81 (4.31)	-2.62** (5.82)	0.80 (-3.40 to 5.01)

Exp = experimental group, Con = control group, *p < 0.05, **p < 0.01.

Table 3. Mean (SD) of groups, mean (SD) difference within groups, and mean (95% CI) difference between groups.

Muscle effort (%MVC)	Stance phase				Swing phase				Adjusted between-group difference	
	Pre-training		Post-training		Pre-training		Post-training		Stance phase	Swing phase
	Exp (n = 15)	Con (n = 12)	Exp (n = 15)	Con (n = 12)	Exp (n = 15)	Con (n = 12)	Exp (n = 15)	Con (n = 12)	Exp minus Con (95% CI)	Exp minus Con (95% CI)
RA	3.23 (1.46)	2.93 (1.50)	9.73 (5.86)	6.17 (2.84)	2.90 (1.70)	2.63 (1.11)	10.62 (3.84)	6.03 (2.85)	4.43* (0.48 to 8.39)	4.33* (1.67 to 6.70)
EO	15.85 (4.55)	12.61 (6.07)	7.34 (3.76)	8.05 (4.19)	12.98 (9.22)	8.85 (4.50)	8.60 (9.25)	7.03 (4.38)	-3.29 (-10.73 to 2.83)	-2.56 (-10.21 to 5.07)
ES	25.40 (9.95)	24.35 (9.74)	10.45 (5.05)	21.12 (8.60)	27.58 (11.52)	26.65 (14.15)	10.50 (6.32)	22.31 (13.23)	-11.71** (-16.51 to -6.68)	-12.74** (-18.87 to -6.60)
HF	13.12 (9.60)	14.69 (8.78)	9.60 (4.69)	11.72 (7.58)	21.33 (6.56)	18.00 (5.02)	9.16 (4.40)	13.64 (4.42)	-0.55 (-8.51 to 7.42)	-7.81** (-11.02 to -4.60)
GMED	19.50 (6.12)	22.27 (7.40)	13.59 (6.30)	20.58 (8.28)	9.00 (6.71)	10.29 (7.10)	16.63 (10.59)	13.27 (7.09)	-4.23 (-9.87 to 1.42)	4.65 (-4.05 to 13.35)
GMAX	17.33 (9.27)	20.99 (6.76)	9.27 (4.38)	18.18 (6.14)	14.06 (10.39)	16.30 (11.46)	20.52 (14.57)	31.44 (19.00)	-5.25* (-8.79 to -1.71)	-8.35* (-19.47 to 2.78)
AL	21.74 (9.81)	23.14 (8.07)	15.31 (7.94)	21.39 (5.36)	14.50 (4.95)	20.57 (5.13)	12.67 (8.91)	20.51 (9.88)	-4.68* (-12.05 to 2.70)	-1.77 (-10.06 to 6.52)
BF	18.94 (11.18)	19.22 (7.21)	12.36 (10.23)	18.08 (10.13)	22.36 (5.78)	20.87 (5.08)	10.20 (3.97)	16.27 (5.48)	-12.93** (-22.76 to -3.10)	-7.55** (-12.98 to -2.12)
RF	22.82 (9.01)	22.86 (6.93)	11.45 (5.34)	19.68 (6.61)	20.75 (7.49)	16.04 (6.28)	11.04 (6.16)	15.63 (7.46)	-8.20** (-12.11 to -4.30)	-9.30** (-16.37 to -2.22)
VM	22.95 (11.97)	19.33 (8.03)	14.44 (8.61)	22.34 (10.59)	15.46 (5.72)	14.22 (5.35)	10.45 (4.98)	14.29 (10.79)	-11.52** (-19.10 to	-5.08* (-13.71 to

									-3.96)	3.55)
TA	11.57 (3.91)	13.43 (4.92)	10.54 (3.71)	11.60 (4.46)	20.52 (5.37)	20.50 (6.17)	15.43 (5.81)	16.76 (4.58)	0.80 (-3.48 to 5.07)	-1.36 (-5.68 to 2.97)
GCM	28.44 (12.90)	24.30 (9.10)	15.72 (5.87)	21. 40 (7.67)	8.85 (3.78)	6.08 (2.68)	5.68 (3.61)	3.51 (2.07)	-9.83** (-17.50 to -2.15)	-0.61 (-4.00 to 2.78)

Exp = experimental group, Con = control group, *$p < 0.05$, **$p < 0.01$

RA = Rectus Abdominis, EO = External Oblique, ES = Erector Spinae of the lower back, HF = Hip Flexor, GMAX = Gluteus Maximus, GMED = Gluteus Medius, RF = Rectus femoris, VM = Vastus Medialis, AL = Adductor Longus, BF = Biceps Femoris, TA = Tibialis Anterior, GCM = the medial part of Gastrocnemius

Figures

Figure 1

Gait Enhancing and Motivating System (GEMS)

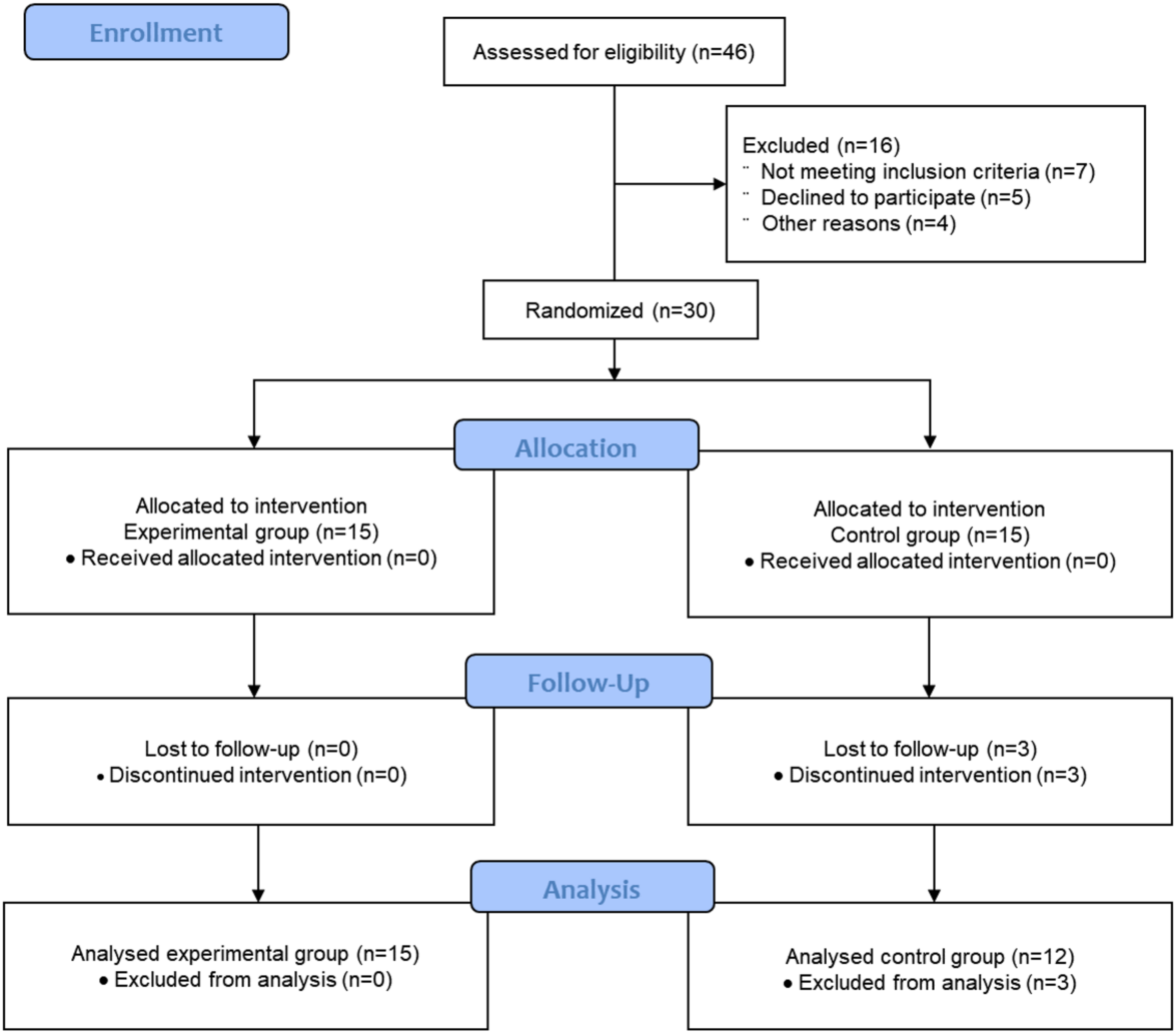

Figure 2

CONSORT flow diagram of this study.

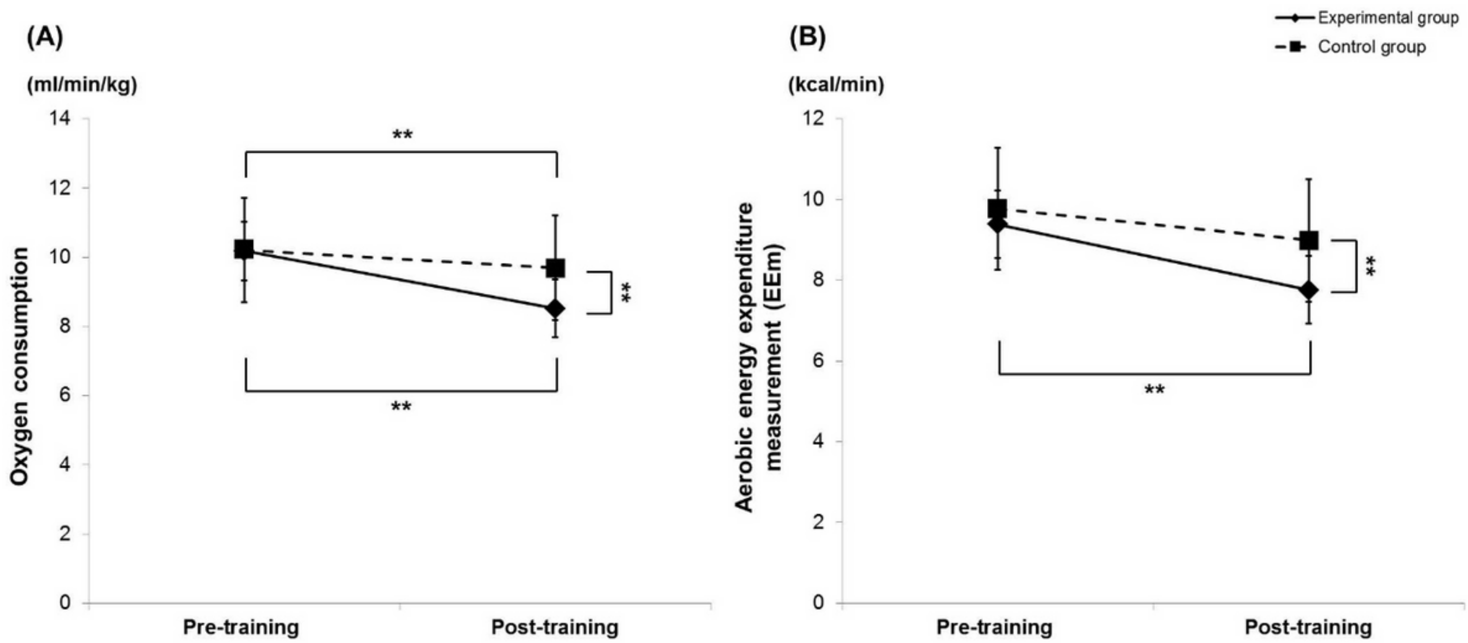

Figure 3

Oxygen consumption (ml/min/kg) and aerobic energy expenditure measurement (EEm) (Kcal/min) results of cardiopulmonary metabolic energy consumption measurements for both groups after intervention. (A) There were significant difference between pre- and post-training (**$p < 0.01$) and between the experimental and control group (**$p < 0.01$) in oxygen consumption. The reduction in oxygen consumption was about 16.31% after intervention in experimental group. (B) There were significant difference between pre- and post-training (**$p < 0.01$) and between the experimental and control group (**$p < 0.01$) in EEm. The reduction in EEm was about 17.36% after intensive gait training with GEMS in experimental group.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CONSORT2010Checklist.pdf