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Effect of anterio-posterior weight-shift training with visual biofeedback in patients with step length asymmetry after subacute stroke

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Effect of anterio-posterior weight-shift training with visual biofeedback in patients with step length asymmetry after subacute stroke

Directed by Professor Deog Young Kim

The Doctoral Dissertation
submitted to the Department of Medicine,
the Graduate School of Yonsei University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Medical Science

Yea Jin Jo

December 2023

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And finally to my mother, thank you for always being there to love and support me. I would never have been able to come this far without your teaching and guidance. I love you so much.

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ABSTRACT

Effect of anterio-posterior weight-shift training with visual biofeedback in patients with step length asymmetry after subacute stroke

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(Directed by Professor Deog Young Kim)

Post-stroke patients typically exhibit an asymmetric gait pattern. Previous studies have shown that visual feedback for weight-shift may be helpful to obtain a symmetrical posture after stroke. However, no randomized control trial study has been conducted on the therapeutic effect on gait asymmetry and patterns in subacute stroke. This study aimed to investigate the effect of anterio-posterior weight-shift training with visual biofeedback (AP training) in subacute stroke patients on gait asymmetry and pattern.

Forty-six subacute stroke patients with gait asymmetry were randomly assigned to the AP training group or the control group. The AP training group received conventional gait training and AP training 5 times per week for 4weeks. The control group received the same intensity of conventional gait training with patient education for self-anterior weight shifting. Gait analysis and energy consumption were assessed before and after training. Step length asymmetry, plantar pressure analysis and gait-related behavioral parameters (functional ambulation category, self-selected walking speed, maximum safe walking speed, Berg balance scale, Fugl-Meyer assessment, medical research council score, functional independent measure-mobility score, timed up and go test) were assessed at before training, during training, after training, and 4 weeks after training. The groups' results were compared using a repeated measures analysis of variance test with post-hoc test.

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The AP training group had significantly improvement in step length asymmetry, plantar pressure parameters, gait-related behavioral parameters (Fugl-Meyer assessment score, Berg balance scale score, medical research council score on knee extensor, ankle dorsiflexor) compared to the control group ($p < 0.05$). However, there was no significant between-group difference with respect to gait analysis parameters, energy cost and other gait-related behavioral parameters.

In conclusion, AP training may help improve the asymmetric step length in stroke patients, and also improve anterior weight shifting, balance, and motor function in subacute stroke patients.

Key words : stroke, gait asymmetry, weight bearing gait training

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Effect of anterio-posterior weight-shift training with visual biofeedback in patients with step length asymmetry after subacute stroke

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I. INTRODUCTION

Post-stroke hemiparetic gait is most commonly characterized by an asymmetric pattern of walking associated with contralateral motor weakness, motor control deficits, sensory and/or proprioceptive loss, and/or ataxia.[1-3] Previous studies has described step length asymmetry in stroke patients as an important variable in gait rehabilitation.[2-5] Allen et al., the step length asymmetry showed two aspects in which the step length of the paretic side was longer or shorter than that of the step length of the non-paretic side, and they reported that the intervention strategy should be different according to each aspects.[3] This study focused on the patients walked with longer paretic step length then non-paretic step length. The shortened non-paretic step length is associated to impaired forward propulsion, which is generated through the anterior-posterior ground force of the paretic side that enables the trunk to progress forward while the non-paretic side is in swing.[6,7] The ground reaction force is a force generated by the weight-bearing surface, post stroke patients are characterized weight-bearing asymmetry with a shift in the mean position of the center of pressure toward the non-paretic side.[8] Therefore, we hypothesized that weight shift training to the paretic side is suitable for improving the asymmetric step length and it will be accompanied by improvement of related variables such as decreased walking velocity[3,9], inefficient walking, poor balance, and increased fall rates[10,11]. Additionally, recent studies

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have reported that visual feedback effectively promotes weight shifting in stroke patients, improving asymmetric posture[12], walking velocity[13,14], balance control[13], and asymmetric weight distribution[15]. Previous studies expected that weight shift training using visual feedback would be effective for symmetrical gait patterns.[12] However, there are no randomized control clinical trials on the therapeutic effect of gait asymmetry on walking. Our study group developed an anterio-posterior weight-shift training system with visual feedback (AP training) for improved step length asymmetry.[16] We already conducted a single-blinded randomized controlled clinical trial study on AP training in chronic stroke patients and confirmed the therapeutic effect not only step length asymmetry but also temporospatial parameters, foot distribution, and walking speed. After the study, we expected that AP training would be more effective in acute stroke patients because most of the functional gains tend to be achieved during the first 12 weeks after stroke.[17] In this study, we used a protocol modified for acute stroke rehabilitation by complementing the limitations found in the previous study. Therefore, in this single blind randomized controlled trial, we aimed to investigated that the effect of the AP training in acute stroke patients with step length asymmetry through various parameters.

II. MATERIALS AND METHODS

1. Participants

Participants were stroke patients admitted to the department of rehabilitation medicine at Sinchon Severance hospital between June 2014 and June 2020. The study was conducted in accordance with the declaration of Helsinki, and approved by the institutional review board of severance hospital, Seoul (No. 4-2014-0383). This study was registered on http://www.clinicaltrials.gov/ and accessed on 1 January 2020 (Identifier: NCT04637737). In this study, informed consent was obtained in the rehabilitation center’s motion analysis room.

Patients had to have met the following criteria to be included: (1) be hemiplegic patients and have had a stroke within the preceding 6 months, (2) be able to walk 10 m

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independently, (3) have received a score of 15 or higher on the Korean-Mini Mental State Examination, (4) have an asymmetrical gait pattern with a step length asymmetry ratio (SLAR) greater than 1.1, (5) have agreed to participate in writing to participate in this study, (6) understood the purpose of this study and was able to adapt to the treatment process, and (7) was over 19 years old. Patients were excluded if they met any of the following criteria: (1) suffer from quadriplegia or overlapping hemiplegia, (2) have a musculoskeletal or nervous system disorder, (3) have had more than one stroke, or (4) be judged by a researcher to not otherwise be suitable for participation.

The sample size for this study was estimated as follows. A preliminary study involving five stroke patients was conducted to estimate the sample size required for the main study. SLAR and weight shifting were assessed at before training and after training. The change in the patients' average SLAR in the preliminary study was 1.008 (± 0.61). Therefore, the mean change in the SLAR value was assumed to be 1.008 in the training group and 0.4 in the control group (40% of that in the training group), and the standard deviation in both groups was assumed to be 0.61. Factoring a power of 80% and an alpha of 0.05, seventeen patients each were required for the treatment group and the control group. Assuming a dropout rate of 30%, a total of 46 patients were enrolled.

2. Study design

This study was conducted as a single-blind randomized controlled trial (Fig 1). Patients were randomly placed into either the AP training group or the control group. Both groups were received 30 m of conventional gait training for 4 weeks. The AP training group also received 30 m of AP training 5 times per week for 4 weeks. The control group was educated on weight-shifting to improve their posture and were encouraged to do weight-shift training themselves at their bedside but did not receive visual feedback training.

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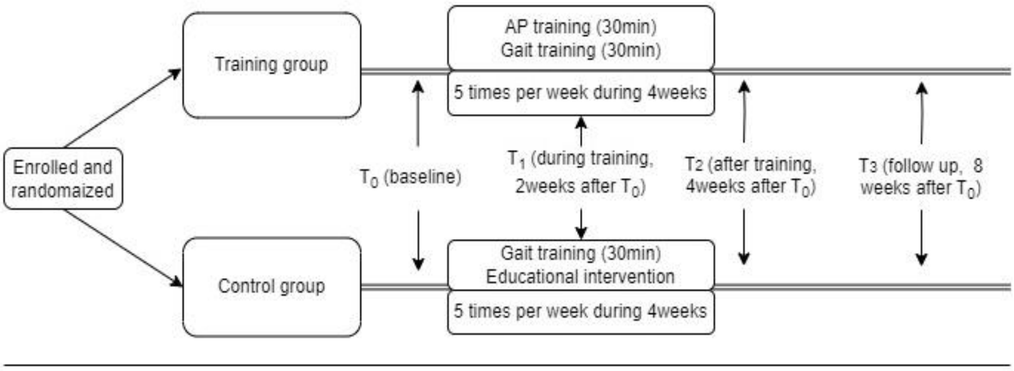

Figure 1. Study design

All patients' step length asymmetry, plantar pressure analysis and gait related behavior parameters were assessed at before training (T0), after 2 weeks of training (T1), after 4 weeks of training (T2), and 4 weeks after training finished (T3). Gait analysis and energy consumption were assessed at T0 and T2 (Table1).

Table 1. Timepoints for measurement of parameters

	Before training	During training	After training	Follow up
Primary outcome	O	O	O	O
Secondary outcome				
Plantar pressure analysis	O	O	O	O
Gait related behavior parameters	O	O	O	O
Gait analysis	O		O	
Energy consumption	O		O	

"O" represents the measuring timepoints.

3. Anterio-posterior weight-shift training using visual feedback

In this study, we used an AP training system developed by our study group to give real-time feedback to patients about how they were shifting their weight by measuring and processing plantar pressure in real time using F-Scan hardware system and software

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development kit (Tekscan, Inc., South Boston, MA, USA).[16] Each training unit was divided into an evaluation session and a training session. Before starting the training unit, each participant attached a motion tracker to the ankle and pelvis of the affected side to measure the posture. The tracker was used to prevent the patients from using a compensatory posture of bending the knee when shifting weight to the affected side.[14]

First, the participants underwent the evaluation session (Fig 2). In the basic position, the patient placed the affected foot 30 cm in front of the unaffected foot with both legs shoulder-width apart. In the evaluation session, subjects were asked to shift their weight anteriorly onto their affected foot as much as possible while receiving visual feedback on how much pressure was applied to each foot. The center of pressure (CoP) trajectory of the feet was measured 10 times. A target value was set by adding 5% to the average of the CoP trajectories.

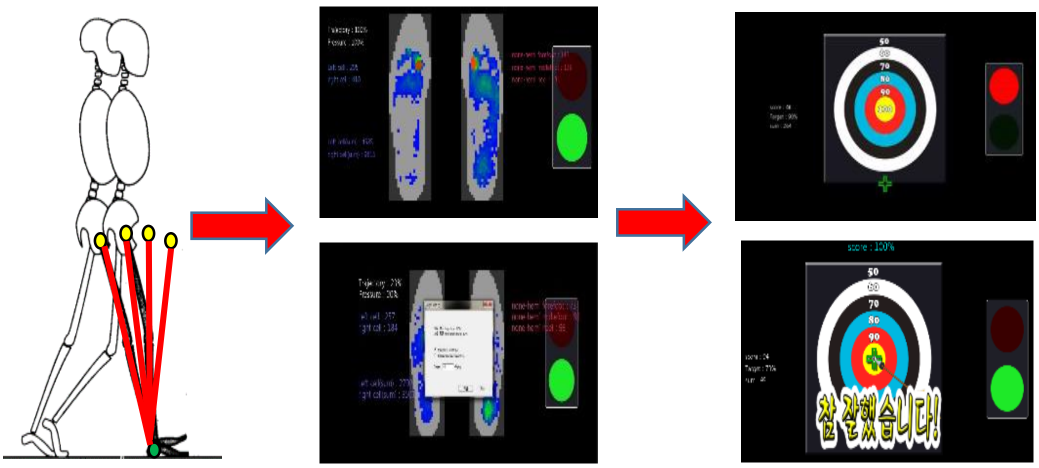

Figure 2. Anterio-posterior weight-shift training using visual feedback. The score of the archery target shows not only how much weight the patient is bearing on affected foot, but also the CoP trajectory has shifted anteriorly

In the training session, subjects were asked to shift their weight anteriorly onto their affected foot as much as possible while receiving visual feedback on how much trajectory moves applied to the affected foot and then move their unaffected foot forward one step.

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When the CoP trajectory reached the target value during push-off, an arrow was placed in the center of the target board, corresponding to 100 points, and the phrase “Good job” was displayed on the monitor and played over the system’s speakers (Fig. 2). Then the patients had to continue moving until they were in the correct position, which was when the pelvis had moved ahead of the ankle malleolus as determined through the hip and ankle sensors. If the CoP trajectory not reached the target value during push-off, an arrow was placed as much as the trajectory percentage, the phrase “Try harder” was displayed on the monitor and played over the system’s speakers. If the participant’s pelvis were not far enough ahead, the phrase “Keep going to get the correct posture” was displayed on the monitor and played over the system’s speakers. Each training session took 30 m composed of two rounds of 10 m of training and 5 m of rest.

4. Outcome measurements

A. Primary outcomes

(1) Gait asymmetry

The participants’ step length asymmetry including step length asymmetric index (SLAI), step length asymmetry ratio (SLAR), affected side step length (ASL), and unaffected side step length (USL) were obtained using the HMER4 body pressure measurement system (Tekscan, Inc., Norwood, MA, USA).[18] During each training session, 10 footstep images were obtained by having the participants take walking 10 times across a 231.2 cm x 88.4 cm sensing area which had 7,072 force-sensing resistors, which was equivalent to 0.3 sensors per cm^2.[19] The average of the images was used for analysis. Step length asymmetric index was calculated according to the following formula: *(paretic step length - non-paretic step length) / (0.5 * (paretic step length + non-paretic step length))*

The asymmetry index for stance time, swing time, double support time, and the intra limb ratio of swing and stance were also calculated using temporospatial data obtained from a 3D motion analysis system (Vicon Peak, Englewood, CO, USA).

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B. Secondary outcomes

(1) Plantar pressure analysis

Contact area, contract pressure, peak pressure, trajectory length, and the number of back movements (NOB) were measured using insole pressure as measured by an F-Scan plantar pressure measurement system (Tekscan, Inc., Norwood, MA, USA). Insoles were trimmed to each participant’s foot size and placed in each of their shoes after removing the original insoles. Data was measured by having them walk for 30 m.

(2) Gait-related behavioral parameter

Gait-related behavioral parameters were functional ambulatory category (FAC)[20], Fugl-Meyer assessment scale (FMA) score [21], functional independent measure (FIM) score, medical record council (MRC) grading of muscle power for lower extremities, self-selected walking speed (SSWS)[22], maximal safe walking speed (MSWS)[22], time up and go (TUG) score[23], and Berg balance scale (BBS) score[24]. All participants were evaluated by an occupational therapist. SSWS was calculated by having the participants walk 10 m on flat ground at their usual speed 3 times and averaging how long it took them each time.[22] MSWS was calculated the same way as SSWS except that participants were asked to walk as quickly as possible.[22] Time Up and Go was measured by asking participants to begin in a sitting position, stand up, walk 3 meters, turn around, and then sit again. This was repeated 3 times and the average duration was used in the analysis.[23]

(3) Gait analysis and energy consumption

These parameters were obtained by recording participants walking 8 m at a speed they selected 3 times using the VICON MX-T10 Motion Analysis System (Oxford Parameters, Inc., Oxford, UK) and using the average of the results in the analysis.[16] The temporospatial parameters were cadence, stride time, opposite foot contact, opposite foot off, single support, double support, step time, single support time, double support time, stance phase, swing phase, step length, stride length, walking speed, stance time, and swing time.

The kinematic parameters included following parameters: PSA1, pelvic maximal anterior tilit angle; HSA1, hip maximal flexion angle at initial contact; HSA2, hip maximal flexion angle at swing; HSA3, hip minimal flexion angle at stance; HCA1, hip maximal abductor angle; HCA2, hip maximal adductor angle; KSA1, knee flexion in initial contact; KSA2, knee minimal flexion angle at stance; KSA3, knee maximal flexion angle at swing; ASA1, ankle dorsiflexion angle at initial contact; ASA2, ankle maximal dorsiflexion angle at stance; ASA3, ankle maximal plantarflexion at swing.

Kinetic data included the maximal moment, generation, and absolution of the hip, knee, and ankle in the sagittal plane.

Energy consumption was measured every 30 seconds while having participants walk around a 20-m oval track in bare feet at a comfortable speed for 5 m using a KB1-C system (Aerosports, Inc., Ann Arbor, MI, USA). The oxygen consumption rate and oxygen consumption ratio were obtained using the average value collected over 3–5 m.[25]

5. Statistical analysis

The characteristic analysis used Two-sample t-test or descriptive statistics. All variables were analyzed by using the repeated-measure analysis of variance (RMANOVA) with post-hoc test with Bonferroni correction. $p < 0.05$ was interpreted as a meaningful result. SPSS version 20.0 for window was used for the analysis. (SPSS, Chicago, IL, USA).

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III. RESULTS

Fig. 3 shows the number of participants who were assessed for eligibility, the number who were included and the analysis, and the reasons for the difference. Fifty-five patients were assessed for eligibility, of which 9 patients were excluded because they did not qualify the inclusion criteria. A total of 46 patients were randomly assigned to the training group (n=23) and control group (n=23). In the training group, 1 patient dropped out during training, and 3 patients were lost to follow-up. In the control group, 1 patient dropped out during training and 1 patient was lost to follow-up. Finally, 19 patients in the training group and 21 patients in the control group were analyzed. At before training, there was no significant difference between the groups in terms of age, sex, lesion side of stroke, type of stroke, FAC, duration, FMA, FIM, BBS, walking speed, asymmetric index, or ratio of step length (Table 2).

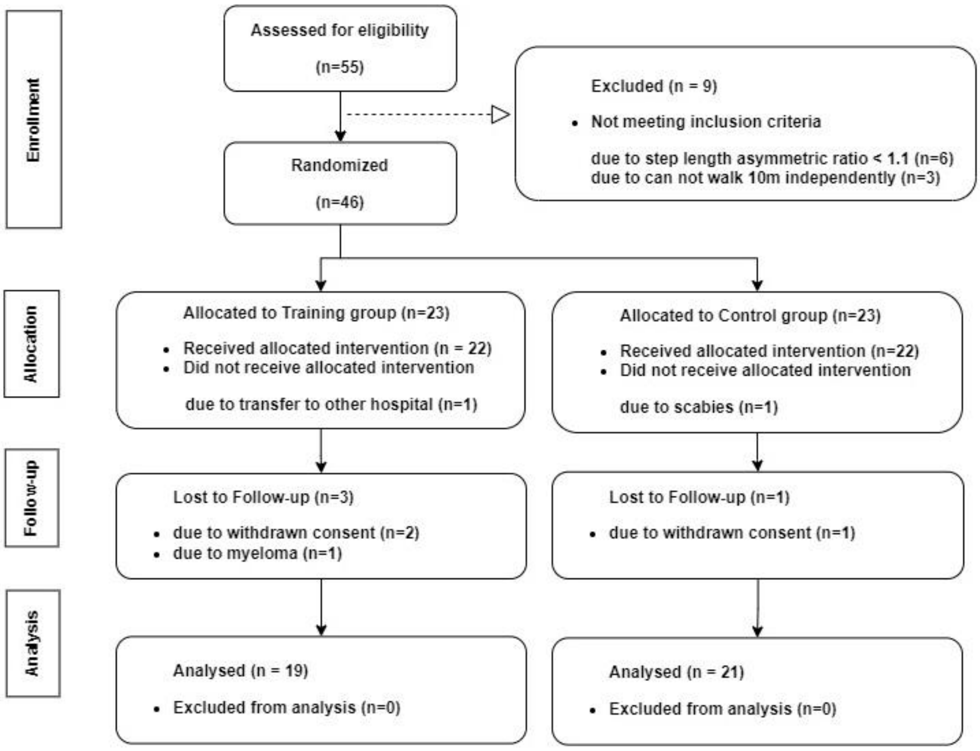

Figure 3. Participants consort flow diagram of study recruitment

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Table 2. Baseline characteristics of subjects.

Characteristic	AP training group (n = 19)	Control group (n = 21)	*p value*
Age (years)	57.7 ± 17.7	52.0 ± 14.0	0.267
Sex (male)	10 (52.6)	14 (66.7)	0.366
Lesion side of stroke (left)	9 (47.4)	11 (52.4)	0.752
Type of stroke			0.141
Ischemic	15 (78.9)	12 (57.1)	
Hemorrhagic	4 (21.1)	9 (42.9)	
FAC			0.587
3	13 (68.4)	14 (66.7)	
4	6 (31.5)	7 (33.3)	
Duration from onset	97.0 ± 59.8	81.1 ± 54.2	0.383
FMA	39.9 ± 17.0	43.6 ± 22.1	0.558
FIM_mobility	18.4 ± 2.7	17.1 ± 4.1	0.255
BBS	25.4 ± 7.3	24.6 ± 7.9	0.756
MSWS (m/s)	0.3 ± 0.1	0.2 ± 0.1	0.408
SSWS (m/s)	0.2 ± 0.1	0.2 ± 0.1	0.869
TUG (s)	46.7 ± 24.6	56.1 ± 64.1	0.555
SLAR	3.6 ± 4.1	2.5 ± 2.5	0.301
SLAI	0.7 ± 0.5	0.5 ± 0.4	0.285

Data presented as mean ± standard deviation or frequency (%); FAC, Functional ambulation category; FMA, Fugl-Meyer assessment; FIM, functional independent measure; BBS, Berg balance scale; MSWS, maximum safe walking speed; SSWS, self-selected walking speed; TUG, timed up and go; SLAI, step length asymmetric index; SLAR, step length asymmetric ratio.

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1. Primary outcome

The asymmetrical gait parameters at before training did not differ between the AP training group and the control group. Repeated measured analysis of variance revealed a significant interaction between $\text{Time}_{(T0,\ T1,\ T2,\ T3)}$ and $\text{Intervention}_{(\text{training, control})}$ with regard to USL (F(4.929), p = 0.009) and SLAI (F(6.160), p = 0.008), indicating that the AP training group's USL and SLAI scores increased more than the control group's over time (Fig. 4).

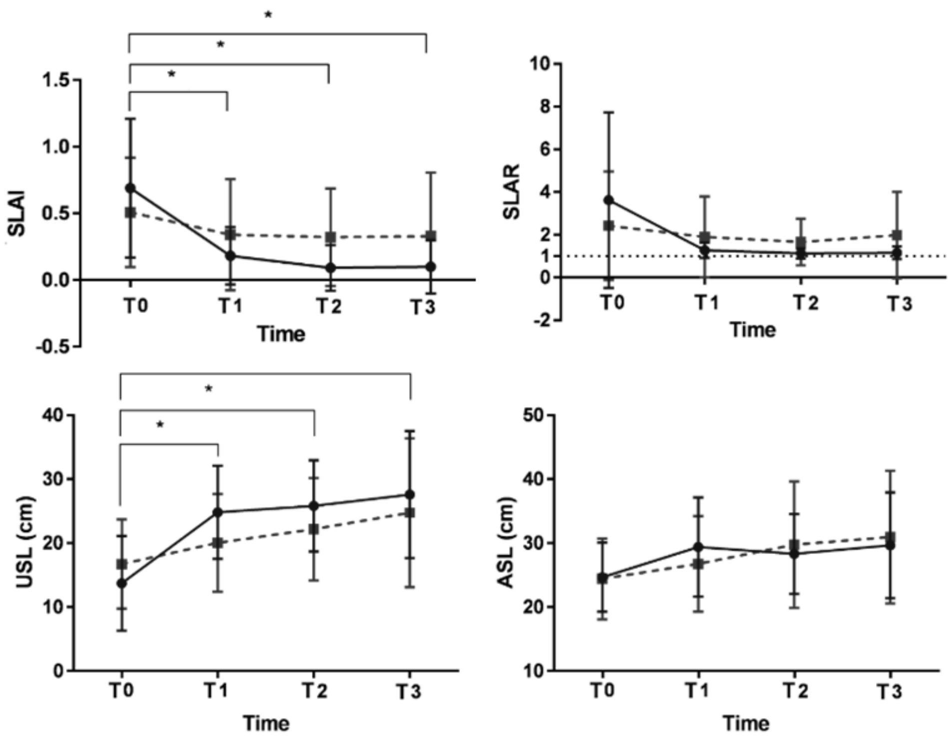

Figure 4. Comparison of step length parameters measured by BPMS through a time × intervention factor interaction *post-hoc* test between the training group (solid line) and control group (dotted line) before training (T0), during training (T1), after training (T2), and at post-training 4-week follow up (T3). * *Adjusted p-values < 0.05* was statistically significant for time × intervention interaction according to *post-hoc* tests. SLAI, step length asymmetric index; SLAR, step length asymmetric ratio; USL, un-affected step length; ASL, affected step length.

Post hoc comparisons showed that the AP training group's SLAI was better at T1, T2, and T3 than at T0 (p = 0.000, 0.000, and 0.000, respectively), indicating that the AP training group's SLAI increased during the treatment period and remained elevated 4 weeks after training ended. Asymmetry index of stance time, swing time, double support time, and SW/ST were not significantly different between the groups over time (Table 3).

Table 3. Comparison of asymmetric index of temporospatial walking parameter

Asymmetric index	AP training group		Control group		*p value*
	Before training	After training	Before training	After training	
Stance time	-12.2 ± 8.6	-14.2 ± 11.3	-15.9 ± 9.3	-16.4 ± 9.8	0.666
Swing time	59.2 ± 34.9	50.0 ± 29.0	61.1 ± 30.9	49.1 ± 24.8	0.679
Double support	1.3 ± 4.2	0.8 ± 6.7	0.5 ± 6.2	0.2 ± 7.9	0.666
SW/ST	69.4 ± 37.5	61.8 ± 32.5	74.8 ± 30.6	63.3 ± 26.6	0.634

Data presented as mean ± standard deviation; SW/ST, swing/stance time.

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2. Secondary outcome

A. Plantar pressure analysis

An RMANOVA test on affected side forefoot contact area, midfoot contact area, total foot contact area revealed a significant interaction between $Time_{(T0,\ T1,\ T2,\ T3)}$ and $Intervention_{(training,\ control)}$ (F(3.118), p = 0.040; F 4.673, p = 0.009; and F 3.832, p = 0.021, respectively), indicating that forefoot contact area, midfoot contact area, and total foot contact area were significantly higher after training for the AP training group than the control group (Table 4). An RMANOVA on affected side forefoot contact pressure, midfoot contact pressure, and total foot contact pressure revealed a significant interaction between $Time_{(T0,\ T1,\ T2,\ T3)}$ and $Intervention_{(training,\ control)}$ (F(4.307), p = 0.014; F(4.394), p = 0.010; and F(4.307), p = 0.015, respectively), indicating that forefoot contact pressure, midfoot contact pressure, and total foot contact pressure were significantly higher after training in the AP training group than the control group. Post hoc comparisons showed that, compared to T0, at T1, T2, and T3 forefoot contact area (p = 0.031, 0.001, 0.004, respectively), midfoot contact area (p = 0.011, 0.001, 0.003, respectively), total foot contact area (p = 0.003, 0.001, 0.004, respectively), forefoot contact pressure (p = 0.001, 0.000, 0.000, respectively), midfoot contact pressure (p = 0.042, 0.003, 0.001), and total foot contact pressure (p = 0.002, 0.014, 0.009, respectively) were significantly higher after training in the AP training group than the control group. These results indicated that the AP training group had significantly better forefoot contact area, midfoot contact area, total contact area, forefoot contact pressure, midfoot contact pressure, and total contact pressure during training and retained this improvement 4 weeks after the end of training. However, hindfoot contact area, hindfoot contact pressure, and peak contact pressure were not significantly different between the groups over time.

On the unaffected side, RMAONOVA tests revealed a significant interaction between $time_{(T0,\ T1,\ T2,\ T3)}$ and $intervention_{(training,\ control)}$ for forefoot contact area (F(2.937), p = 0.036) (Table 4). Post hoc comparisons showed that, compared to T0, at T2, T3, and T4 the AP training group had significantly higher forefoot contact area (p = 0.017, 0.045, 0.156, respectively), which indicated that the AP training group had significantly better forefoot contact area during AP training and retained this improvement 4 weeks after the end of training. The other parameters did differ significantly between the groups over time.

With regard to asymmetrical indices, RMANOVA revealed a significant interaction between time$_{(T0, T1, T2, T3)}$ and intervention$_{(training, control)}$ for forefoot contact pressure (F(3.236), *p* = 0.034) indicating that forefoot contact pressure increased more over time in the AP training group than the control group. Post hoc comparisons showed that, compared to T0, at T2, T3, and T4 forefoot contact pressure (*p* = 0.061, 0.001, 0.000, respectively) was higher in the AP training group than the control group, which indicated that the AP training group had significantly better forefoot contact area during AP training and retained this improvement 4 weeks after training ended. The other asymmetrical indices did not significantly differ between the groups over time.

With regard to foot scan trajectory, RMANOVA revealed a significant interaction between time$_{(T0, T1, T2, T3)}$ and intervention$_{(training, control)}$ for affected side AP trajectory (F(5.372), *p* = 0.003) and AP trajectory asymmetrical index (F(4.597), *p* = 0.019), indicating that affected side AP trajectory and AP trajectory asymmetrical index were significantly better in the AP training group than the control group. Post hoc comparisons showed that, compared to T0, at T1, T2, and T3 affected side AP trajectory (*p* = 0.002, 0.001, 0.001, respectively) was increased in the AP training group than in the control group and showed tendency for increase on the unaffected side. This indicated that the AP training group showed a significant improvement in the AP trajectory during training and that this improvement persisted for 4 weeks after the completion of training. The other foot scan trajectory parameters were not significantly different between the groups.

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Table 4. Comparison of plantar pressure analysis

Affected side	AP training group				Control group				*p* value
	Before training	During training	After training	Follow up	Before training	During training	After training	Follow up	
Contact area (mm^2)									
Forefoot	27.1±30.6	39.2±24.5	57.5±34.9*	56.0±42.1*	26.3±21.0	20.7±21.8	32.7±26.5	40.8±28.7	0.029
Midfoot	92.7±49.0	120.6±4*	149.7±54.2*	150.7±66.0*	106.4±64.0	99.2±53.0	116.0±52.5	117.0±58.0	0.004
Hindfoot	119.6±40.5	131.0±50.7	125.2±51.4	129.3±43.4	103.0±33.1	97.1±38.1	108.8±34.1	97.4±40.5	0.189
Total	239.5±93.5	290.8±89.6*	331.9±111.9*	337.4±132.4*	235.5±90.1	216.9±89.4	257.5±82.5	255.2±91.1	0.012
Contact pressure (kPa)									
Forefoot	26.4±34.6	51.7±46.9*	80.0±64.6*	80.7±63.3*	25.3±18.05	22.0±19.1	32.9±25.0	48.4±47.3	0.006
Midfoot	96.4±54.9	140.8±73.4	173.4±76.4*	202.9±107.3*	135.9±96.7	143.5±84.3	159.4±89.8	152.7±94.6	0.006
Hindfoot	185.2±80.2	213.2±88.7	190.5±67.0	211.6±114.2	181.1±97.6	174.5±101.8	180.2±88.6	173.4±117.7	0.523
Total	308.1±92.7	400.4±84.8*	420.0±121.3	487.4±214.0*	342.4±82.3	339.5±86.3	372.1±90.1	374.3±159.9	0.033
peak	418.7±134.4	477.8±118.6	489.5±161.8	566.1±256.3	430.7±99.0	417.5±94.7	473.7±152.2	479.6±163.4	0.306
Trajectory (mm)									
AP	43.3±65.9	72.6±56.0*	78.6±56.9*	91.1±57.3*	70.6±50.1	64.4±51.5	68.8±63.1	69.0±61.1	0.001
ML	6.3±5.0	9.2±7.8	10.2±8.0*	10.8±8.1*	10.9±6.5	9.7±7.3	8.3±4.9	8.7±7.1	0.018
NOB	1.4±0.6	1.6±0.8	1.5±0.7	1.6±0.9	1.3±0.7	1.7±0.7	1.3±0.5	1.3±0.5	0.553

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Table 4. Comparison of plantar pressure analysis

Unaffected side	AP training group				Control group				*p value*
	Before training	During training	After training	Follow up	Before training	During training	After training	Follow up	
Contact area (mm^2)									
Forefoot	69.7±36.9	89.9±43.3	84.9±35.3	84.0±34.31	82.4±46.0	76.7±38.3	73.9±38.1	78.5±32.1	0.036
Midfoot	146.4±56.3	164.9±55.2	162.1±57.7	158.7±68.4	177.0±49.9	174.0±51.3	161.0±50.0	168.3±55.0	0.177
Hindfoot	126.5±31.1	138.5±33.7	135.1±18.6	132.7±29.2	139.5±26.7	139.2±26.7	137.0±20.8	127.1±29.2	0.269
Total	342.4±106.5	393.3±119.9	382.0±88.4	375.3±115.5	398.9±104.0	389.9±99.7	372.0±83.1	374.1±103.1	0.071
Contact pressure (kPa)									
Forefoot	113.5±70.9	124.8±56.8	155.4±97.6	148.3±86.7	120.6±73.7	104.6±66.8	122.7±91.2	127.0±64.2	0.267
Midfoot	180.0±93.2	194.2±93.4	225.1±103.1	217.1±95.7	194.6±58.3	205.3±101.7	200.4±94.3	207.6±84.3	0.411
Hindfoot	239.2±105.3	229.9±63.5	237.0±49.9	254.7±146.7	247.4±69.4	231.3±78.6	272.2±72.7	223.4±95.4	0.272
Total	532.8±213.3	549.0±178.2	608.7±176.8	620.2±222.7	562.6±143.5	540.9±185.7	595.3±174.0	558.2±179.4	0.528
peak	701.4±275.8	667.5±228.5	758.7±270.1	753.2±268.2	716.0±210.9	678.5±243.2	734.9±216.8	710.4±233.9	0.866
Trajectory (mm)									
AP	140.0±29.9	145.2±42.7	155.0±26.4	154.5±23.1	159.7±24.0	157.5±26.8	141.4±39.3	153.0±33.2	0.053
ML	7.3±5.8	7.3±5.4	7.8±6.0	6.7±5.7	8.4±6.7	6.6±4.3	9.9±7.7	9.1±4.6	0.621
NOB	2.6±2.6	2.4±1.6	2.5±1.5	2.4±1.7	2.5±1.3	2.5±1.1	2.1±1.0	2.4±1.2	0.739

Data presented as mean ± standard deviation; * *Adjusted p-values < 0.05* was statistically significant for time × intervention interaction according to *post-hoc* tests. AP, anterio-posterior; ML, medio-lateral; NOB, number of back movement;

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B. Gait-related behavioral parameter

There was no significant difference in clinical evaluation parameters at T0 between the groups (Table 5). RMANOVAs revealed a significant interaction between time$_{(T0,\ T1,\ T2,\ T3)}$ and intervention$_{(training,\ control)}$ for knee extensor MRC score, ankle dorsiflexor MRC score, FMA, and BBS (F(4.626), p = 0.007; F(3.579), p = 0.036; F(3.276), p = 0.033; F(5.738), p = 0.005, respectively), indicating that the AP training group had significantly better knee extensor MRC scores, ankle dorsiflexor MRC scores, FMA, and BBS during training than the control group and maintained this improvement 4 weeks after training ended. Post hoc comparisons showed that, compared with T0, at T1, T2, and T3 knee extensor MRC score (p = 0.031, 0.001, 0.004, respectively), ankle dorsiflexor MRC score (p = 0.011, 0.001, 0.003, respectively), FMA (p = 0.003, 0.001, 0.004, respectively), and BBS (p = 0.001, 0.000, 0.000, respectively) were better in the AP training group than the control group, which indicated that the AP training group had significantly better knee extensor MRC scores, ankle dorsiflexor MRC scores, FMAs, BBSs during AP training and maintained this improvement 4weeks after training ended. However, MSWS, SSWS, FAC, FIM, and fall index were not significantly different between the groups over time.

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Table 5. Comparison of gait-related behavioral parameters.

	AP training group				Control group				*p value*
	Before training	During training	After training	Follow up	Before training	During training	After training	Follow up	
MRC on									
Hip flexor	3.1±0.6	3.2±0.6	3.5±0.8	3.7±0.7	3.1±0.7	3.3±0.7	3.3±0.7	3.5±0.8	0.288
Hip extensor	3.3±0.7	3.5±0.8	3.7±0.7	3.9±0.7	3.1±0.8	3.3±0.8	3.3±0.8	3.5±0.8	0.340
Knee flexor	3±0.7	3.2±0.7	3.5±0.8	3.7±0.7	2.9±0.8	3.1±0.8	3.1±0.9	3.3±0.9	0.081
Knee extensor	3.2±0.9	3.4±0.8	3.7±0.7*	3.8±0.8*	3.2±0.9	3.3±0.7	3.2±0.8	3.3±1	0.007
Ankle dorsiflexor	1.8±1.1	2.4±1.1*	2.6±1.1*	3±1.4*	2±1.2	2±1.2	2.2±1.1	2.5±1.2	0.036
Ankle plantarflexor	2.4±1.2	2.8±1.3	2.9±1.3	3.2±1.3	2.1±1.4	2.2±1.3	2.3±1.3	2.6±1.2	0.270
MSWS (m/s)	0.3±0.1	0.4±0.2	0.4±0.3	0.5±0.3	0.2±0.1	0.3±0.2	0.4±0.2	0.4±0.2	0.944
SSWS (m/s)	0.2±0.1	0.3±0.1	0.3±0.2	0.4±0.2	0.2±0.1	0.3±0.2	0.3±0.2	0.4±0.2	0.914
TUG (s)	46.8±24.6	38.9±24.2	34.3±19.9	28.7±10.7	56.1±64.2	51.8±55.6	43.1±48.2	38.6±31.1	0.836
FMA	39.9±17	49.5±20.9*	54.7±22.1*	58.5±20.6*	43.7±22.1	48.2±22.3	51.4±21.1	53.7±21.9	0.033
FAC	3.3±0.5	3.8±0.6	4.2±0.6	4.4±0.6	3.3±0.5	3.6±0.6	3.9±0.7	4.0±0.7	0.210
FIM mobility	18.4±2.7	21.3±3.8	24.6±4.6	26.6±5.6	17.1±4.1	19.1±4.2	22.3±5.5	24.4±6.2	0.857
BBS	25.4±7.3	36.8±6.6*	43.8±6.9*	45±8.6*	24.7±7.9	29.3±8.9	34.5±9.6	38.3±9.7	0.005

Data presented as mean ± standard deviation; * *Adjusted P-values < 0.05* was statistically significant for time × intervention interaction according to *post-hoc* tests. MRC, medical research council; MSWS, maximum safe walking speed; SSWS, self-selected walking speed; TUG, timed up and go; FMA, Fugl-Meyer assessment; FAC, functional ambulation category; FIM, functional independent measure; BBS, Berg balance scale.

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C. Gait analysis and energy consumption

At T0, there was no significant between-group difference with respect to energy consumption (Table 6). RMANOVAs revealed a significant interaction between time($_{T0, T2}$) and intervention($_{training, control}$) for O_2 cost (F(3.213), p = 0.042), indicating that the control group had significantly decreased O_2 cost than the AP training group.

Table 6. Comparison of energy consumption

	AP training group		Control group		*p value*
	Before training	After training	Before training	After training	
O_2 cost (mL/kg/m)	0.7±0.4	0.6±0.4	0.8±0.4	0.5±0.3*	0.042
O_2 rate (mL/min/kg)	8.0±2.3	7.9±1.8	7.9±1.7	7.8±2.1	1.000

Data presented as mean ± standard deviation; * $p < 0.05$ was statistically significant for time × intervention interaction.

In terms of temporospatial, kinetic, and kinematic parameters, there were no significant differences between the two groups at before training or over time (Table 7, 8, 9).

Table 7. Comparison of temporospatial walking parameters

	AP training group		Control group		
	Before training	After training	Before training	After training	*p value*
Cadence (step/min)	57.4±14.1	62.6±20.3	53.2±15.6	58.8±19.1	0.809
Walking speed (m/s)	0.2±0.1	0.3±0.2	0.2±0.1	0.3±0.1	0.742
Stride time(s)	2.3±0.8	2.2±0.9	2.5±0.8	2.3±0.7	0.214
Step time (s)	1.2±0.3	1.2±0.5	1.3±0.4	1.2±0.5	0.271
Single support time (s)	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.876
Double support time (s)	1.5±0.8	1.3±0.9	1.6±0.8	1.3±0.7	0.574
Stance time (s)	1.7±0.8	1.6±0.9	1.8±0.9	1.5±0.7	0.370
Swing time (s)	0.6±0.3	0.6±0.2	0.7±0.4	0.7±0.5	0.316
Stride length (m)	0.4±0.1	0.5±0.2	0.4±0.1	0.5±0.2	0.298
Step length (m)	0.3±0.1	0.3±0.1	0.3±0.1	0.3±0.1	0.376

Data presented as mean ± standard deviation;

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Table 8. Comparison of kinematic parameters

	AP training group		Control group		
Affected side	Before training	After training	Before training	After training	*p value*
Pelvic max anterior tilit angle at ST	18.4±5.3	18.1±4.3	20.7±4.9	19.1±3.5	0.439
Hip max flexion angle at IC	27.6±11.7	28.7±9.0	28.8±8.7	27.9±5.7	0.400
Hip max flexion angle at SW	33.2±11.3	34.1±8.5	36.8±8.0	35.5±7.0	0.373
Hip min flexion angle at ST	13.1±10.6	10.1±10	13.1±8.6	10.4±7.9	0.925
Hip max abduction angle	3.1±5.6	3.6±4.6	5.3±4.2	5.3±3.4	0.778
Hip max adduction angle	-6.4±6.4	-6.6±3.8	-4.9±2.7	-4.7±3.0	0.750
Knee flexion angle at IC	15.6±8.1	13.8±7.3	14.1±7.7	12.3±6.3	0.997
Knee min flexion angle at ST	8.8±10.2	7.2±10.2	5.9±9.0	5.6±8.0	0.658
Knee max flexion angle at SW	34.2±13.2	38.6±13.5	33.6±11.2	33.0±10.0	0.142
Ankle DF angle at IC	-13.9±5.8	-13.8±6.1	-14.8±9.1	-13.2±8	0.362
Ankle max DF angle at ST	2.7±8.6	3.6±6.9	2.5±7.4	4.2±6.2	0.678
Ankle max PF at SW	-17.2±8.2	-16.8±7.3	-18.0±10.1	-14.4±8.4	0.095

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Table 8. Comparison of kinematic parameters

	AP training group		Control group		
Unaffected side	Before training	After training	Before training	After training	*p value*
Pelvic max anterior tilit angle at ST	18.8±5.4	18.2±4.2	21.2±5.4	19.3±3.8	0.442
Hip max flexion angle at IC	38.5±8.7	40.2±6.4	40.9±8.3	39.2±7.4	0.183
Hip max flexion angle at SW	39.8±9.4	42.6±6.3	43.0±9.3	42.8±6.5	0.185
Hip min flexion angle at ST	9.7±9.2	7.0±7.2	8.3±8.6	5.8±7.5	0.970
Hip max abduction angle	3.8±4.6	4.1±4.6	4.5±3.9	3.7±4.9	0.441
Hip max adduction angle	-8.2±5.1	-8.9±5.1	-7.7±6.3	-8.9±6.8	0.754
Knee flexion angle at IC	27.1±7.6	26.3±7.1	26.7±5.6	24.8±8.7	0.651
Knee min flexion angle at ST	16.0±7	13.6±8.0	11.0±6.9	11.8±5.9	0.090
Knee max flexion angle at SW	55.4±7.8	59.4±8.5	55.4±10.4	60.3±9.0	0.720
Ankle DF angle at IC	0.7±4.6	-1.5±6.2	1.1±4.3	-2.8±6.6	0.432
Ankle max DF angle at ST	15.6±4.0	14.2±3.7	15.4±5.4	14.5±4.2	0.693
Ankle max PF at SW	-4.9±5.6	-9.4±7.1	-6.8±6.5	-11.6±6.6	0.873

Data presented as mean ± standard deviation; ST, stance phase; IC, initial contact; SW, swing phase; DF, dorsiflexion; PF, plantarflexion;

Table 9. Comparison of kinetic parameters

	AP training group		Control group		
	Before training	After training	Before training	After training	*p value*
Affected side					
Hip max flexion moment	0.4±0.2	0.3±0.1	0.3±0.2	0.3±0.1	0.512
Hip max extension moment	-0.3±0.1	-0.3±0.	-0.3±0.1	-0.4±0.2	0.260
Hip max power generation	0.8±0.3	0.8±0.4	0.7±0.2	0.8±0.3	0.794
Hip max power absolution	-0.9±0.8	-0.8±0.6	-0.7±0.7	-0.6±0.7	0.945
Knee max flexion moment	0.3±0.2	0.3±0.2	0.2±0.2	0.2±0.3	0.975
Knee max extension moment	-0.2±0.1	-0.2±0.1	-0.2±0.1	-0.1±0.1	0.991
Knee max power generation	1.8±1.2	1.8±0.9	1.6±1.0	1.7±1.0	0.736
Knee max power absolution	-0.3±0.1	-0.3±0.1	-0.3±0.1	-0.2±0.1	0.612
Ankle max PF moment	0.6±0.3	0.6±0.2	0.6±0.2	0.6±0.3	0.907
Ankle max DF moment	-0.0±0.0	-0.0±0.0	-0.0±0.1	-0.0±0.1	0.980
Ankle max power generation	9.2±0.7	9.1±1.3	9.2±0.8	9.3±0.8	0.554
Ankle max power absolution	-0.1±0.0	-0.1±0.0	-0.1±0.0	-0.1±0.0	0.816
Unaffected side					
Hip max flexion moment	0.5±0.2	0.5±0.2	0.5±0.2	0.4±0.1	0.560
Hip max extension moment	-0.5±0.2	-0.5±0.2	-0.4±0.2	-0.5±0.3	0.840
Hip max power generation	0.6±0.2	0.8±0.2	0.7±0.3	0.7±0.3	0.256
Hip max power absolution	-1.6±0.6	-1.7±0.4	-1.4±0.5	-1.5±0.5	0.766
Knee max flexion moment	0.7±0.2	0.7±0.2	0.6±0.2	0.6±0.3	0.948
Knee max extension moment	-0.2±0.0	-0.2±0.1	-0.2±0.1	-0.2±0.0	0.407
Knee max power generation	3.1±0.7	3.1±0.5	2.7±0.8	2.9±0.8	0.366
Knee max power absolution	-0.7±0.2	-0.7±0.2	-0.6±0.2	-0.6±0.2	0.895
Ankle max PF moment	0.8±0.2	0.8±0.2	0.7±0.2	0.8±0.2	0.246
Ankle max DF moment	-0.0±0.0	-0.0±0.0	-0.0±0.0	-0.0±0.1	0.511
Ankle max power generation	9.6±0.8	9.7±0.7	9.4±0.5	9.3±0.7	0.612
Ankle max power absolution	-0.1±0.1	-0.2±0.1	-0.2±0.1	-0.1±0.2	0.082

Data presented as mean ± standard deviation; PF, plantarflexion; DF, dorsiflexion;

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IV. DISCUSSION

The effect of AP training on gait asymmetry already reported in our previous study in chronic stroke patients. In this study, we tried to confirm the effect of AP training in the sub-acute stroke patients, as we know it is first randomized control trial study in sub-acute stroke patients using biofeedback in weight shifting training. In this study, sub-acute stroke patients who received AP training with traditional rehabilitation showed significant improvement in step length asymmetry, forefoot contact area and pressure, Berg balance scale score, and Fugl-Meyer assessment scale of lower extremity compared to their counterparts who received only educational intervention with traditional rehabilitation.

1. Primary outcome

According to our study results, AP training group showed significant improvement in step length asymmetry compared to the control group. Reismane et al., emphasized the importance of motor adaptation through repetitive training to improve gait asymmetry.[26] In my opinion, AP training appropriately reflected “functional activity”, “biofeedback”, and “repetitive gait training”, which were emphasized in previous studies.[26-28] In common with this study’s result, the previous studies were reported that repetitive weight-shifting training to the affected side was effective in improving step length asymmetry, and they used compelled weight shift training[29] and body weight support training.[30] Conversely, Sheikh et al., did not confirm that the effect of gait training combined with compelled body weight shift therapy was better than gait training alone on improving gait symmetry.[31] The authors discussed that the training would have been more effective through increasing the use of paretic limb in “functional activities”.[31] AP training induces the patient to repeat the gait cycle (from the initial contact on the affected side to the mid-stance phase on the unaffected side) with weight shift to the affected side while playing an archery game with biofeedback. Taken together, we suggest that AP training is a more effective training method than educational intervention for symmetrical gait.

Step length asymmetry is related to propulsive force from the paretic leg [2], walking speed[2,32,33], balance[34], metabolic cost of walking[33] etc.. In this study's results, sub-acute stroke patient who received AP training had better gait symmetry from 2nd week of training (T1) than sub-acute stroke patient who received only educational intervention and the difference in symmetrical change maintained until 4 weeks after training (T3). At the same time (T1 ~ T3), study's results demonstrated that the propulsive force from the paretic leg and balance ability were significantly improved in the training group than control group. In walking speed, the AP training group tended to improve the average maximum walking speed by 0.1 m/sec compared to the control group, but there was no statistical difference. However, this study did not confirmed improvement in metabolic cost of walking. In the following secondary outcome, we will discuss at the findings in more detail in secondary outcome.

2. Secondary outcome

A. Plantar pressure analysis

The factors that affect asymmetrical gait are very diverse, and many studies have mentioned that it is important to improve step length asymmetry along with proper weight transfer when they walking.[35] The AP training group had significantly more contact area and contact pressure for the anterior two-thirds of their feet and had a greater affected side AP trajectory than the control group. It proves the increase in propulsive force during push-off. Also, can demonstrate an improvement in step length asymmetry with proper weight distribution in the AP training group, not just increasing step length on the affected side. These results were consistent with those of previous studies that weight-shift training with biofeedback helped patients more effectively distribute their weight.[36,37] Also, Nunzio et al. reported that participants who received weight-shift training with biofeedback had a significantly better CoP asymmetry index than those who did not.[37] In contrast to our findings, a recent meta-analysis of visual feedback training in standing in acute and subacute stroke subjects showed no effect on weight distribution, postural sway, or gait compared to conventional therapy.[38] Van peppen et al., indicating that training of postural control should be applied while performing the gait-related tasks itself.[38] This is similar to the importance of motor adaptation in functional activities mentioned above and AP training was appropriate training for performing the gait-related tasks.[26,39-41] Also, interactive rehabilitation programs potentially entail an effective adaptive motor learning process resulting in better functional outcomes[42,43] and visual feedback is one form of effective interactive training.[27,28] Therefore, improvements in weight distribution and trajectory observed in this study suggested that weight shift training with biofeedback during AP training were more effective than educational intervention for weight disturbance.

Among the results of this study, increasing the area and pressure of the forefoot, midfoot, and total foot means increased propulsive force during push-off. Padmanabhan et al. reported that improving step length asymmetry without improving propulsion is not effective for patient's overall gait.[5] The results of this study were more meaningful because it confirmed improvement in step length asymmetry with increasing forward propulsion while walking.

B. Gait related behavior parameters

In gait related behavior parameter's results, the AP training group had significantly better balance control with improved lower extremity motor ability than the control group. Our results were similar to those of other studies that showed that visual feedback training affected balance and motor fucntion.[13,44-46] Importantly, Lauziere et al., reported that there are strong relationship between motor function of the paretic lower extremity, balance control, weight bearing distribution, and gait asymmetries in stroke patients.[4] Previous studies found that ankle dorsiflexor strength, ankle plantarflexor strength, knee extensor strength, plantarflexor peak torque and motor function of the paretic lower extremity measured with FMA significantly correlated with spatiotemporal asymmetry. The behavior parameters shown improvement in this study are very similar to those related to the spatiotemporal asymmetric factors mentioned in the previous studies.[47,48] The AP training

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group had a higher knee extensor MRC score than the control group as a result of their higher BBS, allowing them to better shift their weight to the affected side to balance better and walk more safely.[49]

C. Gait analysis and energy consumption

This study did not confirmed improvement in energy consumption, temporal asymmetry, kinetic and kinematic parameter. We expected that improvement in step length asymmetry lead to reduce double support time and increase paretic single support time.[50] Also, previous study suggested an important role of plantar flexor muscles and hip flexor muscles in step length asymmetry.[4] In this study, the AP training group tended to show reduced double support time and improved angular variables of hip and ankle. However, these gains were observed for both groups and between-group difference was not statistically significant. There were only few RCT studies that used kinematic data to outcome measure, and there are also did not confirm the significance between groups.[51,52] Further research is needed to confirm the correlation between functional recovery and gait kinematic parameters. In another interpretation, Nikamp et al. explained that 3D gait-analysis measured in specialized gait laboratory was affect walking parameters[53], and we also necessary to consider whether the unfamiliar environment affected the patient's gait during 3D gait analysis.

In comparison of energy consumption, we replicated prior findings showing that improving step length symmetry with visual feedback had no significant effect on metabolic cost.[5,54,55] Also, the previous study reported that no assertions can be made about the relationship between energy expenditure and spatiotemporal symmetry in stroke.[4] Padmanabhan et al. demonstrated that post-stroke often retain the ability to walk with symmetric step lengths (symmetric steps); however, the resulting walking pattern remains effortful.[5] Actually, patient who received AP training paid more attention to gait symmetry while attending research compared to the control group. Wutzke et al. argued that long-term correction and learning are necessary to symmetrical walking with reduced energy

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consumption.[35] Therefore, it is expected that energy consumption can be reduced by reducing the concentration required for symmetrical walking through more intense and repetitive training.[35] We expected to reduce energy consumption if the stroke patients receive the AP training for at least 3 months or more and symmetrical walking in stroke patients becomes a habit without motor planning.

Although the sub-acute phase, these patients already have compensatory patterns that may require a longer time to change.[56] AP training used the trackers to prevent the patients from using a compensatory posture of bending the knee when shifting weight to the affected side. The AP training group tended to show improved knee minimal flexion angle at stance phase by 2.4 degree. In contrast, the control group did not improve knee minimal flexion angle at stance phase. This suggests that compensatory strategies may have been minimized when shifting weight to the affected side in the AP training group compared to the control group, even though the differences between groups were not statistically significant. Thus, we believe that AP training is an effective training method to help stroke patients bear weight on the affected side in an appropriate posture.

3. Limitations and further study

Some limitations of this study should be considered while interpreting the results. First, all participants were receiving acute management in severance hospital, so they received a lot of intervention during study participation. We tried to give the same intervention intensity for all study participants to eliminate bias. Second, we did not confirm improvement in temporal asymmetry. I think it is need for further studies with a larger number of subjects should conducted because other behavioral parameters related to temporal asymmetry were significantly improved in the AP training group than the control group. Third, we trained stroke patients for 4 weeks. The period of this study was in consideration of the period of hospitalization for acute rehabilitation in Korea, but if possible, a long-term training study would yield more positive results.

This study conducted in RCT study with a training method tailored to the latest research

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trends. The strength of this research was that it collected and analyzed various data such as 3D motion analysis, plantar pressure analysis, and clinical data. There are not many studies in which the usage parameters have been analyzed in this study, so it is hoped that it will be helpful for future RCT studies.

Our research focus on visual feedback, but recent study reported that tactile and detailed auditory feedback also have been shown to be effective in helping to improve the gait patterns of stroke patients.[57,58] Ma et al. reported that a wearable vibro-tactile biofeedback device had an immediate effect on plantar loading and gait pattern in chronic stroke patients.[59] Therefore, further research should be conducted to determine how to best combine visual, tactile, and auditory biofeedback to maximize the effectiveness of stroke gait rehabilitation.

The future goal of gait rehabilitation for stroke patients is not simply to walk, but to improve the quality of the gait pattern. Also, there is a need for diverse and easy-to-access rehabilitation training methods that can improve the quality of patients' walking pattern. Recently, many wireless trackers and pressure sensors have been developed, and if a wireless system is applied to AP training, stroke patients will be able to do high-quality home training on their own.[60]

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V. CONCLUSION

In this randomized control trial study investigated that the effect of the AP training which is the repeated the gait related process in acute stroke patients with step length asymmetry through various parameters. According to this study's result, AP training group significantly improved in step length asymmetry, weight disturbance, balance control, motor function of lower extremity such as ankle dorsi/plantarflexor strength, knee extensor strength than control group. However, there were no differences between groups in temporal asymmetry, energy consumption, kinetic and kinematic parameter. Taken together, these results show that AP training improved the stroke patient's asymmetric gait pattern. Therefore, AP training may improve patients' asymmetric gait patterns or prevent them from worsening. So, this study suggests that clinicians should consider on the weight shift training with biofeedback in all patient with shorter non-paretic step length during gait rehabilitation. Early gait pattern has a significant impact on later independent walking, it is recommended to provide AP training to subacute stroke to improve asymmetrical gait patterns.

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APPENDICES

Acronyms and Abbreviations

AP	Anterio-posterior
AP training	Anterio-posterior weight-shift training with visual biofeedback
ASL	Affected side step length
BBS	Berg balance scale
CoP	Center of pressure
FAC	Functional ambulation category
FIM-mobility	Functional independent measure-mobility
FMA	Fugl-Meyer assessment
K-MMSE	Korean-mini mental state examination
ML	Mediolateral
MRC	Medical research council score
MSWS	Maximum safe walking speed
NOB	Number of back movement
RMANOVA	Repeated-measure analysis of variance
SLAI	Step length asymmetric index
SLAR	Step length asymmetric ratio
SSWS	Self-selected walking speed
TUG	Timed up and go test
USL	Unaffected side step length

Evaluation time points

T0	Before training
T1	During training (2weeks)
T2	After training (4weeks)
T3	After training 4weeks follow up (8weeks)

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ABSTRACT (IN KOREAN)

비대칭적 보행 패턴을 보이는 아급성기 뇌졸중 환자에게 시각적 피드백을 이용한 전후 방향의 족 저압 체중 이동 훈련이 미치는 영향

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조 예 진

뇌졸중 환자는 전형적으로 비대칭적인 보행 패턴을 가진다. 선행 연구에서는 시각적 피드백을 이용한 체중이동 훈련이 대칭적인 자세를 얻는데 효과적일지도 모른다고 밝혔다. 그러나 아직 비대칭적 보행 비대칭이나 패턴에 대한 치료적 효과를 확인한 연구는 없었다. 본 연구에서는 시각적 피드백을 이용한 전후 체중이동 훈련이 아급성기 뇌졸중 환자의 비대칭적 보행 패턴에 효과적인지 조사하는 것을 목적으로 진행하였다.

연구에는 46명의 비대칭적 보행패턴을 가진 아급성기 환자가 등록 되었고, 무작위 배정을 통해 두 그룹으로 나뉘었다. 훈련 군은 고식적 보행훈련과 AP 훈련을 각각 주 5회 4주동안 받았다. 대조군은 고식적 보행훈련을 주 5회 4주동안 받고, 스스로 훈련할 수 있도록 체중이동 자세에 대한 교육을 받았다. 훈련 전과 후 3차원 동작 분석과 산소소모량 검사를 시행했다. 보폭 비대칭, 족 저압 분석과 보행 관련 평가 functional ambulation category (FAC), self-selected walking speed(SSWS), maximum safe walking speed (MSWS), Berg balance scale (BBS), Fugl-Meyer assessment (FMA), medical research council score (MRC), functional independent measure-mobility (FIM), timed up and go test (TUG))를 훈련 전, 훈련 중, 훈련 후, 훈련 후 4주후 시점에 평가했다. 모든 평가 변수의 그룹간 유의성

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확인 시 반복측정 분산분석과 사후검정을 진행했다.

보폭 비대칭 지수, 건측 보폭, 환측의 AP 트라젝토리, AP 트라젝토리의 비대칭 지수는 훈련 군에서 대조 군과 비교하여 유의하게 개선되었다. FMA, BBS, 무릎 폄 근의 MRC 점수와 발목의 등쪽 굽힘 근의 MRC 점수에서 훈련 군이 대조 군에 비해 유의하게 개선되었다. 환 측의 앞발, 중간 발, 전체 발의 접촉 면적과 압력에서 훈련 군이 대조 군에 비해 유의하게 개선되었다. 하지만 SSWS, MSWS, TUG, FIM-mobility, O_2cost, O_2rate에서는 두 군간 유의성이 없었다.

이 연구의 결과는 AP training 이 아급성기 뇌졸중 환자의 비대칭적인 보행 패턴을 개선시키는데 도움을 줄 수 있을 것이라고 제안한다.

핵심되는 말: 뇌졸중, 비대칭적 보행, 체중이동 훈련