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Effects of treadmill training with optic flow on balance and gait in individuals following stroke: randomized controlled trials

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Abstract

Objective: This study examined the effects of treadmill training with optic flow on the functional recovery of balance and gait in stroke patients.

Design: Randomized controlled experimental study.

Participants: Thirty patients following stroke were divided randomly into the treadmill with optic flow group ($n = 10$), treadmill group ($n = 10$) and control group ($n = 10$).

Interventions: The subjects in the experimental group wore a head-mounted display to receive speed-modulated optic flow during treadmill training for 30 minutes, while those in the treadmill group and control group received treadmill training and regular therapy for the same time, three times a week for four weeks.

Main measures: The data were collected using timed up-and-go test, functional reach test, 10-m walk test, and six-minute walk test before and after treatment.

Results: The timed up-and-go test in the treadmill with optic flow group (5.55 ± 2.04) improved significantly greater than the treadmill (1.50 ± 0.93) and control (0.40 ± 0.84) groups. The functional reach test in the treadmill with optic flow group (2.78 ± 1.44) was significantly higher than the control group (0.20 ± 0.16) only. The gait velocity in the treadmill with optic flow group (0.21 ± 0.06) showed a significant decrease compared to the treadmill (0.03 ± 0.02) and control (0.01 ± 0.02) groups. Finally, the six-minute walk test in the treadmill with optic flow group (24.49 ± 11.00) showed significant improvement compared to the treadmill training (4.65 ± 3.25) and control (1.79 ± 3.08) groups.

Conclusion: Treadmill using optic flow speed modulation improves the balance and gait significantly in patients with stroke who are able to participate in physical gait training.

Keywords

Stroke, gait performance, postural control

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Introduction

The impairments caused by stroke, such as a decreased range of motion, muscular weakening, changes in muscle tone, sensory deficits, abnormal postural responses and cognitive problems are often reported to cause dysfunction in balance and gait, even though disability characteristics can vary depending on the damaged area.[1] The impairments of most significance to gait are a slow gait cycle and gait speed, temporal asymmetry in the affected and less affected limbs, short stance phase and relatively longer swing phase in the affected limb, which decreases the walking ability and reduces the endurance, resulting in difficulties in the independent activities of daily living.[2]

Most important factors for independent gait training involve full weight-bearing, balance and coordination. Treadmill training has been used in clinics as a therapeutic approach for improving the gait in the stroke population,[3,4] and has been reported to assist postural stability.[5] On the other hand, visual information about the direction and speed of walking provides incongruity compared to the proprioceptive input during treadmill training.[6]

Recently, the optic flow developed by locomotion, such as controlling the direction and location of where to put one's foot down to avoid obstacles while walking, acts as a clue and proves that the gait parameter is improved by the optic flow speed adjustment.[6,7] The optic flow is the pattern of the visual information about the direction and speed generated by the relative motion between a patient's eye and the surrounding environment.[8] When the patient identifies the incongruity between optic flow and their proprioceptive information from the lower extremities, walking speed is accustomed to diminish the incompatibility.[9,10]

The postural stability is improved by the optic flow concentration during a visual task,[7] and visual control of locomotion improves the ability to maintain postural stability.[11] Lamontagne *et al.*[6] reported changes in gait velocity caused by changing the speed of optic flow in the stroke population. The great improvement in gait speed was observed at a constantly changing optic flow speed rather than in a continually changing one. Speed control of optic flow was found to increase the gait velocity in stroke patients but this was a cross-sectional study. Therefore, a study that demonstrates the treatment effects of training is needed. Treadmill with optic flow contributes to improving the gait and balancing abilities in stroke patients but there have been few studies on the training effects of treadmills with optic flow.

For this reason, this study examined the effects of a treadmill with optic flow in the stroke population using the changes in optic flow speed, a comparison of treadmill training for balance and gait, and treadmill with optic flow that uses the changes in optic flow speed to provide an effective training method for balance and gait rehabilitation in stroke patients.

Methods

Thirty-six persons with a chronic hemiparetic stroke were recruited from J Hospital using a leaflet explaining the study information. Four participants were excluded because they were unable to walk for 15 minutes. The patients were divided randomly into three groups (treadmill with optic flow group, treadmill group and control group) by an independent person who picked one of the sealed envelopes before the start of the intervention. All subjects signed an informed consent form after receiving information on the study purpose, procedure, possible benefits and risks, privacy and use of data. The study was approved by the human research ethics committee of all participating institutions.

The study design of the experiment was the pre-test–post-test control group design. All subjects were evaluated before training and at the end of the four-week training period. Because of another treatment and the lack of participation, two participants dropped out before the post-test, one in the treadmill with optic flow group and one in the treadmill group. Therefore, 10 patients in each group finished this experiment (Figure 1).

The detailed subject criteria were as follows: (1) hemiparetic stroke patients six months after diagnosis; (2) patients who could walk on their own for more than 15 minutes; (3) patients without visual disabilities or hemianopia; (4) patients who had a mini-mental state examination score of 21 or higher[12]; and (5) Brunnstrum stage >4.[13] Table 1 lists the general characteristics of the three groups. Exclusion criteria were cardiovascular problems, orthopaedic and other neurological diseases except stroke for influencing gait.

Interventions

The treadmill with optic flow group underwent the exercises for four weeks, three times a week, for 30 minutes each day, whereas the treadmill and control groups received treadmill training only and stretching added range of motion exercises for the same time.

The treadmill with optic flow group can control and adjust the speed of optic flow applied to each patient, and the treadmill with optic flow environment is a programme which reproduces the environment of walking on a street. The treadmill with the optic flow programme employed computer hardware for the output, and was applied to the subjects using a head-mounted device (MSP-209, Kowon Technology, Seoul, Korea). Before applying the optic flow speed, the gait speed of each subject was evaluated by performing a 10-m gait test, and was re-tested every week. Based on the studies by Lamontegne *et al.*[6], stable

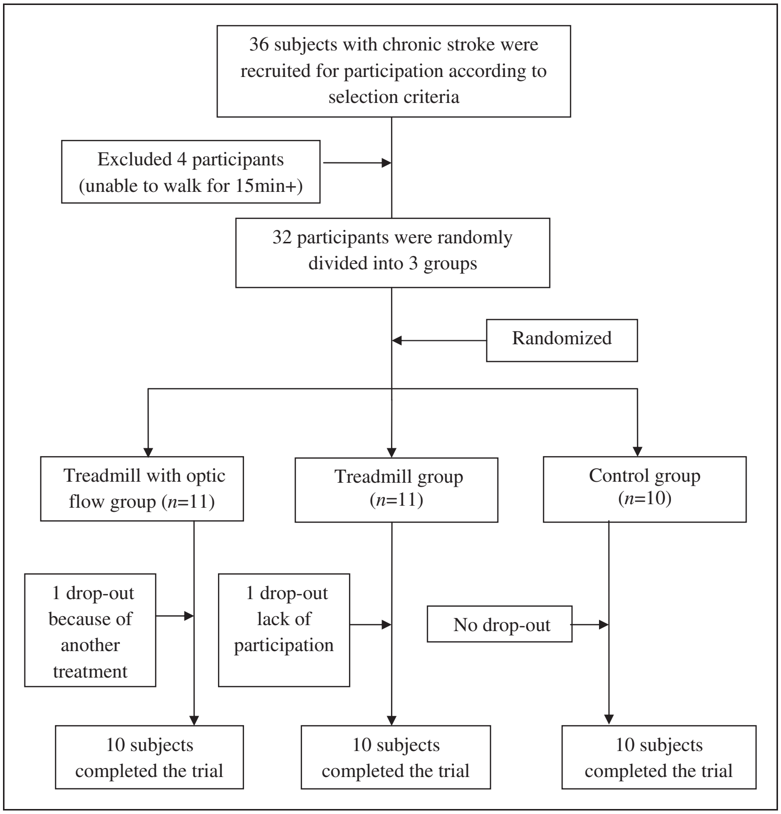

Figure 1. Flow diagram of participants through the study.

Table 1. General characteristics of the subjects

Variable	TOF group	Treadmill group	Control group	x^2/F	*P*
Gender					
Male	6	4	6	1.071	0.585
Female	4	6	4		
Age (year)	55.9 (6.5)	56.3 (7.6)	56.1 (7.8)	0.007	0.993
Post-stroke duration (months)	14.1 (4.4)	13.5 (4.0)	15.1 (7.4)	0.343	0.713
MMSE	24.2 (2.3)	23.7 (2.0)	24.7 (3.5)	0.356	0.704
Aetiology					
Ischaemic	6	3	6	2.400	0.301
Haemorrhage	4	7	4		
Paretic side					
Right	6	6	5	0.271	0.873
Left	4	4	5		
Brunnstrome stage					
Stage 4	8	7	6	0.952	0.621
Stage 5	2	3	4		

MMSE, Mimi Mental State Examination; TOF group, treadmill with optic flow group.

and inconsistent optic flow was determined, and applied in seven sections: 0.25, 0.5, 1.0, 1.5, 2, and 1.5, and 1.0 times the gait speed of each patient, and a training period of 1, 1, 2, 3, 4, 3, and 1 minute for each section. This study was performed two times for 15 minutes, and a set interval of five minutes was taken for the resting time. The patients wore earphones to adapt to the head-mounted device for five minutes before the experiment and for auditory control. Treadmill (Sky Life 5300, Iljin Sports, Seoul, Korea) training measured the 10-m gait speed of the patients, and then executed the treadmill training based on the measured stable gait speed. The treadmill speed was increased by 0.1 km/h each time once the patient could walk stably for more than 20 seconds.[14]

The treadmill group underwent treadmill training only, controlling the difficulty using the same method in the treadmill with optic flow group, i.e. treadmill speed was increased by 0.1 km/h each time once the participants could walk stably for more than 20 seconds. This study was performed two times for 15 minutes, and a set interval of five minutes was taken for the resting time. The control group received general stretching added range of motion exercises in the less and more affected sides of the trunk, arms and legs for the same time. For conventional physical therapy, exercise therapy was performed using the traditional motor development theory and neurodevelopmental treatment based on motor learning theory. All patients who participated in this study received conventional physical therapy five times a week for four weeks (Figure 2).

All subjects who used a treadmill wore a suspension device for safety purposes. To prevent subjects from experiencing a fall during training, the therapist stood beside the subjects and the subjects were allowed to grab the handrails but were discouraged from using them to assist in weight support.

Outcome measures

Two physical therapists with clinical experience of therapeutic intervention for stroke populations were used for rehabilitation training and other physical therapists, with experience of clinical measures, used this study for the blinding measurements. Education and practice on how to use the devices took place one week before the experiment and measurement.

In the timed up-and-go test, each patient was instructed to sit with their back against a chair with an armrest. On the cue, 'Go', the patient was asked to stand up, walk at a comfortable speed to the marked point, which was three metres away from the chair, turn around, walk back, and sit down in the chair.[15] The time taken to do this process was measured three times using a stopwatch, and the mean value was recorded. The intra-rater ($r = 0.99$) and inter-rater ($r = 0.98$) reliabilities demonstrated high reliability.[16]

The functional reach test was developed to measure the motional balancing ability, and evaluate the stability limitations. The measurement methods were as follows. Each subject was asked to stand against a wall 10 cm away with their shoulder flexed 90○ and their fists clenched. They were then asked to reach as far forward as they could, keeping their arm parallel to the floor. The movement distance of the metacarpophalangeal joint was measured.[17] The evaluation–re-evaluation reliability ($r = 0.89$) and intra-rater reliability ($r = 0.98$) were within the acceptable range.[18]

As a method for evaluating the walking speed, the 10-m walk test measured the time that each subject took to move at the highest speed, and was calculated in m/s unit. To remove the increasing and decreasing time that takes place in the beginning and end of the walking test, each subject was asked to walk a 14-m distance, and the speed of the midrange (10 m) was measured. Timing with a stopwatch began

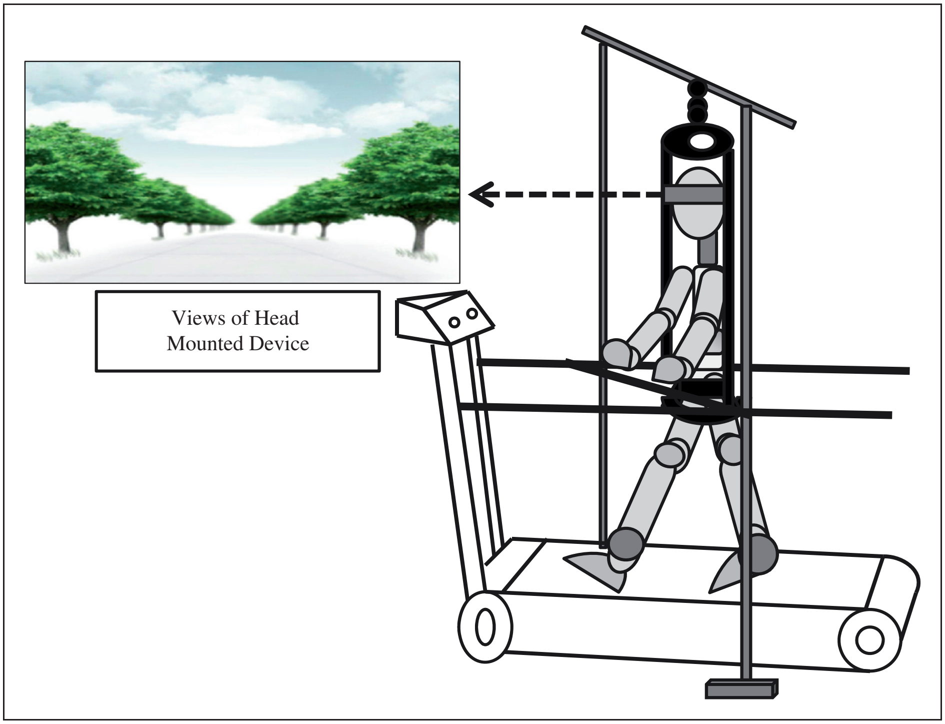

Figure 2. The training apparatus on the treadmill with optic flow. Participants were asked to maintain their walking pattern on an upright posture regardless of the changing treadmill speed.

when the subject was instructed 'Go' and ended when the subject crossed the 10-m marker. This was measured three times and the average was used for analysis.[19] The inter-rater and intra-rater reliability was high ($r = 0.89$ to 1.00). [20]

The six-minute walk test was developed as a gait evaluation method to measure the maximum distance that a person can walk, and evaluates the maximum cardiopulmonary functions. The distance from the starting point of gait on the track for six minutes, and the round track (50 m of a single loop, every 10 m maker) in a large indoor space were added and recorded.[20] Timing with a stopwatch was read for six minutes and the tester directed comments with the standardized statements of 'You are doing well' or 'Keep up a comfortable and safe pace' for the attending tests. The tester also monitored the rating of perceived exertion in participants. The test has been shown the high score of test–retest reliability.[21]

Data analysis

This study used the SPSS 12.0 program for data analysis. Kolmogorov–Smirnov was used for the general property and variables of the subjects. One-way analysis of variance (ANOVA) was used to compare the change in the scores of the pre- and post-treatment in each group, and a post-hoc test using the least significant difference (LSD) method was employed to compare each group. The significance level was set to $P < 0.05$.

Results

After training, the time of timed up-and-go test in the treadmill with optic flow group was significantly greater than the treadmill and control groups. The changeable time score before and after training was 5.55 ± 2.04, 1.50 ± 0.93 and 0.40 ± 0.84 in the treadmill with optic flow, treadmill and control groups respectively. The distance of the functional reach test in the treadmill with optic flow group (mean changeable distance, 2.78 ± 1.44) was significantly higher than the control group (mean changeable distance, 0.20 ± 0.16) but not the treadmill group (mean changeable distance, 2.38 ± 1.59). The distance of the functional reach test in the treadmill group improved significantly compared to the control group (Table 2 and Figure 3).

The gait velocity in the treadmill with optic flow group (mean changeable velocity, 0.21 ± 0.06) showed a significant decrease compared to the treadmill group (mean changeable velocity, 0.03 ± 0.02) and control group (mean changeable velocity, 0.01 ± 0.02). Finally, the distance of the six-minute walk test in the treadmill with optic flow group (mean changeable distance, 24.49 ± 11.00) showed significant improvement compared to the treadmill (mean changeable distance, 4.65 ± 3.25) and control (mean changeable distance, 1.79 ± 3.08) groups (Table 2 and Figure 3).

Discussion

This study examined the effects of treadmill training in stroke patients using the optic flow to change speed, a comparison of the treadmill training for balance and gait performance in patients with chronic hemiparetic stroke. These results revealed several significant findings. First, the improvement in the timed up-and-go test was greatest in the treadmill with optic flow group compared to the other groups. Second, the increase in distance after treatment was greatest in the treadmill with optic flow group in the functional reach test. Third, the gait velocity was greater in the treadmill with optic flow group than the others. Finally, the endurance of the gait performance after training was greater in the treadmill with optic flow group than the others.

Treadmill training was reported to be an effective method for restoring the gait function by providing a task-oriented repetitive practice.[3,22,23] Task-oriented repetitive training promotes new connections within the remaining brain tissue, or acts as a stimulus to form an effective and functional connection,[24] and increases the neuroplasticity that focuses on

Table 2. Modulation of balance and gait by changing optic flow

	TOF group		Treadmill group		Control group			
Variable	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	F-value	P
Balance parameters								
TUG (sec)	18.8 (3.5)[a,b]	13.2 (2.0)	19.4 (4.6)	17.9 (4.5)	20.5 (4.7)	20.0 (5.0)*	38.224	<0.001
FRT (cm)	28.0 (1.3)[a]	30.7 (1.3)	28.0 (1.7)[c]	30.4 (2.5)	28.0 (2.3)	28.2 (2.3)	12.403	<0.001
Gait parameters								
10MWT (m/sec)	0.5 (0.2)[a,b]	0.7 (0.2)	0.5 (0.2)	0.5 (0.2)	0.5 (0.1)	0.5 (0.1)	32.460	<0.001
6MWT (m)	240.3 (20.9)[a,b]	264.8 (18.6)	237.7 (25.4)	242.3 (26.0)	239.1 (22.0)	240.9 (22.4)	77.236	<0.001

6MWT, six-minute walk test; 10MWT, 10-metre walk test; FRT, functional reach test; TOF, treadmill with optic flow; TUG, timed up-and-go test.

*mean(SD)

[a] Statistically significant difference between treadmill with optic flow group and control group.

[b] Statistically significant difference between treadmill with optic flow group and treadmill group.

[c] Statistically significant difference between treadmill group and control group.

reorganization of the central nerve system. In addition, an improved balancing ability and effective motor learning with a faster gait speed occurs.[25]

The visual feedback in virtual reality motivates patients to voluntarily participate in their treatment,[26,27] increases their concentration,[26,27] contributes to postural stability leading to normal gait patterns,[27,28] improves the balance and walking ability in stroke patients,[29-31] and can decrease the risk of falling.[32] Various and intensive training would cause positive plastic changes in neural reorganization.[33] The treadmill with optic flow group showed significant improvement in timed up-and-go test, 10-m walk test, and six-minute walk test compared to the treadmill and control groups post-treatment. Yang *et al.*[14] reported that the use of virtual reality provides motivation and psychological stability to stroke patients, increases the neural plasticity by repetitive training of the affected lower extremities, leading to an improvement in the balancing and walking performance.

An increase in the optic flow speed is better training because it recognizes the optic flow speed quicker than that of the subject's gait speed, and decreases the incongruity of proprioceptive sensory information received from the visual input and lower extremities.[6] This optic flow provides information on the expected movement speed[6,34,35] and the direction in an environment.[6,36,37] Moreover, it forms the basis of visual information that can be used in the direction and speed control of walking, which has a strong influence on the human gait velocity.[38]

The role of sensory input is important for maintaining balance, and the integrated performance of visual, somatosensory and vestibulosensory is essential.[39] Somatosensory was reported to be the most important factor in providing information related to balance.[40] Varraine *et al.*[35] examined how the optic flow and lower extremity somatosensory feedback is determined by interactions between sensory cues, and reported that the visual information modification due to optic flow modifies the visual information and integrated information from somatosensory feedback. The treadmill with optic flow group and treadmill group showed significant improvement in the functional reach test distance than the control group post-treatment. This is because treadmill training was reported to improve the lower extremity muscle strength in stroke patients,[41] improve the symmetry in the lower extremities,[3] and improve the function of postural control by increased the stability in the lower extremities.[42]

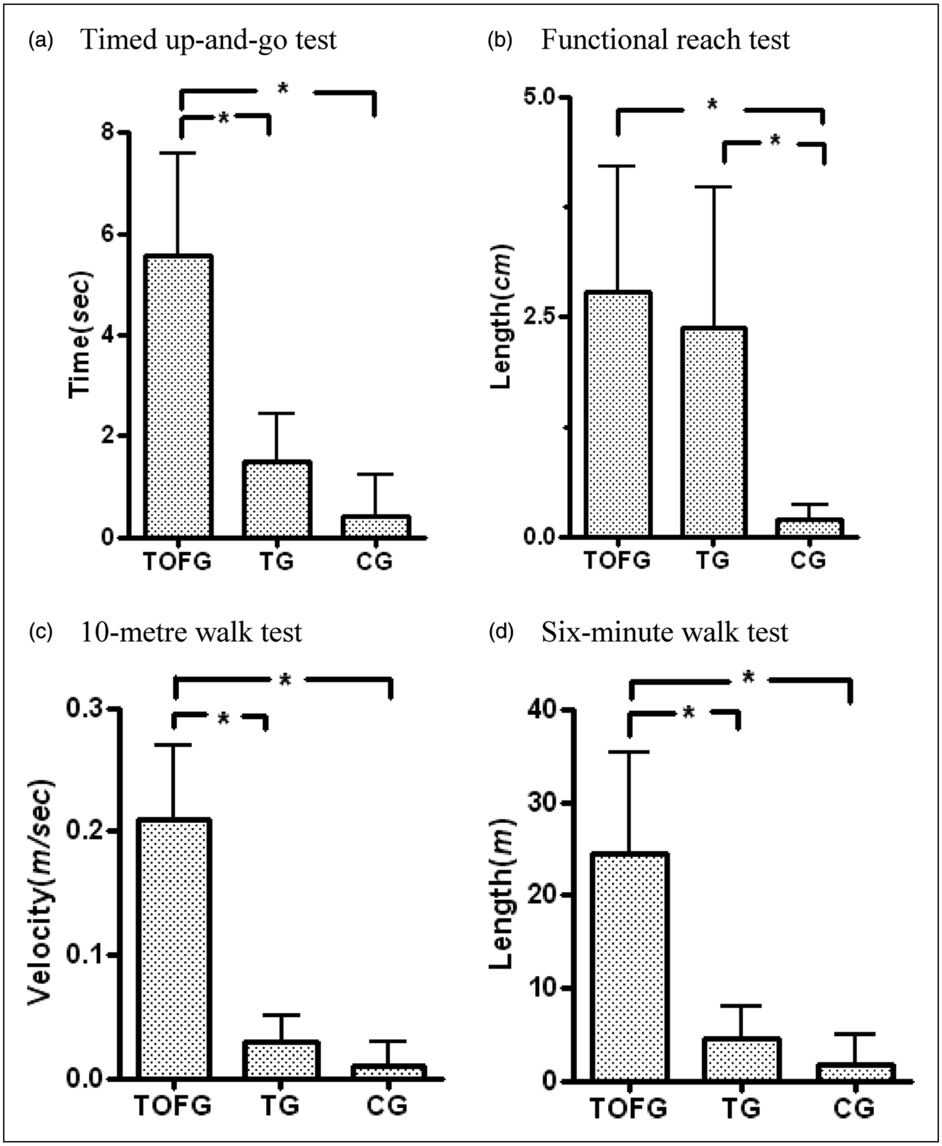

Figure 3. The change scores between pre- and post-test of four clinical measures. This figure depicts the scores of the timed up-and-go test, functional reach test, 10-metre walk test, and six-minute walk test among treadmill with optic flow (TOFG), treadmill (TG) and control (CG) groups. $^{*}P < 0.05$.

Previous studies suggested the effect of visual feedback on brain reorganizations in stroke populations.[43,44] Reorganization of the brain through treadmill with optic flow in stroke patients was also reported to play an important role in increasing the neural plasticity leading to the recovery of movement. Reorganization of the functional cerebral cortex and movement recovery can be obtained by learning new movement techniques, and increasing the treatment intensity to make patients use their affected side.[45] Although this study did not examine any brain-imaging tools to measure the effects of a treadmill with optic flow, the treadmill with optic flow would increase brain reorganization and neural plasticity in chronic stroke patients.

These results cannot be generalized to physical therapy for patients with the acute and subacute stage of hemiparetic stroke, because the participants were in the chronic phase of the disease. In addition, this study included a small number of subjects. It is expected that future studies with a larger number of subjects will improve the internal and external validities. In addition, a short intervention period as well as follow-up might limit the functional gains. Practice is an important factor that affects the functional outcomes. The training methods in treadmill with optic flow can be manipulated systemically to create similarity between virtual and real environments in terms of the intensity of practice and to provide appropriate motor relearning.

Clinical messages

- Treadmill with optic flow can be a useful approach for restoring postural stability and gait performance in individuals with chronic hemiparetic stroke.
- Treadmill training using optic flow speed modulation improves the balance and gait significantly in persons with stroke who are able to participate in physical gait training.

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