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Original Article

Walking gait changes after stepping-in-place training using a foot lifting device in chronic stroke patients

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Abstract. [Purpose] The goal of this study was to investigate the efficacy of stepping-in-place training using a foot lifting assist device on the walking gait of chronic hemiparetic stroke patients. [Subjects] Seven patients with chronic hemiplegic stroke (age 80.9±4.9 years) who were attending a local adult daycare facility participated in this study. [Methods] The participants had 2 or 16 weeks of intervention after a baseline period of 2 weeks. Evaluations were performed before the baseline period and before and after the intervention period. The evaluation consisted of a two-dimensional motion analysis of walking and stepping-in-place exercises and a clinical evaluation. [Results] Walking speed increased in three participants after 2 or 16 weeks of intervention. The swing phase percentage increased in the paretic gait cycle, and the time from non-paretic heel contact to paretic heel off decreased during stepping-in-place in these participants. [Conclusion] Given that the transition from the support phase support to the swing phase was shortened after the intervention, the stepping-in-place exercise using the device designed for this study may improve the muscle strength of the lower limb and coordination in the pre-swing phase of the paretic limb.

Key words: Chronic hemiplegia, Walking, Stepping-in-place

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INTRODUCTION

Gait recovery is a major objective in the rehabilitation program for individuals with poststroke hemiparesis[1)]. Treadmill training[2)] and treadmill training with harness support[3–5)] have been reported to be effective methods for retraining walking. Hollands et al. reported that repetitive task-specific practice, an intervention that consists of repeating a specific task to regain a functional movement, appeared to be a promising approach to restore gait coordination[6)]. Patients with hemiplegic stroke who participated in these studies were able to walk. In contrast, physical therapy in acute stroke patients tends to focus on improving a specific muscle activity or a partial movement of some task due to poor muscle strength. Recovery of function after stroke has been attributed to and based on reorganization of the brain in several reports[7–9)]. Additionally, some studies support the hypothesis that such a neurologic change is greatly affected by repeated practice of the movement task, which indicates that functional reorganization of the brain may be highly associated with use of the cerebral cortex and its frequency[10–12)].

When performance of a task is improved by movement training, transfer of learning occurs in the background in motor skill learning, and this occurs due to the dynamic similarity of the movements[13–15)]. Therefore, the therapist should determine

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*Corresponding Author. Kanichirou Murata (E-mail: km-ms.reha-pt.08@kuc.biglobe.ne.jp) the component of the movement that is lacking or insufficient in the patient and then elaborate the exercise according to the needed movement to regain a determined task as described by Carr and Shepherd[16].

There is a method to improve the walking ability in adult patients with hemiparesis according to exercises designed to increase weight-bearing and weight transfer on the paretic lower limb. The underlying foundation of such intervention is that improving the symmetry of weight-bearing while in the bipedal stance can result in balance and locomotor performance improvements. Davies[17] reported that most patients with hemiparesis have difficulty propelling the paretic limb in the swing phase. Kramers De Quervain et al.[18] reported that the duration of the pre-swing phase was prolonged in patients who had the slowest gait speed, thus further emphasizing the importance of improving the muscular strength and coordination of the paretic side during the pre-swing phase. The weight transfer from one lower limb to the other is important for locomotion and is a requirement for walking and stair climbing[19]. During rapid single-leg flexion movements in the standing position, the lateral horizontal ground reaction force components are lower in subjects with hemiparesis than in healthy subjects[20], and weight transfer to the non-paretic limb is insufficient[21, 22]. Consequently, the ability to elevate the paretic foot in tasks that require single-leg stance is compromised. For these reasons, hemiparetic patients tend to first incline the upper body to the support side and then elevate the paretic foot. Therefore, we focused our attention on the stepping-in-place movement task to improve the paretic swing phase in the gait, and we designed a spring-loaded takeoff board device to assist the lifting of the paretic foot.

The purpose of this study was to investigate the effect of the training device designed to assist heel elevation during repetitive stepping-in-place exercise on motor function and walking ability in patients with chronic hemiplegic stroke. We hypothesized that motor function of the paretic lower limb would be improved, lateral movement of the upper body would be reduced during paretic limb lifting, the pre-swing phase of the gait would be shorter, and the step length would be longer.

SUBJECTS AND METHODS

Ten subjects (6 males and 4 females) with chronic hemiparetic stroke volunteered for this study. Three subjects dropped out during the intervention period. Thus, seven participants (4 males, 3 females; age 80.9±4.9 years) from a community-dwelling population who were users of an adult daycare facility ultimately participated in this study. Six participants had right hemiparesis, and one participant had left hemiparesis. Such neurological deficiencies were the consequence of either cerebral infarction or cerebral hemorrhage due to an initial (n=4) or a recurrent (n=3) stroke. The time post stroke ranged from 3 to 32 years. Five participants were able to ambulate independently, and two participants required supervision or minimal assistance to walk. Six participants used a straight cane, and one participant used a four-point cane. Four individuals used an ankle-foot orthosis (Table 1). The participants attended an adult daycare facility 2–4 times a week. The inclusion criteria were as follows: (1) able to maintain the standing position independently, and (2) able to walk at least 10 m on flat ground with or without minimum assistance in walking balance. The exclusion criteria were as follows: (1) clinical signs of heart failure, (2) any orthopedic or neurologic conditions in addition to the stroke, and (3) gross cognitive sequelae. This clinical study was approved by the Kanazawa University Medical Ethics Screening Committee (approval number: 432). Written informed consent to participate in this study was obtained from all participants. They were also allowed to continue the exercise for an arbitrary period upon request.

An A-B study was applied as follows: During phase A (baseline), the participant received the usual care provided in the adult daycare facility. During phase B (intervention), the participant performed an additional exercise task (stepping movement) that consisted of repeatedly lifting the paretic foot in the standing position for approximately 20 minutes using a specific device designed for this study at the adult daycare facility. Each phase was performed for 2 weeks. However, two participants wanted to voluntarily continue the exercise, and they were also evaluated after a total of 16 weeks of intervention (Eva4). The subjects were evaluated three or four times. Each evaluation consisted of a clinical evaluation and a kinematic analysis, which were performed before phase A and before and after phase B (designated hereafter as Eva1, Eva2, Eva3, and Eva4, respectively). All evaluations and interventions were performed in the adult daycare facility the participants attended.

The device used during phase B consisted of a spring-loaded takeoff board that assisted the lifting of the foot heel in the stepping movement (Fig. 1). The participants performed the stepping-in-place exercise using this device during the intervention phase. The exercise using this device has three characteristics. First, depending on the ability of the participant, the amount of assistance required to lift the paretic foot is adjusted by changing the number of springs of the device. Second, movement using this device is similar to movement of the lower limbs in the walking pre-swing phase, promoting hip joint flexion, knee flexion, and ankle plantar flexion. We considered that a sense of motion closer to real walking was more likely to be obtained. Third, a loading feedback sensation is obtained by applying weight to the paretic foot against the device's spring. It is thought that this is effective for improving the movement in the pre-swing phase that allows transition from stance to swing to be accomplished. Therefore, it is expected that the walking pattern (improvement of the paretic swing) is improved by performing the movement using this device in patients with hemiplegia. We hypothesized that repetition of the stepping-in-place exercise using this device would be effective for improving the motor function of the lower limbs and for improving walking function. In other words, we designed a movement task based on transfer of learning. The strength of the springs was adjusted to allow for a standing position when they were stepped on and to allow for easy heel lifting. The movement speed was adapted according to the participant's ability to perform the exercise for approximately 20 minutes,

Table 1. Initial characteristics of the participants

Participants	PA	PB	PC	PD	PE	PF	PG
Gender	M	F	M	M	F	M	F
Age (years)	83	81	84	80	71	84	78
Weight (kg)	56.2	58.1	55.2	66.4	59.2	54.7	50.8
Time after stroke (years)	6	9	17	3	10	32	11
Type of stroke	Ischemic	Ischemic Ischemic (recurrent)	Hemorrhagic Ischemic	Ischemic	Ischemic	Ischemic Hemorrhagic Ischemic	Hemorrhagic
Hemiparetic side	Left	Right	Right	Right	Right	Right	Right
MAS							
Hip	1	1	1	3	0	2	1
Knee	2	0	1	3	1	1	2
Ankle	2	1	1	1	1	1	1
LE-FMA	15	21	9	9	19	11	25
Use of an orthosis	AFO	—	—	AFO	—	AFO	AFO
Walking aid	T-cane	T-cane	T-cane	Quad-cane	T-cane	T-cane	T-cane
FAC	3	5	4	2	4	3	4

MAS: Modified Ashworth Scale (0–5); LE-FMA: lower extremity subscale of the Fugl-Meyer Assessmen; FAC: Functional Ambulation Category (0–5); AFO: ankle-foot orthosis

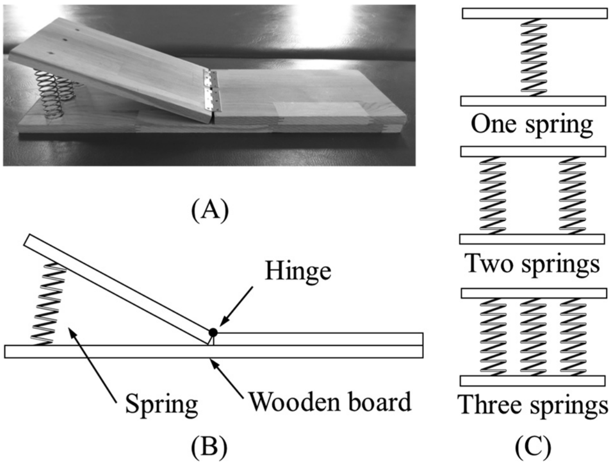

Fig. 1. The device that assists the lifting of the foot heel: (A) picture of the device, (B) schematic illustration of the device (side view), (C) schematic illustration of the device (rear view) and adjustment by the number of springs

including rest breaks. Rest breaks were included to conform to the needs of the participants.

To test the efficacy of the interventions, a clinical evaluation and kinematic analysis of the stepping-in-place and walking exercises were performed for each evaluation time.

The motor function of the lower limbs was assessed using the lower extremity items (maximum score = 34 points) of the Fugl-Meyer assessment (FMA), and walking ability was assessed using the 10-m walking test and Functional Ambulation Category (FAC). The spasticity of the lower limbs (e.g., hip, knee, and ankle joint) was assessed using the Modified Ashworth Spasticity Scale (0–5). In the 10-m walking test, the subjects were asked to walk a 12-m gait track; the first and last meters were excluded from measurement, leaving a 10 m measurement section. The subjects were instructed to walk at their own preferred speed. The time and steps required for them to walk the measurement section were recorded. The 10-m walking test was performed twice.

A two-dimensional motion analysis of movement in the sagittal plane of walking and in the frontal plane of the stepping-in-place was performed. The stepping-in-place exercise was chosen to examine the lateral movement of the upper body and double support duration. Hemispheric reflection markers (1 cm in diameter) were placed on the spinal column for the spinous process of the 5th lumbar vertebra and bilateral posterior extremity of the heel. One digital camera (EX-ZR800, Casio Computer Co., Ltd., Tokyo, Japan) mounted on a tripod was positioned approximately 5 m perpendicular to the plane of each movement. Each movement was recorded using the digital camera at 240 frames/sec. Two-dimensional coordinate data were calculated using a motion analysis software package (Frame-DIAS IV, DKH Co., Ltd., Tokyo, Japan).

For the participants who required an ankle-foot orthosis, the measurement motion was performed with them wearing shoes, while for the other participants, the measurements were performed while barefoot. In addition, all participants were allowed to use their cane as needed. Care was taken to maintain the same measurement conditions for each evaluation in all participants. As the walking was performed in the paretic sagittal plane, 3 trials with a distance of 5 m were performed. The stepping-in-place test was evaluated from behind the subjects and was performed approximately 20 times in the same position. The subjects were instructed to perform both motions at a self-selected comfortable and safe speed.

The walking speed (m/sec) and cadence (steps/minute) were calculated using the 10-m walking test. For the purpose of the calculation, from each of two trials, the result that was higher in value was selected. It is assumed that the single stance phase becomes shorter and the double supporting phase becomes longer as the walking speed becomes slower and that the swing phase in natural walking accounts for 40% of the gait cycle. In other words, we hypothesized that the double supporting phase is shortened and that the swing time is extended and becomes closer to 40% of the gait cycle as the walking speed is increased. Therefore, the walking motion of 1 gait cycle was used for the kinematic analysis. The following values were calculated from the walking video: duration of one gait cycle and swing phase of the paretic side (1 GC duration in sec, Sw duration in sec) and the percentage of the swing phase to one gait cycle (%Sw). The paretic step length (m) was calculated using the coordinates of the bilateral heel markers. For these parameters, the means of the 3 walking trials were calculated.

The motions from the 6th to 15th repetitions of the stepping-in-place motion (20 in total) were used for the kinematic analysis. For the stepping-in-place exercise, it was assumed that the lateral movement of the center of gravity becomes smaller and that the duration from non-paretic foot touchdown to lifting of the paretic foot is shortened as the walking speed increases. Therefore, the following values were calculated during the stepping-in-place exercise: lateral amplitude of L5 (L5-amp in m) and the time from non-paretic heel contact to paretic heel off (HC-HO duration in sec). The mean values for the stepping-in-place motion were calculated from ten motions.

To test the changes compared with baseline, the Wilcoxon signed-rank test was used to assess the difference between Eva1 and Eva2 for each evaluation result. Considering the physical and emotional condition variability of each participant, the efficacy of a given intervention was tested by comparing the mean of the results for Eva1 and Eva2 with the Eva3 or Eva4 results. A p value of 0.5 or lower was considered significant for all statistical comparisons.

RESULTS

The seven hemiplegic patients who participated in this study completed the intervention period of 2 weeks. No adverse effect was detected due to the intervention. The durations of exercise and rest were carefully considered so that the intervention would not cause any significant fatigue or overload. Five of seven participants were able to continue the exercise task for 20 minutes in each session. Two participants (PA, PE) expressed positive opinions, such as “the sensation of the paretic foot touching the floor became more perceptible” and “it seems good” during the stepping-in-place exercise. These two participants voluntarily continued the exercise for 14 more weeks after the 2-week intervention period, for a total of 16 weeks of the intervention. Upon obtaining their consent, they were again evaluated after 16 weeks of the intervention (Eva4). Two participants (PD, PE), who were not able to perform the exercise for 20 minutes due to less physical endurance, performed the exercise for shorter periods than the others (15 min and 10 min, respectively). Additionally, PD refused to undergo the kinematic analysis for the stepping-in-place motion due to a feeling of fatigue on the evaluation day.

Overall, no significant difference was found at the end points between Eva1 and Eva2 compared with baseline ($p> 0.05$). The average valued were calculated for Eva1 and Eva2, was and they were compared with the results for Eva3; no significant difference was found between the values ($p> 0.05$). However, an increase in walking speed was found in select participants. Therefore, each evaluation outcome after the intervention (Eva3 or Eva4) was compared with the average of Eva1 and Eva2 as the baseline (mean of Eva1 and Eva2) for each participant. The percentages of increase or decrease for Eva3 and Eva4 compared with the baseline values are shown in Table 2.

A walking speed gain was found in three participants (PA +15.4%, PE +15.0%, PG +13.0%), and, furthermore, a cadence gain was found for PE and PG (PE +10.1%, PG +1.9%). However, no change in walking speed was detected in the four other participants, and for PF, walking speed became slower (−19.2%). The scores for the lower extremity subscale of the Fugl-Meyer assessment (LE-FMA) of three subjects (PC, PD, PF) were lower than those ofthe other participants.

Considering the parameters in the kinematic analysis of the three subjects who demonstrated increased walking speeds (PA, PE, and PG), the main changes were as follows: Sw duration was extended in PA and PG (PA +22.0%, PG +8.3%), and the step length was increased in PA (PA +20.7%). Furthermore, these three participants had some changes in common. The %Sw in walking increased. PA and PE obtained increases closer to 40% (PA 40.7%, PE 37.1%). Additionally, the HC-HO duration of the stepping-in-place motion decreased in these three patients (PA −75.0%, PE −46.9%, PG −37.0%).

In contrast, the kinematic analysis results of the four participants whose walking speed did not increase were as follows. For PB, the time from the support and swing phase became shorter, and the HC-HO duration of the stepping motion

Table 2. Clinical assessment and the kinematic parameters of walking and stepping-in-place of each participant

Participants		PA	PB	PC	PD	PE	PF	PG
Clinical assessment								
Walking speed (m/sec)	Baseline	0.65	0.58	0.31	0.16	0.4	0.26	0.23
	Eva3	0.68	0.59	0.30	0.17	0.41	0.21	0.26
		(+4.6)	(+1.7)	(−3.2)	(+6.3)	(+2.5)	(−19.2)	(+13.0)
	Eva4	0.75				0.46		
		(+15.4)				(+15.0)		
Cadence (steps/min)	Baseline	102.5	84	75.1	43.9	78.1	56.7	74.6
	Eva3	98.2	88.6	69.1	46.6	78.5	51.0	76.0
		(−4.2)	(+5.5)	(−8.0)	(+6.2)	(+0.5)	(−10.1)	(+1.9)
	Eva4	98.9				86		
		(−3.5)				(+10.1)		
LE-FMA (score/34)	Baseline	14.5	21	9	9	19.5	11	24.5
	Eva3	15	21	9	9	20	9	25
	Eva4	16				21		
Walking								
1 GC duration (sec)	Baseline	1.18	1.56	1.69	2.45	1.72	2.77	1.68
	Eva3	1.27	1.41	1.89	2.34	1.63	2.66	1.71
		(+7.6)	(−9.6)	(+11.8)	(−4.5)	(−5.2)	(−4.0)	(+1.8)
	Eva4	1.23				1.41		
		(+4.2)				(−18.0)		
Swing phase duration (sec)	Baseline	0.41	0.53	0.57	0.52	0.57	0.54	0.48
	Eva3	0.5	0.4	0.72	0.34	0.6	0.59	0.52
		(+22.0)	(−24.5)	(+26.3)	(−34.6)	(+5.3)	(+9.3)	(+8.3)
	Eva4	0.5				0.52		
		(+22.0)				(−8.8)		
%Sw (%)	Baseline	34.8	33.9	33.7	22.5	33.2	19.6	28.8
	Eva3	38.9	28.5	37.9	14.4	37	22.1	30.6
		(+11.8)	(−15.9)	(+12.5)	(−36.0)	(+11.4)	(+12.8)	(+6.3)
	Eva4	40.7				37.1		
		(+17.0)				(+11.7)		
Step length (m)	Baseline	0.29	0.31	0.34	0.1	0.32	0.24	0.17
	Eva3	0.3	0.29	0.35	0.07	0.31	0.20	0.17
		(+3.4)	(−6.5)	(+2.9)	(−30.0)	(−3.1)	(−16.7)	(±0)
	Eva4	0.35				0.34		
		(+20.7)				(+6.3)		
Stepping-in-place								
L5-amp (m)	Baseline	0.14	0.13	0.09		0.08	0.14	0.11
	Eva3	0.12	0.12	0.12		0.05	0.13	0.1
		(−14.3)	(−7.7)	(+33.3)		(−37.5)	(−7.1)	(−9.1)
	Eva4	0.12				0.06		
		(−14.3)				(−25.0)		
HO-HC duration (sec)	Baseline	0.44	0.19	0.32		0.32	1.04	0.27
	Eva3	0.12	0.12	0.49		0.25	0.85	0.17
		(−72.7)	(−36.8)	(+53.1)		(−21.9)	(−18.3)	(−37.0)
	Eva4	0.11				0.17		
		(−75.0)				(−46.9)		

Eva1: evaluation performed before phase A; Eva2: evaluation performed before phase B; Eva2: evaluation performed after phase B; Eva4: evaluation performed 16 weeks after intervention. The baseline value is the mean of Eva1 and Eva2. LE-FMA: lower extremity subscale of the Fugl-Meyer Assessment; GC: gait cycle, L5-amp: lateral amplitude of L5; HO-HC duration: time from non-paretic heel contact to paretic heel off; %Sw(%): percentage of the swing phase in a gait cycle. The values in parentheses indicate the percentages of increase or decrease of Eva3 and Eva4 compared with the baseline.

decreased (−36.8%). For PC, the 1 GC duration (+11.8%) and Sw duration (+26.3%) increased, and %Sw (37.9%) became closer to 40% in the walking motion. For PF, the HC-HO duration in the stepping-in-place motion and 1 GC duration in the walking motion decreased, showing some improvement (HC-HO duration −18.3%, 1 GC duration −4.0%).

DISCUSSION

This study focused on the stepping-in-place exercise to improve the paretic swing of the hemiplegic gait. Thus, a spring-loaded takeoff board was designed to assist the heel elevation of the stepping-in-place early phase. Performing the stepping-in-place exercise using this device in patients with chronic hemiparesis, we hypothesized that the motor function of the paretic lower limb would be improved, the lateral movement of the upper body would be reduced during paretic limb lifting, the pre-swing phase of the gait would become shorter, and the step length would become longer. According to the results, the improvements shown by the participants differed, with each participant showing specific improvements in different areas.

The time after the initial stroke (ranging from 3 to 32 years), baseline FMA (ranging from 9 to 25 points), and walking speed (ranging from 0.16 to 0.65 m/sec) of the participants in this study varied widely. Six of the 7 participants used a cane or ankle-foot orthosis as a walking aid, and 2 of the 7 participants (PE, PG) required supervision or minimal assistance in walking. Compared with the study subjects of Kramers De Quervain et al.[18)] and Turns et al.[23)], who also conducted gait analyses of patients with hemiparesis, the present participants had a longer time after stroke, worse disorder of paretic limb motor function, and slower walking speed. Two participants (PC, PD) were unable to complete the 20-minute exercise task even with resting time, but other participants were able to complete the exercise task. Furthermore, the frequency of intervention was not uniform (from 2 to 4 times a week). Thus, probably due to the wide individual differences in physical endurance, walking ability, motor function of the lower extremity, and the movement pattern of the paretic lower extremity among the participants in the present study, the intervention showed no common effectiveness in the present participants.

Two participants (PA, PE) who had positive impressions of the exercise showed an increase in walking speed and cadence after four months of performing the exercise. Additionally, through the 2-week intervention, the walking speed and cadence of PG increased. The level of spasticity of the lower extremity of the participants was assessed using the Modified Ashworth Scale (MAS). The participants' spasticity ranged from 0 to 2, except for participant PD (ranged from 1 to 3), showing similarity in spasticity levels between participants with and without improved results. In the kinematic analysis, three participants (PA, PE, and PG) had increases in the duration ratio of the swing phase in the non-paretic gait cycle and shortening of the time from non-paretic heel contact to the paretic heel off during stepping-in-place. The swing phase time was also extended for PA and PG, and the step length was increased for PA. The FMA scores (ranging from 15 to 25 points) in the baseline period for the three participants who showed improvement (PA, PE, and PG) were higher than those of PC, PD, and PF (ranging from 9 to 11 points). In the flexor/extensor synergy of the hip and knee joints item of the FMA, participants who showed no improvement scored 1 point, whereas participants with improvement scored 2 points. Kramers De Quervain et al.[18)] and Turns et al.[23)] reported that patients who walked slower were unable to perform gait movements without a synergy pattern. Additionally, Kramers De Quervain et al.[18)] reported that the duration of the pre-swing phase was prolonged for patients who had the slowest gait velocities and that the goal of therapy should therefore be focused on muscle strength and coordination improvement of the hemiplegic side, especially during the pre-swing phase. Garcia et al.[24)] reported that the frequency of stepping in the stepping-in-place motion was slower than in walking but that the stepping-in-place motion incorporates reciprocal, rhythmic lower extremity movement patterns similar to gait. In other words, the participants who were able to perform lower limb synergy patterns at a certain intensity transferred the weight from the supporting limb to the swing phase limb in the stepping-in-place exercise faster, which could have contributed to the smooth pre-swing phase and improved walking speed. Thus, the stepping-in-place training using the foot lifting device seems to be appropriate for hemiplegia patients who are able to show extension synergy of the lower extremity and enough upper limb support to maintain the standing position.

PC showed constant knee extension and ankle plantar flexion through all gait cycles. PD and PF showed larger knee flexion and ankle dorsiflexion with weight-bearing during the stance phase, and PD had excessive pelvic hiking and toe drag during the swing phase. In addition, two participants (PC, PD) were unable to complete the movement task for 20 minutes due to a lack of physical endurance. The participants with weaker support force of the lower extremity and with flexion/extension movement difficulties showed knee buckling, a trunk and pelvic compensation strategy during stepping-in-place exercise. The lower limb spasticity level of the participants ranged from 0 to 2, except for PD (1 to 3). Therefore, the motion task ability seems to be more related to motor function than to the existence of spasticity. The participants with weaker support force of the lower extremity needed assistance to induce the stepping-in-place exercise manually by the therapist during the motion task using the foot lifting device. PB had higher motor function of the lower extremity than the other participants and showed a normal knee pattern in the stance phase; however, PB also showed excessive ankle plantar flexion and hip flexion during the swing phase. Due to this participant's high ability to swing the paretic limb, the effect of the intervention might not have been evident.

These results suggest that patients with relatively high walking ability and motor function had positive effects from the intervention. Some studies have reported that locomotor parameters were improved after 6 months of combined functional training and 8 weeks of one-leg exercise[25, 26)]. Therefore, the movement task in the present study may be effective for paretic lower limb movement in the paretic heel off from non-paretic heel contact, but some form of long-term intervention is necessary to improve step length.

This study focused on the movement of the lower limbs during the pre-swing phase of the gait cycle, and a movement task was designed. Movements of the hip joint, knee, and ankle induced by paretic foot heel elevation with spring assistance were expected to be induced. In this way, by obtaining a motion sensation close to normal gait, the sensory feedback was expected to effectively improve movement. For the muscle activity in the pre-swing phase, Perry27) reported that the activity of the ankle plantar flexion muscle decreases as the body weight is rapidly transferred from one limb to the other and that the residual gastrocnemius flexor muscle action moves the tibia forward, flexing the knee. Additionally, in the stepping-in-place exercise, vertical control of the center of mass (COM) is mainly required. Jansen et al.28) reported that the ankle plantar flexor muscles (soleus, gastrocnemius) had the same function in vertically controlling the COM during the loading response period of forward and backward walking. Therefore, we hypothesized that the flexion of the knee by gastrocnemius activity would be improved through exercise in which the heel is moved up and down. Insufficient flexion of the paretic lower limbs during the pre-swing phase was observed before the intervention in the three participants (PA, PE, PG) whose walking speeds increased. Thus, this repetitive movement task may contribute to improving the control of the paretic lower limb in the pre-swing phase.

Most participants in this study had chronic hemiparesis and were aged 75 years or older. The participants who had relatively higher walking ability and better motor function showed better results after the training period. There were large differences among the individuals in the time after stroke, the level of lower limb functional impairment, and walking ability. Additionally, considering the results of two participants who continued exercising for 16 weeks, the 2-week intervention is probably insufficient for obtaining the desired effects in patients with chronic hemiparesis. To determine the efficacy of the movement task, it is necessary to perform future studies with larger sample populations, longer intervention periods, and prior classification of the gait pattern of the participants. In this study, the effect of the intervention was investigated using kinematic analysis; however, use of the electromyographic method may be necessary to investigate more detailed effects of this exercise task with the assistive device.

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