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Case Study

Effects of task-specific paretic ankle plantar flexor training on walking in a stroke patient: a single-case study

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Abstract. [Purpose] The purpose of this study was to examine the effects of task-specific plantar flexor training on walking ability indices in a patient with a paretic ankle. [Subject and Methods] The subject was a 65-year-old male patient with right hemiplegia due to a left medullary ventral infarction. An ABA' single-subject design was adopted. The independent variable was a task-specific plantar flexor training exercise, similar to that during walking, targeting the paretic ankle. The dependent variables were the isometric ankle plantar flexor strength, maximum walking speed, step length, and trailing limb angle in the paretic terminal stance phase. The B study phase was divided into B1 and B2 phases. A two standard-deviation-band method was used to evaluate improvement. [Results] Improvements in the paretic plantar flexor strength, maximum walking speed, step length, and trailing limb angle in the B2 phase were observed. The improvements in the maximum walking speed, step length, and trailing limb angle were sustained in the A' study phase. [Conclusion] These results suggest that task-specific plantar flexor training exercise is efficacious in improving the walking ability index of a paretic ankle.

Key words: Task-specific training, Ankle plantar flexor, Walking ability

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INTRODUCTION

Previous studies have shown that the walking speed in stroke patients is insufficient[1)]. A close relationship between walking speed and an individual's ability to perform activities of daily living has been reported[2)]. Thus, improvement in walking speed is an important goal for stroke patients in physical therapy, as it expands the patient's field of activities after discharge. Furthermore, establishing a physical therapy plan contributes to improvements in walking speed.

The plantar flexor strength in the paretic ankle is strongly related to maximum walking speed[3)], and a reduction in its strength is a cause of limited walking speed[4)]. However, simple ankle plantar flexor strengthening, without consideration of the specific activities during walking, does not improve walking speed[5, 6)]. In contrast, task-specific training exercises, such as step and step-up exercises, are effective in improving walking speed[7)]. Specifically, ankle plantar flexor function is mainly active in single-leg stance phase[8)]. Thus, it may be important to conduct paretic ankle plantar flexor training exercise that is similar to the single-leg stance condition, which involves the joint angle, angular velocity, and lower extremity load to improve walking speed in stroke patients.

To our knowledge, no study has examined the effects of task-specific paretic ankle plantar flexor training exercise that is similar to walking.

The purpose of the present study was to investigate the effects of task-specific plantar flexor training exercise on walking ability indices, including waking speed and step length, in a patient with a paretic ankle.

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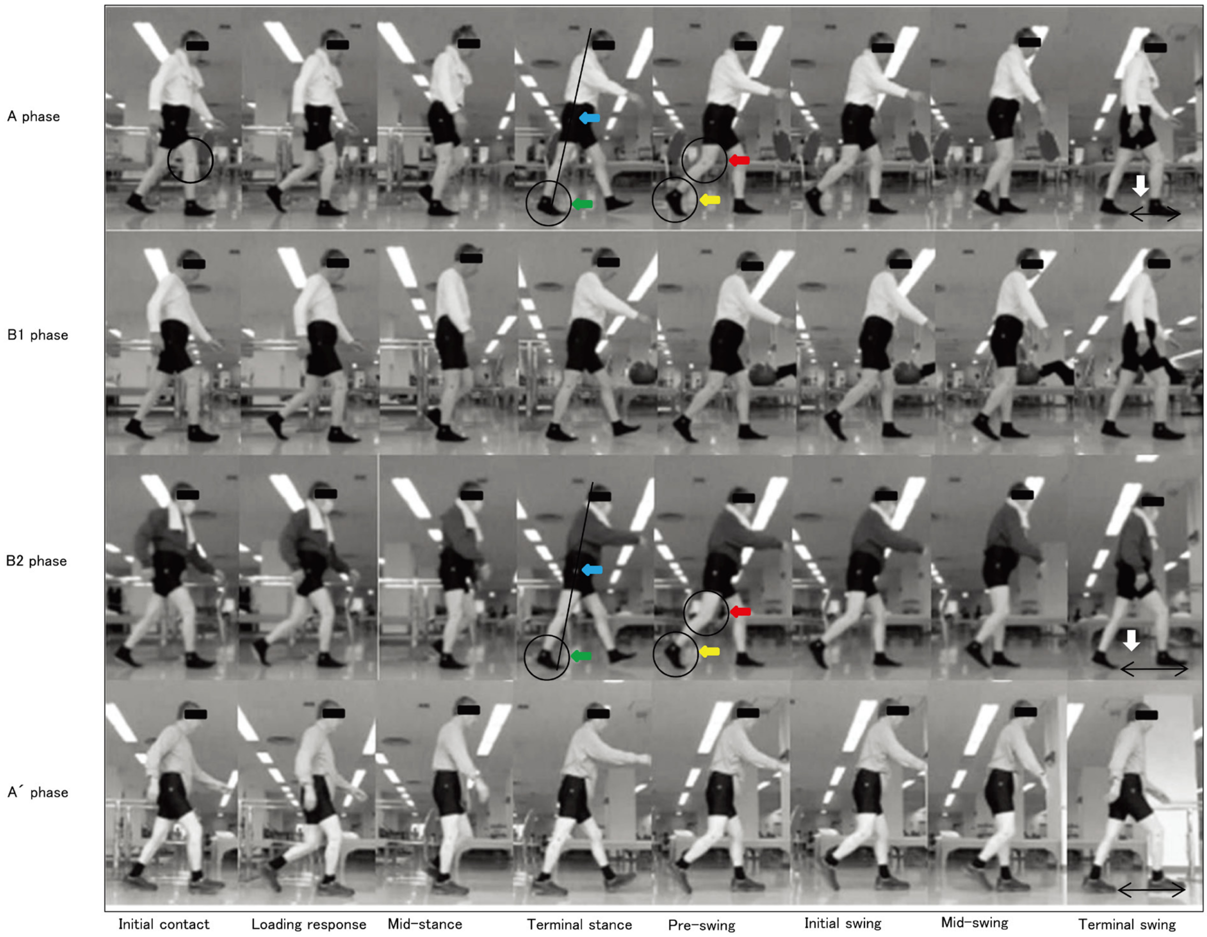

Fig. 1. Gait changes across study phases. Compared to that in phase A, the hip extension angle (blue arrow) and heel lift distance (green arrow) at the paretic terminal stance were increased in phase B2, while there were no changes in the ankle plantar flexion angle (yellow arrow) and knee flexion angle (red arrow) in the paretic pre-swing. An increase in the right step length (white arrow) at the paretic terminal swing in phases B2 and A' was observed.

SUBJECT AND METHODS

The subject was a 65-year-old male patient (height 155 cm, weight 53 kg) who developed right hemiplegia 116 days after a left medullary ventral infarction. The subject had a history of type 2 diabetes mellitus, hypertension, and hyperlipidemia. At the beginning of the study, the patient's right lower extremity was in Brunnstrom recovery stage V, and exhibited mild sensory deficits. The right ankle dorsiflexion range of motion was 20°, the other lower extremity joints were normal. The muscle tone in the right knee extensor and ankle plantar flexor were increased to a modified Ashworth scale score of 2. The plantar flexor strength in the paretic ankle was decreased, as it was impossible for the patient to raise his right heel in the right leg standing position. The right lower extremity muscle strength was normal. His walking ability was at the level of outdoor-independent ambulation. His gait was in the knee flexion position at the paretic initial contact phase. No rapid ankle plantar flexion and knee flexion were observed in the paretic pre-swing phase. The swing was not smooth (Fig. 1).

An ABA'-type single-subject study design was adopted. The independent variable was a task-specific plantar flexor training exercise (task-specific training), similar to movement during walking, targeting the paretic ankle. The dependent variables were the isometric ankle plantar flexor strength, circumference of the lower leg, maximum walking speed, step length, and trailing limb angle at the paretic terminal stance phase. The periods of this ABA' design were distributed as follows: 26 days in phase A, 52 days in phase B, and 24 days in phase A'.

A physical therapist instructed the patient in range of motion exercises for the paretic lower extremity, which included a standing practice. These exercises were performed once or twice weekly in the outpatient clinic during phases A and A'. The patient also performed walking exercise at home for 60 minutes every day. In the B phase, a task-specific training exercise was added to the A-phase exercises, which consisted of adopting the step position, with the non-paretic lower extremity placed forward one step, followed by a paretic heel raise (Fig. 2). This exercise was performed with the lower extremity

Table 1. Changes in the dependent variables over time

	Average value of A phase	2SD	A phase				B1 phase			
Paretic plantar flexor strength (kgf/kg)	0.22	0.07	0.26	0.19	0.25	0.20	0.25	0.28	0.22	0.24
Non-paretic plantar flexor strength (kgf/kg)	0.77	0.17	0.87	0.71	0.69	0.81	0.83	0.86	0.75	0.83
Circumference of paretic lower leg (cm)	30.7	0.4	30.7	30.7	31.0	30.5	30.7	30.5	30.5	30.5
Circumference of non-paretic lower leg (cm)	30.1	0.5	30.0	30.0	30.5	30.0	30.2	30.2	30.1	30.1
Maximum walking speed (m/min)	76.7	4.3	74.1	77.9	75.9	78.9	77.9	77.9	74.1	75.0
Step length (cm)	52.6	0.0	52.6	52.6	52.6	52.6	52.6	55.6	52.6	55.6
Trailing limb angle (°)	15.2	3.4	13.3	14.4	15.6	17.3	18.5	19.3*	19.0*	15.6

Table1 Continue

	B2 phase				A' phase			
Paretic plantar flexor strength (kgf/kg)	0.35*	0.38*	0.34*	0.39*	0.36	0.25	0.31	0.29
Non-paretic plantar flexor strength (kgf/kg)	0.83	0.83	0.90	0.92	0.86	0.87	0.93	0.92
Circumference of the paretic lower leg (cm)	30.6	30.5	30.8	30.7	30.7	30.8	30.8	30.7
Circumference of the non-paretic lower leg (cm)	30.1	30.1	30.1	30.2	30.2	30.0	30.0	30.0
Maximum walking speed (m/min)	80.0	80.0	84.5*	83.3*	81.1*	82.2*	82.2*	80.0
Step length (cm)	55.6*	55.6*	58.8*	62.5*	62.5*	62.5*	62.5*	62.5*
Trailing limb angle (°)	18.8*	19.3*	19.0*	20.5*	21.8*	19.1*	19.4*	17.8

*The value is outside the 2SD band. Improvement was determined as more than two consecutive data points in the B1, B2, and A' phases (considered separately) that exceeded the 2SD band constructed from the phase A data.
2SD: 2 standard deviation.

Fig. 2. Task-specific training. A heel-raised position is shown. Task-specific training was performed with the lower extremity joint angle like that in the paretic terminal stance phase. This exercise required 2 seconds to raise the heel, 1 second to maintain the heel-raised position, and 2 seconds to descend from the heel-raised position. The patient was instructed to perform this exercise in 3 sets of 20 repetitions each, with a load of about 40 kg on the paretic lower extremity. This exercise was performed at a target of subjective substantial fatigue.

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Once a week, the dependent variables were measured, and the patient's ambulation was videotaped for gait analysis. Plantar flexor strength was measured using a handheld dynamometer (μ-tas F-100, Anima Co.), as in a previous study[9)]. Limb position was measured while the patient was seated. The knee and ankle were kept in 90° flexion, and the knee was secured with a belt just above the knee joint. Plantar flexor strength was measured as the force exerted at the metatarsal heads of the foot. The plantar flexor strength was measured twice, and the maximum value was divided by the patient's body weight to calculate the torque-to-weight ratio. The circumference of the lower leg, which was marked distal to 7 cm from the lower edge of the fibula head, was measured using a vinyl tape measure. Prior to this study, the reproducibility of the assessments for the plantar flexor strength and circumference of the lower leg was confirmed. Specifically, healthy men underwent two assessments by the same examiner on different days, and the intraclass correlation coefficient (ICC) was calculated.

The patient was asked to walk at his maximum speed as fast as he could without discomfort in the center 10 meters of a 14-meter walkway. The time and number of steps were measured from the initial contact of the step that first exceeded the start line to the initial contact of the step that first exceeded the finish line. The maximum walking speed and step length were calculated based on the amount of time required and the number of steps taken. The trailing limb angle[10)] at the paretic terminal stance was measured by evaluating the patient's gait in the sagittal plane, as observed from the videotaped session. The digital camera (EX-ZS26, Casio Co.) was set at a distance of 3 meters from the walkway, at a height of 38 cm from the floor surface. The paretic terminal stance was defined as the time just before the non-paretic lower limb initially contacted the surface, but after the paretic heel had taken off. Image processing software (Image J, National Institutes of Health) was used to obtain a still image, and the trailing limb angle was defined as the angle formed by a perpendicular line extending from the paretic greater trochanter to the floor and a line between the paretic greater trochanter and outer malleolus.

To determine whether improvements occurred, the 2-standard-deviation-band method[11)] was adopted. The B phase was divided equally into B1 and B2 phases. If there were more than two consecutive data points within the B1, B2, and A' phases (considered separately) that exceeded the 2-standard-deviation band constructed from the phase A data, improvement was considered to have occurred.

This study paid full attention to the protection of the subject, in accordance with the Declaration of Helsinki (1975, revised 1983). The content of the study was verbally explained to the patient, including the handling of all personal information, and written informed consent was obtained.

RESULTS

The ICC (1,1) for the assessments of the plantar flexor strength and circumference of the lower leg were 0.86 and 0.96, respectively, indicating high reproducibility. The longitudinal changes in the dependent variables are shown in Table 1. Improvements were observed in the trailing limb angle in the B1 phase, and the paretic plantar flexor strength, maximum walking speed, step length, and trailing limb angle in the B2 phase. Furthermore, the improvements in the maximum walking speed, step length, and trailing limb angle were sustained in the A' phase.

The longitudinal changes in gait across study phases are depicted in Fig. 1. Compared to that in the A phase, the hip extension angle and heel lift distance at the paretic terminal stance were increased in the B2 phase, while there were no changes in the ankle plantar flexion angle and knee flexion angle in the paretic pre-swing. Increases in the right step length at the paretic terminal swing were also observed in phases B2 and A'.

DISCUSSION

In the present single-patient study, additional task-specific training improved walking ability indices and the plantar flexor strength in the paretic ankle. Thus, the results of this single-case study suggest that task-specific training is effective in improving walking ability in patients with a paretic ankle. In healthy subjects, the contraction form of the ankle plantar flexor changes from eccentric to isometric in mid-stance, while it remains concentric from the terminal stance to the pre-swing[12)]. The ankle joint angular velocity has been reported to be slow at the time of dorsiflexion, but fast at the time of plantar flexion[13)]. In the present study, the task-specific training exercise included slow ankle joint motion and isometric contraction. This training was meant to mimic the ankle dorsiflexion phase of the paretic single-leg stance. This similarity, in conjunction with the patient's improvement in plantar flexor strength, rendered controlled ankle dorsiflexion and heel lifts possible in the paretic single-leg stance.

An increase in the paretic hip extension angle is thought to contribute to passive elastic energy accumulation in the paretic hip flexor at the terminal stance. Furthermore, a study investigating passive elasticity during walking found that the contribution of the passive elasticity of the hip flexor is high in the single-leg stance[13)]. Specifically, the ratio of the passive joint moment to the net joint moment of the hip flexor at the terminal stance was up to 35%, and the ratio of the passive joint power to the net joint power at pre-swing was up to 58%. Thus, it appears that the hip flexion power due to passive elasticity was increased at the time of the paretic pre-swing, as the hip joint extension angle was increased at the terminal stance in the B2 phase in the present study. As a result, the maximum walking speed and step length were improved. Previous studies have reported that an increase in the trailing limb angle in stroke patients is a major factor for improving propulsion force[14, 15]. Thus, in the present study, it appears that the propulsion force of the paretic lower extremity increased, as the trailing limb angle increased, and additionally, the maximum walking speed improved. However, there was no rapid ankle plantar flexion in the paretic pre-swing in the B2 phase. A previous study reported that approximately 75% of gait speed improvement can be accounted for by increases in work during the paretic hip extension in the early stance and push-off[16]. Since rapid ankle plantar flexion was not recognized after task-specific training in the present study, it appears that this was not associated with the improvement in the maximum walking speed.

The present study found an improvement in plantar flexor strength after the task-specific training. The task-specific training involved a sustained muscle contraction with elevation for 2 seconds, rest in the elevated position for 1 second, and a muscle contraction with a descent for 2 seconds, without a relaxing phase. This method is known as a low-intensity resistance exercise with slow movement and tonic force generation[17]. It has been reported that even with a light load of 50% of one repetition maximum, the intramuscular environment becomes hypoxic, stimulating muscle strengthening. Because the patient's fatigue was close to his limit at the end of each set, we estimated the load in the present study to be about 50% of one repetition maximum. Furthermore, the observed muscle strengthening was considered to have been achieved via the same mechanism as low-intensity resistance exercise with slow movement and tonic force generation.

The main limitation of the present study is that it is a single-subject study. The generalization of the present results will require verification in additional cases. In addition, there was no rapid ankle plantar flexion and knee flexion at the paretic pre-swing, as the ankle plantar flexion angular velocity was late during the concentric contraction phase of the task-specific training. Thus, it might be necessary to add exercises similar to the pre-swing phase in order to improve motion in this phase.

In conclusion, the results of the present study suggest that a task-specific ankle plantar flexor training exercise, similar to that during walking, is effective in improving walking ability indices in stroke patients with a paretic ankle.

Conflict of interest

None.

REFERENCES

1) Brandstater ME, de Bruin H, Gowland C, et al.: Hemiplegic gait: analysis of temporal variables. Arch Phys Med Rehabil, 1983, 64: 583–587. [Medline]
2) Perry J, Garrett M, Gronley JK, et al.: Classification of walking handicap in the stroke population. Stroke, 1995, 26: 982–989. [Medline] [CrossRef]
3) Kim CM, Eng JJ: The relationship of lower-extremity muscle torque to locomotor performance in people with stroke. Phys Ther, 2003, 83: 49–57. [Medline]
4) Nadeau S, Gravel D, Arsenault AB, et al.: Plantarflexor weakness as a limiting factor of gait speed in stroke subjects and the compensating role of hip flexors. Clin Biomech (Bristol, Avon), 1999, 14: 125–135. [Medline] [CrossRef]
5) Ouellette MM, LeBrasseur NK, Bean JF, et al.: High-intensity resistance training improves muscle strength, self-reported function, and disability in long-term stroke survivors. Stroke, 2004, 35: 1404–1409. [Medline] [CrossRef]
6) Milot MH, Nadeau S, Gravel D, et al.: Effect of increases in plantarflexor and hip flexor muscle strength on the levels of effort during gait in individuals with hemiparesis. Clin Biomech (Bristol, Avon), 2008, 23: 415–423. [Medline] [CrossRef]
7) Yang YR, Wang RY, Lin KH, et al.: Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. Clin Rehabil, 2006, 20: 860–870. [Medline] [CrossRef]
8) Lamontagne A, Malouin F, Richards CL, et al.: Mechanisms of disturbed motor control in ankle weakness during gait after stroke. Gait Posture, 2002, 15: 244–255. [Medline] [CrossRef]
9) Fujiwara K, Toyama H, Asai H, et al.: Regular heel-raise training focused on the soleus for the elderly: evaluation of muscle thickness by ultrasound. J Physiol Anthropol, 2010, 29: 23–28. [Medline] [CrossRef]
10) Kesar TM, Reisman DS, Perumal R, et al.: Combined effects of fast treadmill walking and functional electrical stimulation on post-stroke gait. Gait Posture, 2011, 33: 309–313. [Medline] [CrossRef]
11) Miller EW, Combs SA, Fish C, et al.: Running training after stroke: a single-subject report. Phys Ther, 2008, 88: 511–522. [Medline] [CrossRef]
12) Neptune RR, Kautz SA, Zajac FE: Contributions of the individual ankle plantar flexors to support, forward progression and swing initiation during walking. J Biomech, 2001, 34: 1387–1398. [Medline] [CrossRef]
13) Whittington B, Silder A, Heiderscheit B, et al.: The contribution of passive-elastic mechanisms to lower extremity joint kinetics during human walking. Gait Posture, 2008, 27: 628–634. [Medline] [CrossRef]
14) Hsiao H, Knarr BA, Higginson JS, et al.: Mechanisms to increase propulsive force for individuals poststroke. J Neuroeng Rehabil, 2015, 12: 40. [Medline] [CrossRef]
15) Hsiao H, Knarr BA, Pohlig RT, et al.: Mechanisms used to increase peak propulsive force following 12-weeks of gait training in individuals poststroke. J Biomech, 2016, 49: 388–395. [Medline] [CrossRef]
16) Parvataneni K, Olney SJ, Brouwer B: Changes in muscle group work associated with changes in gait speed of persons with stroke. Clin Biomech (Bristol, Avon), 2007, 22: 813–820. [Medline] [CrossRef]
17) Tanimoto M, Ishii N: Effects of low-intensity resistance exercise with slow movement and tonic force generation on muscular function in young men. J Appl Physiol 1985, 2006, 100: 1150–1157. [Medline] [CrossRef]