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Research Article

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Effects of a Real-time Plantar Pressure Feedback during Gait Training on the Weight Distribution of the Paralyzed Side and Gait Function in Stroke Patients

Tae-Wu Kim, PT, BSc · Yong-Jun Cha, PT, PhD[1]†

Dept. of Physical Therapy, Yuseung Wellness Rehabilitation Hospital
[1]Dept. of Physical Therapy, College of Health and Medical Science, Daejeon University

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| Abstract |

PURPOSE: This study was conducted to investigate the effect of a real-time pressure feedback provided during gait training on the weight weight distribution of the inner part of mid-foot in paralyzed side and gait function in stroke patients.
METHODS: A total of 24 patients with hemiplegic stroke in a rehabilitation hospital were randomly assigned to the experimental and control group. All participants (n = 24) performed 15 min of comprehensive rehabilitation therapy 5 times a week for a period of 4 weeks. Additionally, the experimental group and control group underwent gait training with a real time feedback and general gait training, respectively, for 15 min five times a week for 4 weeks. Weight distribution and gait function were measured before and after the 4-week training.
RESULTS: Significant increases in the weight distribution (WD), stance time (ST) and step length (SL) of the paralyzed side, and a significant decrease in the 10 m walking test (10 MWT) observed after training in the two groups ($p < .05$). The experimental group showed larger changes in the all variables than the control group (WD, +10.5 kg vs. +8.8 kg, $p < .05$; ST, 12.8 s vs. 4.9 s, $p < .05$; SL, 4.9 cm vs. 1.7 cm, $p < .05$; 10 MWT, -3.5 s vs. -1.0 s, $p < .05$, respectively).
CONCLUSION: Gait training with a real-time feedback might be effective in improving the normalization of weight bearing of the paralyzed lower extremity and gait function of stroke patients, and be considered to be a more effective gait training for improving the abilities than the general gait training.

Key Words: Gait training, Plantar pressure, Stroke, Visual feedback

Ⅰ. Introduction

Stroke causes impairment of sensory, motor, perception, and cognitive functions due to damage to blood vessels in the brain [1]. Sensory and motor impairment due to stroke is a major factor in the decrease in balance and gait function of stroke patients [2], and makes it difficult for stroke patients to walk on their own, including daily life, and to even stand up [3,4].

For stroke patients to walk independently, it is necessary

†Corresponding Author : Yong-Jun Cha
cha0874@dju.kr, https://orcid.org/0000-0002-8553-7098

to shift their weight appropriately to the paralyzed side [5]. However, stroke patients support more weight on the non- paraplegic side than on the paralyzed side when walking, and the step width and step length also show an asymmetric pattern between the paralyzed side and the non-paralyzed side [6]. Such asymmetry between the two lower extremities eventually increases postural sway during walking, and the increased postural sway has a negative effect on walking speed and maintaining a standing posture, making it more difficult to improve gait function [7,8].

Various interventions are being carried out to increase the weight bearing on the paralyzed side to improve the walking function of stroke patients. There is a sensory feedback training, a postural control training using a game machine, and a dual task training [9-11]. In particular, sensory feedback training is used as a major intervention to improve the asymmetrical gait pattern of stroke patients using visual or auditory sensory feedback [12,13]. However, the feedback provided in previous studies has limitations in directly determining and performing weight on the paralyzed side in real time by the patient himself during gait training. In addition, during the normal gait stance phase, supination and pronation of the foot occur repeatedly at the subtalar joint, thereby distributing the weight evenly on the inner and outer parts of the foot. However, in the case of stroke patients, the weight of the foot is excessively supported on the outer parts rather than the inner parts during the stance phase [14,15]. However, previous studies so far have focused on training methods to increase the anterior-posterior weight shifting [16,17]. Therefore, this study was conducted to investigate the effect of real-time visual feedback provided to stroke patients on the weight distribution and gait function of stroke patients, and to compare the effects with general gait training. This study hypothesized that gait training, which provided real-time visual feedback on the plantar pressure distribution of the midfoot during the stance phase, would be more effective in improving function than general gait training.

Ⅱ. Methods

1. Participants

The subjects of this study were those who had been diagnosed with hemiplegia for more than 3 months after being diagnosed with stroke due to cerebral infarction or cerebral hemorrhage. The inclusion criteria of participants are as follows: a participant who can walk independently for more than 10 m without the use of a walking aid or ankle joint orthosis, a participant with good cognitive function to understand and put into practice both the instructions of the therapist and examiner (those with a score of 24 or higher on the Korean simple mental state test). The exclusion criteria of participants are as follows: a person with visual-perceptual disabilities, a person with musculoskeletal disorders such as fractures or dislocations of the paralyzed lower extremities, a person with deep respiratory disease that may cause extreme fatigue or difficulty breathing during training.

Among a total of 30 stroke patients being treated at two rehabilitation hospitals located in Daejeon city and Gyeongsang province, 24 people finally met the criteria for subject selection. All subjects voluntarily agreed to participate in the experiment after being fully explained about the purpose and process of the study. This study was conducted after the approval of the Research Ethics Committee of Daejeon University (IRB No. 1040647-202204-HR-003-02).

Twenty-four subjects were randomly assigned to 12 subjects in the experimental group, who provided real-time visual plantar pressure feedback during gait training, and 12 subjects in the control group, who performed general gait training with the aid of a therapist. All participants (n = 24) received neurological physiotherapy and gait training for 30 minutes, 5 times a week, for a total of 4 weeks. For neurological physiotherapy, range of motion exercise, muscle strengthening exercise, and balance training were performed for 15 minutes. Additionally, the

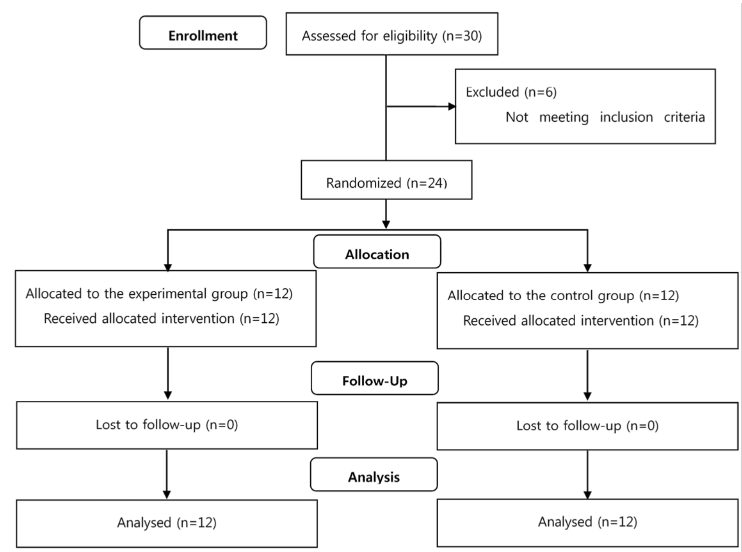

Fig. 1. CONSORT diagram showing study flow. CRT, comprehensive rehabilitation therapy.

experimental group performed gait training with visual plantar pressure feedback, and the control group performed general gait training for 15 minutes. All participants were allowed to rest for 5 minutes between neurological physiotherapy and gait training. The gait training was conducted in a round-trip 20 m straight-distance walking section installed in the treatment room. To investigate the effect of the intervention for 4 weeks, the distribution of weight on the paralyzed side and gait function were measured before and after the intervention (Fig. 1).

Fig. 2. KITRONYX components to provide real-time visual plantar pressure.

2. Intervention

1) Gait training with a real-time visual plantar pressure feedback

During gait training, a visual plantar pressure feedback information was provided to induce equal weight support on the inner part and outer part of the paralyzed foot during the mid-stance phase of the paralyzed lower extremity. To provide a visual plantar pressure feedback information in real time, MP-2513 (Kytronix, Inc, KOREA), a pressure distribution measurement kit, was used (Fig. 2). A software program called Snowforce3 (Kytronix, Inc, KOREA) is loaded in the MP-2513. This program provides visual information about the pressure distribution for each sole part with high resolution transmitted from the smart insole, which consists of 118 sensing nodes. The information for plantar pressure distribution on the inner part of the midfoot during the mid-stance phase provides visual information through the PC monitor that the color becomes red as the pressure increases and the color becomes lighter as the pressure decreases. In this study, all subjects assigned to the experimental group were asked to check the plantar pressure on the inner part of the midfoot during the stance phase on the paralyzed side through a monitor in real time. In order to provide real-time feedback, one therapist moved the laptop monitor according to the patient's gait visual area. The patient checked the monitor in real time and confirmed that the inner part and outer part of the midfoot are displayed in the same red color. At the same time, a physical therapist with over 5 years of clinical experience confirmed that the color of the inner and outer parts of the plantar pressure was maintained as red with an equal concentration for less than 2 seconds. After that, the therapist instructed the participant to strike the heel of the non-paralyzed side to the floor, which is the next step of gait. To prevent possible safety accidents during gait training, the therapist assisted in the stance and swing phase of the paralyzed lower extremity on the paralyzed side of the patient.

2) General gait training

The subjects assigned to the control group were given general gait training. General gait training was performed under the same conditions and environment as gait training in the experimental group. A physical therapist with over 5 years of clinical experience assisted with gait training. In the same manner as in the experimental group, the therapist instructed the participant to strike the heel of the non-paralyzed side to the floor, which is the next step of gait. To prevent accidents, the therapist assisted in the stance and swing phase of the paralyzed lower extremity on the paralyzed side of the patient.

3. Outcome Measures

1) Weight distribution

Gait Checker GHW-1100 (GHiWell Co., Ltd, Korea) was used to measure the weight distribution of the inner part of the mid-foot on the paralyzed side during static standing. To measure the weight distribution of the inner part of mid-foot all subjects were asked to look forward 45 degrees and maintain a standing posture while standing on the mat with their arms comfortably dangling. Before the weight distribution measurement, all subjects were asked to hold the standing posture for 10 seconds on a trial basis in order to ensure that all subjects could stably maintain the standing posture. When it was judged that it could be stably maintained after 10 seconds, the wight distribution at the time of holding for 5 seconds immediately was measured. The weight distribution was measured three times in total, and the average value of the three measurements was finally calculated.

2) Gait function

Among the gait function variables, gait speed was evaluated through a 10 m walking test (10 MWT), and the step time and the step length on the paralyzed side were evaluated using Gait Checker GHW-1100 (GHiWell Co., Ltd, Korea). For the 10 MWT, the time required to move a distance of 10 m excluding the first 2 m and the last 2 m from the measurement was measured using a stopwatch while the subject walked a total of 14 m straight walking path at a comfortable speed. This test method is reported to have a reliability of 0.78 in the test-retest when the walking speed of stroke patients is evaluated[18]. To check the step length and step length of the paralyzed side using the Gait Checker, the examiner had the subject stand in front of the walking mat 2 m and wait, and with the examiner's start signal, the subject started walking and passed over the walking mat 2 m to stop at the point. The walking speed on the walking mat for each subject was set to walk at the same comfortable pace as usual. The step time and step length are calculated automatically from the pressure sensor inserted into the mat while the subject walks on the walking mat. Gait function was measured by a physical therapist with 5 years of clinical experience without information on this study, each measurement

Table 1. Demographic Characteristics of the Participants at the Baseline

	Experimental group (n = 12)	Control group (n = 12)	x^2/t	P
Sex (male/female)	10/2	8/4	.889	.346
Damage factor (Infarction/hemorrhage)	6/6	3/9	1.600	.400
Paretic side (left/right)	5/7	5/7	.000	1.000
Age (years)	60.17 ± 5.49	58.17 ± 5.31	.907	.374
Height (cm)	163.67 ± 5.63	166.67 ± 7.48	-1.111	.279
Weight (kg)	60.42 ± 7.58	62.75 ± 10.20	-.636	.531
Onset (month)	5.42 ± 1.73	5.42 ± 1.88	.000	1.000
MMSE-K (score)	28.25 ± 1.42	28.08 ± 1.38	.291	.773

Values are expressed frequency or mean (SD).
Experimental group, gait training with visual plantar pressure feedback; Control group, general gait training
MMSE-K, Korean version of mini mental status examination.

variable was measured a total of 3 times, and the average value of the 3 measurements was finally calculated.

4. Data Analysis

The analysis of data collected through this study was performed in SPSS ver. 26.0 program was used for statistical processing. After the normality test for all data, the general characteristics of the subjects were presented using the chi-square test and descriptive statistics. A paired-sample t-test was used to compare the mean difference before and after the intervention within each group. An independent t-test was performed to compare the mean difference between the two groups before and after the intervention and the mean change before and after the intervention. The statistical significance level was set to .05.

Ⅲ. Results

1. General characteristics of the subjects

The results of comparison of the general characteristics of the study subjects are shown in Table 1, and there was no statistically significant difference between the two groups in sex, age, height, weight, onset duration, damage factor, and paretic side ($p > .05$).

2. Comparison of weight distribution in the inner part of midfoot before and after intervention between the two groups

Table 2 shows the comparison of the weight distribution of the inner part of mid-foot of paralyzed side during static standing before and after intervention between the experimental group and the control group. In both groups, the mean weight on the inner part of mid-foot was significantly increased after the intervention compared to before the intervention ($p < .05$). In the comparison between the two groups for the amount of change before and after the intervention, there was a significant difference in the test. The experimental group had a more significant increase by 2 kg than the control group ($p < .05$).

3. Comparison of gait function before and after intervention between the two groups

Table 2 shows the comparison results of gait function before and after intervention between the experimental group and the control group. In all of the 10 m walking

Table 2. Pre- to Post-training Changes in Weight Distribution and Gait Function Variables in the Two Study Groups

		Experimental group (n = 12)	Control group (n = 12)	*t*
10 MWT (s)	Pre	28.07 ± 1.72	28.06 ± 2.02	.027
	Post	23.92 ± 1.26	25.49 ± 2.22	-2.141[b]
	t	12.691[a]	10.380[a]	
	△(post-pre)	-4.16 ± 1.14	-2.57 ± .86	-3.884[b]
Step time (s)	Pre	.48 ± .06	.53 ± .12	-1.329
	Post	.72 ± .12	.70 ± .11	.495
	t	-9.849[a]	-10.038[a]	
	△(post-pre)	.24 ± .09	.17 ± .06	2.458[b]
Step length (cm)	Pre	23.87 ± 2.83	23.88 ± 2.78	-.009
	Post	28.90 ± 2.83	26.19 ± 2.61	2.438[b]
	t	-26.178[a]	-12.977[a]	
	△(post-pre)	5.03 ± .67	2.31 ± .62	10.393[b]
Weight distribution (kg)	Pre	30.21 ± 3.08	31.41 ± 3.84	-.845
	Post	33.67 ± 2.77	32.81 ± 4.00	.617
	t	-17.468[a]	-12.799[a]	
	△(post-pre)	3.46 ± .69	1.39 ± .38	9.144[b]

Values are expressed as mean (SD).
Experimental group, gait training with the real-time visual plantar pressure feedback; Control group, general gait training.
10 MWT, 10 m walking test.
[a]*Significanlty different* ($p < .05$) from the pre-tests.
[b]*Significanlty different* ($p < .05$) in gains between the two groups.

test, step time and step length of the paralyzed side, the mean values of the experimental group and the control group after the intervention were significantly different from the mean values before the intervention ($p < .05$). In the comparison between the two groups for the amount of change before and after the intervention, there were significant differences in all three variables ($p < .05$). In the 10 m walking test, the experimental group decreased by 2.5 s more than the control group, the experimental group increased 7.9 s more than the control group in the step time, and the step length increased 3.1 cm more in the experimental group than the control group ($p < .05$).

Ⅳ. Discussion

This study was conducted to investigate the effect of a real-time visual plantar pressure feedback provided during gait training for stroke patients on the weight distribution of inner part of mid-foot in the paralyzed side and gait function of stroke patients. As a result, the gait training with the real-time visual plantar pressure feedback significantly improved both the weight distribution of the inner part of mid-foot on the paralyzed side and gait function of the stroke patient compared to before training, and there was a greater improvement than general gait training. This result is consistent with the hypothesis of this study that gait training with the real-time visual plantar pressure feedback will make the weight distribution of stroke patients more even than general gait training, and that it will be more effective in improving gait function.

In the two gait trainings conducted in this study, the average value of weight distribution of the inner part of mid-foot of the paralyzed side during static standing increased significantly compared to before the intervention, and gait training with the real-time visual plantar pressure feedback showed a more significant increase than the general gait training. This result is considered to be because the feedback information on the plantar pressure distribution provided in real time when the stroke patient supports weight during the mid-stance phase makes it easier to apply the weight support of the stroke patient to the paralyzed foot. Visual feedback using a foot print or monitor of the paralyzed lower extremity during gait training increased plantar pressure of forefoot by 19% and plantar pressure of hindfoot by 40% in chronic stroke patients[19,20]. The results of this previous study support the results of this study in which the weight distribution on the foot of paralyzed side was increased after the intervention. It is difficult for stroke patients to evenly load the weight on the paralyzed and non-paralyzed side while maintaining a static standing posture [21]. Therefore, the results of this study, which increased the weight distribution on the paralyzed foot while maintaining the static standing posture, are expected to have a positive effect on the improvement of the ability to support the weight evenly between the two lower extremities and improve the static balance ability of stroke patients.

The amounts of changes in stance time and step length on the paralyzed side between the two gait training methods conducted in this study, gait training with the real-time visual plantar pressure feedback showed a more significant improvement than the general gait training. These results suggest that the gait training with the visual plantar pressure feedback is more effective in improving the gait function of stroke patients. This training method is considered to increase the step time because the patient himself lengthened the weight bearing time to the sole of the foot to achieve the goal of weight bearing in the inner part of mid-foot. In addition, the reason that the step length was longer means that the stance time on the paralyzed side was longer and thus the weight bearing was more stable during the paralyzed stance phase. If the weight bearing of the paralyzed side is more stable, it is thought that it can provide an environment in which the heel strike of the non-paralyzed side is easier and longer. Since stroke patients mainly show equinovarus, genu recurvatum, spastic ankle joint in the lower extremity of the paralyzed side[22,23], it is difficult to lengthen the weight bearing time during the stance phase on the paralyzed side. In addition, since the reduced step time of the paralyzed side compared to the non-paraplegic side makes the swing phase of the non-paraplegic side difficult, the step length is also shortened as a result[24]. Therefore, it is judged that the gait training with the visual plantar pressure feedback performed in this study might play an important role in reducing the typical abnormal gait pattern of stroke patients. Ki provided an auditory feedback signal when a pre-set target of weight support was achieved in the paralyzed stance phase during gait training in stroke patients. As a result, it was reported that gait training that provided auditory feedback increased the stance time of paralyzed side by 6.5 s more than the general gait training[25]. These results are consistent with the results of this study, in which the gait training with the real-time visual feedback during the stance phase on the paralyzed side is more effective in increasing the step time of paralyzed side than general gait training. Winstein et al.[26] conducted a balance training that provided visual feedback to 17 hemiplegic patients using a monitor to make the weight support of both lower extremities symmetrical while maintaining a static standing posture. As a result, it was reported that the step length increased by 20.3 cm more than before the intervention. These results are consistent with this study in which gait training with the real-time visual feedback using a monitor further increased the step length of stroke patients.

In the comparison between the two gait trainings for the 10 m walking test before and after the intervention conducted in this study, the gait training with the real-time visual plantar pressure feedback showed a more significant decrease than the general gait training. Training methods that can increase the weight bearing on the paralyzed side of stroke patients and increase gait speed are effective in achieving qualitative and quantitative improvement of gait function in stroke patients[27,28], therefore, the results of this study are clinically meaningful for the improvement of gait function in stroke patients. Kim et al.[29] reported that the weight shifting training applied during walking reduced the 10 m walking test time by 1.4 s more than the general gait training in stroke patients. These results are consistent with the results of this study, in which gait training with visual plantar pressure feedback improved gait speed more than general gait training.

The general application of the results of this study has the following limitations. First, in order to provide real-time plantar pressure feedback, which is the main intervention in this study, there is the inconvenience of moving the monitor according to the patient's visual perception space. Second, the equal distribution of inner and outer foot pressure during the mid-stance phase of the paralyzed lower extremity was made under the final confirmation of the therapist. Therefore, there is a limitation that agility and relatively high cognitive function are required to visually judge and perform the patient's own visual judgment during gait training. Third, the visual plantar pressure feedback provided in this study focused on the stance phase of the paralyzed lower extremity. Therefore, there is a limitation in that it cannot be an intervention method that can contribute to the normalization of swing phase in the paralyzed lower extremity. However, this study is judged to be clinically meaningful in that it suggests a more effective gait training method for gait normalization and gait function improvement in stroke patients. Future research is expected to supplement the limitations of this study and to actively research a feedback intervention method that can control the swing phase of the paralyzed side by the stroke patient's own judgement.

Ⅴ. Conclusion

This study was conducted to investigate the effect of the real-time visual plantar pressure feedback provided during gait training for stroke patients on the weight distribution of paralyzed side and gait function of stroke patients. As a result, gait training with the real-time visual plantar pressure feedback was effective in increasing weight distribution on the paralyzed side and improving gait function in stroke patients, and there was a more significant improvement than the general gait training. Therefore, gait training with the real-time visual plantar pressure feedback is considered to be a more effective training method for normalization of weight distribution on the paralyzed side and improvement of gait function than general gait training.

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