

# The effects of gait velocity on the gait characteristics of hemiplegic patients

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**Abstract.** [Purpose] The present study investigated the effects of gait speed on temporal and spatial gait characteristics of hemiplegic stroke patients. [Subjects and Methods] Twenty post-stroke hemiplegic patients participated in the present study. To enhance the reliability of the analysis of the gait characteristics, the assessments were conducted three days per week at the same time every day. Each subject walked maintaining a comfortable speed for the first minute, and measurement was conducted for 30 seconds at a treadmill speed of 1 km/hour thereafter. Then, the subjects walked at a treadmill speed of 2 km/hour for 30 seconds after a 30-minute rest. The differences in the measurements were tested for significance using the paired t-test. [Results] The measures of foot rotation, step width, load response, mid stance, pre-swing, swing phase, and double stance phase showed significant difference between the gait velocities. [Conclusion] The present study provides basic data for gait velocity changes for hemiplegic patients.

**Key words:** Gait characteristics, Gait velocity, Hemiplegia patients

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## INTRODUCTION

Stroke patients' general neurologic deficiencies lead to gait disturbances. The general characteristics of their gait include reduced gait velocity, inefficient gait, reduced muscle cooperation, and spatiotemporal asymmetry. Reduced control of muscle activities, muscle weakness, and spasticity-related changes characterize stroke patients' gait disturbance. In addition, symmetric gait is the most important determinant for the recovery of stroke patients' ambulatory functions<sup>1)</sup>.

Stroke patients' gaits have been reported to be related to sensory deficiencies, abnormal muscle activity, or abnormal postural mechanisms<sup>2)</sup>. The most important problem in post-stroke hemiplegic patients' physiological activities is gait disturbance. Hemiplegic patients require postural control plans for ambulatory functions and standing, and they show functional gait disturbance when postural control is insufficient<sup>3)</sup>.

Many researchers have reported that stroke patients' hipflexor<sup>4)</sup>, kneeextensor<sup>5)</sup>, and ankle plantarflexor<sup>6)</sup> muscle strengths are correlated with comfortable and fast gaits and that, in particular, postural instability in the pre-swing phase affects gait velocity<sup>7)</sup>. Suzuki et al. reported that according to

results based on the use of isokinetic muscle strength equipment, knee extensor muscle strength was closely related to gait velocity in mild or moderate strokepatients<sup>8)</sup>.

Clinically, spasticity and abnormal muscle activity or tone are two general characteristics of stroke patients. However, the level of correlation between stroke patients' spasticity/abnormal muscle tone and their gait velocity is still controversial. Some researchers have reported that stroke patients' gait velocity is correlated with the stages of recovery of the motion of the hemiplegic side lower extremity such as Brunnstrom's recovery stage<sup>9)</sup> or the Fugl-Meyer Motor Assessment<sup>10)</sup>. For instance, Nadeau et al. noted that Fugl-Meyer balance scores are correlated with high gait velocity and comfortable gait velocity in mild or moderate stroke patients<sup>11)</sup>. However, Suzuki et al. argued that standing balance and maximum gait velocity were not correlated with each other in stroke patients with a good sense of balance, since stroke patients showed less than 30 cm difference in the movement distance of their center of foot pressure, and approximately 10 seconds in their level of standing balance<sup>8)</sup>.

Stroke patients' gait velocities are slower than those of healthy adults and they show asymmetric spatiotemporal gait characteristics. In several previous studies, researchers have reported that stroke patients' average gait velocities range from 0.18 to 1.03 m/s<sup>12)</sup>, while those of healthy adults are approximately 1.4 m/s<sup>13)</sup>.

In another study, gait asymmetry was identified through the measurement of kinematic, kinetic, and spatiotemporal parameters<sup>14)</sup>. Chen et al. reported that in a comparison of stroke patients' gait velocity and general adults' gait velocity, the lower extremities of stroke patients show asymmetry at the beginning of the swing phase and the stance phase<sup>15)</sup>.

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The present study was conducted to investigate the association between and gait parameters. Hemiplegic patients walked at gait velocity different gait velocities and differences in gait parameters according to gait velocity were determined to examine their relationships.

## SUBJECTS AND METHODS

The present study was conducted observing the research ethics described in the Declaration of Helsinki and the research ethics regulations of the hospital. Sufficient explanations were provided to all the study subjects, who gave their written consent before participating in the study. There were 20 subjects in the study, 12 males and 8 females. Their average age was  $59.19 \pm 4.18$  years, and their average time after the onset of stroke was  $15 \pm 3.24$  months. The affected side was the right side of 8 patients and the left side of 12 patients.

The subjects of this study were 20 hemiplegic stroke patients who recovered independent gait after receiving rehabilitation treatment focused on gait and balance at a rehabilitation hospital located in Hwaseong City, Gyeonggi-do. The study subjects were patients who were scheduled to receive occupational therapy along with balance and gait training based on neurodevelopment treatment two hours a day, five times a week. The inclusion criteria were: ability to walk independently without a walking aid; at least six months from onset of stroke; ability to properly communicate and comprehend instructions; no visual, auditory, or vestibular disabilities; no orthopedic problems that might have influenced balance of the lower extremities; and willingness to participate in the experiment after receiving an explanation of the purposes of this study. Patients with the following conditions were excluded: severe cardiac disorders or uncontrollable hypertensive lesions that might lead to difficulties with gait; complaints of pain in the lower extremity during gait due to orthopedic problems; and neuropsychiatric issues.

The subjects did not perform strenuous exercise before the study began. To enhance the reliability of the analysis of gait characteristics, the assessments were conducted three days per week at the same time every day. The assessments were repeated 30 minutes after the initial assessment to enhance reliability. Measurement was conducted three times at the two gait velocities, and the subjects were allowed to rest when necessary. The subjects were instructed to wear comfortable shoes and were allowed to use walking aids when necessary.

In this study, the gait velocities were measured using ground reaction forces on a treadmill (Zebris Medical GmbH, FDM-T system, Isny, Germany). The treadmill used for gait analysis was 1.5 m long, 0.5 m wide, and had 5,378 sensor plates. The data were obtained at a sampling rate of 120 Hz.

In the present study, the temporal and spatial elements of gait were measured. Each patient walked maintaining a comfortable speed for the first minute, and measurement was conducted for 30 seconds at a treadmill speed of 1 km/hour thereafter. Then, the subjects walked at a treadmill speed of 2 km/hour for 30 seconds after a 30-minute rest. The patients

did not hold the safety bar when walking on the treadmill and foot rotation, step width, load response, mid-stance, pre-swing, swing, and double-stance phases were derived from measurements made at the different walking speeds.

SPSS ver. 17.0 statistical software was used for the statistical analysis of the collected data. The paired t-test was used to verify the significance of the changes between the gait velocities. Values of  $p < 0.05$  were considered statistically significant.

## RESULTS

Foot rotation at the 1 km/hour gait was  $23.0^\circ$  on the hemiplegic side and  $9.3^\circ$  on the unaffected side, and at 2 km/hour it was  $21.8^\circ$  on the hemiplegic side and  $9.7^\circ$  on the unaffected side, with both sides showing significant differences. The step width was  $19 \pm 1$  cm at 1 km/hour and  $21 \pm 2$  cm at 2 km/hour, a significance difference. The load response at 1 km/hour was  $26.4 \pm 3.1\%$  on the hemiplegic side and  $21.3 \pm 2.9\%$  on the unaffected side, and at 2 km/hour it was  $21.2 \pm 2.1\%$  on the hemiplegic side and  $19.9 \pm 2.2\%$  on the unaffected side, with the values of both sides showing significant differences. The mid-stance ratio was  $18.9 \pm 3.1\%$  on the hemiplegic side and  $33.3 \pm 2.7\%$  on the unaffected side at 1 km/hour, and  $22.7 \pm 1.2\%$  on the hemiplegic side and  $36.1 \pm 1.9\%$  on the unaffected side at 2 km/hour with the values of both sides indicating significant differences. The pre-swing was  $21.2 \pm 2.2\%$  on the hemiplegic side and  $26.4 \pm 3.3\%$  on the unaffected side at 1 km/hour, and  $19.9 \pm 1.7\%$  on the hemiplegic side and  $21.2 \pm 1.8\%$  on the unaffected side at 2 km/hour with the values of both sides indicating significant differences. The swing phase was  $33.5 \pm 3.1\%$  on the hemiplegic side and  $18.9 \pm 1.6\%$  on the unaffected side at 1 km/hour, and  $36.3 \pm 2.9\%$  on the hemiplegic side and  $22.7 \pm 1.4\%$  on the unaffected side at 2 km/hour. With the values of both sides indicating significant differences. The double stance phase was  $47.8 \pm 3.7\%$  at 1 km/hour and  $41.2 \pm 2.7\%$  at 2 km/hour, a significant difference.

## DISCUSSION

In hemiplegic patients, hemiplegic side lower extremity malfunction in the swing phase and compensation are correlated. Hemiplegic patients begin having difficulty properly using the kinetic force of the hemiplegic side lower extremity in the pre-swing phase due to inadequate thrust from the hemiplegic side hip flexor<sup>16)</sup> and ankle plantarflexor<sup>11)</sup>. Such patients have difficulty bearing weight during the peak in the last part of the single-leg stance phase and do not generate sufficient force during the forward movement of both lower extremities, which affects their gait patterns, resulting in asymmetrical gait<sup>17)</sup>. In hemiplegic patients' gait cycles, weight shifts to the hemiplegic side play an important role in standing on one foot, preventing shaking by providing stability to the lower extremity as well as to the trunk<sup>18)</sup>. In the present study, when gait parameters were examined at the two different speeds of 1 km/hour and 2 km/hour, the changes in load response were found to be  $26.4 \pm 3.1\%$  on the hemiplegic side and  $21.3 \pm 2.9\%$  on the unaffected side at 1 km/hour, and  $21.2 \pm 2.1\%$  on the hemiplegic side and

19.9±2.2% on the unaffected side at 2 km/hour. The mid stance ratio was found to be 18.9±3.1% on the hemiplegic side and 33.3±2.7% on the unaffected side at 1 km/hour, and 22.7±1.2% on the hemiplegic side and 36.1±1.9% on the unaffected side at 2 km/hour. The pre-swing ratio was found to be 21.2±2.2% on the hemiplegic side and 26.4±3.3% on the unaffected side at 1 km/hour, and 19.9±1.7% on the hemiplegic side and 21.2±1.8% on the unaffected side at 2 km/hour.

The swing phase ratio at the two different speeds of 1 km/hour and 2 km/hour were 33.5±3.1% on the hemiplegic side and 18.9±1.6% on the unaffected side at 1 km/hour and 36.3±2.9% on the hemiplegic side and 22.7±1.4% on the unaffected side at 2 km/hour. The double stance phase ratio was 47.8±3.7% at 1 km/hour and 41.2±2.7% at 2 km/hour.

Similar to the results of the present study, previous studies have reported that hemiplegic patients have difficulty standing on one foot on the hemiplegic side, compared to healthy persons, and that related compensation appears frequently. In general, most hemiplegic patients' weight bearing and thrust for walking activities tend to be stronger on the unaffected side than on the hemiplegic side<sup>19)</sup>. In addition, the decline in hemiplegic side muscle activity shown in the hemiplegic side stance phase in hemiplegic patients' gait cycles aggravates decreases in plantar pressure for forward thrust, shaking of the upper body, and pelvic instability<sup>20)</sup>.

Hemiplegic patients and healthy persons show differences in other gait elements as well. Step widths are greater in hemiplegic patients, and this is associated with unstable balance. Hemiplegic patients' asymmetry appears more prominently in step lengths, and the unaffected side and the hemiplegic side step lengths are not the same<sup>15)</sup>.

In the present study, step widths on the hemiplegic side were 19±1.0 cm at 1 km/hour and 21±2.0 cm at 2 km/hour. Foot rotation at the different speeds were 23.0±1.7 degrees on the hemiplegic side and 9.3±0.8 degrees on the unaffected side at 1 km/hour, and 21.8±1.9 degrees on the hemiplegic side and 9.7±0.9 degrees on the unaffected side at 2 km/hour.

Similar to the present study, previous studies have also demonstrated that in cases of mild hemiplegia, with no deficits in cognitive ability and visual perceptual ability, ambulatory ability (gait velocity, spatiotemporal asymmetry) and physical disorders (muscle strength, lower extremity motor and sensory functions, the degree of spasticity of the hemiplegic side ankle plantar flexor) are correlated.

Previous studies have also suggested that in cases of mild hemiplegia, gait velocity and asymmetry are directly related to physical disorder. Therefore, in the case of gait training for hemiplegic patients, the goals should be established after first considering physical disorder<sup>21)</sup>.

Hemiplegic patients' show significant differences between hemiplegic side support and unaffected side support at the start of gait. Steps involving weight bearing on the hemiplegic side lower extremity are shorter than those of the unaffected side lower extremity. Therefore, in the case of hemiplegic patients, weight bearing on the hemiplegic side lower extremity tends to decrease when gait begins, and during the stages of support by the unaffected side lower extremity tends to increase compared to healthy adults<sup>22)</sup>. Previous studies' findings are consistent with those of the present study.

Typical characteristics of post-stroke hemiplegic patients' gait are long gait cycles, low gait velocity, asymmetry of gait between the hemiplegic side and the unaffected sides, and short strides on the hemiplegic side which result in high ratios of the swing phase<sup>23)</sup>. The findings of the present study are similar to those of previous studies.

During hemiplegic patients' gait, the ratio of weight bearing by the hemiplegic side lower extremity decreased, and the length of weight-bearing time on both feet increased<sup>24)</sup>. Our present results are consistent with those of previous studies conducted by Hesse et al.<sup>25)</sup> and Kirker et al.<sup>26)</sup>. Our results are attributable to hemiplegic patients' lack of ability to control balance during weight-bearing by the hemiplegic side lower extremity, which aggravates instability during weight bearing. It for hemiplegic patients to bear weight on the unaffected side lower extremity longer than on the hemiplegic side lower extremity, and longer than normal adults as well. The amount of time increases to compensate for hemiplegic patients' generation of insufficient thrust by the hemiplegic side lower extremity<sup>22)</sup>.

The results of previous studies and the present study are consistent, indicating that hemiplegic patients' gait show shorter unaffected side swing phases, longer unaffected side weight bearing, shorter hemiplegic side weight bearing, and longer hemiplegic side swing phases than healthy adults, as well as instability in weight bearing related to differences in gait velocities. The present results provide basic data for gait velocity changes for hemiplegic patients.

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