**Abstract.** [Purpose] The aim of this study was to determine if gait index predicts the efficacy of weight-support treadmill training (BWSTT) in hemiplegic stroke patients. [Participants and Methods] In total, 21 patients who had sustained a hemiplegic stroke, on an average 71 days prior, and could walk independently on level ground were included in the study. BWSTT was performed under 20% of bodyweight unloading at the maximum speed possible for each participant to a perceived level of fatigue of 15 on the 20-point Borg scale. The immediate effects of BWSTT were evaluated as the change in the following variables, calculated from 5 level ground gait cycles; walking speed and rate, root mean square, coefficient of variability, auto-correlation coefficient, and single leg stance time ratio. All indices were calculated from the triaxial accelerometer attached to the waist of the participant. Linear regression was used to identify predictive variables of BWSTT effectiveness. [Results] Only single leg stance time ratio on level ground was extracted as a predictor of BWSTT effectiveness. [Conclusion] Single leg stance time ratio was a predictive factor of improved gait symmetry after BWSTT and therefore, could be used as a factor to select patients who might benefit from BWSTT as a component of stroke rehabilitation.

**Key words:** Stroke hemiplegia, Body Weight Support Treadmill Training, Triaxial accelerometer

**INTRODUCTION**

Body Weight Support Treadmill Training (BWSTT) is commonly used in post-stroke gait rehabilitation. Harness support reduces the load on the lower extremity during gait\(^1\) and significantly attenuates the spastic response of the lower extremity during gait\(^2\). The harness further minimizes the risk of falls and allows gait training to begin in the early stages of stroke recovery\(^3\), thus providing greater opportunity for gait training than ground walking\(^4\). However, a 2017 systematic review\(^5\) did not provide conclusive evidence for the therapeutic effects of BWSTT. In addition, BWSTT was not found to be superior to other gait training approaches in improving walking speed or endurance. However, BWSTT was effective for those who were able to walk independently on level ground; as such, we can speculate that the effectiveness of BWSTT was influenced by baseline walking ability. Our previous study of BWSTT in 17 stroke patients\(^6\) found that the bilateral symmetry during level ground walking before training was associated with the measured effectiveness of BWSTT. The purpose of this study was to evaluate the value of various gait indices in predicting the efficacy of BWSTT.

**PARTICIPANTS AND METHODS**

Our study was approved by the Research Ethics Board of the International University of Health and Welfare (approval number: 15-Ifh-43), and all participants provided written informed consent.
This was a prospective observational study of the immediate effects of BWSTT among patients with a stroke hemiparesis. The 21 patients included in our study group had sustained hemiplegic stroke 71.24 ± 22.21 days prior to the BWSTT and were able to walk independently on level ground. Patients with higher brain and cognitive impairments were excluded. Relevant characteristics of the study group are summarized in Table 1.

The Biodex Unweighing System (NY, USA) was used for BWSTT, with a T650MS treadmill (SportsArt, Tainan City, Taiwan). The BWSTT protocol was based on our previous study and included the following parameters: 20% body weight unloading; treadmill speed to the maximum steady state walking speed for each individual; training up to a self-reported fatigue level on the 20-point Borg scale.

The gait indices were measured before and after the BWSTT. To exclude the acceleration and deceleration phases, the calculations were made from a 10 m walk on level ground at a distance of 2 m before and after the acceleration phase. Participants were allowed to use the devices (canes and orthotics) they normally used in daily activities. A triaxial accelerometer (LegLog; Bisen, Hyogo, Japan) was attached over the third lumbar vertebra. The acceleration data were sampled at a frequency of 200 Hz. Steady state epochs of the waveform for each gait cycle were identified visually, with steady state data from 5 gait cycles used to calculate the following gait indices: the root mean square (RMS) of the waveform averaged over the 5 gait cycles, providing an index of sway; the coefficient of variability (CV), quantify the degree of variation in the waveform over the 5 gait cycles, providing an index of stability; and the auto-correlation coefficient (AC), which quantifies the degree of coincidence in the waveform within each of the 5 gait cycles, providing an index of regularity. As previous research indicated that BWSTT can improve left/right symmetry, we also calculated the single leg stance time ratio as the index of symmetry, with improvement in this index being the primary outcome of a positive effect of BWSTT on post-stroke gait. In our previous study, the single leg support time ratio on level ground walking correlated with the rate of improvement in the BWSTT single leg support time ratio. Therefore, we hypothesized that the ability to walk on level ground may be a predictor of the improvement in the single leg support time ratio by BWSTT. Based on this reasoning, a single regression analysis was conducted with the BWSTT improvement in the single leg support time ratio as the objective variable and the ability to walk on level ground as the explanatory variable.

The normality of the distribution of the measured variables was assessed using the Shapiro-Wilk test; the change in gait index before and after the BWSTT was assessed using parametric and nonparametric statistics as appropriate, depending on the results of the test of normality. Single regression analysis was conducted to evaluate the effect of gait index on the improvement in the single leg stance time ratio by BWSTT on level ground. All analyses were performed with using R2.8.1., with the level of significance set at 5%.

RESULTS

The characteristics of the target population are shown in Table 1. Regarding the effect of BWSTT, no significant change was observed in any of the gait indices (Table 2). The regression analysis indicated that the single leg stance ratio during level ground walking was the only gait index that was positively associated with improved symmetry of gain (i.e., further improvement of the single leg stance ratio) after training. Therefore, gait symmetry prior to BWSTT is an important consideration when selecting patients for whom BWSTT could be effective in improving level ground gait (Table 3).

DISCUSSION

The single leg stance time ratio during level ground walking was associated with a significant improvement in single leg stance time ratio after BWSTT, reflective of increased symmetry in level ground gait after training. Therefore, in addition to walking independence at the time of intervention, previously identified as an important factor to predict a benefit of BWSTT, our findings indicate that the single leg stance time ratio may also be a useful index to predict benefits of BWSTT. Stroke is

Table 1. Descriptive characteristics of the study participants

| Characteristic                          | n=21                        |
|----------------------------------------|-----------------------------|
| Age (years) (mean ± SD)                | 69.45 ± 10.21               |
| Gender (n)                             | Male=13, Female=8           |
| BMI (kg/m²) (mean ± SD)                | 22.47 ± 3.51                |
| Days since onset (mean ± SD)           | 71.24 ± 22.21               |
| BRS (n per stage)                      | II=2, III=3, IV=6, V=8, VI=2 |
| Paralysis side GMT (n per GMT)         | 2=7, 3=7, 4=7               |
| Non-paralysis side GMT (n per GMT)     | 3=3, 4=14, 5=4              |
| Deep sensory disturbance (n)           | Yes=4, No=17                |

BMI: body mass index; BRS: Brunnstrom Recovery Stage; GMT: gross muscle test.
associated with different degrees of gait impairments, including paralysis, muscle weakness, and sensory impairments. These impairments increase the required compensation by the contralateral lower extremity, which results in gait asymmetry. Since BWSTT promotes gait symmetry, it makes sense to extract a symmetry measure, such as the one-leg stance-time ratio, as a feature of the effectiveness of BWSTT on gait, particularly when we consider that gait asymmetry leads to the slower walking speed observed after a stroke.

In the present study, improvement in the gait symmetry index after BWSTT was not associated with improvement in either level ground walking speed and walking rate. A longitudinal study would be important to clarify the relationship between improvement in gait symmetry after BWSTT and other gait indices. The gait indices that we used in our study can be easily calculated from a single triaxial accelerometer, which is informative in this respect. In addition, the primary result we used, the single leg stance time ratio, can be measured using simple technology, such as floor reaction forces or foot switches, and thus can be easily calculated.

A limitation of the present study is that it was a validation of the immediate effect of BWSTT and, therefore, the long-term effects of the intervention were not considered. In addition, due to the relatively small sample size and the variability in stroke and demographic characteristics among participants, it was not possible to identify a cutoff value for the gait symmetry index to determine improvement after BWSTT. Finally, we did not assess how the use of a walking aid affected the measured gait

### Table 2. Comparison of gait index, before and after BWSTT

|                      | Before       | After        |
|----------------------|--------------|--------------|
| Walking speed (m/s)  | 0.97 ± 0.27  | 1.04 ± 0.51  |
| Walking rate (steps/s) | 1.85 ± 0.46  | 1.84 ± 0.56  |
| RMS                  |              |              |
| Left-right           | 4.02 ± 2.33  | 3.64 ± 2.41  |
| Vertical             | 4.39 ± 1.9   | 3.95 ± 2.49  |
| Anterior-posterior   | 4.25 ± 2.29  | 4.00 ± 2.32  |
| CV                   |              |              |
| Left-right           | 15.34 ± 6.43 | 18.4 ± 5.61  |
| Vertical             | 21.23 ± 11.21| 18.65 ± 7.33 |
| Anterior-posterior   | 18.51 ± 8.43 | 15.43 ± 9.41 |
| AC                   |              |              |
| Left-right           | 0.25 ± 0.21  | 0.22 ± 0.31  |
| Vertical             | 0.44 ± 0.35  | 0.33 ± 0.21  |
| Anterior-posterior   | 0.23 ± 0.11  | 0.25 ± 0.14  |
| Single leg support time ratio | 0.78 ± 0.12 | 0.80 ± 0.19 |

Data are presented as mean ± SD. RMS: root mean square; CV: coefficient of variability; AC: autocorrelation coefficient.

### Table 3. Relationship between the rate of improvement of the single leg support time ratio by BWSTT and the ability to walk on level ground

| Explanatory variables                               | R² | B       | 95% CI     |
|-----------------------------------------------------|----|---------|------------|
|                                                     |    |         | Lower      | Upper      |
| Walking ability on level ground                     |    |         |            |            |
| Walking speed (m/s)                                 | 0.09 | 0.09 | −0.06 | 0.26 |
| Walking rate (steps/s)                              | 0.05 | −0.05 | −0.15 | 0.06 |
| RMS Left-right                                      | 0.16 | −0.01 | −0.03 | 0.01 |
| Vertical                                            | 0.19 | −0.04 | −0.08 | 0.03 |
| Anterior-posterior                                  | 0.21 | −0.02 | −0.05 | 0.01 |
| CV Left-right                                       | 0.18 | −0.02 | −0.06 | 0.05 |
| Vertical                                            | 0.08 | −0.02 | −0.05 | 0.02 |
| Anterior-posterior                                  | 0.08 | −0.01 | −0.05 | 0.02 |
| AC Left-right                                       | 0.09 | 0.22 | −0.16 | 0.61 |
| Vertical                                            | 0.03 | 0.12 | −0.27 | 0.51 |
| Anterior-posterior                                  | 0.17 | 0.14 | −0.03 | 0.32 |
| Single leg support time ratio                       | 0.85 | 0.56 | 0.42 | 0.68 * |

*p<0.05. RMS: root mean square; CV: coefficient of variability; AC: autocorrelation coefficient; CI: confidence interval.
symmetry index. The single leg stance time ratio on level ground walking may be a predictor of the effectiveness of BWSTT in further improving the symmetry of level ground walking in patients with a hemiplegic stroke. Future research is warranted to determine the cutoff value indicative a clinically meaningful effect of BWSTT as a component of stroke rehabilitation.

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**Conflict of interest**

There are no conflicts of interest to declare.

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