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Quantitative assessment of the gait improvement effect of LSVT BIG® using a wearable sensor in patients with Parkinson's disease

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ABSTRACT

Background: The main effects of Lee Silvermann Voice Treatment-BIG® therapy (LSVT-BIG) on gait function are improvements in gait speed and stride length. Considering the mechanism of this improvement, LSVT-BIG may affect joint angles of the lower extremities. Therefore, further investigation of the effect of LSVT-BIG on gait function, especially joint angles, is needed.
Methods: Patients with Parkinson's disease (PD) who were eligible for LSVT-BIG were recruited. We measured the following items pre- and post-LSVT-BIG: MDS-Unified Parkinson's Disease Rating Scale (MDS-UPDRS), Functional Independence Measure (FIM), timed up and go test (TUG), and gait parameters using RehaGait®. Gait parameters included gait speed, stride duration and length, the standard deviation of stride duration and length, cadence, the ratio of the stance/swing phase, and the flexion and extension angles of the hip, knee, and ankle joints. Range of motion (ROM) was calculated as the difference of values between the maximum flexion and extension angles of each joint.
Results: Twenty-four participants completed the LSVT-BIG. Significant improvement was observed in the MDS-UPDRS (mean changes: Part I, −2.4 points; Part II, −3.5 points; Part III -8.9 points), TUG (−0.61 s), gait speed (+0.13 m/s), stride length (+0.12 m), flexion and extension angles and ROM of the hip joints (flexion, +2.0°; extension, +2.0; ROM, +4.0°). Enlargement in ROM of the hip joint was strongly correlated with increase in gait speed and stride length ($r = 0.755$, $r = 0.804$, respectively).
Conclusions: LSVT-BIG enlarged flexion and extension angles and ROM of the hip joint significantly. Change of ROM of the hip joint was directly related to the increase in stride length and gait speed observed in patients with PD after LSVT-BIG.

1. Introduction

Parkinson disease (PD) is a neurodegenerative disease, with symptoms that include rigidity, slowness, tremor, and altered postural

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reflex [1]. As a result of these motor disturbances, gait impairment is one of the main clinical problems observed frequently in PD patients. Typical characteristics of gait in PD are low speed, reduced step length, and increased cadence [2,3]. However, rehabilitation therapy can improve motor symptoms, including gait function, in PD [4].

In 2005, a symptom-specific rehabilitation program was developed called the Lee Silvermann Voice Treatment-BIG® therapy (LSVT-BIG) [5]. LSVT-BIG is mainly composed of motor training with high-amplitude movements. Participants who receive LSVT-BIG perform the given task at least 4 days per week for 4 weeks. The therapy is well-established and participants for LSVT-BIG keep training with a certificated therapist [5]. The effectiveness of LSVT-BIG for improving gait function has been established through several trials [6–8], with improvement of gait speed and stride length being strongly supported [8–10]. The advantage of LSVT-BIG over conventional rehabilitation programs has been shown by randomized control studies [10,11]. LSVT-BIG mainly focuses on PD patients with Hoehn & Yahr Grade II or III. However, the effect of LSVT-BIG is also promising for patients with either milder or more severe conditions [12,13].

RehaGait® (HASOMED, Magdeburg, Germany) is a wearable gait analysis system that uses 7 sensors to measure various gait parameters. This system can evaluate quantitatively not only basic gait spatiotemporal parameters, but also the joint angles of the lower extremities [14–16]. The joints of the lower extremities, especially the knee and hip joint, affect the increase in stride length in healthy people [17]. Increased range of motion in the hip and knee joints by LSVT-BIG has been confirmed using motion capture [18]. However, quantitative studies of joint movement through LSVT-BIG are limited. This study aimed to investigate the changes in ROM of the lower extremity joints in PD patients using a wearable sensor to clarify the mechanism of LSVT-BIG improvement of motor function.

2. Materials and methods

2.1. Participants and intervention

All participants had no symptoms of cognitive impairment (Mini-Mental State Examination score >23) and were independent in their activities of daily life. They were admitted to JA Nagano Koseiren Kakeyu Misayama Rehabilitation Center Kakeyu Hospital to receive LSVT-BIG by certificated physical and occupational therapists properly trained in its use. Participants were instructed to exercise by the LSVT-BIG program for 1 h per day as a daily session, and complete 4 or 5 sessions per week for 4 weeks. The participants were also encouraged to do daily homework tasks. The therapist in charge of accomplishing LSVT-BIG for each participant checked for adherence to homework tasks at the beginning of therapy every day. The therapist set the number of tasks, which varied among the participants. All participants had no change in medication for parkinsonism during LSVT-BIG.

This study was approved by the Ethics Committee of Shinshu University School of Medicine (No. 4629; date of approval, April 2, 2020) and conformed to the principles described in the Declaration of Helsinki. All participants provided written informed consent.

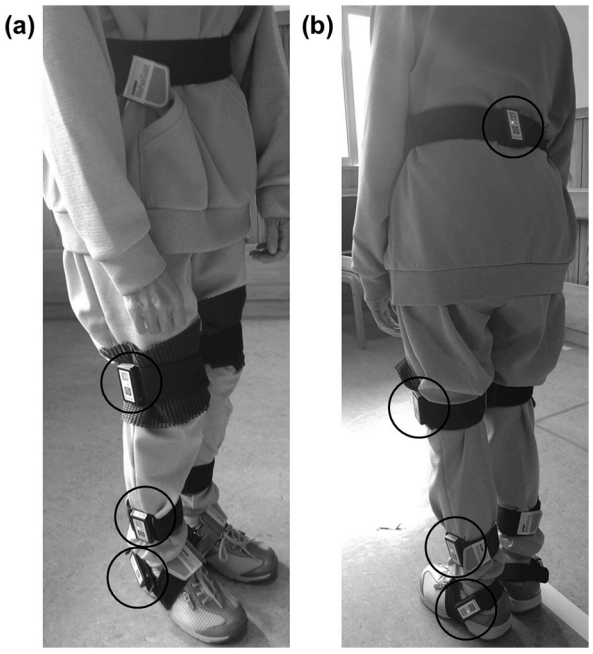

Fig. 1. (a) An anterior view and (b) a posterior view of the lower extremities with the RehaGait® system. We used 7 sensors (1 sensor at the waist, 2 sensors at both sides of the knee joints, and 4 sensors at both sides of the ankle joints) in this study. Circles indicate the position of the sensors.

2.2. Measurements

We assessed the following within 7 days before beginning (pre-LSVT-BIG) and after finishing LSVT-BIG (post-LSVT-BIG): MDS-Unified Parkinson's Disease Rating Scale (MDS-UPDRS) [19], Functional Independence Measure (FIM) [20,21], timed up and go test (TUG), and gait parameters (using RehaGait) (Fig. 1). In the measurement of gait function, participants were instructed to walk 10 m on a flat floor at a comfortable speed (3 times). We collected the following gait parameters using RehaGait: gait speed, stride duration and length, standard deviation of stride duration and length, cadence, the ratio of the stance/swing phase on the left and right sides, and maximum flexion and extension angle of hip, knee, and ankle joint angles on the left and right sides. In The range of motion (ROM) of the hip, knee, and ankle joints was calculated as the difference between the maximum flexion and extension angles of each joint. The mean value of each parameter in 3 measurements was used in the analysis. For the gait phase and angle of each joint, the mean value of the left and right side was used in the analysis. All measurements were conducted under *on* status.

2.3. Statistical analysis

The assumption of a normal distribution was assessed by the Kolmogorov-Smirnov test and normal Q-Q plot. The differences in all measurements between pre-and post-LSVT-BIG were analyzed by a paired *t*-test or a Wilcoxon signed-rank test depending on the result of the Kolmogorov-Smirnov test. The effect size was calculated by Cohen's d for a paired *t*-test and Cliff's Delta for a Wilcoxon singed-rank test. The correlation between normally distributed measurements was analyzed by the Pearson correlation coefficient. All statistical analyses were performed using R (Foundation for Statistical Computing, Vienna, Austria). The level of significance was set at $p < 0.05$ in all tests.

3. Results

Twenty-four participants completed LSVT-BIG. Characteristics of the participants are shown in Table 1. One participant was in Hoehn & Yahr Grade I and 1 participant was in Grade II, while the rest were in Grade III. The mean disease duration and levodopa equivalent dose were 6.1 years and 743 mg/day, respectively.

The Kolmogorov-Smirnov test showed that MDS-UPDRS part IV, FIM scores, the standard deviation of stride time and duration, the ratio of the stance/swing phase, and all subscores of MDS-UPDRS were not distributed normally ($p < 0.05$). The changes in MDS-UPDRS, FIM, TUG, and gait parameters between pre- and post-LSVT-BIG obtained by RehaGait are shown in Table 2. Gait parameter analysis with RehaGait showed that LSVT-BIG significantly increased gait speed ($d = -0.55$, $p = 0.003$) and stride length ($d = -0.52$, $p < 0.001$). On the other hand, LSVT-BIG did not increase cadence ($d = -0.07$, $p = 0.617$) or influence stride duration ($d = 0.04$, $p = 0.869$), standard deviation of stride length ($d = -0.26$, $p = 0.230$), standard deviation of stride duration ($d = -0.05$, $p = 0.627$), and gait phase ($d = \pm 0.19$, $p = 0.346$).

As for the angle of the lower limb joints, LSVT-BIG significantly increased the maximum flexion and extension angle of the hip (flexion; $d = -0.57$, $p = 0.004$, extension; $d = 0.39$, $p = 0.027$). LSVT-BIG increased ROM of the hip, knee, and ankle joints by 4.0° (95% confidence interval: 1.59° – 6.36°), 1.8 (95% confidence interval: −1.0° – 4.6°), and 1.7 (95% confidence interval: −0.95° – 4.3°), respectively (Fig. 2). Among these, the difference in ROM of the hip joints was statistically significant ($d = -0.52$, $p = 0.002$), whereas that in the knee and ankle joints were not significant (knee: $d = -0.25$, $p = 0.196$; ankle: $d = -0.25$, $p = 0.197$). The correlation analysis between the amount of improvement of gait speed and stride length and ROM of the joints is shown in Table 3. There was a strong correlation between the amount of improvement of ROM of the hip joint and gait speed and stride length ($r = 0.755$, $p < 0.001$; $r = 0.804$, $p < 0.001$, respectively).

The MDS-UPDRS part I (Non-Motor Aspects of Experiences of Daily Living; $d = 0.48$, $p = 0.003$), part II (Activities of Daily Living; $d = 0.70$, $p < 0.001$), and part III (Motor Examination; $d = 0.66$, $p < 0.001$), and TUG ($d = 0.22$, $p = 0.029$) improved significantly. The changes of subscores of each part in MDS-UPDRS are shown in Supplementary Table 1. In the MDS-UPDRS part I and part III, the following subscores prominently improved: anxious mood ($d = 0.46$), rigidity of right and left lower extremities ($d = 0.40$, 0.35, respectively), and toe tapping of right foot ($d = 0.34$).

Table 1
Characteristics of participants at the time of hospital admission.

Number of participants		24
Age (years), mean ± SD		68.8 ± 7.6
Sex (male/female)		12/12
Disease duration (years), mean ± SD		6.1 ± 3.6
LED (mg), mean ± SD		743 ± 343
Hoehn & Yahr Scale (n)	I	1
	II	1
	III	22

SD, standard deviation; LED, Levodopa equivalent dose.

Table 2
The change of measurements through LSVT-BIG.

			pre LSVT-BIG mean ± SD	post LSVT-BIG mean ± SD	effect size (*d*) 95% CI	*p*-value
MDS-UPDRS		part I	7.9 ± 5.4	5.5 ± 3.6	0.48 (0.17–0.79)	0.003
		part II	8.0 ± 5.2	4.5 ± 3.2	0.70 (0.37–1.03)	<0.001
		part III	19.3 ± 13.6	10.4 ± 10.2	0.66 (0.41–0.91)	<0.001
		part IV	3.5 ± 3.5	2.4 ± 2.7	0.20 (−0.12 – 0.49)	0.070
FIM score		Motor	84.6 ± 6.1	86.8 ± 4.0	−0.19 (−0.48 – 0.15)	0.001
		Cognitive	33.9 ± 1.9	34.1 ± 1.8	−0.05 (−0.32 – 0.22)	0.180
Timed up and go test (s)			7.89 ± 2.80	7.28 ± 2.79	0.22 (0.03–0.40)	0.025
Gait speed (m/s)			1.04 ± 0.22	1.17 ± 0.24	−0.55 (−0.91 to −0.19)	0.003
Stride length (m)			1.08 ± 0.23	1.20 ± 0.24	−0.52 (−0.78 to −0.26)	<0.001
SD of stride length (m)			0.08 ± 0.12	0.10 ± 0.12	−0.26 (−0.55 – 0.08)	0.230
Stride duration (s)			1.04 ± 0.10	1.04 ± 0.12	0.04 (−0.26 – 0.34)	0.869
SD of stride duration (s)			0.07 ± 0.06	0.07 ± 0.06	−0.05 (−0.36 – 0.28)	0.627
Cadence (steps/min)			116.7 ± 10.9	117.6 ± 13.3	−0.07 (−0.35 – 0.21)	0.617
Stance phase (%)			64.0 ± 3.6	63.1 ± 3.4	0.19 (−0.15 – 0.49)	0.346
Swing phase (%)			36.1 ± 3.6	36.9 ± 3.4	−0.19 (−0.49 – 0.14)	0.346
The maximum angle and ROM of the joints (degrees)	hip	flexion	19.1 ± 3.5	21.1 ± 3.5	−0.57 (−0.96 to −0.19)	0.004
		extension	−16.4 ± 5.2	−18.4 ± 4.9	0.39 (0.05–0.73)	0.027
		ROM	35.5 ± 7.8	39.5 ± 7.4	−0.52 (−0.84 to −0.20)	0.002
	knee	flexion	47.8 ± 6.8	49.5 ± 7.7	−0.24 (−0.62 – 0.14)	0.202
		extension	−0.44 ± 0.08	−0.47 ± 0.06	0.41 (−0.11 – 0.93)	0.101
		ROM	48.2 ± 6.8	50.0 ± 7.8	−0.25 (−0.63 – 0.13)	0.196
	ankle	flexion	13.5 ± 5.1	13.7 ± 6.8	−0.03 (−0.29 – 0.22)	0.797
		extension	−14.5 ± 5.6	−15.9 ± 6.1	0.25 (−0.17 – 0.67)	0.235
		ROM	27.9 ± 5.6	29.6 ± 7.3	−0.25 (−0.64 – 0.14)	0.197

MDS-UPDRS, MDS-Unified Parkinson's Disease Rating Scale; FIM, Functional Independence Measure; SD, standard deviation; CI, confidence interval; ROM, range of motion.

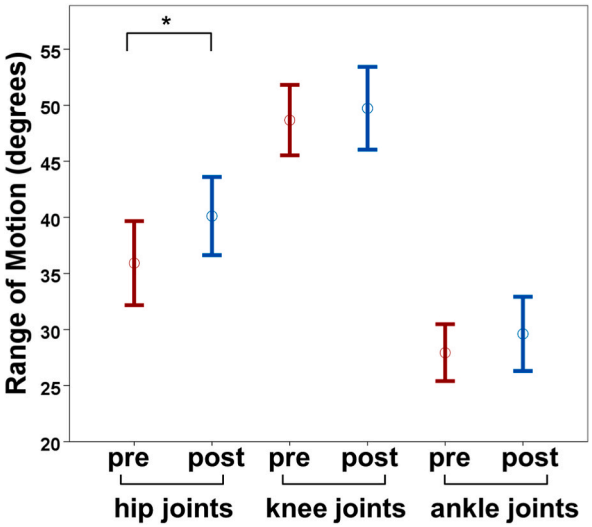

Fig. 2. The change in the range of motion of the ankle, knee, and hip joints through LSVT-BIG. Circles represent mean value and bars represent 95% confidence intervals. An asterisk represents the statistical significance ($p < 0.05$). "pre" and "post" represent the time of measurements. pre, pre-LSVT-BIG; post, post-LSVT-BIG.

Table 3
The correlation coefficients (95% CI) between the amount of improvement of gait parameters and range of motion (ROM) of the joints.

		Gait speed	Stride length
The ROM of the joints	hip	0.755 (0.506–0.888) $p < 0.001$	0.804 (0.592–0.911) $p < 0.001$
	knee	0.144 (−0.274 – 0.518) $p = 0.500$	0.255 (−0.165 – 0.597) $p = 0.229$
	ankle	0.345 (−0.102 – 0.676) $p = 0.126$	0.400 (−0.038 – 0.709) $p = 0.072$

CI, confidence interval; ROM, range of motion.

4. Discussion

Our results suggest that the main effect of LSVT-BIG on gait function is the improvement of gait speed and stride length, which is consistent with previous studies [8–10]. In addition, our results indicate that LSVT-BIG increases both the flexion and extension angle of the hip joints, and, consequently, enlarges ROM of the hip joint. In particular, enlargement of ROM of the hip joint was more prominent than that of the knee joint. Cadence did not change significantly in this study, which is compatible with the main concept of LSVT-BIG being amplitude-based behavioral intervention [5].

The moment of the knee and hip joints and propulsive forces at the stance phase powered by the biceps femoris and soleus have significant effects on stride length modulation in healthy adults [17,22]. Gaining power in the lower extremities, especially the biceps femoris and soleus muscles, enlarges the extension angle of the hip and ankle joint, respectively [23,24]. A similar relationship between stride length and muscle power has also been shown in PD patients. PD patients have decreased isokinetic muscle strength, including the flexors and extensors of the hip and knee [25–27], and training the muscles in the lower extremities improves stride length and gait velocity [28,29]. Participants repeatedly try to move stronger and bigger than usual during LSVT-BIG, which improves muscle strength, including that of the muscles of the lower limb mentioned above, resulting in the development of stride length, gait velocity, and enlargement of ROM of the hip joint in this study. A previous study using 3-dimensional motion capture revealed an enlargement of ROM not only in the hip joint, but also in the knee joint [18]. In this study, however, a significant change in ROM of the knee joint was not confirmed. On the other hand, enlargement of ROM of the hip joint was significantly correlated with increases of stride length and gait speed, and was the main factor for the gait improvement by LSVT-BIG.

In our study, the MDS-UPDRS part III score was improved by LSVT-BIG, consistent with previous studies [8,30]. Regarding subscores, the rigidity score of the lower extremities was remarkably improved. Rigidity reduces interlimb coordination in PD patients and limits the ability to adapt arm and leg coordination patterns during walking [31,32]. The reduction of rigidity through LSVT-BIG suggests that the ability to modify coordination patterns in the extremities is relatively preserved. In addition, the effect sizes of gait and postural stability were relatively higher than other subscores. The results suggest that the regeneration of walking posture could be induced by LSVT-BIG, as associated with the improvement of the motion of the lower limb. Improvement of gait stability after LSVT-BIG was also reported in previous studies [33,34], consistent with our results. In this study, 9 participants had freezing of gait (FOG) at the beginning of LSVT-BIG, and the MDS-UPDRS 3.11 (Freezing of Gait) score improved in 6 of the 9 participants (Supplementary Table 3). There was no prominent difference in gait parameters and characteristics between with or without improvement of FOG. Although a previous case series showed a similar trend that LSVT-BIG has a potential to relieve FOG, the main factor for improving FOG remained incompletely understood [35]. Thus, the effect of LSVT-BIG on FOG remains unclear.

Interestingly, MDS-UPDRS parts I and II were also improved by LSVT-BIG in our study. However, each effect size of subscores in part II was not prominent. The change of MDS-UPDRS part II score was not highly affected by a specific item, but was the result of the overall improvement of each subitem in part II. In MDS-UPRDS part I, the subscore of anxious mood was improved prominently. Recently, the effect of LSVT-BIG on non-motor symptoms was also investigated [11,36], and showed that LSVT-BIG significantly improved the severity of depression and anxiety in PD participants as compared with control participants, although the sample size was small [36]. Improvement of non-motor symptoms including anxiety is associated with motor function in PD patients [37]. In addition, cognitive behavioral therapy is effective for relieving anxiety in PD patients [38]. LSVT-BIG includes behavioral therapy with self-awareness as one of the main features [5]. Therefore, LSVT-BIG may improve anxiety not only by exercise training, but also by cognitive behavioral training. Improvement in the psychological condition is another advantage of LSVT-BIG.

In this study, we utilized RehaGait whose reliability has been validated by several studies with healthy individuals, healthy seniors, and patients with severe hip osteoarthritis [14–16]. We successfully demonstrated the mechanism of the effect of LSVT-BIG on gait in PD patients, suggesting that RehaGait is also effective in gait analysis for PD patients.

Limitations of this study include its small number of participants and the absence of long-term follow-up after LSVT-BIG. In addition, this study was planned as exploratory research without prior estimation of sample size. The statistical power is 0.70, under the condition that the sample size is 25 and the effect size is 0.52 (the effect size of the change of hip joint ROM). Thus, the statistical power of this study was slightly limited. In addition, we could not investigate all factors that might influence gait function during LSVT-BIG, such as the amplitude of the arm swing. Improvement of upper limb functions might influence the gait of PD patients in this study because LSVT-BIG is not a simple gait training.

5. Conclusions

A wearable gait sensor revealed that enlargement of ROM of the hip joint is a main factor in the increase in stride length and improvement of gait speed after LSVT-BIG. The gait speed, stride length, TUG, and MDS-UPDRS parts I, II, and III also improved after LSVT-BIG. Moreover, LSVT-BIG may relieve rigidity in the lower limb and non-motor symptoms, especially anxiety, in PD patients.

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Data statements

The authors confirm that the data supporting the findings of this study are available within the article and/or its supplementary

materials.

Production notes

Author contribution statement

Atsuhiro Matsuno, Akira Matsushima: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Masashi Saito, Kazumi Sakurai, Katsuyuki Kobayashi: Conceived and designed the experiments; Performed the experiments.

Yoshiki Sekijima: Conceived and designed the experiments; Wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16952.

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