

## **Abstract**

**BACKGROUND:** Parkinson's disease (PD) is characterized by small, slow movements affecting balance and gait. Lee-Silverman-Voice-Treatment-(LSVT)-BIG is an intensive intervention aiming to restore normal amplitudes of movements. This study aimed to examine whether LSVT-BIG influences dynamic balance and gait in persons with PD.

**METHODS:** We used a Single-Subject-Experimental-Design with three phases; phase A (2 weeks) with no treatment, phase B (4 weeks) with LSVT-BIG-treatment and LSVT-BIG-home-training, and phase C (7-8 weeks) with LSVT-BIG-home-training. Two persons with PD participated. Outcome measures included the Mini-Balance-Evaluation-Systems-Test (Mini-BESTest) with its four subcomponents ("anticipatory postural adjustments", "postural responses", "sensory orientation", "balance during gait"), the Step-Test (ST) and 10-Meter-Walk-Test-fast (10MWT-fast). The participants were assessed 6, 4 and 8 times during phase A, B and C, respectively. During phase B, they received 16 individual 1-hour LSVT-BIG-treatment sessions and completed between 28 and 39 1-hour sessions LSVT-BIG-home-training. During phase C, they were encouraged to complete one session of home-training every day.

**RESULTS:** The Mini-BESTest-total-score, "balance during gait", ST and 10MWT-fast improved significantly in both participants. One participant demonstrated improved "postural responses". Two of the Mini-BESTest subcomponents were not sensitive to possible improvements.

**CONCLUSION:** LSVT-BIG may have a positive effect on dynamic balance and gait-speed in persons with PD.

**Keywords:** intensive exercise therapy, motor training, physiotherapy, rehabilitation, therapeutic exercise, walking

## **Introduction**

Parkinson's Disease (PD) is a common neurodegenerative disease that affects 1-2% of the population over the age of 65 [1, 2]. Body stiffness, tremor, decreased motor precision, and small, slow and hesitant movements characterize the disease. Many patients experience problems with gait characterized by asymmetry, a forward bent posture and reduced walking speed related to short, shuffling steps, increased cadence and increased time in double limb support [3, 4, 5]. Moreover, they may have difficulties with transitioning from one movement to another [6]. Postural instability, including altered body alignment and reduced balance, are commonly seen [7]. Balance may be divided into static and dynamic balance, where static balance can be defined as the ability to maintain a base of support with minimal movement and dynamic balance as the ability to perform a task while maintaining a stable position [8]. Poor dynamic balance is associated with balance problems during gait, transfers, external perturbations and dual tasking [9]. Persons with PD often have these problems and need visual or verbal feedback in order to walk with proper steps and complete tasks with appropriate movement size.

Physiotherapy can be fundamental to maintain or improve functional ability or to reduce secondary complications in persons with PD. As reviewed by Rocha et al [10] interventions that include external cueing (such as visual cues and verbal instructions) seem to have a positive effect on several gait parameters. Further, intensive exercise therapy also appears to be beneficial in improving balance and walking performance [11, 12]. Lee Silverman Voice Treatment BIG (LSVT-BIG) is designed to treat specific symptoms related to deficits in movement patterns in people with PD, and is thought to affect bradykinesia and hypokinesia [13, 14]. The treatment consists of intensive training with focus on high-amplitude movements rather than velocity, with exercises consisting of multiple repetitions, high intensity and increasing complexity [13, 14]. Training of amplitude rather than speed has been chosen as the main focus in the treatment since training of velocity can induce faster movements while it does

not consistently improve movement amplitude and accuracy [15, 16] In contrast, training of amplitude results in bigger, faster and more precise movement, which is important for dynamic balance and gait and critical for adapting to natural environments. The LSVT-BIG program incorporates internal feedback mechanisms i.e by encouraging the patients to focus on how it feels like to move big. The goal is to alter the person's perception of his/her own movement in order to restore normal amplitudes of movements in daily activities. Because balance and gait are essential for daily activities and the basis of most aspects of physical function, it is of high interest to study if the program has an effect on these important parameters.

Previously, six studies have examined the effect of LSVT-BIG on either gait alone, or on both balance and gait [17, 18, 19, 20, 21, 22]. A randomized trial, including 60 participants, compared LSVT-BIG training with either group training of Nordic Walking or with domestic, non-supervised exercises [17]. The LSVT-BIG group improved significantly more than the other two groups with regard to the Timed Up and Go (TUG) test, and significantly more than the domestic home training group regarding the gait speed. Another randomized study, including 42 participants, compared the standard protocol of LSVT-BIG training to a shorter protocol of LSVT-BIG exercises [18]. Both groups showed equal improvement in gait speed, endurance and TUG. Furthermore, in a non-controlled trial, including 18 participants, a significant improvement was seen in stride length after LSVT-BIG intervention [19]. Similarly, a case-report with three participants found improvements in both balance and gait as per Functional Reach Test (FRT), Functional Gait Assessment (FGA) and TUG [21]. In contrast, another small study including 8 participants did not see significant changes in gait speed and TUG [20]. Recently, a study using a more comprehensive measurement of balance (the Berg Balance Assessment (BBA)), in addition to measurements of gait (gait speed and FGA), reported that eight of the nine participants with mild symptoms had improved their performance in at least one of these measurements after LSVT-BIG intervention [22].

In conclusion, six studies have evaluated the effect of LSVT-BIG on gait and balance, and all but one have used relatively simple outcome measures such as TUG. However, because balance deficits in PD are multifactorial, it is of interest to know if the intervention has an effect not only on balance in general, but also which balance components benefit the most from LSVT-BIG. By use of the Mini Balance Evaluation Systems Test (Mini-BESTest) as an outcome measure, it is possible to evaluate if dynamic balance and subsystems of dynamic balance “anticipatory postural adjustments”, “postural responses”, “sensory orientation” and “balance during gait” are affected by the treatment. This knowledge may help the physiotherapist select the most appropriate treatment for their patients.

All previous studies are so-called “pre–post” studies, where the participants are assessed before and after treatment. A single-subject experimental design (SSED) study is a research design in which the participant serves as his/her own control [23, 24]. Studies employing SSEDs can address the effects that the intervention may have on performance at the individual level in contrast to the studies using traditional group designs where averages of the groups are compared. Moreover, SSEDs differ from the “pre–post” study in that measurement of the dependent variable occurs repeatedly and frequently *during* the intervention phase. In contrast to group comparison approaches, which usually need a large number of subjects, a SSED involves only a few participants. SSED research methods are a cost-effective approach to identifying interventions that are appropriate for large scale analysis. They may also give an indication of the suitability of different functional tests for future studies.

The hypothesis of this study was that LSVT-BIG through the achievement of bigger, faster and more precise movements would influence gait, dynamic balance and its components in persons with PD. Because no previous study had explored the effects of LSVT-BIG on the subcomponents of dynamic balance and because the measurement of these components is quite comprehensive, we found that a SSED study would be a suitable research design. This design

provides an opportunity to assess the effectiveness of individualized treatment and may indicate whether the Mini-BESTest and its subcomponents might be useful in larger studies.

The aim of this single subject experimental study was to investigate the potential benefits of LSVT-BIG on gait, dynamic balance and components of dynamic balance in two persons with PD.

## **Methods**

### ***Study design***

A SSED study, with ABC-phases, was used to obtain detailed and repetitive information regarding possible changes in the participant's performances [24]. The ABC-design is a multiple treatment design where the participants are exposed to a non-treatment phase (A), a first intervention phase (B) and a second intervention phase (C).

Participant 1 and 2 (described in detail below) were followed closely for 13 and 15 weeks, respectively. The participants were assessed three times a week during baseline (A). This phase lasted 2 weeks. During the first intervention phase (B) that lasted four weeks, the participants were assessed once a week. The first intervention phase (B) was followed immediately by a second intervention phase (C) lasting 7-8 weeks. The participants were assessed twice a week during the first two weeks of this phase (C<sup>1</sup>) and again twice a week during the last two weeks of this period (C<sup>2</sup>).

All assessments were performed in the same sequence and between 08.30 and 10.00 for participant 1 and between 09.30 and 13.00 for participant 2. One of the researchers (TTK) performed the assessments and a clinical specialist in neurological physiotherapy performed the treatments. Written, informed consent was obtained, and the regional ethics committee approved the study.

## *Participants*

Participants with PD living in Sandefjord, Norway, were eligible for the study. The inclusion criteria were stable stage of idiopathic PD, capability to follow instructions and ability to walk 10 meters without walking aids. The exclusion criteria were: other diseases that may affect balance and gait, having participated in LSVT-BIG treatment prior to this study and planning to start new treatments (including change in medication) during the study period. In order to recruit study participants, information about the study was posted at physiotherapy institutes and residential care facilities that people with PD regularly frequent. Only two persons responded. They both fulfilled the inclusion and exclusion criteria and agreed to participate.

Participant 1 was a 71-year-old-man, diagnosed PD in early 2011. He lived in an apartment with his wife, walked without walking aids and was self-reliant in activities of daily living. He described his main problems as unsteadiness and having difficulty walking outdoors. He also experienced problems related to dressing himself (especially shirts and jackets), bed mobility and writing. He sometimes also had tremors in his right arm and felt stiffness in his whole body. His PD symptoms remained stable throughout the day. For medication he used Sinemet 100 mg four times a day. Prior to the study, he participated in a physiotherapy supervised exercise group 2-3 times a week and did individual exercises tailored by a physiotherapist 2 times a week. At the beginning of the study, the physiotherapist who implemented the measurements, described the participant as having a forward flexed posture in standing, flexed knees, slightly flexed hips, protracted and internally rotated shoulders, slightly flexed elbows and a forward head posture. During ambulation, the flexed posture increased, together with decreased rotation of the trunk and decreased right arm swing. The physiotherapist described that he walked with a somewhat reduced speed and shuffled his feet. Rotation of the neck, trunk and hips, as well as hip flexion, were all reduced.

Participant 2 was a 70-year-old-man, diagnosed with PD in late 2010. He lived in a single-family home with his wife, walked without walking aids and was self-reliant in activities

of daily living. He described his main problems as decreased fine motor skills, such as writing, increased time needed with eating, and problems with speech articulation. There was little variation of his PD symptoms throughout the day. For medication, he used Sinemet 100 mg three times a day and Requip depot twice a day. Prior to the study, he participated in a physiotherapy supervised exercise group twice a week and individually tailored strength training once a week. At the beginning of the study, the physiotherapist who implemented the measurements, described the participant as having a flexed posture, bilateral genu varum, protracted shoulders, slightly flexed elbows and a forward head posture in standing. The right elbow was held in more flexion than the left elbow. During ambulation, the flexed posture persisted. Moreover, the physiotherapist described that he walked quickly, but had decreased rotation of the trunk, reduced left arm swing and almost no right arm swing. In sitting, trunk and neck rotation were reduced, especially towards the right side. Furthermore, internal rotation of the left shoulder as well as flexion, abduction and external rotation in both shoulders were limited.

### ***Intervention***

During the first intervention phase (B), both participants received a standardized one-hour LSVT-BIG training four times a week supervised by a certified LSVT-BIG instructor. In addition, they were instructed to practice the same LSVT-BIG exercises at home for ten hours a week; once a day on days with supervised training and twice a day on days without supervised training. For a detailed description of the LSVT-BIG concept, see the study of Fox et al 2012 [14].

The first seven exercises consisted of 8-20 repetitions of standardized whole-body movements in sitting and standing. The movements were performed with maximal amplitude in multiple directions, including stepping, reaching, and stretching. The following five exercises included functionally, goal-directed activities of daily living based on the participant's self-

identified movement problems. For participant 1, these self-selected activities consisted of practicing standing up from sitting, turning around in bed, transitioning from supine to sitting on the bed, combing his hair and donning his socks. For participant 2, they consisted of practicing standing up from sitting, buttoning and unbuttoning his jacket, handwriting and donning his socks and sweater. One component from each of these activities was selected and performed five times with large amplitude. All 12 exercises were gradually adjusted by increasing duration, amplitude (bigness/effort, within normal limits), and complexity of tasks. The physiotherapist provided continuous feedback and encouraged the participants during their performance. Further they used tactile and visual cues to shape quality and movement amplitude. The aim was to trigger motor activity, improve the quality of movements and, hopefully, recalibrate their sensory perception of normal amplitude of movements. The amount of time used on the first 12 exercises was 30 minutes or more. The exercises were performed with a self-perceived effort level of 80-90 % of maximum focus on BIG movements.

In exercise 13, the participants walked with excessive movement, with variations such as walking across obstacles, with large arm swings, excessive flexion of the hips and knees, long strides, straight posture and changes in direction. Exercise 14 consisted of one complex multilevel task tailored to achieve the participant's goal and interest. The degree of difficulty was progressively increased and the activity was changed throughout the intervention phase. For participant 1, the exercises were composed of getting in and out of bed, vacuuming, walking around town and getting dressed and undressed. For participant 2, the exercises included placing dishes in the cupboard, walking outdoors in varying terrain and getting dressed and undressed.

In accordance with the LSVT-BIG concept, the participants were recommended to perform the exercises for the rest of their lives and to integrate big movements into their everyday living. We therefore decided to start the second intervention phase (C) directly after the first intervention phase (B), and not withdraw treatment in a new control phase. The second intervention phase (C) consisted of individual LSVT-BIG home training one hour a day and the



participants were encouraged to resume earlier group exercises and/or individual exercises supervised by a physiotherapist. Phase C was thereby thought to reflect the participants future daily life regarding exercises.

The participants were asked to log their daily exercises from the beginning of the first intervention phase (B) until the end of the second intervention phase (C). The registrations were categorized into four types of activity; 1: LSVT-BIG training with an LSVT-BIG instructor, 2: LSVT-BIG home training, 3: Group exercises and 4: Individual exercises supervised by a physiotherapist.

### ***Measurements***

Balance and gait were measured by use of the Mini Balance Evaluation Systems Test (Mini-BESTest), the Step Test (ST) and the 10-Meter Walk Test fast (10MWT-fast).

The Mini-BESTest, a short version of BESTest, is designed to measure dynamic balance [25]. It consists of 14 items, grouped into 4 subcomponents of dynamic balance: “anticipatory postural adjustments”, “postural responses”, “sensory orientation” and “balance during gait”. All items are scored on an ordinal scale where 0 is severe, 1 is moderate and 2 is normal performance. The maximal total score is 28 points [9]. For the subcomponents “anticipatory postural adjustments”, “postural responses” and “sensory orientation” the maximal score is 6 points and for “balance during gait” 10 points. In individuals with PD the Mini-BESTest has excellent inter-rater reliability with an interclass correlation (ICC) ranging between 0.91 and 0.99 [9, 26] as well as excellent test-retest reliability (ICC=0.92 to 0.98 [9, 26]. The test is valid [27] and can predict fallers among persons with PD [9, 28].

The ST measures the number of times a person is able to place the same foot on and of a 7.3 centimeter high step, as quickly as possible, within 15 seconds [29]. This test is reliable and valid for persons with stroke [29, 30, 31]. In our study, the participants were asked to alternately

place the left and right foot on the step. They practiced the test once, and completed three trials thereafter; with a 60 second rest break between each trial.

The 10MWT-fast measures the time used for walking 10 meters. In this study the participants walked 12 meters in total, one meter prior to and one meter after the integrating distance. Walking speed was measured for the 10-meter integrated distance. The instruction was: “walk as fast as possible”. The participants practiced the test once, and performed three trials thereafter; with a 60 second break between each trial. The test-retest reliability for the 10MWT-fast is excellent in persons with PD (ICC  $\geq 0.96$ ) [32, 33]. The test is valid [32] and can predict fallers among persons with PD [34].

### ***Data analysis***

Results are visually illustrated by graphs. Statistically significant changes were defined according to the two standard deviation bands (2SD-band) method [24, 35]. If at least two consecutive data points after the baseline phase falls outside the 2SD range, it indicates a significant change in performance.

## **Results**

### ***Participant 1***

The total score of the Mini-BESTest increased during phase B. By the end of phase B/beginning of phase C and throughout phase C, the results improved significantly compared to baseline (Figure 1). The measurements of the subcomponent “anticipatory postural adjustments” showed that the participant had a mean score of 5.3 points at baseline, with a +2 SD of 7.0 points, which is above the maximal score (=6 points) of this test. At follow-up, the maximal score was reached 10 of 12 times (Figure 2). The score of the subcomponent “postural responses” did not change significantly during the study (Figure 3). As for the subcomponent “sensory orientation”, the participant had a maximal score of 6 points five of six times during

baseline and 11 of 12 times at follow up (Figure 4). The score of the subcomponent “balance during gait” increased significantly by the end of phase B/beginning of phase C and was significantly higher than baseline during phase C<sup>1</sup> and C<sup>2</sup> (Figure 5). Moreover, the results of the ST improved significantly during phase B and continued to improve during phase C<sup>1</sup> and C<sup>2</sup> (Figure 6). The time to walk 10 meters (assessed by the 10MWT-fast) decreased significantly during phase B and decreased further during phase C<sup>1</sup> and C<sup>2</sup> (Figure 7). As shown in figure 8, the participant completed 16 hours of LSVT-BIG training supervised by an LSVT-BIG instructor and 39 hours of LSVT-BIG home training in the first intervention phase (B). During the second intervention phase (C) he completed 40 hours of LSVT-BIG home training, 16 hours group exercises and 10 hours of individual exercises supervised by a physiotherapist.

Of note is that this participant stopped using Sinemet after phase C<sup>1</sup>.

### ***Participant 2***

The Mini-BESTest-total-score improved significantly during phase B and remained significantly higher than baseline in phase C<sup>1</sup> and C<sup>2</sup> (Figure 1). The measurements of the subcomponent “anticipatory postural adjustments” showed that the participant had a mean score of 4.7 points at baseline, with a +2 SD of 6.3 points, which is above the maximal score (=6 points) of this test. At follow-up (Phase B and C) the maximal score of the test was reached 9 of 12 times (Figure 2). Further, the score of the subcomponent of “postural responses” had improved significantly by the end of phase B/beginning of phase C and was significantly higher than baseline in phase C<sup>1</sup> and C<sup>2</sup> (Figure 3). Regarding the subcomponent “sensory orientation” the participant had a maximal score of 6 points four of six times during baseline and reached the maximal score at all follow-up measurements (Figure 4). The subcomponent “balance during gait” improved significantly in all phases after baseline; phase B, C<sup>1</sup> and C<sup>2</sup> (Figure 5). The ST also improved significantly during phase B and continued to improve during phase C<sup>1</sup> and C<sup>2</sup> (Figure 6). The time to walk 10 meters (assessed by the 10MWT-fast) decreased during phase B

and decreased even further in phase C<sup>1</sup> and C<sup>2</sup>, where the results were significantly different from baseline (Figure 7). The participant completed 16 hours of LSVT-BIG training supervised by an LSVT-BIG instructor and 28 hours of LSVT-BIG home training in the first intervention phase (B) (Figure 8). During the second intervention phase (C), he completed 37 hours of LSVT-BIG home training, 7 hours group exercises and 5 hours of individual exercises supervised by a physiotherapist.

## **Discussion**

The results of this single subject experimental study indicate that LSVT-BIG training may have a positive impact on dynamic balance and gait speed in persons with idiopathic PD. The LSVT-BIG program consists of intensive training with focus on high-amplitude movements. The hypothesis was that LSVT-BIG through the achievement of bigger, faster and more precise movements would influence gait, dynamic balance and its components. Both participants improved significantly with regard to the Mini-BESTest-total-score, the subcomponent “balance during gait”, the ST and 10MWT-fast. One participant showed improved “postural responses”. Our participants were at a relatively high functional level already at baseline. With regard to the subcomponents of Mini-BESTest, two of them, “anticipatory postural adjustments” and “sensory orientation”, were not sensitive for possible improvements.

The results of the Mini-BESTest total score and the 10MWT-fast are not only statistically significant, but also appear to have clinical relevance. The Mini-BESTest total score has an established cut-off score of 19 points [28] and the 10MWT-fast has a cut-off score of 1.3 m/s [34] for the risk of falling in people with PD. During phase B the total score of the Mini-BESTest revealed a positive trend as it increased to 23 and 27 points for participant 1 and 2, respectively. These scores indicate a decreased risk of falling. A relatively high test-score was maintained throughout phase C, in that all measurements stayed above the cut-off score. For the

10MWT-fast, the mean values during baseline (A) were 1.3 m/s for participant 1 and 1.6 m/s for participant 2. During phase B the gait speed increased continuously, and by the end of this phase, participant 1 had a gait speed of 1.7 m/s and participant 2 had a gait speed of 2.0 m/s suggesting that the risk of falling decreased. The gait speed increased further during the later phases, with a mean of 2.1 m/s and 2.3 m/s, respectively, in phase C<sup>2</sup>.

This is the first study to evaluate the effect of LSVT-BIG on dynamic balance and its subcomponents as assessed by the Mini-BESTest. However, previous studies have examined the effect on different aspects of gait, including gait speed. Janssens et.al [21], showed that gait, evaluated by use of the FGA, improved in all three participants with a score indicating a decreased risk of falling. Moreover, and in line with our results, Ebersbach et.al [17, 18] found that gait-speed increased after the intervention. In contrast, however, gait-speed did not change significantly in the study by Farley and Koshland [19].

The goal of LSVT-BIG is to alter the person's perception of his/her own movement in order to restore normal amplitudes of movements in daily activities. We do not know exactly why our participant's achieved better dynamic balance or faster gait. At baseline (A), both participants had a posture characterized by flexion. In persons with rigidity, the flexor muscle tone, which is more dominant than extensor muscle tone, contributes to the characteristic forward flexed posture that is frequently observed in people with PD [7]. Contractile- and non-contractile structures adapt to the changing posture, which may lead to changes in body alignment, range of motion and flexibility. As a result, this adapted posture affects a person's ability to maintain balance and influences their walking pattern [36]. Contractures, poor alignment and alteration in the effectiveness and strength of the muscles inhibit appropriate postural activity during expected and unexpected balance disturbances. The big movements used in LSVT-BIG may have improved the participant's range of motion. Furthermore, the intensive training with multiple repetitions combined with an increased amount of daily activity most likely leads to increased muscular strength. This may explain the results of our study. In order to

examine this hypothesis, we call for studies where muscle strength and biomechanical constraints have been assessed. Moreover, it would have been of interest to know if some of the LSVT-BIG exercises had greater effect on balance and gait than other LSVT-BIG exercises, or whether different exercises of the same frequency could have provided similar results. Finally, several possible benefits of the intervention, such as changes in postural alignment, changes in step length and cadence were not assessed. A registration of the quality of movements, for instance, by use of three-dimensional motion assessments and detailed measures of gait parameters using an electronic walkway, would also be of high interest to study.

Even though a randomized controlled trial is considered to be the gold standard for examining the effect of an intervention, the results may not always be helpful in choosing the right treatment for a single person [37]. A SSED-study is quite similar to clinical practice and gives the opportunity to assess the effectiveness of individualized treatment [23]. We followed both participants closely during each phase of the study. This gave us detailed information about the participants and their responses to treatment with clear signs of improved balance and gait. These findings cannot be generalized to a broader population of patients with PD, however, and larger studies and controlled trials examining the possible benefits are therefore necessary.

According to our study protocol, we intended to include two persons with PD. If more persons had responded and fulfilled the criteria for participation, the two would have been selected by drawing lots. The low number that were interested in the study could indicate that the intervention and all the measurements required had been perceived as too strenuous or too time-consuming. We therefore anticipate that those who participated most probably were highly motivated for physiotherapy. Moreover, physical immobility and geographical constraints are barriers that limit patient accessibility to intensive treatment, making selection bias likely.

One strength of the present study is that the same therapist treated both participants during all of the LSVT-BIG sessions, and one researcher (TTK) completed all of the data collection. The study would have been strengthened further if a data collector, blinded to the

purpose of the study, had been engaged. For logistic reasons, however, this was not possible and we can therefore not exclude that the results may be somewhat influenced by knowledge about the intervention and the treatment periods. On the other hand, most outcomes were measured in time or distance (several parts of the Mini-BESTest, the ST, the 10MWT-fast), and therefore hardly affected by the tester.

In clinical trials, the selection of appropriate measurement tools is important. Balance deficits in PD are multifactorial and measurement tools detecting different aspects of balance are important. In the present study, we used the Mini-BESTest to evaluate balance. In contrast to TUG and FRT used in most previous studies assessing the effect of LSVT-BIG [17, 18, 20, 21], this test measures several aspects of dynamic balance. Moreover, as compared to the BBA, the Mini-BESTest total score has no ceiling effect for mild PD [26, 38], it is more effective in discriminating between those with and without postural response deficits [38] and predicts the risk of falls slightly better [9, 39]. In this study there were, however, problems related to the subcomponent “anticipatory postural adjustments” and “sensory orientation”. Both had a clear ceiling effect so that possible improvements during the study could not be captured.

The Mini-BESTest and the 10MWT are found to be reliable and valid in persons with PD [9, 26, 27, 32, 33, 40]. The revised version of the ST used in the present study still needs to be examined with regard to reliability and validity for persons with PD.

Measurements were taken three days a week during baseline (A), twice a week during the second intervention phase (C), and only once a week during the first intervention phase (B). More measurements during phase B may have strengthened the study. Together with the intensive treatment, however, we believe that more frequent measurement taking would have been too strenuous for the participants.

In phase C, there is approximately one month between early- (C<sup>1</sup>) and late follow-up measurements (C<sup>2</sup>). In future studies, it would be of interest to follow the participants over a longer period of time in order to get a picture of real, long-term effects. One limitation of the

present study is that the second intervention phase (C) was less standardized than the first intervention phase (B), thereby making it more difficult to reproduce. The study would clearly have been strengthened if we had obtained more information about the type, frequency and intensity of the exercises performed in phase C. Furthermore, we do not know if the observed maintenance or improvement in phase C was due to the individual LSVT-BIG home training, the combined effect of this training and other exercises and/or carry-over of the LSVT-BIG principles to other activities of daily living.

Finally, as for many clinical studies, one must have in mind that the novelty of participating in a research project, the awareness of being observed and assessed could lead to a temporary increase in performance (The Hawthorne effect). Moreover, although most often seen already during baseline, we cannot exclude that a learning effect of the assessments could have taken place later in the study period. The intensive assessment scheme may also have presented a training effect itself, leading to additional performance improvements.

We conclude that the results of the present study indicate that dynamic balance and gait in persons with PD may improve after training with LSVT-BIG. However, in order to fully evaluate this effect, sensitive measures of all subcomponents of dynamic balance as well as larger and well designed, randomized trials are needed.

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## Figure captions

**Figure 1:** Mini Balance Evaluation Systems Test for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). The maximal score of the test is 28 points. Note: the y-axis does not start at 0.

**Figure 2:** Subcomponent “anticipatory postural adjustments” for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). The maximal score of the test is 6 points.

**Figure 3:** Subcomponent “postural responses” for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). The maximal score of the test is 6 points.

**Figure 4:** Subcomponent “sensory orientation” for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). The maximal score of the test is 6 points.

**Figure 5:** Subcomponent “balance during gait” for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). The maximal score of the test is 10 points.

**Figure 6:** Step Test for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). Y-axis shows number of steps taken within 15 seconds. Note: the y-axis differs for participant 1 and 2, and does not start at 0.

**Figure 7:** 10-Meter Walk Test fast for participant 1 and 2 at baseline (A), first intervention phase (B) and second intervention phase (C). Second intervention phase consists of early follow-up (C<sup>1</sup>) and late follow-up (C<sup>2</sup>). Note: the y-axis does not start at 0.

**Figure 8:** Hours of weekly exercises for participant 1 and participant 2 during the first intervention phase (B) (week 1-4) and the second intervention phase (C) (week 5-11/12).