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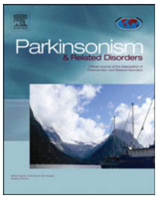

The effects of vibrotactile biofeedback training on trunk sway in Parkinson's disease patients

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Background: Postural instability in Parkinson's disease (PD) can lead to falls, injuries and reduced quality of life. We investigated whether balance in PD can improve by offering patients feedback about their own trunk sway as a supplement to natural sensory inputs. Specifically, we investigated the effect of artificial vibrotactile biofeedback on trunk sway in PD.

Methods: Twenty PD patients were assigned to a control group ($n = 10$) or biofeedback group ($n = 10$). First, all patients performed two sets of six gait tasks and six stance tasks (pre-training assessment). Subsequently, all subjects trained six selected tasks five times (balance training). During this training, the feedback group received vibrotactile feedback of trunk sway, via vibrations delivered at the head. After training, both groups repeated all twelve tasks (post-training assessment). During all tasks, trunk pitch and roll movements were measured with angular velocity sensors attached to the lower trunk. Outcomes included sway angle and sway angular velocity in the roll and pitch plane, and task duration.

Results: Overall, patients in the feedback group had a significantly greater reduction in roll ($P = 0.005$) and pitch ($P < 0.001$) sway angular velocity. Moreover, roll sway angle increased more in controls after training, suggesting better training effects in the feedback group ($P < 0.001$).

Conclusions: One session of balance training in PD using a biofeedback system showed beneficial effects on trunk stability. Additional research should examine if these effects increase further after more intensive training, how long these persist after training has stopped, and if the observed effects carry over to non-trained tasks.

1. Introduction

Postural instability is a main feature of Parkinson's disease (PD) [1]. It is a primary risk factor for falls: about two thirds of PD patients have fallen within the past year [2]. Moreover, 90% of all patients will fall at some point in their lives [3]. Falls can cause major injuries [4] and recurrent falls can markedly reduce quality of life [5]. Therefore, it is important to improve balance in PD patients, and reduce their risk of falling.

Measures of trunk sway can provide useful information about balance deficits and the tendency to fall in PD [6]. Reduced trunk sway is highly correlated with a reduction in falls in elderly [7] and a greater postural sway has shown to be a predictor of falls in PD patients [2,8,9]. Therefore, providing information about trunk sway to patients could help improve their balance. One way to accomplish this is via artificial biofeedback systems that act as a supplement to natural sensory inputs, providing additional sensory information about body sway to the brain [10].

Several studies have examined the direct effects of biofeedback on balance in healthy subjects and in patients with postural deficits. Auditory [11], vibrotactile [12], or multi-modal feedback increased postural stability in both young [13,14] and elderly healthy subjects [15] by reducing trunk sway. Additionally, auditory [16] and vibrotactile [17–19] biofeedback reduced trunk sway in vestibular loss patients.

The aforementioned studies examined the direct effects of biofeedback on balance. Another approach would be to implement a training course assisted by a biofeedback system, and compare this to a similar training without biofeedback, by reassessing all subjects without the device. This would clarify whether the feedback device offers any carry-over effects. One study has used this approach in healthy subjects and found a significantly greater improvement after biofeedback training compared to conventional training [20]. Recently, a pilot study, which did not control for

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conventional training alone, examined the effect of a 6-week biofeedback training in PD patients and found subtle improvements in balance outcomes [21]. Stimulated by these findings, we aimed to investigate the short-term carry-over effects of one training session involving real-time vibrotactile biofeedback, as compared to a similar session of non-biofeedback training in PD patients. The effects of this training were examined by quantifying trunk sway during several everyday stance and gait balance tasks.

2. Methods

2.1. Subjects

Twenty patients with PD participated in this study (Table 1). Disease severity was assessed using the motor examination subscale of the Unified PD Rating Scale (UPDRS) [22], Hoehn & Yahr stages [23], and disease duration. Balance and gait were evaluated using the Tinetti Mobility Index [24]. Balance confidence was assessed with the Activities-specific Balance Confidence scale [25]. Cognitive function was determined using the Mini Mental State Examination and Frontal Assessment Battery. All participants were tested while on medication. We calculated levodopa equivalent dosages to express dose intensity of different antiparkinsonian drug regimens on a single scale [26]. Exclusion criteria included causes of balance impairment other than PD, inability to walk without walking aids, cognitive or psychiatric disturbances, and severe co-morbidity. Each participant provided written informed consent according to the Declaration of Helsinki prior to participation. All experimental procedures were approved by the local ethics committee.

2.2. Study design

All patients started with an initial balance assessment to obtain baseline measurements (pre-training assessment). This assessment included six gait tasks and six stance tasks that were presented in increasing order of difficulty. The gait tasks included: walking 9 m at preferred speed with eyes open and with eyes closed, 'get up and go' for 3 m (without turning), walking 9 m with a cognitive dual task (counting back in sevens), walking 9 m with a motor dual task (carrying a glass of water), and walking 15 tandem steps with eyes closed. The stance tasks included: standing with feet together with eyes open and with eyes closed, standing with feet together on foam with eyes open and with eyes closed, standing on one leg with eyes open, and tandem stance with eyes closed. This gait and balance assessment was performed twice.

Immediately after the pre-training assessments all participants received a training session. This balance training consisted of a subgroup of the 12 tasks used in the pre-training assessments. The six tasks selected for training were: standing with feet together with eyes closed, standing on one leg with eyes open, tandem stance with eyes closed, standing with feet together on foam with eyes closed, walking 9 m at preferred speed with eyes open, and walking 15 tandem steps with eyes closed. This series of tasks was executed five times consecutively. During all stance tasks patients were instructed to stand as still as possible. After training both groups repeated the balance assessment with all 12 tasks twice (post-training assessment). All assessments were executed on the same day with no intervals – except frequent resting periods – in between the assessments.

Table 1
Subject characteristics.

	Feedback group ($N = 10$)	Control group ($N = 10$)	P-value*
Age (years)	59.3 ± 2.0	58.6 ± 2.5	0.83
Gender (% women)	20%	20%	1.00
Disease duration (years)	3.7 ± 0.8	3.9 ± 0.8	0.86
UPDRS part III (affected side)	17.9 ± 2.7	15.4 ± 1.1	0.41
H&Y score (1–5)	1.6 ± 0.1	1.6 ± 0.2	0.81
ABC score (max. 100)	90.1 ± 3.0	91.7 ± 3.9	0.74
MMSE (max. 30)	28.7 ± 0.3	28.8 ± 0.4	0.84
FAB (max. 18)	16.5 ± 0.8	16.4 ± 0.3	0.91
Tinetti balance (max. 16)	15.9 ± 0.1	15.9 ± 0.1	1.00
Tinetti gait (max. 12)	12.0 ± 0.0	12.0 ± 0.0	1.00
LED (mg/day)	397.1 ± 71.8	412.1 ± 119.0	0.71

Data reflect means ± standard error of the mean. N = number of subjects; MMSE = Mini Mental State Exam; FAB = Frontal Assessment Battery; UPDRS = Unified Parkinson's Disease Rating Scale; H&Y = Hoehn & Yahr; LED = levodopa equivalent dose. * Significance was assessed by a Student's t-test ($P < 0.01$).

2.3. Balance assessments

During the balance assessments, trunk sway was measured using two angular velocity sensors worn on the back at level L1-L3 (Fig. 1) and which measure anterior-posterior (pitch) and mediolateral (roll) movements of the trunk (SwayStar™ device; Balance International Innovations GmbH, Switzerland) [27]. During the recordings histograms of pitch and roll displacements were created by dividing the peak-to-peak angular displacement range into 40 bins. Subsequently, the 90% range of the peak-to-peak values was determined by excluding the extreme 5% of values in the histogram [15]. This range was used for further measurements and analyses. The SwayStar output also served as input for the feedback device in the feedback group, as shown in Fig. 1.

2.4. Intervention

Participants were randomly assigned to the control group or feedback group. Patients in the feedback group received real-time biofeedback, but only during the balance training session. Control subjects received the same balance training without any biofeedback. Patients in the feedback group were not allowed to practice with the feedback system, as this by itself would already serve as training.

Biofeedback was provided using a balance biofeedback system (BalanceFreedom™, Balance International Innovations GmbH, Switzerland). This biofeedback system consists of a headband that is connected to the angular velocity sensors at the lower trunk (Fig. 1) and that provides vibrotactile, acoustic and/or visual biofeedback. In this study we only used vibrotactile biofeedback, which was provided at a frequency of 250 Hz by eight vibrotactile sensors spaced equally around the headband. We considered that it would be too difficult for PD patients if different feedback modalities were administered. Visual feedback could not be used for the eyes closed tasks and auditory feedback (being binominal) is difficult to interpret. Therefore, we chose to use only vibrotactile feedback. None of the subjects in this study reported changes in proprioception or altered cutaneous sensations at the head as a result of the vibration. Furthermore, the sensation of vibrotactile cues is facilitated by the craniofacial nerves, which lie close to the cortical centers involved in perception and integration of sensory modalities for balance control. This proximity to the cortical centers is beneficial, since it may eliminate potential errors in sensory integration and delays in sensory transmission that occur in older adults [28,29]. Activation thresholds were set at 40% of the 90% ranges of pitch and roll sway angular velocity derived during the second balance assessment of the first session, for each subject and for each task separately [13,15]. Once activated due to crossing the threshold, the vibrotactile feedback at the corresponding site remained active as long as the threshold was exceeded. We chose to use velocity rather than position feedback, because previous results indicated that velocity feedback is more effective for improving balance during gait in vestibular loss patients [16]. Moreover, trunk sway velocity during stance is an indication of falling tendency in PD [6].

2.5. Statistical analysis

The outcome measures included duration until completion of the task (only for the walking tasks), the 90% range of pitch and roll sway angle and the 90% range of pitch and roll sway angular velocity. For all subjects we averaged the outcome measures of the first two and the last two balance assessments. These were defined as pre-training and post-training balance assessment, respectively. Then, we calculated the difference between pre- and post-training assessment for each outcome measure with the following formula: ((posttraining − pretraining)/pretraining) * 100%. As a result, a negative difference indicated less sway after training, and thus an improvement in balance.

All data were normalized using log-transformation. For all outcome measures we examined the differences in effect of training between the control group and the feedback group by means of an analysis of covariance (ANCOVA). Therefore, we used the outcome during post-training balance assessment as a dependent variable, 'group' as a fixed factor, and the outcome during pre-training balance assessment as a covariate.

Furthermore, we studied within each subject group separately if there was a significant effect of training for each outcome measure with a paired samples t-test between pre- and post-training balance assessment. Additionally, we examined different subsets of tasks (eyes open, eyes closed, training tasks, non-training tasks, dynamic tasks, and static tasks) to further explore differences in training effect between both patient groups. Due to multiple comparisons level of significance (α) was set at $P = 0.01$.

3. Results

3.1. Duration

Patients in the feedback group needed more time to complete the gait tasks (ANCOVA, significant main effect of group, $P = 0.01$). Therefore, we corrected for task duration in all other statistical tests, by adding it as an additional covariate in the ANCOVA model.

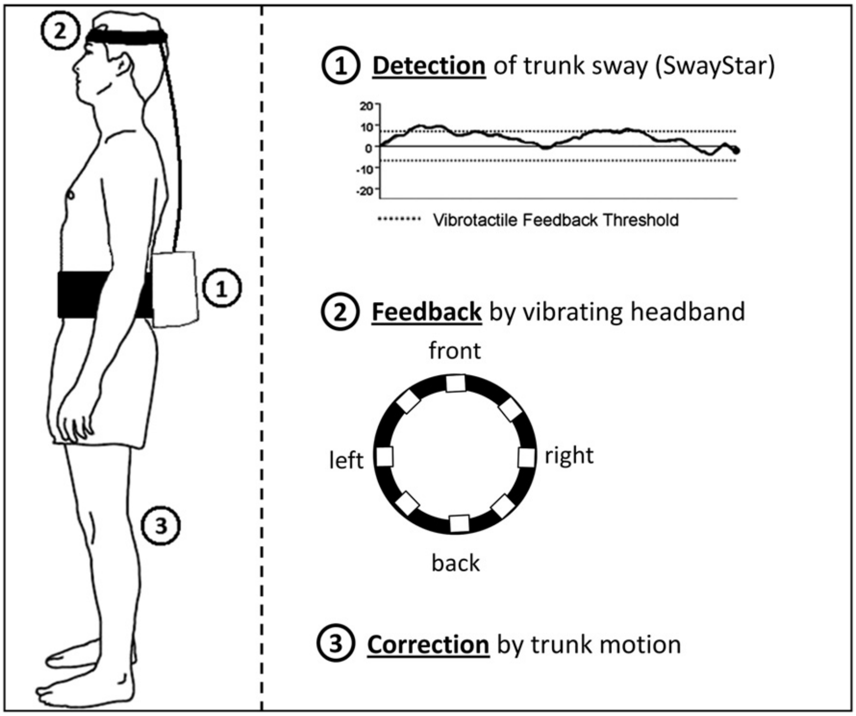

Fig. 1. Schematic illustration of the SwayStar and biofeedback system. When trunk sway crosses the threshold of anterior-posterior or mediolateral sway (1), feedback will be transduced to the subject by a vibrating sensor in the headband in the corresponding direction of movement (2). The subject is asked to correct sway by moving the trunk away from direction indicated by the vibrator (3) until the trunk sway is back within threshold values, and no more feedback vibrations are felt.

3.2. Effect of training

Fig. 2 illustrates the general effect of the training intervention. Univariate ANOVA showed that there were no differences in pre-training balance assessment outcomes between the control group and the feedback group for all tasks. After the training intervention, patients in the feedback group had a greater reduction in roll sway angle (ANCOVA, significant main effect of group, $P < 0.001$) and in roll sway angular velocity (ANCOVA, significant main effect of group, $P = 0.005$). This can be attributed mainly to the increase in roll sway angle in the control group (difference from baseline: 13.8% ± 3.6%; paired samples *t*-test: $P = 0.012$) and the decrease in roll sway angular velocity in the feedback group (difference from baseline: −6.2% ± 3.3%; paired samples *t*-test: $P < 0.001$).

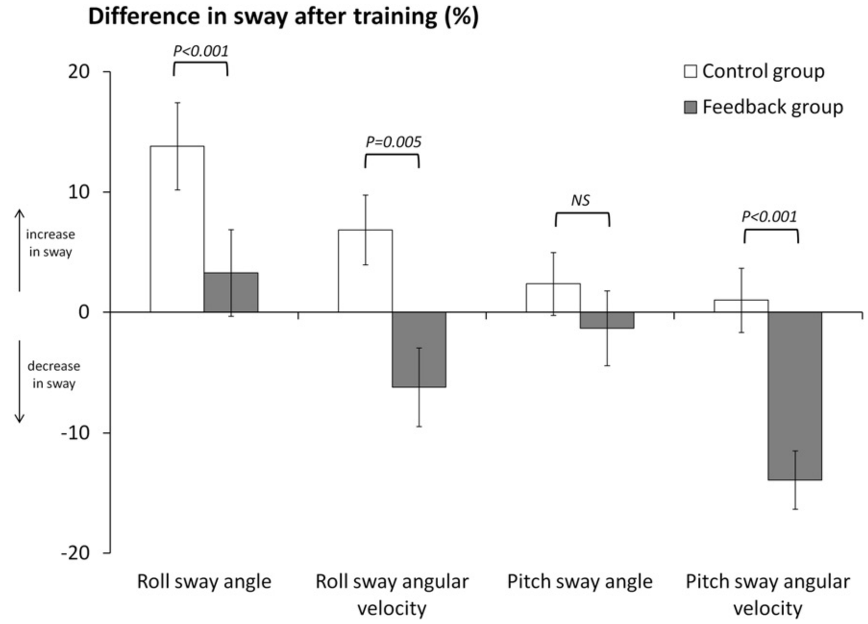

Fig. 2. Mean effect of training. Mean effect (and standard errors of the mean) of training on roll sway angle, roll sway angular velocity, pitch sway angle, and pitch sway angular velocity in the control group and in the feedback group. Negative values indicate less sway after training (improvement). *P*-values for significant differences between subjects groups, assessed with an ANCOVA, are shown in the graph. NS = not significant.

Table 2
Mean differences (%) in training intervention effect between feedback and control group for different subsets of tasks and outcome measures separately.

Task subset	Roll sway angle (degrees)	Roll sway angular velocity (degrees/second)	Pitch sway angle (degrees)	Pitch sway angular velocity (degrees/second)
Trained tasks 6 tasks	15.1 ± 8.1[a]	13.5 ± 7.5	8.6 ± 6.0	17.3 ± 5.8[a]
Non-trained tasks 6 tasks	5.9 ± 6.3	12.6 ± 4.5	−1.3 ± 5.4	12.6 ± 4.3[a]
Gait tasks 6 tasks	8.4 ± 4.3[a]	13.1 ± 3.9	−1.8 ± 4.6	14.8 ± 5.0
Stance tasks 6 tasks	12.7 ± 9.1	13.0 ± 7.7	9.1 ± 6.6	15.1 ± 5.0[a]
Tasks with eyes open 7 tasks	8.1 ± 6.2	13.0 ± 4.4[a]	0.6 ± 5.1	14.2 ± 4.2[a]
Tasks with eyes closed 5 tasks	13.9 ± 8.7[a]	13.1 ± 8.5	7.9 ± 6.6	16.0 ± 6.4

Data are shown as mean differences ± standard error of the mean.

[a] Feedback group had a significantly larger improvement after training compared to the control group, assessed with an ANCOVA ($P < 0.01$).

Within the feedback group pitch sway angular velocity significantly improved after training (difference from baseline: −13.9% ± 2.4%; paired samples *t*-test: $P < 0.001$). As a result, pitch sway angular velocity also improved more in the feedback group after the training intervention compared to controls (ANCOVA, significant main effect of group, $P < 0.001$, Fig. 1). There was no difference between groups in pitch sway angle.

3.3. Post-hoc tests – between groups

To further explore the differences found between the feedback and control group, we analyzed subsets of the tasks separately by means of an ANCOVA (Table 2). While pitch sway angle showed no improvement in the feedback group compared to controls during the subsets of tasks, we found that the improvement in pitch sway velocity was present during most of the subsets. Pitch sway velocity decreased significantly more in the feedback group for trained tasks ($P = 0.008$), non-trained tasks ($P = 0.005$), stance tasks ($P = 0.001$), and eyes open tasks ($P = 0.002$), and showed a trend towards more improvement during gait tasks ($P = 0.012$).

Roll sway angle improved more in the feedback group during trained tasks ($P = 0.003$), gait tasks ($P = 0.001$), and eyes closed tasks ($P = 0.004$), while roll sway angular velocity decreased more in the feedback group during eyes open tasks ($P = 0.009$).

3.4. Post-hoc tests – within groups

When we examined the differences within each group by means of a paired samples *t*-test, we found that in the feedback group pitch sway angular velocity decreased for each subset of tasks after training: non-trained, trained, stance, gait, eyes open, and eyes closed tasks (all with $P < 0.001$). Duration was increased, but only for the non-trained tasks ($P = 0.003$). Roll sway angular velocity was improved for trained tasks ($P = 0.001$), stance tasks ($P < 0.001$), and eyes open tasks ($P = 0.01$). There were no significant differences in roll and pitch sway angle.

In controls we only observed significant differences in the roll plane. Roll sway angle increased for the non-trained ($P = 0.009$) and the eyes open ($P = 0.005$) tasks. Furthermore, roll sway angular velocity increased for gait tasks ($P < 0.001$) and duration decreased for trained tasks ($P = 0.005$).

4. Discussion

In this study we examined the short-term carry-over effect of balance training in PD patients with a biofeedback system, as compared to balance training without feedback. We found that vibrotactile biofeedback training may be more beneficial for balance in PD patients compared to conventional balance training, and this effect was evident even after the training session. Biofeedback-based balance training was most effective in the anterior-posterior plane. In the mediolateral plane feedback training was especially effective during gait tasks.

4.1. Effects of biofeedback training

Previous studies have shown direct effects of on-line vibrotactile biofeedback in healthy subjects [12] and in vestibular loss patients [17–19], and a short time carry-over effect in healthy subjects [20]. Furthermore, one recent pilot study examined the effects of a 6-week auditory biofeedback training in PD patients [21], showing subtle improvements in balance, but without a control group. In addition to these results, we have now shown that biofeedback balance training in PD may indeed be more beneficial than conventional training without biofeedback, even after one training session.

Since roll sway angle, roll sway angular velocity, and pitch sway angular velocity were decreased in the biofeedback group compared to controls, we believe that biofeedback-based balance training can improve balance in PD. In older adults, reduced trunk sway is highly correlated with a reduction in falls [7]. More recently, several studies showed that greater postural sway in both mediolateral and anterior-posterior direction in PD patients is a predictor of falls [2,8,9]. We therefore speculate that decreasing trunk sway in PD patients may reduce the actual fall risk in daily life, but of course this remains to be demonstrated in further prospective studies with falls in daily life as outcome.

Moreover, our results show that even during tasks that were not trained with biofeedback, pitch sway angular velocity was also reduced compared to controls. This suggests that biofeedback training is beneficial not only for the specific tasks that were trained, but may also contain a carry-over effect leading to more general balance improvement.

Patients in the feedback group took longer to complete the gait tasks after balance training. This may reflect greater concentration and more awareness of task performing, and this may have contributed to the difference with controls. However, the group differences remained significant after correction for task duration, suggesting a real beneficial effect of feedback training.

4.2. Future studies

We have shown that training with biofeedback can reduce trunk sway, even after one training session, but much more work remains to be done. First, the present intervention was brief and not very intensive. It would be interesting to examine whether longer or more intensive biofeedback training would offer greater benefit to PD patients. Second, our present results show that most improvements occurred in the anterior-posterior plane. This is also the plane that causes greatest balance difficulties in PD, particularly when patients fall backwards [30,31]. We therefore feel that offering feedback in particularly this backward direction might have the greatest potential for improving balance in PD. However, for gait analysis we would still recommend to look at the roll plane as well, since increased mediolateral sway during walking has been associated with falls in PD [32]. Third, it would be interesting to look at carry-over effects, determining whether the training effects can persist for one or more weeks after the actual training intervention, and which intensity is required to achieve a sustained improvement. Finally, we examined a small number of PD patients with a mild disease severity and without cognitive decline. Additionally, our patients had a relatively good balance as indicated by the high Tinetti scores. This limits the generalizability of our findings. Therefore, future studies should focus on the effect of biofeedback training in a larger study population with more advanced PD and more distinct balance disorders, including patients with cognitive deficits.

Conflicts of interest

All authors, except JH Allum, declare that they have no conflicts of interest. JH Allum also works as a consultant for the firm producing the equipment (SwayStar™) used in this study.

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