



Vibrotactile neurofeedback balance training in patients with Parkinson's disease: Reducing the number of falls[☆]

Marcos Rossi-Izquierdo^{a,*}, Arne Ernst^b, Andrés Soto-Varela^c, Sofía Santos-Pérez^c, Ana Faraldo-García^c, Ángel Sesar-Ignacio^d, Dietmar Basta^b

^a Department of Otolaryngology, University Hospital Lucus Augusti, Spain

^b Department of Otolaryngology at ukb, Hospital of the University of Berlin, Charité Medical School, Berlin, Germany

^c Department of Otolaryngology, University Hospital of Santiago de Compostela, Spain

^d Department of Neurology, University Hospital of Santiago de Compostela, Spain

ARTICLE INFO

Article history:

Received 10 October 2011

Received in revised form 25 June 2012

Accepted 3 July 2012

Keywords:

Balance training

Parkinson's disease

Vibrotactile neurofeedback training

Computerized dynamic posturography

Body sway analysis

VertiGuard

ABSTRACT

The aim of this study was to assess effectiveness of balance training with a vibrotactile neurofeedback system in improving overall stability in patients with Parkinson's disease (PD).

Ten patients diagnosed with idiopathic PD were included. Individualization of the rehabilitation program started with a body sway analysis of stance and gait tasks (Standard Balance Deficit Test, SBDT) by using the diagnostic tool of the applied device (VertiGuard[®]-RT). Those tasks with the poorest outcome as related to age- and gender-related controls were included in the training program (not more than six tasks). Improvement of postural stability was assessed by performing SBDT, Sensory Organization Test (SOT) of Computerized Dynamic Posturography (CDP), Dizziness Handicap Inventory (DHI), activity-specific balance confidence scale and recording the number of falls over the past three months. Furthermore, scores of SOT and DHI of 10 PD patients previously trained in an earlier study (by using CDP) were compared with results of those in the present study.

After neurofeedback training (NFT), there was a statistically significant improvement in body sway (calculated over all training tasks), number of falls, and scores of SOT, DHI and ABC. In comparison with CDP-training, a statistically significant higher increase of SOT score was observed for patients after NFT with the VertiGuard-RT device compared to CDP training.

Our results showed that a free-field vibrotactile NFT with VertiGuard[®]-RT device can improve balance in PD patients in everyday life conditions very effectively, which might lead in turn to a reduction of falls.

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1. Introduction

In patients with Parkinson's disease (PD), balance impairment represents a considerable mortality risk from the numerous falls that possibly result. Specifically, 50.8–68.3% of patients experience falls in PD [1,2]. One of the most important associated injuries resulting from falls is hip fracture due to the impaired protective arm reflexes [3]. Falls also have significant psychological and social consequences and represent severe risks for the patients [4].

Furthermore, it is a well-known fact that pharmacological treatment does not decisively improve balance and gait impairments in PD patients [5]. The same holds true for surgical measures

[6]. It was even reported that some PD patients tended to fall more often after deep brain stimulation surgery [7].

The present study was initiated as a result of our earlier investigations in postural stability of PD patients. Patients with PD suffer from balance disorders basically because of deficient processing of visual and vestibular inputs [8]. In some of them, Computerized Dynamic Posturography (CDP) can detect alterations in balance that cannot be detected by routine clinical examination [8]. Deterioration in processing vestibular information in PD does not depend on the stage of the disease [8]. Patients also have reduced limits of body stability, i.e., they are more likely to fall as a result of their diminished base of support [8].

When our patients were assessed by VOR (caloric and rotatory tests) and oculomotor testing, they showed a central vestibular processing deficit [9].

Finally, we reported in a previous study [10] that vestibular rehabilitation with CDP in patients with PD can significantly improve activities of daily life, gait velocity and balance. Moreover, these benefits can persist over a certain period of time.

[☆] A preliminary report was presented at XXVI Bárany Society Meeting (Reykjavik 20th August 2010).

* Corresponding author at: Department of Otolaryngology, University Hospital Lucus Augusti, Calle Dr. Ulises Romero, 1, 27003 Lugo, Spain. Tel.: +34 639354081; fax: +34 982247185.

E-mail address: Marcos_Rossi@hotmail.com (M. Rossi-Izquierdo).

Therefore, rehabilitation with neurofeedback training (NFT) in every-day life conditions seems to be well suited to increase and improve performance of PD patients in dynamic tasks. In these free-field conditions, falls among PD patients commonly occur (e.g., sitting down or standing up). Trunk sway measurements at center of body mass (hip) under such everyday-life conditions showed an increased risk of fall and a much higher trunk sway of PD patients compared to controls [11]. Earlier studies showed a high effectiveness of a free-field auditory NFT to reduce body sway in patients with different peripheral vestibular disorders [12,13]. This type of NFT has distinct disadvantages. In this approach, body sway is encoded as an auditory signal; the patient should maintain postural control in a normal range by responding to an emitted sound (in two dimensions). This is impossible for PD patients since they cannot react in an adequate manner to this non-intuitive information. In contrast to auditory neurofeedback, an intuitive, vibrotactile neurofeedback stimulus (which has a very short reaction time [14]) seems more appropriate to encode individual sway during everyday-life conditions in PD patients.

Thus, the aim of this study was to assess effectiveness of balance training with a vibrotactile NFT system in improving overall stability in PD patients.

2. Methods

2.1. Patients

10 patients diagnosed with idiopathic PD were categorised according to criteria established by Gelb [15] (Hoehn and Yahr [16] III, 6 patients; Hoehn and Yahr IV, 4 patients). The patients (eight male, two female) had an average age of 67 years (53–79 years). On examination, balance was impaired in all patients, with at least 2 points in item 33 of UPDRS [17].

Nine of the PD patients were classified as a “faller” because they had suffered at least one fall over the past three months. All participants gave their, written, informed consent to participate in the study which was in accordance with the Declaration of Helsinki.

We excluded all subjects who used a wheelchair or had additional neurological deficits. None of the patients had a history of peripheral vestibular disease and oto-neurological examination was normal (including absence of spontaneous or induced nystagmus by a head-shaking test and absence of saccadic movements by the Halmagyi test). Also none of the patients had dementia and the score in the Mini-mental test [18] was 25 points or greater.

During the study, all patients took their usual medication for PD and were tested and trained in their ‘on’ state.

2.2. Individualization of the neurofeedback training

Individualization of the rehabilitation program started with a body sway analysis (mobile posturography) by using the diagnostic tool of the Vertiguard[®] device (Vesticure GmbH, Germany) during 14 different everyday life stance and gait conditions (results were compared with inbuilt age- and gender-related normative values).

This body-worn device is fixed on a belt and records body sway in the roll (lateral) and pitch (antero-posterior) planes respectively at the centre of body mass (Fig. 1) under well-defined sensorimotor conditions. In this way, trunk sway is measured by gyrometers at the hip while the subjects are asked to carry out the standard balance deficit test (SBDT) [13]. Elderly subjects (over 59 years) performed the geriatric version of the SBDT (gSBDT). Eight patients performed the gSBDT, while the other two performed the SBDT.

SBDT tasks are shown in Table 1. The following tasks were skipped in gSBDT: standing on one leg with eyes closed and standing on one leg on a foam support surface.

Tasks “stand up” and “sit down” were added as the last two conditions of gSBDT version. Measurement time was 20 s for all stance tasks and as long as required for gait tasks.

2.3. Neurofeedback training (NFT)

Up to six tasks with the most prominent deviations from normative control values were included in the training program. Individual feedback (i.e., vibrotactile response thresholds) were calculated and stored in the device for each patient based on body sway analysis. Training was performed by using the training function of Vertiguard[®]-RT device. This neurofeedback system contains a battery driven main unit (120 mm × 76 mm × 32 mm, 190 g) which is fixed on a belt at the centre of body mass (hip) and one vibration stimulator on the front, back, left and right side, respectively. Vibration stimulators are mounted on the same belt as the main

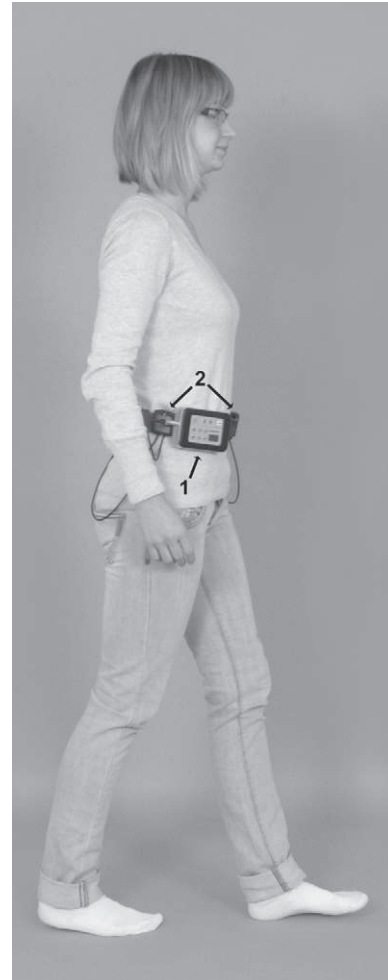


Fig. 1. Vertiguard[®]-RT vibrotactile neurofeedback system with a main unit (1) and vibration pads (2). Only two of the four stimulators are visible in the picture (each arranged at 90° around the hip). The central unit continuously measure body sway during exercises and activate a vibratory stimulator (vibrator) in the direction of excessive body sway.

unit. They were adjustable by sliding over the belt to the correct position in the individual patient (Fig. 1). The main unit determines continuously the coriolis force during body movements in pitch and roll by inbuilt gyroscopes and compares those values with individual preset thresholds for stimulator activation in specific directions.

Training was performed daily under supervision of a physician over 2 weeks (10 sessions, weekend was excluded). A training session consisted of 5 repetitions of six selected training tasks as described above (each repetition lasted 20 s or until the movement was finished). The patient received a vibrotactile feedback signal during

Table 1
Standard balance deficit test (SBDT) consisted of the following tasks.

Tasks
Standing on two legs with eyes open
Standing on two legs with eyes closed
Standing on one leg with eyes open
Standing on one leg with eyes closed
Eight tandem steps with eyes open
Standing on two legs with eyes open on a foam support surface
Standing on two legs with eyes closed on a foam support surface
Standing on one leg on a foam support surface
Eight tandem steps with eyes open on a foam support surface
Walking 3 m with eyes open
Walking 3 m with eyes open while rotating head
Walking 3 m with eyes open while vertically pitching the head in rythm
Walking 3 m forward with eyes closed
Walking over four barriers

training in those directions which showed a higher body sway than preset thresholds. Vibration was reinforced with increasing sway, i.e., the higher it exceeded the preset values, the stronger the vibration was at the corresponding site. No vibrotactile feedback was applied if the patient's sway was below preset thresholds. The patient was instructed to adjust preset thresholds for each training task daily (all directions together) by pressing sensitivity buttons on the main unit until he was able to react adequately to the vibratory neurofeedback signal.

2.4. Outcome measures and data evaluation

Outcome measures were performed before, during (daily SBDT or gSBDT) and after the rehabilitation as well as after three months.

2.4.1. Results of free-field body sway analysis (SBDT or gSBDT)

(a) Mean value of body sway in roll and pitch plane of SBDT/gSBDT.

(b) SBDT composite score (Risk-of-Falling indicator). This value was calculated as the sum of ratios of all tested examinations in SBDT/gSBDT to their age- and gender related normal values in pitch and roll. The norm is based on 246 volunteers (137 females, 109 males) (source: Vesticure GmbH, Pforzheim, Germany). The result is related to body sway of a patient with a 100% risk of falling. Such a patient should have twice as much body sway than normal controls in pitch and roll at each task. The resulting mathematical formula is as follows:

$$\text{SBDT composite score} = \frac{(\sum p_i + \sum r_i) \times 100}{n \times 400} \text{ (Risk-of-Falling indicator)}$$

with p = pitch sway/normal value in %, r = roll sway/normal value in %, n = number of tasks in SBDT/gSBDT.

2.4.2. Composite score of sensory organization test (SOT) of CDP

SOT [19] is a well-established score designed to separate a somatosensory, visual and vestibular input to overall postural stability through measurement of balance parameters in a CDP system (Equitest, Neurocom, Clackmas, OR, USA). Measurements are taken during three replicate 20-s runs under each of the following six sensory conditions: (1) Immobile surface, immobile visual surround, eyes open, (2) Immobile surface, eyes closed, (3) Immobile surface, mobile visual surround, eyes open, (4) Mobile surface, immobile visual surround, eyes open, (5) Mobile surface, eyes closed, (6) Mobile surface, mobile visual surround, eyes open.

Composite score (0–100%) is the weighted average of the scores of all sensory conditions.

2.4.3. Dizziness handicap inventory (DHI) (validated Spanish version [20] or German version [21])

This questionnaire characterizes disability resulting from balance impairment. It helps to quantify how these vestibular symptoms affect the individual's quality of life. Maximum score (representing the greatest disability) is 100.

2.4.4. Activities-specific balance confidence scale (ABC)

In sixteen activities, the patient describes his/her level of confidence in performing activities without losing balance. An ABC score of 0% would indicate "no confidence", 100% "complete confidence" [22].

2.4.5. Number of falls in the last three months:

The number of falls was collected from interview (conducted by a physician). A fall was defined as an unexpected event in which the person inadvertently came to rest on the ground or another lower level.

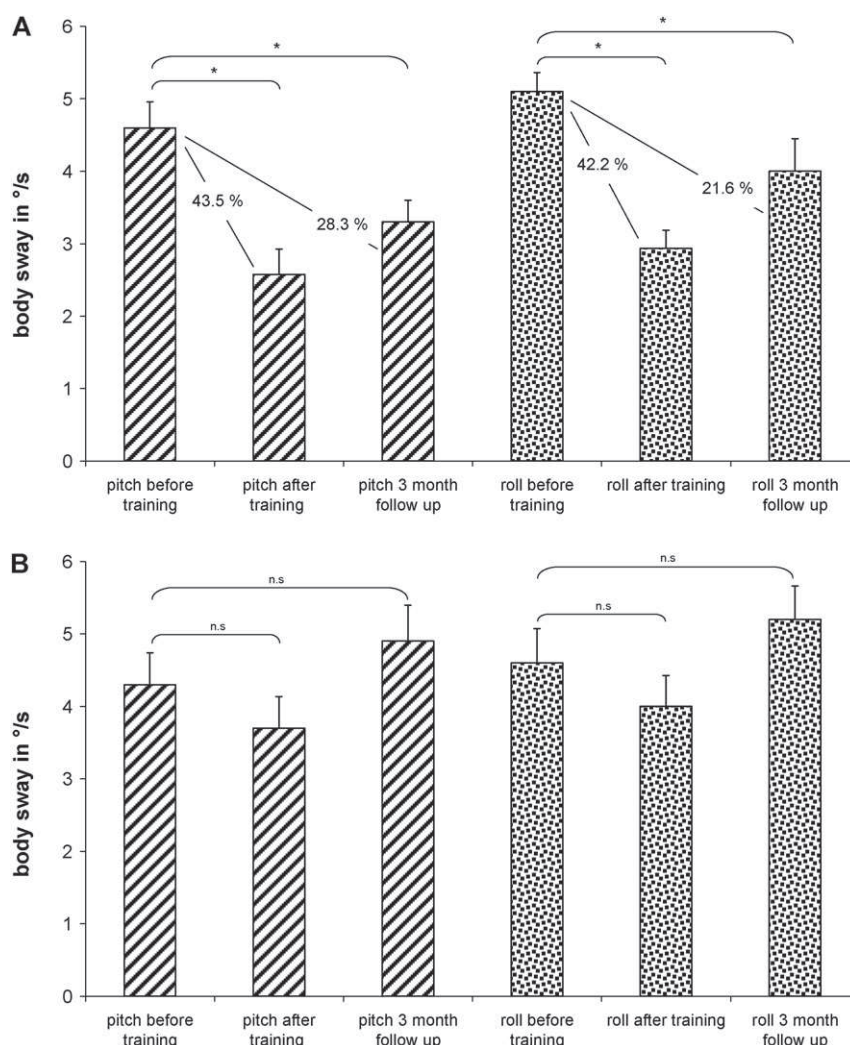


Fig. 2. Mean body sway in pitch and roll direction calculated over all tasks included (A) or not included (B) in the feedback training. Up to six tasks with the most prominent deviations from normative control values were included in the training program. All other tasks were not included in the training program. Results are given before and after the rehabilitation as well as after three months. The statistically significant differences are marked with an asterisk. Error bars represent the standard error of mean.

Minimal required sample size was calculated by using software G*Power 3.1.2 (University Kiel, Germany) [23] based on a given effect size of 0.9, $p = 0.05$ and a statistical power of 0.8 (minimal required sample size was 8).

Statistical analysis was carried out with SPSS 17.0 software package for Windows. Statistical significance was tested in between the patients before treatment, immediately after completing training, and after three months by t -test for dependent samples or Wilcoxon's test (depending on data distribution).

Furthermore, composite score of SOT and DHI (before and after training) of 10 PD patients previously trained in an earlier study (by using CDP [10]) were compared with results of present study by t -test for independent samples. Sample of CDP-study was made up of 10 patients (five men and five women) with an average age of 69.3 years (ranging from 48 to 80 years). Distribution according to Hoehn and Yahr stages was the following: six patients in stage III and four patients in stage IV.

Data distribution was tested by the Kolmogorov–Smirnov-test. Level of significance in all tests applied was $p < 0.05$.

3. Results

3.1. Objective outcome measures

3.1.1. Free-field body sway analysis (mobile posturography)

Total body sway data (as calculated over all training tasks) before, immediately after cessation of training sessions and after 3 months are shown for pitch and roll directions in Fig. 2A.

Immediately after ending the training, a significant decrease in body sway by 43.5% in pitch ($p = 0.001$, Wilcoxon test) and by 42.2% in roll direction, respectively, ($p = 0.001$, Wilcoxon test) were found. After 3 months, these differences continued to be statistically significant (pitch: $p = 0.03$, roll: $p = 0.01$). However, no significant improvements (immediately after training and 3 months later) were observed in those tasks which were not included in training sessions (Fig. 2B).

3.1.2. SBDT composite score (“risk of falling”)

SBDT composite score before starting training was 71.4 (± 5.7) which was decreased to 56.4 (± 4.6) (Fig. 3A) thereafter. This difference was statistically significant ($p = 0.001$, t -test for depended samples). After three months, the composite score of SBDT amounted to 64.4 (± 5.8). This change in the score was not statistically significantly different compared to post-training level ($p = 0.210$, t -test for depended samples).

3.1.3. Force platform measures

The composite score of SOT demonstrated a significant improvement when comparing pre- and post-training results (pre: 47.6 ± 6.9 and post: 66.0 ± 6.3) ($p = 0.019$, t -test for depended

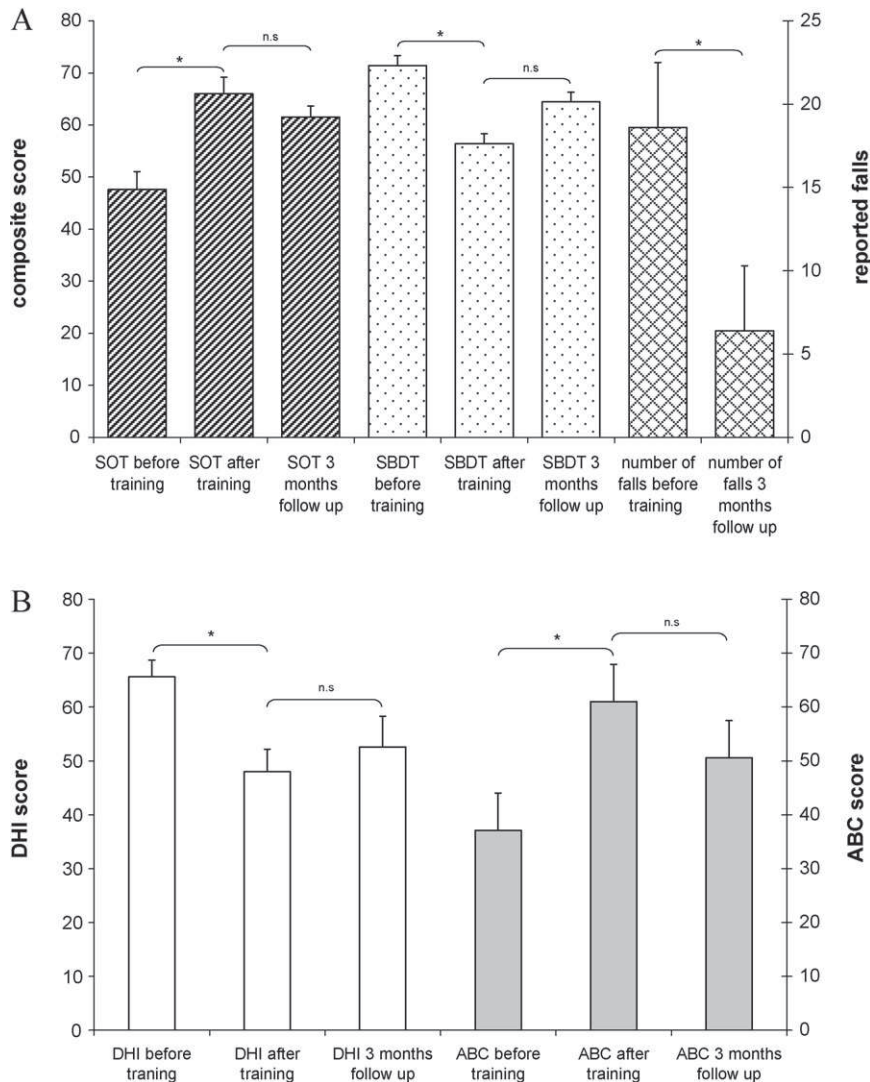


Fig. 3. (A) Scores of composite score of the SOT and the SBDT (or g-SBDT) in the elderly before and after the rehabilitation (immediately and after three months). The number of falls reported in the last three months before and at 3 months follow-up. (B) Scores of the DHI and ABC questionnaires before and after the rehabilitation (immediately and after three months). The statistically significant differences are marked with an asterisk. Error bars represent the standard error of mean.

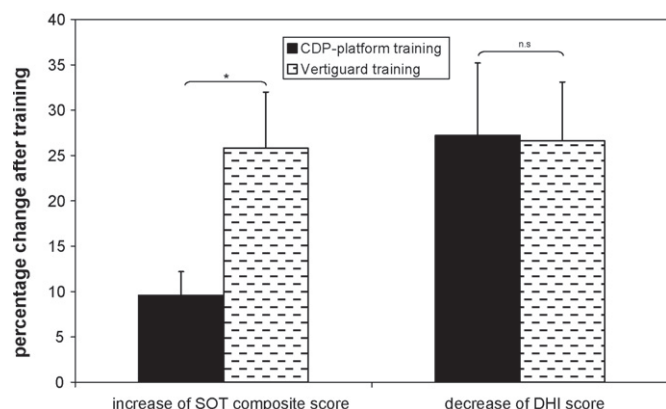


Fig. 4. Percentage change of SOT composite score and DHI score after training in the group of PD patients trained with CDP platform and in the group of PD patients trained with Vertiguard[®]-RT device. The statistically significant differences are marked with an asterisk. Error bars represent the standard error of mean.

samples) (Fig. 3A). After three months, the composite score of SOT was 61.5 (± 4.2). This was not statistically significantly different compared to post-training level ($p = 0.228$, t -test for depended samples).

3.1.4. Number of falls

Average number of falls significantly declined from 18.6 (± 11.4) pre-training to 6.4 (± 5.4) at post-training level ($p = 0.027$, t -test for depended samples) (Fig. 3A).

3.2. Results of the subjective parameters (questionnaires)

3.2.1. DHI scores

DHI scores were statistically significantly decreased when comparing pre- and post-training results (Fig. 3B). This decline amounted to 65.6 (± 3.1) pre-training and 48.0 (± 4.2) post-training ($p = 0.005$, t -test for depended samples). After three months, DHI score changed to 52.6 (± 5.7) which was not more significantly different from post-training results ($p = 0.228$, t -test for depended samples).

3.2.2. ABC Scores

ABC scores were also significantly improved after training (Fig. 3B) from 37.1 (± 5.9) to 61.0 (± 5.7) ($p = 0.001$, t -test for depended samples). However, the score after three months was not more significantly different from post-training results with 50.6 (± 6.6) ($p = 0.100$, t -test for depended samples) (Fig. 3B).

3.3. Comparison of the results of vibrotactile neurofeedback training with a CDP-training in PD patients

A statistically significantly higher increase of SOT composite scores ($p = 0.04$, t -test for independent samples) was observed for patients after NFT with the Vertiguard[®]-RT device compared to a CDP training. This does not hold true for DHI scores ($p = 0.65$, t -test for independent samples) (Fig. 4).

4. Discussion

Balance training may be an effective way to improve postural instability in PD patients. Previously, Cochrane review found that there was insufficient evidence to support or refute the efficacy of physiotherapy in PD [24]. Subsequently, there are different rehabilitation groups that have reported improvement in postural stability in PD patients with different kinds of exercises [10,25,26].

An important outcome of our study was a significant reduction in falls during daily life in patients trained with Vertiguard[®]-RT device. This is particularly relevant because impaired balance in PD patients constitutes a serious morbidity and mortality handicap as falls are the main cause of hospitalization in this population [3]. It could be expected that reducing number of falls after training would give PD patients greater confidence in daily activities and a higher quality of life. Apart from benefits found in objective tests, these results were also accompanied by an improved subjective feeling, as shown by the questionnaire results.

We used an “individualized” rehabilitation program because prior studies have shown that customised exercises are more effective than generic programmes [27]. Specifically, a prior study in PD patients with an audio-biofeedback training reported improvements in balance with an individualized protocol [28]. The training schedule was similar to those of a previous study, which showed a successful vestibular rehabilitation in otolith disorders with auditory NFT in daily-life conditions [13].

Limited improvement in those tasks that were not part of training program would suggest that these tasks should be included in future programs (if more than 6 tasks show pathologic results in body sway analysis). Training with more than six tasks would possibly further enhance the effectiveness of training for these patients.

Similarities in sample size and duration of rehabilitation allow us to compare the efficacy of training with the Vertiguard[®]-RT system and those obtained with CDP platform training (a system with proven efficacy in PD patients [10]). We found an evident advantage in improving overall balance (SOT scores) after NFT with the Vertiguard[®]-RT system which, nevertheless, was not reflected in subjective perception as reported by the DHI questionnaire. On one hand, this dissociation between self-perception and postural handicap is well known for vestibular disorders [29]. On the other hand, both techniques were able to re-mobilize PD patients which led in turn to a similar quality-of-life perception.

Previously, similar NFT systems had applied acoustic, galvanic or visual signals to the patient. These systems are possibly promising in therapy of chronic peripheral vestibular disorders [30]. However, since such a feedback signal is not intuitive as a vibrotactile stimulus, central vestibular disorders (e.g., PD) could be treated very effectively with the Vertiguard[®]-RT device in a rather short period of time.

A limitation of this study is the lack of an appropriate control group with PD patients which could possibly perform a similar training without the feedback signal which was not possible for ethical reasons. This is why we have compared two different treatment options in our study (CDP and Vertiguard).

In essence, the present results may provide evidence that a free-field, vibrotactile, neurofeedback training with the Vertiguard[®]-RT device can decisively improve balance performance in daily-life conditions of PD patients which can lead in turn to a reduction of falls. However, future studies should prove the effect on a larger sample size and should investigate the long-term follow up to be able to conclude on possible re-training intervals.

Acknowledgement

This study was supported by a grant of the German Ministry of Education and Research (BMBF-01EZ0754).

Conflict of interest statement

I would like to inform you that there are not conflicts of interest. No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a

benefit on the authors or on any organization with which the authors are associated.

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Please cite this article in press as: Rossi-Izquierdo M, et al. Vibrotactile neurofeedback balance training in patients with Parkinson's disease: Reducing the number of falls. *Gait Posture* (2012), <http://dx.doi.org/10.1016/j.gaitpost.2012.07.002>