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EFFECTS OF RANDOM WHOLE-BODY VIBRATION ON POSTURAL CONTROL IN PARKINSON'S DISEASE

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We investigated spontaneous effects of random whole-body vibration (rWBV) on postural control in Parkinsonian subjects. Effects were examined in biomechanical tests from a total of 52 patients divided equally into one experimental and one control group. Postural control was tested pre- and post-treatment in two standardized conditions (narrow standing and tandem standing). *The intervention was based on rWBV (ŷ: 3 mm, f: 6 Hz 1 Hz/sec) consisting of 5 series lasting 60 seconds each. The main findings from this study were that (1) rWBV can improve postural stability in Parkinson's disease (PD) spontaneously (2) these effects depend on the test condition. Based on the results of this study, rWBV can be regarded as an additional device in physical therapy in PD.*

Keywords: postural control, postural instability, Parkinson's disease, random whole-body vibration

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INTRODUCTION

Since James Parkinson made first references to falls it is well known that postural instability (PI) is a hallmark of idiopathic PD (Bloem, Beckley, Van Hilten, et al. 1998). In general it occurrs in the late and most advanced stages of the disease (Marchese, Bove, and Abbruzzese 2003), but falls in the relatively early course of PD also have been reported (Bloem, Grimbergen, Cramer, et al. 2001). The high risk of falling in PD is confirmed by some retrospective studies (Ashburn, Stack, Pickering, et al. 2001; Koller, Glatt, and Vetere-Overfield 1989; Magalhaes et al. 2000; Smithson, Morris, and Jansek 1998). Wood et al. (2002) found that the risk of falling is approximately twice in PD patients when compared with that of healthy older people. Due to falls, a loss of functional independence and the risk of being admitted to a nursing home often are reported along with fear of future falls. With respect to the progression of PD Jankovic et al. (1990) speculated about a worse overall prognosis for subjects with a marked PI, which also is associated with an increased mortality in PD patients (Bennett, Beckett, Murray, et al. 1996).

Defectively functioning basal ganglia are an explanation for PI since it is known that this structure is important to control the agonist–antagonist relationship (Dimitrova Horak, and Nutt, 2004). Furthermore, the basal-ganglia quickly modify muscle activation patterns, which are necessary to maintain postural stability (Chong, Jones, and Horak. 2000). Furthermore, some studies have shown that postural reflexes in PD patients differ from those of normal subjects. These abnormalities are thought to contribute to PI (Bloem et al. 1995, 1999; Carpenter, Allum, Honegger, et al. 2004; Dietz, Zijlstra, and Assaiante, et al. 1993; Horak, Nutt, and Nasher 1992;). Moreover PI may relate in part to impaired proprioception and kinaesthesia, respectively (Jobst, Melnick, Byl, et al. 1997; Khudados, Cody, and O'Boyle, 1999; Klockgether, Borutta, Rapp, et al. 1995; Rickards and Cody 1997). Demirci and colleagues (1997) proposed that there is probably proprioceptive feedback present but patients are unable to use it properly for maintaining balance. An abnormal sensory organization like a "breakdown" in the central hierarchy of postural control is discussed in advanced PD as well (Bronte-Stewart, Minn, and Rodrigues et al. 2002).

Due to common problems of PI and a high incidence of falls in PD, further approaches to develop improved therapeutic strategies should be a priority (Bloem et al. 2001). A succesfull treatemt of PD, however, is difficult due to its multifactorial pathophysiology (Bronte-Stewart et al. 2002; Horak et al. 1992; Marchese et al. 2003). Many Parkinson patients have reported that their postural control is worse on medication (Bronte-Stewart et al. 2002). This observation is supported by investigators who pointed out that dopaminergic medication fails to improve postural stability in PD

despite improvements in voluntary movements (Bloem, Beckley, Van Dijk, et al. 1996; Bonnet, Loria, and Saint-Hilaire 1987; Frank, Horak, and Nutt 2000; Jankovic 2002; Koller et al. 1989; Marsden 1994). Moreover Bronte-Stewart et al. (2002) examined a worsening of balance control under L-dopa. In summary it is evident that PI is a severe problem in advanced PD that cannot be treated by medication and surgery sufficiently. But it has been suggested that the practice of physical activities counteracts PI significantly (Perrin, Gauchard, Perrot, et al. 1999).

In previous studies we examined effects of rWBV on reflex activity and postural control in athletes and orthopaedic patients. In both groups the treatment led to significant improvements in postural control, which, were connected with changes in neuromuscular activation patterns (Haas et al. 2004c). Based on theoretical consumptions we also analysed treatment effects on the unified Parkinson's disease rating scale (UPDRS) motor score in PD (Haas et al. 2004b). Significant improvements were primarily found in rigidity, gait, and posture items. Referring to the UPDRS test, we find that postural control is commonly assessed by the retropulsion test. But the value of this test is limited by the lack of normative data, the lack of analysing postural control in medial–lateral direction, and difficulties in standardisation across different subjects (Bloem et al. 1998; Marchese et al. 2003). It also fails to predict falls in PD patients (Bloem et al. 2001). Based on our previous studies the aim of this study was to use biomechanical analyses to prove the effects of rWBV on postural control in PD patients.

MATERIALS AND METHODS

Participants

Fifty-two patients with idiopathic PD participated in this study divided equally into one experimental group (E) and one control group (C). Groups were matched for PI based on the UPDRS. Most of the participants were moderately affected by postural impairment (average UPDRS score for postural control: 1.5 +/– 1.1). Patients were informed about the test situation and gave witnessed informed and written consent to take part in the experiment. All subjects involved in this study were first neurologically assessed in a PD hospital.[1] Patients with dementia, heart diseases, neurological diseases apart from PD, significant dyskinesias, and orthopaedic injuries were excluded. No patient had any features to suggest an atypical or secondary Parkinsonian syndrome.

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Measurements

We used standard assessments of PD severity to get information about the clinical characteristics of the patients—the UPDRS motor score (Fahn, Elton et al. 1987) and the Hoehn and Yahr disability scale (Hoehn, and Yahr 1967); see Table 1. The severity of Parkinsonism ranged from stage III to IV on the Hoehn and Yahr scale, where a wide range of motor disabilities was observed.

Subjects were tested in two standardized conditions on their ability to maintain postural stability on a movable and instable platform (Coordex® - Fa. Ruf, Germany). Condition I was *narrow standing* and condition II was *tandem standing* (see Figure 1). These two conditions are modifications of the "four-test balance scale" (Gardener, Buchner, Robertson, et al. 2001; Rossitier-Fornhoff, Wolf, Wolfson, et al. 1995). The aim was to analyze postural stability in two different positions to obtain information about the influence of the test condition on the result. From a biomechanical point of view, condition II primarily focuses postural control in the medial–lateral direction (M–L), whereas condition I is mainly in the anterior–posterior direction (A–P).

All subjects were able to stand independently during test sessions. They were asked to stand as still as possible for 32 seconds with their arms at their side. This period is long enough to detect differences between subjects clearly, but fatigue is minimized compared with longer testing times (Haas Turbanski, Kaiser, et al. 2004a).

The platform displacements were measured by a two-dimensional acceleration sensor that was attached to the platform. By integrating both acceleration signals twice we got information about the platform displacements in both directions (A–P and M–L). All displacements were summed up for each trial to get an objective value of body sway and to evaluate postural stability. First, three *pretests* were assessed in all subjects in both conditions (*narrow standing* and *tandem standing*). Afterward the treatment was applied to subjects of group E while C subjects had a moderate walk in the hospital lasting as long as the intervention (approximately 15 minutes). Finally, all subjects were retested again for both conditions in three *post-tests*. All patients were tested in the on-phase at peak dose in the levodopa cycle.

Table 1. Clinical Characteristics of the 52 Patients Involved in This Study

	Age (years)	Duration of illness (years)	Hoehn & Yahr (score)	UPDRS motor score	Postural stability (UPDRS)	Levodopa (mg/day)	Distribution of sex
Mean ± SD	69,1 ± 8,9	8,5 ± 0,7	3,3 ± 0,6	40,0 ±11,2	1,4 ±1,1	493,6 ± 192,2	male: 38 female: 14

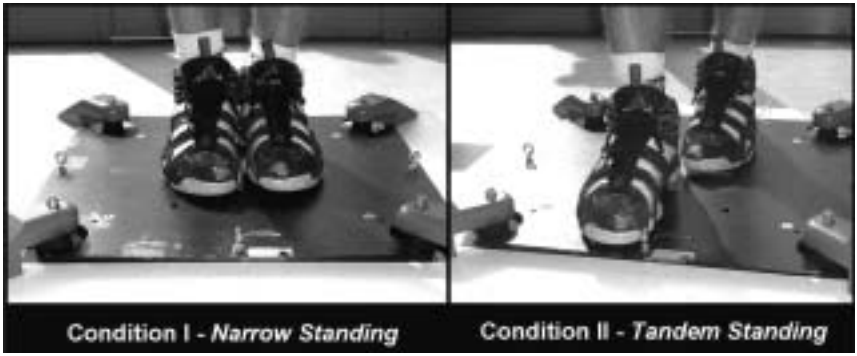

Figure 1. Testing conditions.

Treatment

The treatment was based on rWBV (amplitude: 3 mm, average frequency f: 6 Hz +/– 1 Hz/sec) using a Zeptor®med System (Fa. Scisens, Germany). This frequency range was chosen to generate adequate and variable neuromuscular stimuli and to avoid kinaesthetic illusions, which are found as a result of high frequency sinus waves (see Discussion). In order to avoid fatigue 5 series lasting 60 seconds each were performed. As described above we found positive reactions to this treatment configuration in earlier studies.

Statistical Analysis

A 2-way analysis of variance (ANOVA) for repeated measures was calculated to identify differences within and between pre- and post-tests. In the case of significance, post hoc comparisons (Scheffé) were calculated additionally. In a further step group differences were proved using a 1-way ANOVA and Bonferroni alpha error correction. A significance level of $p<0.05$ was chosen. The software SPSS (11.0) and Statistica were used for statistical analysis.

RESULTS

Condition I—Narrow Standing

Comparison of pre- and post-tests showed improvements in postural control in both groups. In the C group the sway was reduced by 7.1% on average ($p=0.04$) and in the experimental group by 14.9% ($p=0.00$). Within the three pre- and post-tests there were no significant changes in either group. In a further step the pre–post differences of both groups were compared.

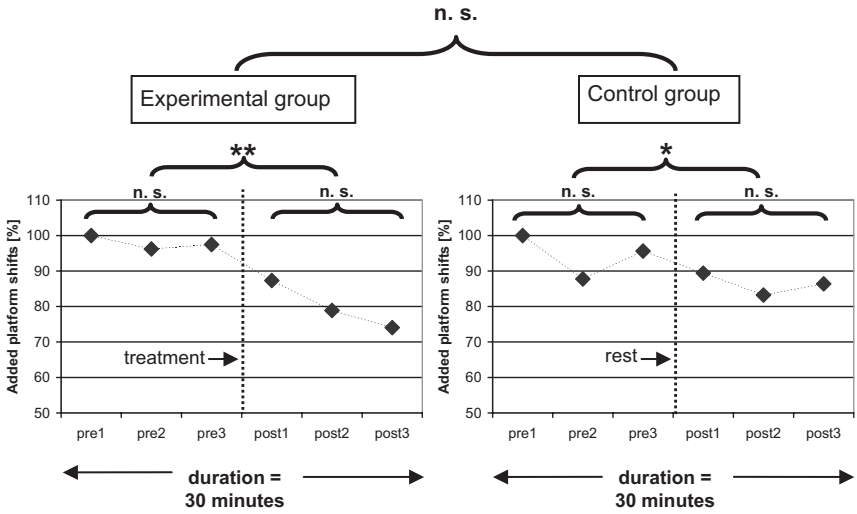

Figure 2. Results of platform displacements in *narrow standing.*

Despite the obviously greater improvements in the E group there was no statistical difference compared with C subjects (p>0.05; see Figure 2).

Condition II—Tandem Standing

Comparison of pre- and post-tests showed improvements in postural control in both groups. In the E group the sway was reduced by 24% on average, whereas in the C group it was reduced by 11.3%. The pre–post differences were significant (p=0.01) in the E group and not significant in the C group (p=0.16). Once again there were no significant improvements within the three pre-tests and within the three post-tests. Analyses of group differences resulted in a significantly higher postural control improvement in the E group (p=0.04; see Figure 3).

In a more detailed evaluation we analyzed platform displacements in both testing situations in the A–P direction and in the M–L direction separately. Despite results of other studies (Dimitrova et al. 2004) there were no significant differences between both directions in our examination, whether in performance or in improvements due to intervention.

DISCUSSION

The main findings from this study were that rWBV can improve postural stability in PD, but these effects depend on the test condition. In condition

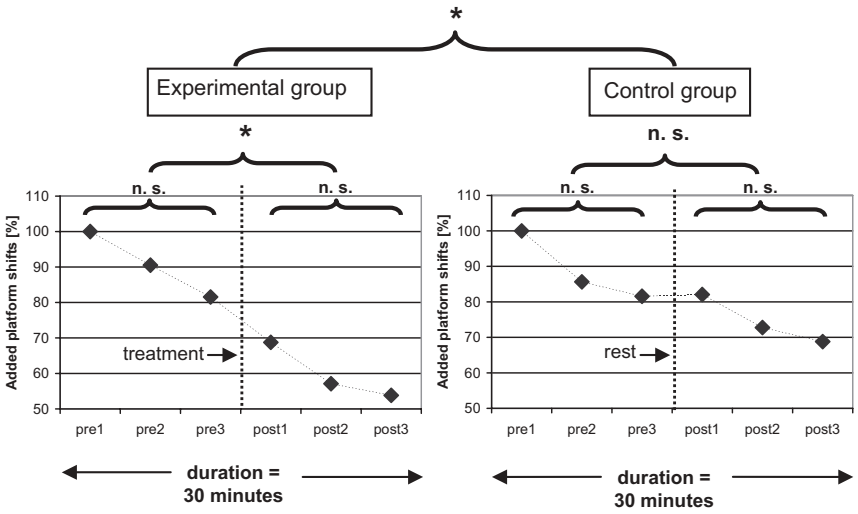

Figure 3. Results of platform displacements in *tandem stance*.

I (narrow standing) the result of group differences failed to achieve the level of significance, but in condition II (tandem standing) positive effects on postural control were assessed.

Effects of Vibration Treatment on Motor Control and Proprioception

Human response to vibration depends strongly on amplitude and frequency, and moreover, on the characteristics of stimuli—e.g., whole-body vibration vs. local vibration applied to a single muscle, and sinusoidal vs. random vibration loads (Griffin 1996; Haas 2002; Haas et al. 2004a). A couple of studies showed that the type of muscular activation depends on vibration parameters, duration of the treatment, and the transfer position. Therefore, vibration stimuli lead to a wide variety of effects on motor control (review article by Haas et al. 2004a).

Since the work of Matthews (1966) as well as Hagbarth and Eklund (1966) it is well known that vibration applied to the muscular-tendon system can elicit reflex muscle contractions. Several studies have found that vibration treatments are able to stimulate the neuromuscular system and improve performance in both strength and power (Bosco, Cardinale, and Tsarpel 1999; Bosco, Iacovelli, Tsarpela, et al. 2000; Delecluse, Roelants, and Verscheuren 2003; Isurrin, Lieberman, and Tenebaum 1994). It has been hypothesised that these findings are based on increased neuromuscular efficiency. According to these results it is assumed that the treatment

modifies neuromuscular coordination spontaneously. Improved afferent and efferent interaction resulting in an optimized coordination of ballistic movements could be responsible for the evaluated results. As a consequence, rWBV improves Parkinson patients' inability to shape muscle responses for changes in postural stability (Dimitrova et al. 2004).

There are two different physiological aspects to be considered: On one hand, corrective torque could be generated quicker to resist the destabilizing displacements of the platform. On the other hand, we hypothesised a reduction of inadequate overproduction of corrective torque since it is known that stretch reflexes are pathologically enhanced in PD patients (Cody, MacDermott, Matthews, et al. 1986; Rickards and Cody 1997). It has been speculated that the overproduction of corrective torque is an underappreciated cause of postural instability (Peterka and Loughlin 2004). Furthermore, in PD abnormal patterns of postural control including excessive antagonist activity were observed (Horak et al. 1992). We assume that the antagonist activity is reduced due to optimized coordination of muscle synergies. We suggest that subjects of our E group, however, were able to activate their leg muscles in a more appropriate and efficient way to maintain balance on the instable platform.

As an increased body sway is associated with poor tactile sensitivity and poor joint position sense in PD (Lord, Clark, and Webster 1991), some suggest that improvements in postural control can be regarded as an optimized ability in proprioception. An efficient sensitivity of muscle spindles and the proper use of kinaesthetic information play an important role in postural control, as the corrective torque is generated through a feedback control system (Peterka 2002). The CNS needs precise information about joint positions to modify movements and reflex activity. In conclusion, it has been hypothesised that the treatment leads to altered sensitivity of muscle spindles via gamma motoneurones. But Ashton-Miller and colleagues (2001) doubt if proprioception really can be improved by exercise. The question is whether better results in balance performance are related to improved efferent motor function exclusively or to optimized proprioception as well. Studies of our own support the idea that proprioceptive feedback is not affected by vibration treatment (Haas, Turbanski, and Schimidtbleicher 2005). Maybe the effect is not a higher sensitivity of muscle spindles but an optimized information selection that leads to optimized postural control.

Besides the effects on the peripheral level, modifications of cortical or subcortical functions can be taken into consideration as well. In PD several brain areas are pathologically activated that might influence peripheral actions like alpha-gamma coactivation. With respect to the supplementary motor area (SMA), a recent study analyzed the brain activation effects of sinus waves and random oscillations (Nelson, Staines, and McIlroy

2004). It was shown that the random stimuli lead to greater activation in the SMA than did sinus oscillations. It is well described that SMA is important for generation and control of complex movements. Apart from SMA functions, Nelson and colleagues (2004) showed that an unpredictable treatment leads to activations of prefrontal areas. On one hand these structures are known to be important for new learning or nonroutine decisions, on the other hand they are less active in PD, which may explain learning and information selection deficits in PD (Rowe, Stephan, Friston, et al. 2002; Sabatini, Boulanoaur, Fabre, et al. 2000). In addition modification of brain activation could result from rWBV applied in this study. It is unclear to what extent, however, SMA activation generated during the treatment can affect postural control spontaneously.

Apart from neuromuscular control, it is evident that vibratory stimuli can modify a wide variety of physiological functions, e.g., changes in hormone concentrations or neurotransmitter releases (Bosco et al. 2000; McCall, Grindeland, Roy, et al. 2000; Nakumara, Moroji, Nagase, et al. 1994;). It is feasible that postural control could be affected by neurotransmitter concentrations, which might play an important role in modification of balance control.

Influence of Parkinsonian Symptoms on Postural Control

Changes in muscle stiffness in PD are to be taken into account as well to explain our results (Dietz, Berger, and Hostmann 1988). In contrast to age-matched controls, a larger coactivation in postural muscles is reported in PD (Dimitrova et al. 2004). This muscle stiffness impairs balance control and rapid reactions to postural disturbances. A recent study of ours shows that treatment with random whole-body has beneficial effects on rigidity in Parkinsonian subjects (Haas et al. 2004a). As a consequence, we theorise that a reduction in rigidity and muscle stiffness, respectively, is responsible for improved postural stability as well (Bartolic, Pirtosek, Rozman, et al. 2005).

A special feature in Parkinsonism is the fact that a simultaneous execution of a cognitive or motor task induced a significant worsening of PI (Marchese et al. 2003; Morris, Iansek, Smithson, et al. 2000). Hence, a shift of attention to the test situation could affect our results. All subjects perform some trials on the instable platform to become familiar with testing conditions before the evaluation begins. There are obviously still habituation effects to be considered, however, in analysing pre-and post-differences (see Figure 3). This phenomenon is explained by the patient's adaptation to the experimental set up. But the significant difference between post-tests of the intervention group and the control group in *tandem standing* show that there are treatment effects involved in the improvements in postural

control. Furthermore, there is neither a significant improvement within the pre-tests nor within the post-tests.

Effects Depend on Test Situation

Due to different results in both tests (s*teady standing* and *tandem stance*), the study at hand shows that the evaluated effects depend not only on the vibration characteristics but also on the test condition. This observation is consistent with the results of Martin and Park (1997), who show that effects of vibration depend on tested motor task and muscle considered.

There is clearly a difference in treatment effects between groups E and C, which becomes obvious in the post-test data in condition I (narrow standing) as well (Figure 2). The level of significance, however, failed. Due to this finding we theorise that the motor task of narrow standing is not sensitive enough to examine treatment effects.

In several studies postural control is examined by the centre of pressure (COP) in a static condition; that is, the platform is not movable and there are no disturbances during standing. It is evident that different results can be expected then. But there is still a lack of comparisons of static and dynamic test conditions in evaluation of postural control in PD.

Placebo Effects

In a couple of studies it was found that placebo treatments can have a strong influence on PD symptoms (De la Fuente-Fernandez, Ruth, Sossi, et al. 2000; Goetz, Leurgans, Raman, et al. 2000). Thus the influence of placebo effects cannot be excluded. But it is unlikely that the effects of our study are totally placebo associated. Goetz and coworkers (2000) analysed placebo-associated symptom changes in early PD. Improvements occurred in all clinical domains, but the effects were not evident in postural control. In contrast to these findings, the study at hand shows significant improvements in postural control. The literature shows no comparable effect in postural control either as a result of placebo treatments or of medication (see Introduction).

CONCLUSION

Due to the fact that medication fails to improve postural balance in PD, development of nonpharmacological therapeutic approaches is warranted to compensate for postural instabilities and to minimize their sequel (Jöbges, Heuschkel, Pretzel, et al. 2004). The treatment of rWBV may help to maintain postural stability and in turn also may enable a physically active way of life. This is an important goal in therapy, as mobility

impairment is the major risk factor of falls (Graafmans, Ooms, Hofstee, et al. 1996).

Based on the results of this study one can speculate about an additional device in physical therapy, for PD patients. Random whole-body vibration could be seen as one part in a "multiple-risk-factor intervention strategy" (Tinetti et al. 1994). This study focussed on spontaneous treatment effects. Future research needs to evaluate long term training adaptations, too. But it is difficult to speculate about long term effects since WBV training as well as medication have an influence on symptoms and PD is characterised by a high heterogeneity in progression.

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