Proprioceptive and sensorimotor performance in Parkinson's disease

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Abstract:

We explored the effects of random whole-body-vibration on leg proprioception in Parkinson's disease. In earlier studies it was found that this treatment leads to improved postural control in these patients. Thus, one could speculate that these effects result from modified proprioceptive capabilities. Twenty-eight Parkinson's disease patients were subdivided in one experimental and one control group. Proprioceptive performance was analyzed using a tracking task basing on knee extension and flexion movements. Treatment consisted of 5 series of random whole-body-vibration taking 60 seconds each. Control subjects had a rest period instead.

Prominent over- and undershooting-errors were found in both groups representing proprioceptive impairments. However, no significant differences became evident neither between pre- and post-tests nor between experimental and control group. One might therefore conclude that spontaneous improvements in postural control are not directly connected with proprioceptive changes. Nevertheless, one should also keep the mind on general aspects and difficulties of analyzing proprioception.

Keywords: Proprioception, Parkinson's disease, postural control

1 Introduction

Disturbances of postural control are prevalent in several nerval diseases and injuries. Due to strong influences of postural control on movement safety, mobility, independence and essential everyday jobs, patients' quality of life is often sustainably impaired. Especially in Parkinson's disease (PD) postural disturbances are regarded as a hallmark and connected with the risk of falling and fall related injuries (e.g. Ashburn et al. 2001; Bennet et al. 1996, Bloem et al. 2001, Ebersbach et al. 2002, Koller et al. 1989; Smithson et al. 1998). As impaired proprioceptive capabilities were also reported in PD, one can speculate about a functional connection. Thus, Rickards and Cody (1997) and Khudados et al. (1999) showed significantly impaired proprioception compared to age matched controls. Rickards and Cody (1997) used high frequent muscle-vibration stimuli (flexor carpi radialis) to analyze proprioceptive capabilities while performing a simple tracking test (wrist-extension movements). In healthy subjects these stimuli generate artificial activations of muscle spindles which lead to kinaesthetic illusions and tracking errors (e.g. Cordo et al. 1995, Kasai et al. 1992, Naito et al. 2002, Haas et al. 2004d for review). By contrast these errors were reduced in PD patients indicating less muscle spindle afferences.

Furthermore the authors report stronger proprioceptive impairments at the more pathologically affected limb of PD patients.

In contrast to the artificial effects known from high frequent muscle-vibration, we showed in earlier experiments that low frequent random mechanical stimuli can reduce PD motor symptoms (Haas et al. 2006, Haas et al. 2003, Haas et al. 2004a, Schmidtbleicher et al. 2005). Especially significant postural control improvements were found in biomechanical analyses (Turbanski et al. 2005, Haas et al. 2004b, Haas et al. 2004c). Schuhfried and co-authors (2005) found similar effects in Multiple Sclerosis patients, using a comparable low frequent random vibration treatment. Referring to these results the aim of this explorative study at hand was to analyze the effects of low frequent random whole-body-vibration on proprioceptive capabilities which might explain postural control improvements.

2 Materials and Methods

Experimental setup: In order to identify the effects of mechanical stimulations on proprioceptive capabilities in PD the study is based on an explorative short term control group design.

Subjects: Twenty-eight subjects diagnosed with idiopathic Parkinson's disease participated in the study. All patients were in stationary care during the experiment. Diagnosis of PD was established by a neurologist of a specialized Parkinson's disease hospital. Patients with dementia, cerebellar signs, abnormal brain imaging or fundamental comorbidities like neuropathy, muscle or joint diseases etc. were not admitted to the study. With respect to reliability of biomechanical measurements patients with dyskinesias, sustainable leg or postural tremor and strong asymmetrical symptom structure (i.e. symptoms detectable exclusively on one side) were not included furthermore. The average patients' age was 63.1 (+/-7.3) years. The Parkinson severity referring to the Hoehn & Yahr stage reached from II to IV. All patients were treated and analyzed in the "on" stage, i.e. taking their normal antiparkinsonian medication (357mg (+/-139) L-DOPA / day). Subjects were quasi-randomly subdivided in one experimental group (19 subjects) and one control group (9 subjects) and the two groups were matched for disease severity.

Treatment: Members of experimental group were treated between proprioception pre- and post-tests with 5 series of random whole-body-vibration (average frequency 6 Hz +/-1 Hz) taking 60 seconds each. Rest time between each series was 60 seconds, too. The treatment was applied using a srt-medical® system (human mobility, Germany). In earlier studies we found that this treatment leads to sustainable and significant postural control improvements. Further details of the treatment are described elsewhere (Haas et al. 2004a, Haas et al. 2004b, Haas et al. 2006, Turbanski et al. 2005). Patients of control group had a rest phase instead, lasting 15 minutes.

Measurements: With respect to earlier proprioceptive analyses we decided to measure proprioceptive performance at the knee joint. This decision is explainable on one hand by new reports that emphasize also proximal joints and muscles to influence postural control (Bloem et al. 2000, Allum et al. 2002). On the other hand the knee joint is more sensitive – referring to movement threshold detection - compared to the ankle joint (Goldschneider 1889, Aston-Miller et al. 2001 for review). Furthermore, limitations of motion by flexibility reasons are more unlikely in the knee joint.

A slowly oscillating target course was presented at a computer screen representing a frequency of 0.25 Hz and amplitude of +/-10°. Participants were asked to reproduce this course – while sitting on a chair - via unilateral repetitive knee extension and flexion movements (figure 1). The knee angle was measured by the use of a goniometer (Biovision) which was fixed at a knee-orthesis (DonJoy). Subjects wear this orthesis at the right extremity.

To ensure accurate proprioceptive performance and to reduce learning and habituation effects all subjects started initially with a training period taking about 25-30 minutes. While at the beginning of this training period reproduction results were viewable at the computer screen, visual feedback was continuously reduced. During testing, reproduction results were unviewable for the patients and no feedback about their success was given. Only graphic information representing the idling 0.25 Hz rhythm was presented on an additional monitor. Exteroceptive feedback was reduced to a minimum during the whole procedure. In contrast to some other experiments no motor driven reproduction task was used on one hand by validility and reliability reasons, and on the other hand to enable quantification of timing performance. Five test-series were performed pre- and post-treatment consisting of 10 extension-flexion cycles each.

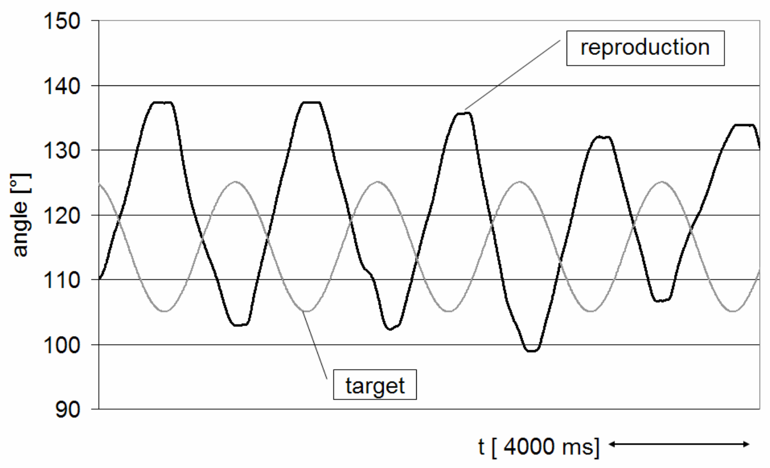


Figure 1: Target- and reproduction-course of proprioceptive testing. Patients were asked to reproduce the target course via repetitive knee-extension and -flexion movements. Reproduction results are measured with a goniometer.

The average maximum and minimum knee angles (higher and lower endpoint) of each series represent the quality of proprioception. Both endpoints were chosen as each parameter is functionally connected with muscle spindle afferents of specific muscle groups, i.e. detection of the maximum angle is primarily related to spindle afferents of knee flexors and vice versa.

Movement velocity (timing) was additionally analyzed as timing deficits are well known and in PD and bradykinesia is a key symptom.

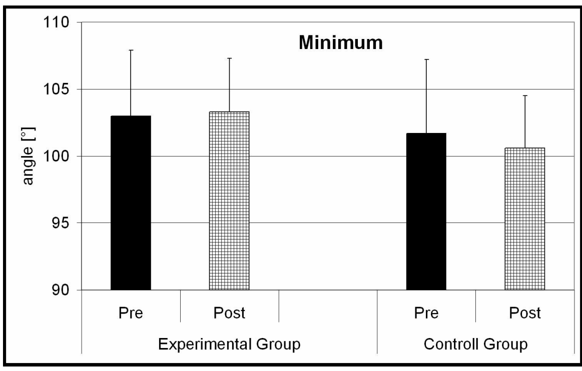
Data Analysis and Statistics: Goniometric data were amplified and sampled at 1000 Hz using a PCMCIA analog-digital converter (DAQ 250i, Ines). All recordings were proved visually for artifacts, low pass filtered at 50 Hz and saved for further data calculations.

Initially, conventional explorative statistics were used to calculate mean and SD values and to prove data distributions. In order to get information about inter-pre and inter-post test changes as well as pre-post differences two-ways ANOVAs for repeated measures were calculated for all parameters and both groups. Additionally, two-ways ANOVAs using average pre- and post-test data and Bonferroni alpha error correction were calculated for group comparisons. Alpha level for statistical significance was set at $p<0.05$ (pre correction).

3 Results

After the initial training session most patients that participated in the study were able to reproduce the target course acceptably precise. Two subjects were excluded during the training session by the reason of highly fluctuating reproduction results. Referring to the treatment, all members of the experimental group tolerated the procedure well and without reporting immediate or delayed adverse effects.

Proprioceptive data is shown in figures (2-4). It appears that both groups produced good reproduction results i.e. average deviations from the target course were low. However, high standard deviations indicate in both groups lower proprioceptive performance. Thus, numerous subjects deviated from the target about 10° and more. Putative satisfactory average data result from the phenomenon that some subjects produced overshooting errors, others undershooting. Referring to the different analyzed parameters, no clear changes or even a trend can be identified neither in minimum or maximum nor in frequency.



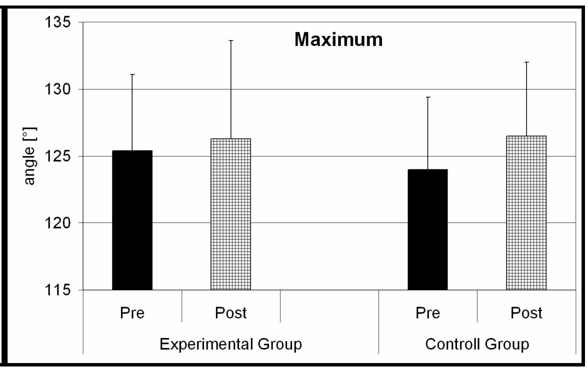


Figure 2 (left): Average minima knee angles (+/- SD) pre and post treatment. All p-values were >0.1, i.e. no significant differences and not even a trend in any comparison became evident.

Figure 3 (right): Average maxima knee angles (+/- SD) pre and post treatment. All p-values were >0.1, i.e. all statistical comparisons failed significance and no trends became evident.

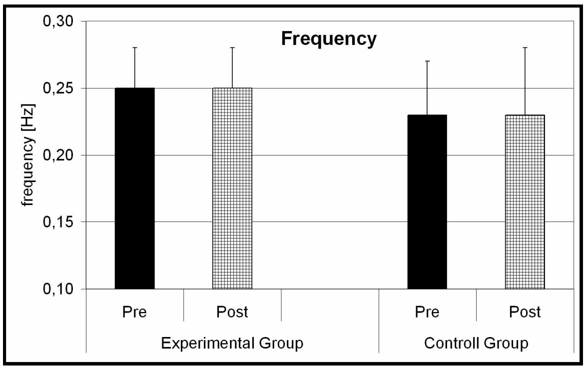


Figure 4: Average movement frequencies (+/- SD) pre and post treatment. All p-values were >0.1, i.e. no statistical significances or even trends could be identified.

Inter-pre and inter-post test analyses show variable reproduction results but no statistical significance or even a trend in any group. Furthermore, low and insignificant modifications in any parameter were found in the pre-post comparison. Thus, also group comparisons failed significance clearly. To sum up, all statistical comparisons failed significance clearly and all p-values were above 0.1 level.

4 Discussion

4.1 General considerations

In summery it became evident in earlier studies that postural control is improved in Parkinson's disease patients after short term random mechanical stimulations. In contrast, after the same treatment no changes in any proprioceptive parameter became evident in the study at hand. One might therefore draw the conclusion that the treatment has no effect on proprioceptive performances. However, it seems also important to analyze the possibilities of measuring proprioception in general. Referring to current reviews (e.g. Aston-Miller et al. 2001 "Can proprioception really be improved by exercise") the trainability of proprioception needs to be discussed (see 4.2). As within both groups a high interindividual variability in proprioceptive performance was found, potential influences of symptom structure or medication are discussed furthermore (see 4.3). With respect to the explorative character of this experiment one should also have a look at alternative neurophysiological functions that might explain treatment related postural control improvements (see 4.4). The following sub-chapters try to clarify these aspects mentioned above.

4.2 Proprioception and Training

Improving proprioceptive capabilities is regarded as an essential component of coordinative training programs. Especially in the field of rehabilitation "proprioceptive training" is regarded as a manifest (Laskowski et al. 1997). This perspective results on one hand from an inflationary use of the term "proprioception". Thus, proprioception describes originally the ability to identify joint positions and to detect movements by the use of specialized mechanoreceptors; i.e. proprioception involves afferent and possibly integrative processes but no efferent mechanisms[1] (Aston-Miller et al. 2001, Dickson 1975, Sherrington 1906/1947). On the other hand a huge amount of studies report proprioceptive impairment after traumatic joint injuries (e.g. Barrack et al. 1989, Barret 1991, Fischer-Rasmussen and Jensen 2000, Laskowski et al. 1997). Thus, it is widely assumed - in a concluding way - that motor control improvements are functionally connected with proprioceptive improvements. Some current studies question this strong connection (e.g. Aston-Miller 2001 for review, Haas et al. 2005). However, experimental data are rare which might be explainable by methodical aspects of 'measuring proprioception' (Roberts et al. 2004). In an earlier study we analyzed potential proprioceptive changes in healthy subjects using a comparable experimental setup (Haas et al. 2005). Analogically, we did not find significant changes in any parameter. Therefore, one might draw the conclusion that motor control improvements are not directly related to proprioceptive changes. However, one should also keep the mind on methodical aspects of proprioception analyses.

Beside analyses of movement threshold detection reproduction tasks are mostly used to quantify proprioceptive capabilities. By methodical reasons the later test method consists of relatively slow movements. In contrast, movement patterns in daily life as well as in sports are characterized by higher velocities. Especially rapid muscular activations are fundamentally involved in postural control, e.g. to compensate ballistic perturbations. This divergence in movement velocity is connected furthermore with activations of different receptor types. Especially muscle spindles elicitations are strongly connected with the velocity of the stimuli. Referring to the principal that 'specific training stimuli lead to specific adaptations' one could speculate that proprioceptive changes occur without becoming obvious. These potential changes might be responsible for detecting ballistic movements. By contrast, the test paradigm we used is characterized by relative slow movements. Therefore, possible proprioceptive modifications remain undetected. However, by validility and reliability reasons it seems impossible to analyze proprioception using ballistic movements. Experiments of Yasuda et al. (1999) might be interpreted analogically. The authors argue that muscle spindles – which are probably the main receptors in the tracking tasks - analyze primarily the velocity of stimuli, whereas joint and cuntaneous receptors control the endpoint of movements. Nevertheless, no significant changes became evident, neither in endpoint nor in velocity (i.e. frequency). Therefore one has to conclude that treatment related postural control improvements are not directly connected with proprioceptive changes. However, as shown above measuring proprioception is a complex procedure and therefore adaptations might never be totally excludable by methodical reasons.

[1] However, current paradigms integrate simple efferent components in order to improve test reliability and validility (Lönn et al. 1999, Quante and Hille 1999, Wilke and Froböse 2003). Anyway, proprioception does not contain complex efferent processes.

4.3 Proprioceptive performance in Parkinson's disease

Multiple studies found impaired sensory and afferent capabilities in PD patients. Though, reports about the modus of impairment (e.g. motion sensation vs. awareness of joint position vs. positioning sense) and the neurophysiological origin (e.g. peripheral vs. central disturbance) are conflicting (Demirci et al. 1997, Zia et al. 2000, Klockgether et al. 1995, Rickards and Cody, Khudados et al. 1999, Schneider et al. 1986, 1987, Lewis and Byblow 2002). Detailed analysis of our data shows a wide interindividual variability. While in some participants a high reproduction performance became evident (comparable to healthy younger subjects), in other patients worse results and high intraindividual variabilities were found. Currently it seems difficult to explain these performance differences by a single and specific physiological or pathological parameter. As proprioceptive disturbance can be identified in multiple basalganglia dysfunction diseases (e.g. Dystonia or Huntington's disease), one could speculate that proprioceptive performance is based on different stages of basalganglia impairment (Seiss et al. 2002). Thus, most patients in the study at hand showed worse reproduction results compared to healthy subjects. However, within the patients we did not identify that proprioceptive performance correlates with disease stage. Another explanation for subjects' interindividual performance variability refers to the influence of medication. There are strong evidences that L-dopa can impair positioning sense of PD patients (Moore 1987, Klockgether et al. 1995, Zia et al. 2000). As it was only possible to test in the "on" phase and L-Dopa is known to produce variable motor reactions, positioning sense might be affected differently and variable proprioceptive performances result.

Furthermore one can speculate about undetected comorbidities (e.g. neuropathy) influencing proprioceptive performance. However, Rickards and Cody (1997) found worse proprioceptive capabilities on the more affected side in PD. Analogically Moore (1987) showed proprioceptive deficits in patients with asymmetrical PD disease. Patients overestimated movement amplitude on the affected side. Thus, it is unlikely that results can be explained by neuropathy or comparable comorbidities.

With respect to central vs. peripheral reasons for proprioceptive disturbances Rickards and Cody (1997) postulate that no evidences exist for a defect of muscle spindle sensitivity or discharge. By contrast, they argue that proprioceptive disturbances result from defective integrations of afferent signals. Under physiological conditions it is believed that basalganglia receive extensive sensory input and integrate these signals for organization of motor output. Especially Ia- afferents seem to have strong modulatory influence on cortical and subcortical activation pattern (Lewis et al. 2001). Animal studies provide further evidences for this peripheral-central interaction. In MPTP (1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine) treated animals an abnormal activity of globus pallidus neurons were found when passive limb movements were applied (Filion et al. 1988). Reduced selectivity of pallidal neurons might also result from pathologically low sensory signal amplifications (De Long et al. 1985, Filion et al. 1988, 1991). However, impaired ability of afferent signal amplification might not explain motor control completely. It is evident that spatial control of movements is updated due to the action of peripheral inputs; coevally movement control varies strongly depending on velocity pattern. Thus, Seiss and co-authors (2002) found a connection between neural pathology and varying time spans. While early proprioception related potentials (90 ms) were normal in PD, longer latency (170 ms) was affected which indicates different processing levels. The authors argue that early proprioceptive signals bypass basalganglia level during integration whereby they remain unaffected. These different levels of signal processing - unaffected vs. affected - might explain that the treatment leads to improved postural control whereas proprioception keeps unchanged.

4.4 Motor control and training in Parkinson's disease

It is widely known that the basalganglia are involved in motor control and motor learning respectively, which explains motor disturbances of PD to a large extent. However, as mentioned above not all components of motor control are impaired in PD patients. There are multiple evidences that the degree of motor impairment depends on cortical processing loads and task complexity. The higher the processing loads and the motor control complexity, the more PD patients are unable to perform adequately. Especially high disabilities can be identified when movements are based on voluntary initiation and during double tasks when parallel processing is necessary (Choi et al. 2005, Chong et al. 2000, Jahanashahi et al. 1995 Jahanashahi and Frith 1998). Furthermore deficits become evident in PD when new timing is introduced (Jackson et al. 1995, Sommer et al. 1999). With respect to this, proprioceptive deficits are explainable since the test paradigm is based on a voluntary movement initiation and it implies a new timing task. In contrast simple motor tasks, automatic motor behavior and simple motor learning are known to be unimpaired or impaired to a lower extent in PD. As postural control is a reflexive and automatised motor behavior and cortical processing loads are relative low (at least during the initial correction phase ≈100 - 200 ms, Quant et al. 2004, Norrie et al. 2002, Rankin et al. 2000) learning and adaptation potentials seem higher. One can speculate that the patients are trained during the treatment to keep up balance and they might be able to transfer these training effects to the postural control tests. The ability of keeping up balance during the treatment might be enabled or supported since it contains strong external cues and it is shown frequently that performance of externally cued movements is high in PD (Choi et al. 2005). Furthermore the type of stimulation is characterized by a coherent signal as well as random and stochastic interferences. These noisy interferences are known to improve signal detection and information processing task-specifically and thereby postural control processes are optimized (Wells et al. 2004, Ward et al. 2002, Stacey and Durand 2000, Manjarrez et al. 2003, Fallon et al. 2004).

In summary the study at hand did not identify changes in proprioceptive performance after short term mechanical training stimuli that reduce PD symptoms and especially postural control disturbances. With respect to general difficulties of measuring proprioception one can not exclude proprioceptive changes, totally. However, no evidences or even trends for proprioceptive changes became evident which lead to the conclusion that one should avoid to stress the term "proprioceptive training".

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