# Vibration Training in Rehabilitation

**D Schmidtbleicher, CT Haas, S Turbanski**

Voluntary muscular activation is disturbed in both neurological disorders and orthopaedic injuries. Methods that enable bypassing this activation circle are of fundamental importance in order to set functional training stimuli. Besides electrical stimulation and robot supported gait the application of vibration has become an alternative and complemental treatment method in rehabilitation. The most findings of physiological and motor control effects of vibratory stimuli result from studies in sport science and basic neurophysiological research. Transferring the effects found in healthy subjects to the different areas of application in rehabilitation seems not possible in a linear way. This paper summarizes the different findings and discusses transfer possibilities and problems.

Key Words: rehabilitation, vibration, neurothrophic factors, SMA

## 1 REQUIREMENTS IN REHABILITATION

Compared to other fields in medicine rehabilitation is a young discipline which has dynamically developed in the last two decades. Today rehabilitation is characterised by multidisciplinary approaches and a huge variety of contents and treatment strategies. In earlier times patients with orthopaedic lesions - like ruptures, fractures and lower back pain - were the main treatment clients and a small amount of physiotherapeutic techniques was used. Continuously the focus of rehabilitation has extended and with it there is increased need to develop new treatment methods and to complement traditional.

Efficient rehabilitation of patients with relatively complex impairment patterns like stroke, spinal cord injury (SCI), brain-trauma (PT), Parkinson’s disease (PD) requires support of medical high-tech equipment. A very popular and successful method is used about 10 years in rehabilitation of SCI patients. A couple of studies showed that restoring locomotion abilities can be achieved in incomplete SCI patients using treadmill training (Dietz et al. 1995, Wernig et al. 1995, 1998 Edgerton et al. 2001). The guiding idea resulted from animal experiments (De Leon et al. 1999). It was found that spinalized rats can use their hindlimbs on treadmill. Rhythmic behaviour of forelimbs triggers and activates spinal-neural-networks (CPG, central-pattern-generator) that are strongly important for generating rhythmic muscular activation. In humans it was found that even involuntary stepping movements generated by a physiotherapist can activate these CPG (Dietz et al. 1995, Wernig et al. 1995, 1998 Edgerton et al. 2001, De Leon et al. 1999). Since a repetitive and continuous CPG stimulation is necessary to enable a better patient outcome, which is difficult to realize by physiotherapists over a long time, a robot systems that generates and controls patients' leg movements was developed. In several experiments it could be shown that this technical support is successfully related to restoring gait functionality (Colombo et al. 2001).

With respect to the financial situation in the medical healthcare area it seems important that technical equipment is multiple usable and thus enable treatment of huge amount of disturbances. At first it seems difficult to realise this as the aims of each single rehabilitation program vary strongly. In neurodegenerative disorders keeping the status quo or diminishing disease progression are primary topics. After brain-trauma, stroke or spinal cord injury relearning purposeful movements and restoring locomotion abilities are of crucial importance. Reducing the risk of falls and avoiding nursing at home are further aims of rehabilitation. Even if these aims and the pathological structure of the different injuries and diseases vary strongly a lack of muscular contractibility and strength can be identified as key element. In some injuries this impairment results from nerval disconnection and paresis. In others an active inhibition occurs, e.g. in patients suffering an ACL rupture (anterior cruciate ligament) reduction of strength is disproportionate higher than muscular atrophy (Urbach et al. 2000). The authors hypothesize that this phenomenon results from an injury related nerval plasticity leading to inhibition in supraspinal areas. The main consequence of these nerval disturbances is an impaired contractibility which leads in a further step to reduced training stimuli and training effects. One possibility to solve this problem is to bypass voluntary muscular activation circles. Besides the use of robot supported locomotion electrical stimulation has been proved to generate involuntary contractions and thereby improve rehabilitation progress. Since it is known that applying vibration to muscular-tendon system can elicit a reflex muscle contraction, therapists began to use this bypassing method in rehabilitation around one decade ago. Anyway amount of rehabilitation related studies is limited.

## 2 BYPASSING VOLUNTARY MUSCULAR ACTIVATION VIA VIBRATORY STIMULATION

In the mid 1960s Matthews (1966) as well as Hagbarth and Eklund (1966) showed in animal and human experiments that a reflex muscle contraction can result as a consequence of applying vibrations to the muscular-tendon system. The physiological background of this phenomenon - mostly known as tonic-vibration-reflex (TVR) - is a stimulation of muscle spindles which generates a monosynaptic reflex. Even if a couple of studies showed that other sensor types like golgi-organs and cutaneous receptors are sensitive for vibratory stimuli as well spindle function is mostly cited.

Besides basic neurophysiological experiments the effects of vibration were primarily analysed in applied exercise physiology and sports science. The guiding idea was to generate involuntary muscular activation and thereby improve performance in strength and power. On average the studies showed inhomogeneous results reaching from slightly negative effects in neuromuscular performance to strong improvement of voluntary contractibility and maximum strength (for review Haas et al. 2004a).

Bosco et al. (1999, 2000) found that a 10-minutes vibration training leads to spontaneous increase of average mechanical power of 8%. Delecluse et al. (2003) and Isurrin and co-workers (1994) report similar results. Mostly it is argued that these improvements in strength result from a Ia-stimulation related increased afferent set that in turn enhances also efferent output and firing rate. Other studies promote about the release of growth hormones and testosterone which might support muscular hypertrophy.

In contrast to these findings Bongiovanni et al. (1990) report that a vibration of 150 Hz reduces dorsiflexion maximal voluntary contraction (MVC) which was connected with reduced EMG activity. Kouzaki and Co-workers (2000) showed that prolonged 30 Hz muscle vibration reduces strength of isometric knee extension. Findings of Samuelson et al. (1989) Jordan et al. (2003) de Ruiter et al. (2003) are comparable. Authors of these experiments argue that inhibitory Ib-signals - as a consequence of golgi-tendon activation - reduce contractibility (Jackson & Turner 2003). Further more Hultborn et al. (1987a, b) speculate about presynaptic inhibition of Ia-afferent terminals.

The huge variety of results might be explainable by the fact that vibratory stimuli act generally on multiple physiological levels which leads to a non linear cause-result function. Anyway the findings cited above are only transferable to patients to a limited extent since they present different physiological bases.

Several studies deal with effects of vibration on coordination and on motor control. The background of these experiments is based on the fact that vibration transfers not only energy but information as well which influence motor control. Verschueren and co-workers (1999a, 1999b) as well as Kasai et al. (1992) proved the influence of vibration using tracking tests. Depending on the vibrated muscle strong coordinative deficits were found. In upright stance vibration stimuli led to involuntary anterior-posterior whole-body sways (Ivanenko et al. 2000a, b, Kavounoudias et al. 1998, 1999). The authors argue that this phenomenon – called kinaesthetic illusion – results from a misinterpretation of the vibratory stimulus. In contrast to these results found in healthy subjects vibrations seem to have a lower impact on coordination in Parkinson's disease patients. Rickards and Cody (1997) and Khudados et al. (1999) showed significant lower impacts of vibrations in PD patients compared to age matched controls. It is hypothesised that differences appear by the reason of a pathologically modified proprioception in PD. These differences between healthy subjects and PD might lead to the conclusion that vibrations have lower influences in patients therefore being an ineffective treatment. But a couple of studies as well as patients' experiences show that the opposite is true.

## 3 THERAPEUTIC EFFECTS OF VIBRATIONS IN PARKINSON'S DISEASE

Numerous PD patients have reported that symptoms are markedly reduced in vibratory situations e.g. train travelling. Some patients expose themselves voluntary to vibratory situation, thus it is reported that a farmer goes every morning for a spin with his tractor in order to reduce symptoms

(Rafael 2004). Further more one of the leading neurologists of the 19th century – Jean Martin Charcot – noticed that vibration is an effective treatment for PD subjects. In order to use vibrations in a therapeutic way he developed a vibration chair – a “chaise trépidante”.

Modern studies support the idea that vibration improves motor symptoms of PD patients as well. Jöbges et al. (2002) found an acute reduction of tremor using local muscle vibration. Even if effects were heterogeneous and the specific mechanisms are not totally understood the authors speculate about some fundamental and interesting principals. Thus brief mechanical perturbations might generate a reset of hypersynchronized nerval rhythm – possibly by changing supraspinal activation circles – which generates tremor dynamics. In several own studies motor control effects of random whole-body-vibration were analysed. Haas et al. (2004b) proved post effects of 5 series of WBV on UPDRS motor score (Unified Parkinson’s disease rating scale) using a controlled and blind folded cross over design. On average symptom improvements of 15.8% were found. Referring to the different symptoms changes of 25% and 24% became evident in tremor and rigidity, but no improvements were found in speech or facial expression. Since a marked connection between the treatment and postural control could be recognized extensive biomechanical analyses were performed in a further step (Haas et al. 2004c, d, Turbanski et al. 2005). Getting valid and reliable data about the effects of vibration on postural control is important by several reasons:

Firstly postural disturbance is a hallmark of idiopathic Parkinson’s disease, especially in the late and most advanced stages of the disease (Bloem et al. 1998, Marchese et al. 2003). Since impaired postural control is often connected with falls and related injuries – risk of falling is approximately twice in PD compared to that of healthy older – patients reduce their daily amount of motion which influences social and psychological aspects and strongly impairs quality of life. Secondly there are good evidences that dopaminergic medication fails to improve postural disturbances and thirdly long-term data of the clinical observations show that the frequently used retropulsion test cannot be regarded as a good predictor of falls and further more it lacks normative data (Wood et al. 2002, Bloem et al. 1998, Marchese et al. 2001, 2003, Jankovic 2002, Mauer et al. 2003).

Using a 2-D moveable platform in own studies it was found that 5 series of random WBV (average frequency 6 Hz) improve postural control significantly. Generally the effects are characterised by a complex structure. Some patients show hardly any effect others improved up to 40 %. Turbanski et al. (2005) showed that effects are related to the test position while in other experiments the influence of medication and impairment degree became evident. Thus highly impaired subjects and patients in the off stage showed better adaptations. Taken all results together a significant beneficial effect can be postulated even if of influences of placebo can not be excluded totally (Haas et al. 2004 b).

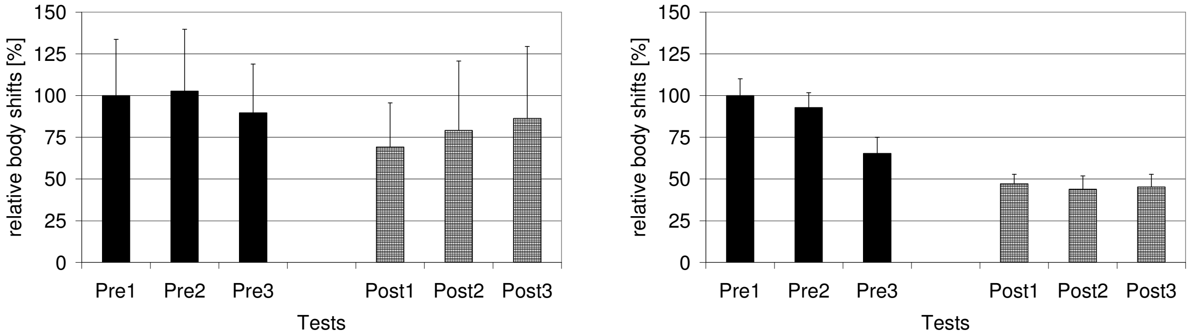


Figure 1: Changes of body sway after 5 treatment series of random whole-body-vibration. Left figure shows results of lowly impaired patients whether right figure presents sway changes of patients with strong postural disturbances.

However, since effects are not limited to motor functions of the legs – which might be explainable by changes in the peripheral nerval system – one has to find further explanations. With respect to the dopamine deficit of PD patients one can speculate that vibrations influence this neurotransmitter system. In some animal studies it was found that vibrations can principally modulate neurotransmitter release in different brain areas but it was also shown that the stimuli-release function is highly nonlinear and strongly connected with duration of the treatment and several vibration parameters (Ariizumi et al. 1983, Ariizumi & Okada 1985). Comparable nonlinear biochemical effects are described in a study of McCall and co-workers (2000). Whether muscle vibration of m. tibialis anterior increase BGH concentration of about 94% vibration of the antagonist leads to 22% reduction.

Referring to studies of Schulz and co-workers (1997, 1998) one can further hypothesize about a connection between the type of vibration and dopamine release. In a couple of animal experiments he showed that release function of dopamine depend on the predictability of a stimulus. Thus unpredictable and novel situations lead to phasic dopamine releases. By the reason of random vibrations we used in the studies cited above lowly predictable stimuli are given which might result in enhanced dopamine releases. Referring to basic functions of the dopamine system – e.g. reinforcement and motor learning – one can speculate in a further step that these short-term biochemical effects can reset pathologically activated brain circuits. However further studies are necessary to prove this hypothesis.

Referring to further findings of basic neurophysiological analyses on one hand and neuropathology of PD on the other hand one can speculate from a different perspective about beneficial effects of vibrations. Thus it is well described that the supplementary motor area (SMA) as well as prefrontal areas are less activated in PD compared to healthy subjects (Playford et al. 1992, Jahanshahi et al. 1995, Catalan 1999 et al.). However, the degree of pathological activation depends on the motor task. In contrast to a free selection of movement initiation external cues lead to less or no differences in SMA activation between PD and healthy subjects. Accordingly vibration treatments provide external cues and therefore might normalizes SMA activation. Based on the results of other training experiments similar explanations can be found. The authors argue that gait training using a treadmill provides external cues and thereby internal cueing problems of PD patients are compensated and motor control is improved (Toledo-Frankel et al. 2004, Capato et al. 2004). Since there are good evidences that SMA is important for generating complex movements – which are impaired in PD - a recent study compared brain activation effects of sinus waves with random oscillations. Both stimuli increased SMA activation, but random oscillation led to significantly higher activations. This is consistent with other experiments which show that random practice is superior to continuous training stimuli especially in later learning phases.

Apart from SMA functions Nelson and colleagues (2004) showed that an unpredictable treatment leads to relatively strong activations of prefrontal areas. On one hand these structures are known to be important for new learning or non routine decision and on the other hand they are less active in PD which may explain learning and information selection deficits. However, it is unclear to which extent SMA activation generated during the treatment can influence post treatment motor control.

The effects presented above might also have beneficial effects in other nerval and psychiatric disorders. On the basis of studies with stroke and MS patients researchers found that a high activation in frontal areas promotes neuroplasticity in the cerebellum which is connected with a better motor outcome. Furthermore there are some evidences that depressive patients show also reduced activation in prefrontal areas as well as deficits in dopamine release. Explorative clinical observations confirm this hypothesis, so tendencies became evident that random vibration stimuli have therapeutic influences on depression.

## 4 VIBRATION IN SPINAL CORD INJURY REHABILITATION

Most knowledge about reorganisation processes in the spinal cord after injury results from human and animal locomotion studies. However, even if training effects are well described nerval adaptations are not well understood. Mostly it is argued that external mechanical stimuli activate spinal CPG. Since vibrations can activate peripheral sensors and neural networks the effects in rehabilitation of SCI patients were proved in a few studies. Gurfinkel and co-workers (1998) applied vibrations (20-60 Hz) directly on different leg muscles (e.g. m. quadriceps, m. biceps femoris, m. triceps surae). Continuous stimulation resulted in quasi-rhythmic locomotor-like stepping movements.

In own studies the effects of weight supported WBV were analysed in different experiments (Haas et al. 2004e, f). Electromyographic single case analyses showed that the stimuli led to repetitive quasi-rhythmic extension-flexion movements in the knee joint. Each movement cycle was connected with a reflex muscle contraction of m. rectus remoris (figure 2). After 6 treatment series each 120 seconds in some patients repetitive activations of different leg muscles was observed which was connected with strong involuntary leg movements. With respect to other evidences we hypothesize that this phenomenon is a result of CPG stimulation which might help to restore locomotion abilities.

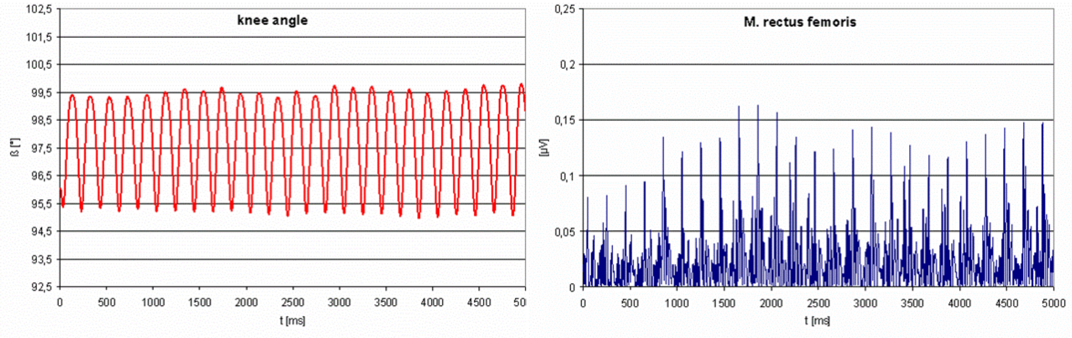


Figure 2: Changes of knee angle and related reflex muscle contraction (EMG) during weight supported vibratory stimulation of an incomplete spinal-cord-injury patient.

This hypothesis was proved in a long-term group comparison basing on a total of 40 incomplete SCI patients. While the control group was treated with traditional methods including locomotion treadmill therapy patients of experimental group were additionally treated daily with 5 to 10 series of WBV. Data analysis show clear and statistically significant advantages in gait performance in the treatment group. Comparable group differences were found in balance tests. One can therefore conclude that vibration training is a successful device to improve quality of SCI rehabilitation.

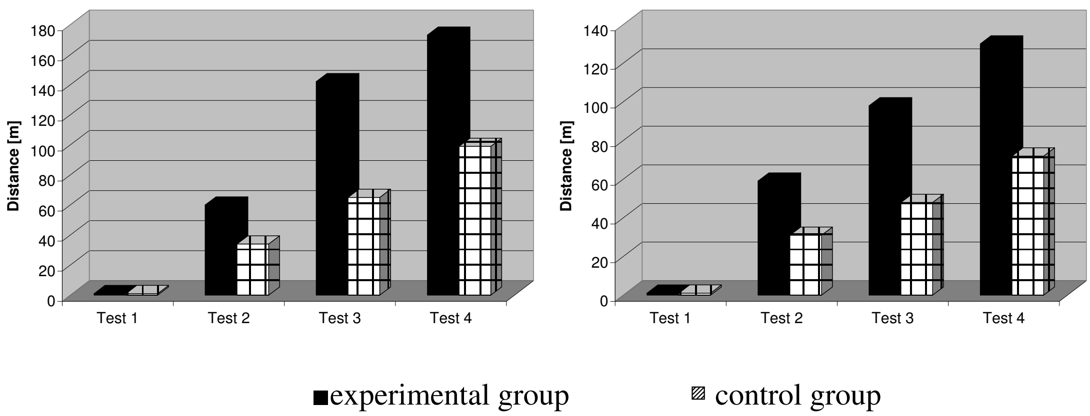


Figure 3: Results of gait tests during rehabilitation process of SCI patients. Left figure shows paraplegic patients, right presents tetraplegic patients. In both impairment groups it was found that patients who were additionally treated with random WBV show significantly better locomotion capacities at each test. All patients were asked in tests to walk unsupported as fast as possible. The bars represent the average walking distance after 120 seconds.

## 5 NEUROPLASTICITY AND NEUROTROPHIC FACTORS

Neurological rehabilitation is generally related to connectivity and plasticity of neural networks. It is known from basic analyses that these processes depend on neurotrophic factors (NTF). Some recent studies found that NTF release can be influenced by exercise. Most researchers believe that a stimulation of NTF release increases nerve growth potential and thereby accelerates rehabilitation in neuro-trauma. Further more exercise experiments with PD animal models present good evidences that well dosed exercise protects nerve cells, ensures survival of the dopamine system and reduces occurrence of PD motor symptoms (Cohen et al. 2003, Tillerson et al. 2002, Chaen et al. 2002). This functionality might be important not only in PD but also in other neurodegenerative disorders like PD, MS or motor neuron disease. Bringing all facts together it is obvious that fast and repetitive stimulations of muscle spindles generate NTF release in the peripheral nerval system as well as in the CNS. Thus swimming or standing have a low influence on NTF whether running leads to higher NTF releases. Since vibration applications are known to stimulate muscle spindles one can speculate that this treatment promotes NTF release. However, vibration training should be limited to a few and short training sessions since cardiovascular stress is a contradictor for an effective use of neurotrophic factors (Gosselink et al 2004, Hutchinson et al. 2004).

## 6 CONCLUSIONS

Impairment patterns of neurological patients are mostly characterised by a combination of physical, cognitive and behavioural components. Effective rehabilitation should take this complex structure into account. In consequence modern rehabilitation involves multidisciplinary approaches. Vibration training is an effective method specially to bypass impaired muscular activation and thereby enables setting of training stimuli, neuromuscular adaptation and improvement of contractibility and strength. However, most knowledge results from studies using healthy subjects. Further studies using patients are necessary since a simple transfer of results is complicated and could promote wrong conclusions.

More over one should pay attention to the complexity of physiological changes generated by vibratory stimulation. In the early rehabilitation phases simple vibration related muscular activation might be suitable, but in later phases variability of vibration treatment becomes strongly important since variable stimulation promotes plasticity and connectivity of neural networks. Further artificial sensory stimulations which generate kinaesthetic illusion should be avoided in later rehabilitation phases in order to avoid neural adaptation and sensory integration of artificial information. In summary vibratory stimulations have potential to improve rehabilitation and thereby increase motor control abilities in several diseases and injuries.

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