

The effect of weightbearing exercise with low frequency, whole body vibration on lumbosacral proprioception: A pilot study on normal subjects

Tania L Fontana, Carolyn A Richardson and Warren R Stanton

School of Health and Rehabilitation Science, The University of Queensland

Patients with low back pain (LBP) often present with impaired proprioception of the lumbopelvic region. For this reason, proprioception training usually forms part of the rehabilitation protocols. New exercise equipment that produces whole body, low frequency vibration (WBV) has been developed to improve muscle function, and reportedly improves proprioception. The aim of this pilot study was to investigate whether weightbearing exercise given in conjunction with WBV would affect lumbosacral position sense in healthy individuals. For this purpose, twenty-five young individuals with no LBP were assigned randomly to an experimental or control group. The experimental group received WBV for five minutes while holding a static, semi-squat position. The control group adopted the same weightbearing position for equal time but received no vibration. A two-dimensional motion analysis system measured the repositioning accuracy of pelvic tilting in standing. The experimental (WBV) group demonstrated a significant improvement in repositioning accuracy over time (mean 0.78 degrees) representing 39% improvement. It was concluded that WBV may induce improvements in lumbosacral repositioning accuracy when combined with a weightbearing exercise. Future studies with WBV should focus on evaluating its effects with different types of exercise, the exercise time needed for optimal outcomes, and the effects on proprioception deficits in LBP patients. [Fontana TL, Richardson CA and Stanton WR (2005): The effect of weightbearing exercise with low frequency, whole body vibration on lumbosacral proprioception: A pilot study on normal subjects. *Australian Journal of Physiotherapy* 51: 259–263]

Key words: Lumbosacral spine, Proprioception, Whole body vibration, 2-D motion analysis, Rehabilitation, Low back pain

Introduction

In Western countries, low back pain (LBP) constitutes a major health care problem. Those who incur the majority of the cost, both personally and financially, are the ones who suffer recurrent chronic pain. Patients with low back pain are known to have altered motor control (dysfunction) in the lumbopelvic region (see Hodges 2004 for a review) and, as various methods of measuring proprioception in the region are devised, evidence is emerging that proprioception is also impaired (Brumagne et al 2000, Brumagne et al 2004, Leinonen et al 2003, Mok et al 2004, Parkhurst and Burnett 1994, O'Sullivan et al 2003). A loss of proprioception would contribute to neuromuscular dysfunction and likely poor segmental stability in low back pain patients, which may lead to an increase in the risk of injury or further injury (Brumagne et al 1999b). Therefore, to treat patients with LBP effectively, proprioception training is usually considered to be an important element of the rehabilitation exercise program.

The challenge for physiotherapists and other health care professionals is to choose the best exercise method to retrain proprioception efficiently in patients with LBP. One approach used extensively in retraining proprioception following injury to an ankle joint is weightbearing exercising on balance boards (Sheth et al 1997). Importantly, this approach improved muscle strength and proprioception not only in the ankle but in other joints including the knee, hip, and lower

spine (Burton 1986). Therefore, balance boards and uneven surfaces, used in conjunction with exercise techniques, have been used for treatment of LBP patients (Richardson et al 2004).

Technological advancement has led to the development of a new form of moving exercise surface, which uses mechanical vibration, and is known as low frequency, whole body vibration (WBV). The exercise platform, which vibrates between 1 and 50 Hz, was originally developed by biomechanical engineers in Europe for use in the space program to prevent bone density changes in astronauts. More recently it has evolved into an exercise device with specific exercise performed on the vibrating platform, depending on the outcome required. Exercise programs incorporating WBV are currently being tested in the areas of sports, geriatrics, and rehabilitation (Bosco et al 1999, Rittweger et al 2002).

The beneficial effects of WBV on muscle function have been, to a large extent, deduced through research on single muscles. Most researchers suggest that vibration can improve strength, power, and flexibility of muscles (Issurin and Tenenbaum 1999), but concur that these changes are likely to be the result of vibration on the proprioceptive receptors in the muscles. Neurophysiological research in this area has focussed on the effect of hand held vibration devices on muscle spindle activity in a specific muscle. The research of Ribot-Ciscar et al (1998, 2002, 2003a, 2003b) has provided information on the way tendon vibration excites primary endings of the

muscle spindles and hence induces reflex muscle contractions to help improve muscle function (i.e. muscles can be facilitated or inhibited). It can also result in disturbed proprioception (Rogers et al 1985) and, when the eyes are closed, in illusions of movement (Goodwin et al 1972).

The complexity of the effect of vibration on the muscle spindle mechanism is highlighted by the many different muscle responses that can result, depending on the parameters of the vibration. For example, vibration time seems to be an important factor in the development of fatigue (Bongiovanni et al 1990). The reported deleterious effects of WBV, including the development of low back pain, have been demonstrated with prolonged vibration in the occupational setting (Wilder and Pope 1996). In addition, recent research on the transmission of vibration through different parts of the body has demonstrated how transmission depends on body position as well as on resonant frequencies of different body parts (Rubin et al 2003).

The effects of vibration have been shown to depend on the properties of the muscle itself, for example the muscle's 'preferred sensory direction', whether a muscle is relaxed or contracting, if position is maintained (static) or associated with movement, whether a muscle is shortened or lengthened, and the combined effect of all the muscles surrounding the joint (Ribot-Ciscar et al 2002, 2003a).

In comparison to single muscle stimulation, the use of the WBV involves applications to large portions of the body. Roll et al (1980) applied vibration to the whole body and to the legs of seated subjects and concluded that vibration acts on the 'extero- and proprioceptive receptors rather than on the vestibular organs'. In the standing situation, the vibration would have an effect, not only on the many muscles and tendons, but on the joint structures. This would likely mean additional potent sensory motor effects through the proprioceptive joint mechanoreceptors. In addition, Johansson et al (1991a, 1991b) have found a close relationship between activation of joint mechanoreceptors and stimulation of the gamma efferents (to sensitise the spindles) which result in increases in muscle 'stiffness' and joint stability. This may also be an important factor in understanding the complex way WBV may enhance proprioception.

Thus it can be argued from neurophysiological research that WBV may be most useful in improving proprioception, even though the complex mechanisms do not allow decisions to be made on ideal parameters for the vibration or the ideal postures and exercises which would achieve an optimal effect. As a starting point, a pilot study was undertaken based on the exercise variables used by Rittweger et al (2002). Using WBV in conjunction with closed chain (weight-bearing) exercise, these researchers successfully reduced pain in LBP patients. The reason for this reduction in pain is unknown. Muscle strength did not improve, however proprioception was not measured. Based on this research, the present pilot study used 18 Hz WBV, in a single bout of five minutes' duration (representing the average time used by Rittweger et al 2002). Due to the likely motor control dysfunctions of muscles in the lumbopelvic region in low back pain patients, and the many vibration and exercise variables associated with WBV, this initial trial was undertaken on normal subjects.

Therefore the aim of this experiment was to determine if five

minutes of low frequency WBV would improve lumbosacral position sense in healthy individuals. If position sense is improved due to weightbearing exercise used in conjunction with WBV, it may become an important modality to assist in the training of lumbosacral proprioception.

Method

Subjects The study sample consisted of 25 individuals, ranging in age 19–21 years. All volunteers were recruited from a student population. Fourteen participants (4 males, 10 females) were randomly assigned to the experimental group and 11 participants (4 males, 7 females) to the control group. Individuals completed the Baecke habitual activity questionnaire (Baecke et al 1982) before involvement in the study, to ensure that they all had average physical levels (40–60 score). The exclusion criteria for whole body vibration included pregnancy, acute thromboses, heart or circulatory conditions, fresh wounds, artificial joints or body parts, spinal pathology, diabetes, epilepsy, acute migraines, acute inflammatory conditions, pacemaker, or tumours (PowerPlate Instructor Course 2002). Importantly for this project, participants were also excluded if they had a history of low back pain or any neurological disorders (vestibular disorders or cerebral trauma), inner ear infections, or hearing loss, which could have affected balance and proprioception.

The Medical Research Ethics Committee of The University of Queensland granted ethical approval for the study. Prior to testing, each participant was informed of the procedure and gave informed consent.

Apparatus and measurements In order to test the effects of WBV on proprioception of the lumbopelvic region, a valid method of testing proprioception was required. The types of techniques considered appropriate for testing joint proprioception are the accuracy of contralateral joint angle matching or a limb segment repositioned in space without the aid of vision (Ashton-Miller et al 2001). This study utilised the methods described by Brumagne et al (1999a) to measure position sense in the lumbosacral region, by repositioning the pelvis without vision.

Lumbosacral repositioning measurements using the Fastrak The lumbosacral repositioning test involved repositioning the pelvis to a criterion position either anteriorly or posteriorly without the use of vision. A modified version of the Brumagne et al (1999a) method for the standard subject position and lumbosacral repositioning was incorporated. Measurements of changes in lumbosacral posture were achieved with a 3-D Space Fastrak system^a. This reliable electromagnetic goniometer is capable of accurately detecting joint displacement in three dimensions, although this study used only two-dimensional analysis. A Fastrak sensor was adhered to the right anterior iliac spine with double-sided tape and the electromagnetic source placed in the vertical plane directly 25 cm posterior to the sacrum (see Figure 1). The co-ordinates of the X-axis represented sagittal physiological movement and were of primary interest in this study. Compatible Fastrak software determined the lumbosacral angular displacement (degrees) from the sensor attached to the anterior superior iliac spine, relative to the electromagnetic source. The software also calculated the angular changes (repositioning error) of the sensor when attempting to match the criterion position. This setup adhered to the usual precautions for the use of the Fastrak (Swinkles and Dolan 1998).

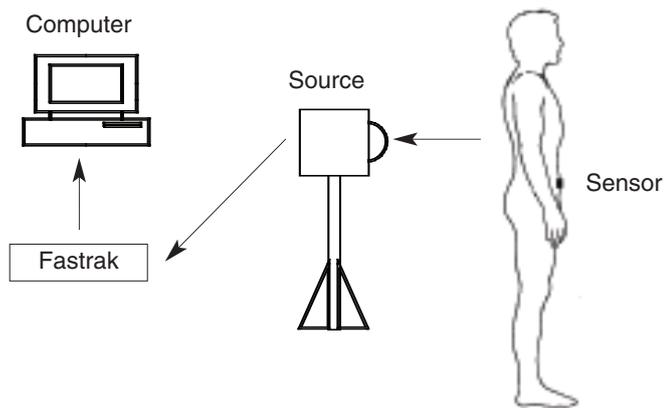


Figure 1. Experimental set up for lumbosacral position sense testing. The sensor was placed on the right anterior superior iliac spine.

Whole body vibration using the Galileo Low frequency, WBV was produced using the Galileo 2000^b involving alternate oscillation of the feet bilaterally, rather than a vertical translation (as in some other WBV models). Frequencies of 1–50 Hz are available, with amplitude changes depending on whether the feet are placed at the centre (reduced amplitude) or to the outside (higher amplitude, 10 mm) of the vibrating platform. In this study, the frequency was set at 18 Hz (Rittweger et al 2002). The participants were positioned on the platform with knees slightly flexed, slight hyperlordosis in the lumbar spine, the lobe of the ear in a vertical line to the heel of the foot and the gaze horizontal (Rittweger et al 2002). The feet were placed apart so that the entire width of the platform was spanned.

Procedure The same researcher directed the investigations throughout, using a standardised protocol to ensure consistency of this test–retest design. The participants were randomly assigned into the control or experimental group by a computerised list of random numbers. Participants were dressed in minimal attire, and the procedure was identical for each. The location of the right anterior iliac spine was established by palpation and a sensor was placed in position.

In the lumbosacral repositioning tests, participants were asked to stand on markers 25 cm apart. The subjects maintained an upright position while pelvic rotation was performed. The participants stood in a natural stance for approximately five seconds, which was designated as the neutral position. The pelvis was tilted 10 times as a warm-up prior to testing. The pelvis was rotated forward and backward until initial resistance was felt. The predetermined position for the test was chosen randomly during the subject's active pelvic tilting (based on the range of motion previously examined). This criterion position was not at the extremes of range, but alternatively in the anterior or posterior pelvic tilt zone (Brumagne et al 1999a).

The subjects were blindfolded to eliminate visual input. Next, the pelvis was rotated forward and backward, twice. Then an attempt to reproduce the criterion position from the neutral position was made. This position was held until the angle was recorded online from the computer display. The same

sequence of events was repeated a further two times, while the subjects were blindfolded. These three measures were averaged for a score of repositioning error for the first pre-test. The repositioning error was established by the difference (in degrees) between the criterion and the matching positions of all trials. A second pre-test was conducted 15 minutes later after the equipment was detached from the subject then reattached.

Verbal instructions for the repositioning task were: 'Stand up straight in a comfortable position that is your neutral position...From your neutral position, rock your pelvis forwards then backwards as far as you can go, 10 times...I will now move your pelvis into a position either forwards or backwards. You have to remember this position, as you will need to go back to it later...From your neutral position, first rock your pelvis fully forward then backward, twice. Then go back to that position, tell me when you have reached it and hold it until I say to relax.'

After testing, the experimental (exercise) group was required to stand for five minutes on the Galileo 2000, in the isometric, closed chain position. If the participants felt insecure, the hand bars were used briefly until balance was regained. The control group was required to stand on the Galileo for five minutes in the same position; however the machine was not switched on. The subjects were then retested for lumbosacral repositioning to calculate the post-test repositioning error (average of three measures).

Statistical analysis The Statistical Package for the Social Sciences (SPSS 10.0) was used to conduct the analyses. A two-way mixed design analysis of variance was performed on the dependent variable of repositioning error. For the analysis an average of the two pre-tests was taken to provide a stable measurement. 'Time' was the repeated measure (pre-test and post-test) while the groups (experimental and control), and the direction of pelvic positioning, were the independent variables (between-subject factors). Scores from the Baecke habitual activity questionnaire were entered as a covariate in the analysis.

In addition, negative and positive signed repositioning errors (undershooting or overshooting the criterion position) were calculated. To determine whether subjects preferred to undershoot or overshoot the proportion of positive and negative signed values were calculated.

Results

The primary result of the analysis was a significant interaction effect between 'time' and 'group' ($F_{(1,20)} = 8.62, p = 0.008$). Five minutes of low frequency, whole body vibration induced a decrease in absolute mean repositioning error, improving repositioning accuracy by 39% or 0.78 degrees. However, the control group displayed a decrease in repositioning accuracy by 42% or 0.55 degrees. The net proportional benefit of the experimental group over the control group at post-test was 53%. In summary WBV overcame the negative effect of holding a static posture in addition to further improving it by 0.23 degrees. There was no significant effect of 'direction' ($F_{(1,20)} = 0.43, p = 0.84$). Sixty-six percent of participants who repositioned the pelvis in the posterior direction undershot the target position ($p = 0.01$). Repositioning accuracy was not dependent on the anterior or posterior repositioning of the pelvis ($p = 0.09$).

The mean range of motion of pelvic tilting in standing was

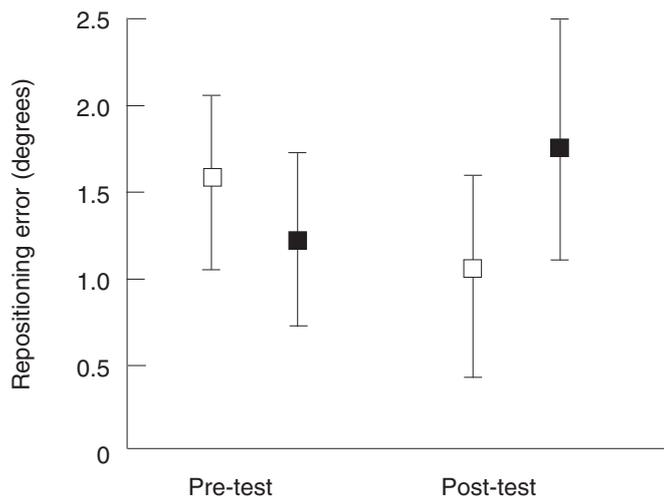


Figure 2. Mean (+ SD) of repositioning error pre and post treatment. A negative difference indicates that whole body vibration decreases repositioning error thus improves position sense.

23.6 degrees (95% CI 18.5 to 28.7). The overall absolute mean repositioning accuracy was 1.73 degrees (95% CI 0.31 to 3.15) for the baseline condition. Figure 2 displays the significant relationship between groups and trials.

Discussion

In this study, a single five-minute bout of WBV (18 Hz) combined with a static, closed chain exercise improved lumbosacral proprioception. This is an important initial finding for two reasons. First, the effect of WBV on lumbopelvic proprioception has not previously been demonstrated and, second, the subjects were given such a small amount of WBV in conjunction with exercise. In addition, these results provide a possible explanation as to why Rittweger et al (2002), with 12 weeks' treatment, found relief of pain and improvement of function in patients suffering from chronic low back pain. These positive effects could have been the result of increased proprioception, and hence improved muscle co-ordination, in the lumbopelvic area.

The reproducibility of the test protocol that was regarded as reliable and stable allowed us to demonstrate individual differences in levels of proprioceptive acuity in healthy individuals with no low back pain. Four of the 25 subjects were notably poor at reproducing some of the positions. These differences between individuals may in part reflect the vestibular apparatus and cognitive processes which include judgment, decision-making, and concentration. It may also reflect different physical fitness levels. However, all effort was made to ensure that all participants had an average physical activity level using the Baecke Habitual Questionnaire (Baecke et al 1982).

Another interesting and significant finding was that participants who repositioned in the posterior direction consistently undershot the target position. Undershooting and overshooting the target has been reported in other vibration studies. A previous vibration study that used a hand-held vibrator (80–120 Hz) revealed that when repositioning to

neutral, undershooting occurred during vibration to the tendon (Brumagne et al 1999b). Conversely, another similar study demonstrated that after the vibration stimulus participants overshoot the criterion position (Rogers et al 1985). The effect of vibration is complex and it is beyond the scope of this study to determine the reason for this undershooting occurring when posteriorly repositioning the pelvis.

The limitations of this pilot study were concerned with the lack of prior investigations on a very new exercise tool. For this reason, exercise prescription may not have been optimal. In addition, measurement of proprioception is a complex testing procedure, where familiarisation may occur from the repetition of a task used in the pre-test. The standing test used in this research was also dependent on balance and body sway of the subject. Strategies such as excluding subjects who would likely have poor balance, ensuring familiarisation with the test and repeatedly testing proprioception, were used to control this variable in the test. Baseline differences, possibly the result of group allocation in a small sample, may limit the generalisability of the finding, but the extent of improvement in the experimental group indicates the need for a study with a larger sample size.

Overall, the findings of this pilot trial suggest that a five minute block of low frequency WBV induces a rapid improvement in proprioceptive ability in the lumbopelvic region. Many aspects of the exercise prescription require further evaluation. In order to obtain an optimal outcome, future studies should consider the many posture and exercise variables, including duration of a single exercise bout and the frequency of the exercise application, as well as details of the vibration parameters. Incorporating vibration exercise into treatment needs to be developed with caution, as prolonged high frequency vibration is known to have detrimental effects on muscles, most particularly increasing fatigue (Bongiovanni et al 1990), and causing, in some circumstances, disturbances in proprioception (Brumagne et al 1999b, Ribot-Cisar et al 1998, Rogers et al 1985).

Future clinical studies on the use of WBV for the rehabilitation of low back pain patients should include outcome measures of lumbopelvic proprioception to allow the relationship between pain relief and possible improvements in level of proprioception to be evaluated.

Footnotes ^aPolhemus Incorporated, Vermont, USA
^bNovotec, Pforzheim, Germany

Acknowledgments The authors wish to thank the students of The University of Queensland who participated in the study. Thanks also to Dr Ross Darnell for his statistical advice and to Tom Johnson and Moshen Amiri for their contribution to the experimental set-up.

Correspondence Associate Professor Carolyn A. Richardson, School of Health and Rehabilitation Science, The University of Queensland, St Lucia 4072. Email: c.richardson@shrs.uq.edu.au.

References

- Ashton-Miller J, Wojtys E, Huston L and Fry-Welch D (2001): Can proprioception really be improved by exercises? *Knee Surgery, Sports Traumatology, Arthroscopy* 9: 128–136.
- Baecke J, Burema J and Frijters J (1982): A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Journal of Clinical Nutrition* 5: 936–942.

- Brumagne S, Cordo P and Verschueren S (2004): Proprioceptive weighting changes in persons with low back pain and elderly persons during upright standing. *Neuroscience Letters* 366: 63–66.
- Brumagne S, Cordo P, Lysens R, Verschueren S and Swinnen S (2000): The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. *Spine* 25: 989–994.
- Brumagne S, Lysens R and Spaepen A (1999a): Lumbosacral repositioning accuracy in standing posture: a combined electrogoniometric and videographic evaluation. *Clinical Biomechanics* 14: 361–363.
- Brumagne S, Lysens R, Swinnen S and Verschueren S (1999b): Effect of paraspinal muscle vibration of position sense of the lumbosacral spine. *Spine* 24: 1328–1331.
- Bongiovanni L, Hagbarth K and Stjernberg L (1990): Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *Journal of Physiology* 423: 15–26.
- Bosco C, Colli R, Introini E, Cardinale M, Tsarpela O and Madella A (1999): Adaptive responses of human skeletal muscle to vibration exposure. *Clinical Physiology* 19: 183–187.
- Burton K (1986): Trunk muscle activity induced by three sizes of wobble (balance) boards. *Journal of Orthopaedic and Sports Physical Therapy* 8: 27–29.
- Goodwin G, McCloskey D and Matthews P (1972): The contribution of muscle afferents to kinaesthesia shown by vibration induced illusions of movement and by the effects of paralysing joint afferents. *Brain* 95: 705–748.
- Hodges PW (2004): Abdominal mechanism in low back pain. In Richardson C, Hodges P and Hides J (Eds): *Therapeutic Exercise for Lumbo-Pelvic Stabilization: A Motor Control Approach for the Treatment and Prevention of Low Back Pain*. Edinburgh: Churchill Livingstone Chapter 10, pp. 141–148.
- Issurin V and Tenenbaum G (1999): Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *Journal of Sports Sciences* 17: 177–182.
- Johansson H, Sjölander P and Sojka P (1991a): A sensory role for the cruciate ligaments. *Clinical Orthopaedics and Related Research* 268: 161–178.
- Johansson H, Sjölander P and Sojka P (1991b): Receptors in the knee joint ligaments and their role in the biomechanics of the joint. *CRC Critical Reviews in Biomedical Engineering* 18: 341–368.
- Leinonen V, Kankaanpää M, Luukkainen M, Kansanen M, Hanninen O, Airaksinen O and Taimela S (2003): Lumbar paraspinal muscle function, perception of lumbar position, and postural control in disc herniation-related back pain. *Spine* 28: 842–848.
- Mok NW, Brauer SG and Hodges PW (2004): Hip strategy for balance control in quiet standing is reduced in people with low back pain. *Spine* 29: E107–E112.
- O'Sullivan PB, Burnett A, Floyd AN, Gadsdon K, Logiudice J, Miller D and Quirke H (2003): Lumbar repositioning deficit in a specific low back pain population. *Spine* 28: 1074–1079.
- PowerPlate Instructor Course (2002): *A Revolutionary Approach to Training*. London: Course Manual.
- Parkhurst TM and Burnett CN (1994): Injury and proprioception in the lower back. *Journal of Orthopaedic and Sports Physical Therapy* 19: 282–295.
- Ribot-Ciscar E, Rossi-Durrand C and Roll J (1998): Muscle spindle activity following muscle tendon vibration in man. *Neuroscience Letters* 258: 147–150.
- Ribot-Ciscar E, Bergenheim M and Roll JP (2002): The preferred sensory direction of muscle spindle primary endings influences the velocity coding of two-dimensional limb movements in humans. *Experimental Brain Research* 145: 429–436.
- Ribot-Ciscar E, Bergenheim M, Roll and Albert FJP (2003a): Proprioceptive population coding of limb position in humans. *Experimental Brain Research* 149: 512–519.
- Ribot-Ciscar E, Butler JE and Thomas CK (2003b): Facilitation of triceps brachii muscle contraction by tendon vibration after chronic cervical spinal cord injury. *Journal of applied Physiology* 94: 2358–2367.
- Roll JP, Martin B, Gauthier GM and Mussa-Ivaldi F (1980): Effects of whole-body vibration on spinal reflexes in man. *Aviation, Space and Environmental Medicine* 51: 1227–1233.
- Richardson C, Hodges P and Hides J (2004): *Therapeutic Exercise for Lumbo-Pelvic Stabilization: A Motor Control Approach for the Treatment and Prevention of Low Back Pain*. Edinburgh: Churchill Livingstone.
- Rittweger J, Just K, Kautzsch K, Reeg P and Felsenberg D (2002): Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise. *Spine* 27: 1829–1834.
- Rogers D, Bendrup A and Lewis M (1985): Disturbed proprioception following a period of muscle vibration in humans. *Neuroscience Letters* 57: 147–152.
- Rubin C, Pope M, Fritton J.C, Magnusson M, Hansson T, McLeod K (2003): Transmissibility of 15-hertz to 35-hertz vibrations to the human hip and lumbar spine: Determining the physiologic feasibility of delivering low level anabolic mechanical stimuli to skeletal regions at greatest risk of fracture because of osteoporosis. *Spine* 28: 2621–2627.
- Sheth P, Yu B and Laskowski C (1997): Ankle disc training influences reaction times of selected muscles in a simulated ankle sprain. *American Journal of Sports Medicine* 25: 538–543.
- Swinkles A and Dolan P (1998): Regional assessment of joint position sense in the spine. *Spine* 23: 590–597.
- Wilder DJ and Pope MH (1996) Epidemiological and aetiological aspects of low back pain in vibration environments – an update. *Clinical Biomechanics (Bristol Avon)* 11: 61–73.