Clin Physiol Funct Imaging (2006) **26**, pp380–384

The acute effects of different whole body vibration amplitudes on the endocrine system of young healthy men: a preliminary study

Marco Cardinale[1,2], John Leiper[2], Julie Erskine[1,2], Mark Milroy[2] and Steve Bell[2]

[1]Olympic Medical Institute, Northwick Park Hospital, London, and [2]College of Life Sciences and Medicine, University of Aberdeen, Aberdeen, UK

Correspondence
Marco Cardinale, Olympic Medical Institute, Northwick Park Hospital, Watford Road HA1 3UJ, Harrow, UK
E-mail: marco.cardinale@boa.org.uk

Accepted for publication
Received 29 May 2006;
accepted 24 August 2006

Key words
anabolic; hormonal responses; vibration

Summary

Whole body vibration (WBV) has been suggested as an alternative form of exercise producing adaptive responses similar to that of resistance training. Very limited information is available on the effects of different vibration parameters on anabolic hormones. In this study, we compared the acute effects of different WBV amplitudes on serum testosterone (T) and insulin growth factor-1 (IGF-1). Nine healthy young recreationally active adult males (age 22 ± 2 years, height 181 ± 6.3 cm, weight 77·4 ± 9·5 kg) voluntarily participated in this randomized controlled (cross-over design) study. The subjects performed 20 sets of 1 min each of WBV exercise in the following conditions: Non-vibration condition (control), low amplitude vibration [low (30 Hz, 1·5 mm peak-to-peak amplitude)] and high amplitude vibration [high (30 Hz, 3 mm peak-to-peak amplitude)]. Blood samples were collected before, after 10 sets, at the end (20th set) and after 24 h of the exercise bout. WBV exercise did not produce significant changes in serum T and IGF-1 either with low or high amplitude when compared with the control condition. The results of this study demonstrate that a single session of WBV exposure with a frequency of 30 Hz and amplitudes of 1·5 and 3 mm does not noticeably alter serum T and IGF-1 levels.

Introduction

Whole body vibration (WBV) has been recently suggested as an alternative form of exercise. This has been due to the effects of WBV on muscle (Bosco *et al.*, 1999; Torvinen *et al.*, 2002a; Cardinale & Bosco, 2003; Delecluse *et al.*, 2003), bone (Verschueren *et al.*, 2004; Ward *et al.*, 2004) and hormonal profile (Bosco *et al.*, 2000).

Whole body vibration is applied through a vibrating platform on which a person stands for a certain period of time. Vibrating platforms currently marketed provide sinusoidal vibrations with amplitudes ranging from <1 to 15 mm and frequencies of oscillations ranging from 15 to 60 Hz (Cardinale & Wakeling, 2005). Static and dynamic squatting exercises on vibrating plates have been previously used to study the effects of a single session of WBV aim of understanding the acute responses of different physiological systems. Cardiovascular and metabolic responses observed with squatting exercise on vibrating plates have suggested that WBV could represent a mild form of exercise for the cardiovascular system (Rittweger *et al.*, 2000, 2001, 2002; Kerschan-Schindl *et al.*, 2001). However, studies focusing on the acute effects of WBV on muscle function have been so far controversial. Torvinen found that 2 min after four sets of 1 min of WBV exercise on a tilting platform, jump height was increased by 2·5% and isometric knee extension force by 3·2% (Torvinen *et al.*, 2002a). Similar findings have been reported by Bosco *et al.* (1999, 2000). Despite these positive findings, it has also been reported that vibration had no acute effect upon maximum isometric torque, rate of force development, vertical jump and muscle activation (Torvinen *et al.*, 2002b; De Ruiter *et al.*, 2003). Recent work from De Ruiter *et al.* (2003) has in fact shown that WBV was not able to produce changes in force-generating capacity in healthy individuals acutely (the vibration protocol consisted of 30 Hz frequency and 8 mm amplitude using a tilting vibrating plate). Similar findings were reported from Torvinen *et al.* (2002b) while exposing healthy individuals to 4 min of WBV with small amplitudes on a whole plate vibrating system (2 mm peak-to-peak).

Hormonal responses to WBV exercise have not been extensively studied. To our knowledge, only two studies have analysed the acute effects of single WBV exercise sessions on anabolic hormones. WBV applied for a total of 10 min at 26 Hz (displacement ± 4 mm) has been shown to improve vertical jumping ability, increase testosterone (T) and growth hormone levels and decrease cortisol levels in young physically active individuals (Bosco *et al.*, 2000). Bosco's study showed the potential of WBV exercise to affect the neuroendocrine system in a similar manner to resistance exercise, however, in this study there was no control condition. A more recent study from Di Loreto *et al.* (2004) conducted with a randomized controlled cross-over design has shown that WBV for 10 min at 30 Hz (displacement ± 4 mm) reduced plasma glucose and increased plasma noradrenaline concentration in 10 healthy men but did not change GH, insulin growth factor-1 (IGF-1) and free and total T. In both studies the same equipment was used (a platform oscillating up and down) producing vibration amplitudes of ±4 mm. As the movement of the platform is sinusoidal, the acceleration transmitted to the body is calculated as $a = A(2\pi f)^2$ (Rittweger *et al.*, 2001) where A is the amplitude of the oscillations and f is the frequency. Small changes in amplitude and frequency determine relatively large changes in acceleration and magnitude of vibration being transmitted to the body.

The effects of vibration on neuromuscular and endocrine systems have been attributed to the increased gravitational load on the subject standing on a vibrating platform with mean G-forces of 3·91 times 1G reaching the tibial tuberosity (Cardinale & Bosco, 2003; Crewther *et al.*, 2004). The increase in gravitational load has been suggested to be similar to the one experienced with conventional resistance exercise. Several studies have shown that acute increases in the circulating levels of anabolic hormones can be observed following a single session of resistance exercise (for a review see Kraemer & Ratamess, 2005). Similar responses were observed by Bosco *et al.* (2000) but were not replicated by Di Loreto *et al.* (2004) with a more appropriate design. The hormonal responses to resistance exercise have been studied manipulating training variables such as training load, number of exercise, sets and repetitions (volume) and relative intensity. WBV transmitted to the body can be controlled in terms of frequency and amplitude both affecting vibration acceleration (magnitude). Currently, there is a large market of vibration exercise devices that allow the user to chose not only vibration frequency, but also vibration amplitude which is in most cases limited to only two options because of technical constraints.

To our knowledge, no study has looked at the effects of WBV amplitude on T and IGF-1 responses in healthy individuals. We hypothesized that a single WBV exercise session acutely increased T and IGF-1 when compared with a control condition. Moreover we hypothesized that WBV performed with the larger amplitude produced the highest hormonal response because of the higher magnitude of accelerations applied to the body.

Methods

Subjects

Nine healthy young recreationally active adult males (age 22 ± 2 years, height 181 ± 6.3 cm, weight 77·4 ± 9·5 kg) voluntarily participated in this randomized controlled study. The subjects gave written informed consent before participating in the study. Ethics approval was obtained from the Grampian University Health Trust Ethics Committee.

Experimental procedures

The study design consisted of three individual treatment days. Treatments were separated by a washout period of 1 week to ensure that any residual effects of a treatment would have disappeared by the next session. The exercise treatments under investigation were: non-vibration condition (control), low amplitude vibration (low) and high amplitude vibration (high). The order in which the subjects received the three treatments (control, low, high) was assigned in a randomized manner. On each treatment day subjects reported to the laboratory in the morning after 10 h of fasting (9 am). Baseline blood samples were collected at rest before treatment (Pre; to determine basal circulating hormonal concentrations), with further blood samples drawn after 10 sets of treatment (Mid), after 20 sets of treatment (Post), and the day after treatment (24 h Post).

Treatment procedures

On the morning of the exercise treatment days and the day after the treatments (24 h Post), subjects reported to the laboratory at 9 am following an overnight fast. After collection of baseline blood samples, subjects completed a standardized warm-up. This consisted of 5 min cycling on a cycle ergometer (Monark 824E; Ergomedic, Verberg, Sweden) at 50 W, 1 min of star jumps and several practice drop jumps. Each treatment session consisted of 10 sets of static half squats of 60 s each with 60 s rest between sets, 5 min rest and another series of ten sets of 60 s each with 60 s rest between sets. Subjects were exposed to the three different treatments (control, low and high) in a randomized order. The vibration conditions were performed with the subject in a half squat position while undergoing vertical sinusoidal WBV using a vibrating platform producing sinusoidal oscillations. Frequency of vibration was 30 Hz, peak-to-peak displacements that were either 3 mm (high amplitude) or 1·5 mm (low amplitude) with calculated magnitudes of 5·4 and 2·7 g respectively (where 1 g = 9·81 ms^2). The two amplitudes were the only ones allowed by the vibrating plate used for the experiment. The control condition consisted of assuming the same position on the same plate with no vibration being present. An upright relaxed posture was adopted during rest periods between sets. Subjects wore a heart rate monitor (Polar electro, Kempele, Finland) to record their heart rate in each condition. The average heart rate value of the last 5 s of each set was recorded and used for statistical analysis.

Blood collection and hormonal analysis

Blood samples (15 ml) were obtained from a superficial forearm vein with minimal stasis for the determination of T and IGF-1 concentrations. An indwelling catheter was inserted and kept patent by flushing with sterile 0·9% NaCl to allow blood collection at further time points during the session. Each blood sample was then centrifuged at c. 17 000 g for 2 min and subsequently stored at −30°C until it was analysed. Hormone concentrations were measured using commercially available kits. Serum T concentration was determined using a Testosterone ELISA kit (ALPCO Diagnostics, Windham, NH, USA), with intra-assay CV 3·78–5·82% and inter-assay CV 3·01–4·44%. Serum IGF-I concentration was determined using an IGF-I Enzyme Immunoassay Test Kit (ALPCO Diagnostics). Assays were carried out in accordance with the manufacturer's instructions. All samples collected from the subjects were analysed in the same assay to discard any inter-assay variation. Commercially available standards and quality control samples were used for both assays (ALPCO Diagnostics).

Statistical analysis

Statistical analyses were performed using the GraphPad Prism 4 (GraphPad Software, Inc., San Diego, CA, USA) statistical package. All data were found to be normally distributed therefore analysis was carried out using parametric statistical tests. A two-way analysis of variance (2-way ANOVA) was used to identify any statistically significant differences with treatment (control, low amplitude vibration and high amplitude vibration) and time as within factors. Data are expressed as mean ± standard error of measurement (SEM). The level of significance was set at $P<0·05$.

Results

Whole body vibration exercise did not produce significant changes in serum T (Fig. 1) and IGF-1 (Fig. 2) either with low or high amplitude when compared with the control condition.

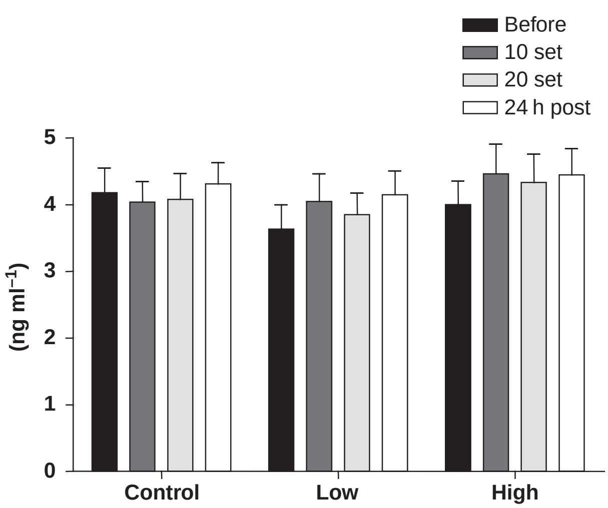

Figure 1 Acute changes in serum testosterone concentrations in control, low and high treatment conditions. Values are mean ± SEM ($n = 9$).

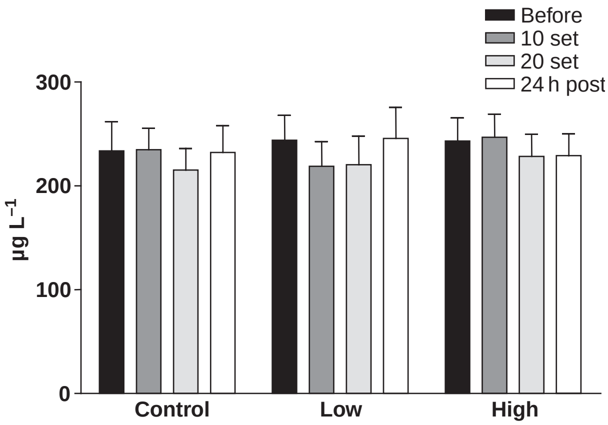

Figure 2 Acute changes in serum insulin growth factor-1 concentrations in control, low and high treatment conditions. Values are mean ± SEM ($n = 9$).

Although T showed a trend to increase after 10 min when vibration was administered ($P = 0·06$).

Heat rate was significantly increased in all exercise conditions when compared with baseline values (Fig. 3). However no significant difference was evident when the treatment conditions were compared.

Discussion

The results of this study demonstrate that a single session of WBV exposure with the amplitudes used in the present study does not noticeably alter serum T and IGF-1 levels. These results are consistent with recent work from Di Loreto et al. (2004) who did not find any changes in T and IGF-1 levels up to 1 h following 10 min of WBV exposure at 30 Hz with 4 mm displacement. An increase in anabolic hormones following a single bout of WBV exercise was previously found by Bosco et al. (2000) who reported significant increases in T and growth hormones following 10 min of WBV exercise at 26 Hz with 4 mm

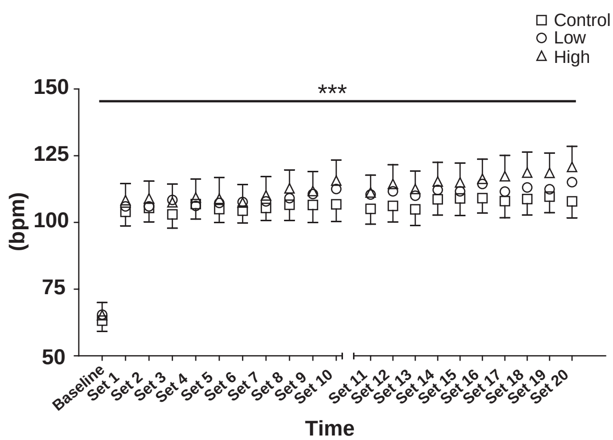

Figure 3 Heart rate during control, low and high treatment conditions. Values are mean ± SEM ($n = 9$). ***Significant difference from baseline value ($P<0·001$).

displacement. However, it should be pointed out that Bosco's experiment was limited by the absence of a control condition.

Whole body vibration exercise has been previously reported to stimulate muscle activity (Cardinale & Lim, 2003; Delecluse *et al.*, 2003). In particular, it has been suggested that WBV could elicit a neuromuscular response very similar to the tonic vibration reflex (Cardinale & Bosco, 2003). This muscle activation has been suggested to be relevant in order to damp the vibrations originated by the plate (Wakeling & Nigg, 2001; Cardinale & Lim, 2003; Cardinale & Wakeling, 2005). Also, this increased muscle activity results in a greater rate of oxygen uptake during exposure to vibrations (Rittweger *et al.*, 2001, 2002). As vibration has been previously suggested to determine specific metabolic and neuromuscular adaptive responses, it was hypothesized that the hormonal milieu would have been altered in a manner similar to that of other forms of exercise and in particular resistance exercise. Because of the effects of long-duration vibration training programmes on bone (Rubin *et al.*, 2004; Verschueren *et al.*, 2004; Ward *et al.*, 2004) and muscle (Delecluse *et al.*, 2003; Roelants *et al.*, 2004) it was deemed probable that anabolic hormones would have been inevitably involved in modulating the adaptive response to vibration stimulation. The results of our study suggest that in healthy young individuals 20 min of WBV exercise is not enough to determine any significant increase in T and IGF-1. During all forms of exercise, acute endocrine activation is triggered by collaterals of the central motor command to the hypothalamic neurosecretory and autonomic centres. These responses are further modulated by proprioceptors and metaboreceptors. Vibration represents a strong stimulation of sensory motor structures, and animal models have shown that WBV is able to induce an increase in serotonin (5-HT), 5-hydroxyindoleacetic acid (5-HIAA) and corticosterone levels (Ariizumi & Okada, 1983) in the brain. Human and animal studies have shown that vibration applied directly to lower limbs muscles is able to increase circulating bioassayable growth hormone (McCall *et al.*, 2000; Gosselink *et al.*, 2004), a result the authors attributed to a muscle afferent–pituitary axis. Furthermore, studies conducted on workers exposed to WBV (frequency 31·5 Hz) have shown significant increases in salivary 3-methoxy-4-hydroxyphenylglycol (MHPG), an index of central sympathetic nervous system activation (Ando & Noguchi, 2003) suggesting that vibration transmitted to the whole body represents a stressful stimulation.

The lack of significant findings could be explained by the relatively low level of neuromuscular stimulation generated by the low amplitudes used in our study. Studies conducted analysing the acute hormonal responses to resistance exercise suggest that anabolic hormones responses relate to heavy loads, short rest periods and large volumes of training (Kraemer *et al.*, 1993; Ahtiainen *et al.*, 2004). Squatting on a vibrating plate with no extra load has been reported to produce an EMG activity in the leg extensors muscles slightly higher (<50%) than the same exercise performed in no vibration conditions (Cardinale & Lim, 2003; De Ruiter *et al.*, 2003) in healthy young individuals. This would mean that the neuromuscular stimulation for a young healthy population would be very low if related to the maximum capabilities and is not comparable with the level of neuromuscular stimulation generated with heavy resistance exercise. Considering the results of our study, muscle activation while squatting on a vibrating plate without added weights, with small vibration amplitudes is unlikely to represent a form of high intensity exercise for well-trained and young individuals hence reducing the possibilities of triggering meaningful adaptive responses similar to that produced by heavy resistance exercise in this population. However, because of the variability of responses, a type II error may also be present in our study that was originally powered to the results of Bosco *et al.* (2000). The observed power of the treatment by time interactions was in fact 0·27 (T) and 0·38 (IGF-1). This suggests that quite a large sample size would be required to achieve 80% power and to rule out a Type II error.

Further studies are required to analyse the acute affects of different WBV frequencies and amplitudes in young individuals. Furthermore, because of the effectiveness of this novel form of exercise on bone and muscle, and the promising acute effects observed in elderly subjects (van Nes *et al.*, 2004) future studies should be conducted in the elderly, in order to provide specific guidelines for safe and effective WBV exercise programmes.

References

Ahtiainen JP, Pakarinen A, Kraemer WJ, Hakkinen K. Acute hormonal responses to heavy resistance exercise in strength athletes versus nonathletes. *Can J Appl Physiol* (2004); **29**: 527–543.

Ando H, Noguchi R. Dependence of palmar sweating response and central nervous system activity on the frequency of whole-body vibration. *Scand J Work Environ Health* (2003); **29**: 216–219.

Ariizumi M, Okada A. Effect of whole body vibration on the rat brain content of serotonin and plasma corticosterone. *Eur J Appl Physiol Occup Physiol* (1983); **52**: 15–19.

Bosco C, Colli R, Introini E, Cardinale M, Tsarpela O, Madella A, Tihanyi J, Viru A. Adaptive responses of human skeletal muscle to vibration exposure. *Clin Physiol* (1999); **19**: 183–187.

Bosco C, Iacovelli M, Tsarpela O, Cardinale M, Bonifazi M, Tihanyi J, Viru M, De Lorenzo A, Viru A. Hormonal responses to whole-body vibration in men. *Eur J Appl Physiol* (2000); **81**: 449–454.

Cardinale M, Bosco C. The use of vibration as an exercise intervention. *Exerc Sport Sci Rev* (2003); **31**: 3–7.

Cardinale M, Lim J. Electromyography activity of vastus lateralis muscle during whole-body vibrations of different frequencies. *J Strength Cond Res* (2003); **17**: 621–624.

Cardinale M, Wakeling J. Whole body vibration exercise: are vibrations good for you? *Br J Sports Med* (2005); **39**: 585–589; discussion 589.

Crewther B, Cronin J, Keogh J. Gravitational forces and whole body vibration: implications for prescriptions of vibratory stimulation. *Phys Ther Sport* (2004); **5**: 37–43

De Ruiter CJ, Van Der Linden RM, Van Der Zijden MJ, Hollander AP, De Haan A. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. *Eur J Appl Physiol* (2003); **88**: 472–475.

Delecluse C, Roelants M, Verschueren S. Strength increase after whole-body vibration compared with resistance training. *Med Sci Sports Exerc* (2003); **35**: 1033–1041.

Di Loreto C, Ranchelli A, Lucidi P, Murdolo G, Parlanti N, De Cicco A, Tsarpela O, Annino G, Bosco C, Santeusanio F, Bolli GB, De Feo P. Effects of whole-body vibration exercise on the endocrine system of healthy men. *J Endocrinol Invest* (2004); **27**: 323–327.

Gosselink KL, Roy RR, Zhong H, Grindeland RE, Bigbee AJ, Edgerton VR. Vibration-induced activation of muscle afferents modulates bioassayable growth hormone release. *J Appl Physiol* (2004); **96**: 2097–2102.

Kerschan-Schindl K, Grampp S, Henk C, Resch H, Preisinger E, Fialka-Moser V, Imhof H. Whole-body vibration exercise leads to alterations in muscle blood volume. *Clin Physiol* (2001); **21**: 377–382.

Kraemer WJ, Ratamess NA. Hormonal responses and adaptations to resistance exercise and training. *Sports Med* (2005); **35**: 339–361.

Kraemer WJ, Fleck SJ, Dziados JE, Harman EA, Marchitelli LJ, Gordon SE, Mello R, Frykman PN, Koziris LP, Triplett NT. Changes in hormonal concentrations after different heavy-resistance exercise protocols in women. *J Appl Physiol* (1993); **75**: 594–604

McCall GE, Grindeland RE, Roy RR, Edgerton VR. Muscle afferent activity modulates bioassayable growth hormone in human plasma. *J Appl Physiol* (2000); **89**: 1137–1141.

van Nes IJ, Geurts AC, Hendricks HT, Duysens J. Short-term effects of whole-body vibration on postural control in unilateral chronic stroke patients: preliminary evidence. *Am J Phys Med Rehabil* (2004); **83**: 867–873.

Rittweger J, Beller G, Felsenberg D. Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin Physiol* (2000); **20**: 134–142.

Rittweger J, Schiessl H, Felsenberg D. Oxygen uptake during whole-body vibration exercise: comparison with squatting as a slow voluntary movement. *Eur J Appl Physiol* (2001); **86**: 169–173.

Rittweger J, Ehrig J, Just K, Mutschelknauss M, Kirsch KA, Felsenberg D. Oxygen uptake in whole-body vibration exercise: influence of vibration frequency, amplitude, and external load. *Int J Sports Med* (2002) **23**: 428–432.

Roelants M, Delecluse C, Goris M, Verschueren S. Effects of 24 weeks of whole body vibration training on body composition and muscle strength in untrained females. *Int J Sports Med* (2004); **25**: 1–5.

Rubin CT, Recker R, Cullen D, Ryaby J, McCabe J, McLeod K. Prevention of postmenopausal bone loss by a low-magnitude, high-frequency mechanical stimuli: a clinical trial assessing compliance, efficacy, and safety. *J Bone Miner Res* (2004); **19**: 343–351.

Torvinen S, Kannus P, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Jarvinen TL, Jarvinen M, Oja P, Vuori I. Effect of a vibration exposure on muscular performance and body balance. Randomized cross-over study. *Clin Physiol Funct Imaging* (2002a); **22**: 145–152.

Torvinen S, Sievanen H, Jarvinen TA, Pasanen M, Kontulainen S, Kannus P. Effect of 4-min vertical whole body vibration on muscle performance and body balance: a randomized cross-over study. *Int J Sports Med* (2002b); **23**: 374–379.

Verschueren SM, Roelants M, Delecluse C, Swinnen S, Vanderschueren D, Boonen S. Effect of 6-month whole body vibration training on hip density, muscle strength, and postural control in postmenopausal women: a randomized controlled pilot study. *J Bone Miner Res* (2004); **19**: 352–359.

Wakeling JM, Nigg BM. Modification of soft tissue vibrations in the leg by muscular activity. *J Appl Physiol* (2001); **90**: 412–420.

Ward K, Alsop C, Caulton J, Rubin C, Adams J, Mughal Z. Low magnitude mechanical loading is osteogenic in children with disabling conditions. *J Bone Miner Res* (2004); **19**: 360–369.

