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Neuromuscular and hormonal responses to a single session of whole body vibration exercise in healthy young men

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Summary

Whole body vibration (WBV) has been proposed as an alternative exercise stimulus to produce adaptive responses similar to resistance exercise. Few studies have analysed acute hormonal responses to WBV.

Purpose To evaluate neuromuscular and hormonal responses to an acute bout of isometric half-squat exercise with and without superimposition of WBV.

Methods Seven healthy males (22·3 ± 2·7 years) performed 10 sets of half squat isometric exercise for 1 min with 1-min rest between sets. Two separate trials were conducted either with WBV [30 Hz; 3·5 g (1 g = 9·81 m·s^2)] or without vibration (Control). Salivary concentration of testosterone and cortisol was collected and maximal isometric unilateral knee extensions (MVC) were completed before, immediately after, 1, 2 and 24 h after treatment.

Results Significant decreases in MVC were observed immediately after (229·4 ± 53·2 Nm), 1 h (231·6 ± 59·9 Nm), and 2 h (233·0 ± 59·1 Nm) after WBV compared with baseline (252·7 ± 56·4 Nm; $P<0{\cdot}05$). No significant change in MVC was recorded in Control. Rate of torque development in the first 200 ms (RTD$_{200\ \mathrm{ms}}$), and salivary testosterone and cortisol concentrations were unaffected in both conditions. However, there was a trend for change over time in cortisol ($P = 0{\cdot}052$), with an increase after WBV and decrease after Control.

Conclusion A 10 min session of intermittent WBV was shown to produce an acute reduction in MVC in healthy individuals, which recovered after 24 h. No significant changes were identified in salivary concentration of testosterone and cortisol suggesting that WBV with low acceleration does not represent a stressful stimulus for the neuroendocrine system.

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Introduction

Over the last decade, vibration applied as an alternative exercise modality has received increasing interest. Investigations have centred on mechanical vibrations that suggest various physiological benefits from this novel exercise intervention on bone and muscle (e.g. Rubin *et al.*, 2001a,b; Roelants *et al.*, 2004a,b). It has been suggested that vibration exercise (VE) may be an alternative to heavy resistance training for stimulating musculoskeletal structures. It may also represent an effective non-pharmacologic, user-friendly therapeutic intervention to target several physiological systems. Previous work has suggested that vibration exposure elicits small but rapid changes in muscle length producing reflex muscle activity in an attempt to dampen the vibratory waves (Cardinale & Bosco, 2003). This reflex muscle activation is likely to be similar to the tonic vibration reflex (TVR; Hagbarth & Eklund, 1966). It seems that the muscle spindle primary endings are most responsive to vibration and thus responsible for the TVR (Roll *et al.*, 1989). For this reason, most of the studies have focused on examining the neuromuscular responses to WBV exercise (for review see Cardinale & Wakeling, 2005).

The endocrine system plays a major role in determining an individual's response to exercise. In particular, changes in the concentration of testosterone and cortisol have received significant attention due to their marked effects on muscle and bone remodelling (for review see Kraemer & Ratamess, 2005). Furthermore, due to their altered circulating levels with different forms of exercise, these hormones have been used to determine the physiological stress imposed during single and repeated exercise sessions. Testosterone is the major circulating androgen in the human male (Rommerts, 1998) and is produced in the hypothalamo-pituitary-testicular axis. Only 2% of testosterone in the blood exists in its free unbound form (Rommerts, 1998), the remaining 98% is bound to circulating proteins, such as serum hormone binding-globulin, which transport the hormone to its target tissues. Only free unbound steroids can enter saliva and the concentration of free testosterone in saliva is proportional to that in blood (Rommerts, 1998; Viru & Viru, 1999). It is only the free form that is able to exert metabolic effects, and contribute to the processes of muscular hypertrophy and bone growth.

Cortisol is the ultimate hormone in the hypothalamo-pituitary-adrenocortical (HPA) axis. Various stressors such as physical and emotional trauma generate afferent signals that eventually result in the secretion of cortisol. The actions of cortisol are largely antagonistic to those of testosterone and consequently the testosterone-to-cortisol ratio has been used as a measure of the body's anabolic–catabolic status (Kraemer, 2000). Alterations in salivary testosterone and cortisol have been observed following a single bout of resistance exercise (Kraemer *et al.*, 2001; Di Luigi *et al.*, 2006) or periods of intense training (Gomez-Merino *et al.*, 2003) in different age groups; suggesting that salivary assays are a useful noninvasive method to detect acute training responses.

Whole body vibration (WBV) exercise has been shown to acutely increase testosterone and growth hormone (GH) in healthy young individuals after a single bout of 10 min (Bosco *et al.*, 2000). However, both Di Loreto *et al.* (2004) and Cardinale *et al.* (2006) did not find any acute changes in testosterone and cortisol in healthy individuals undergoing 5 and 20 min of WBV exercise albeit with relatively small amplitude and frequencies of 27 and 30 Hz respectively. In a recent study Kvorning *et al.* (2006) reported an acute increase in testosterone, GH and cortisol but only when WBV was performed while squatting with a load equal to 10 RM. To our knowledge, no study to date has been conducted to evaluate the acute salivary hormone responses to a single bout of WBV exercise. The aim of this study was to evaluate the neuromuscular and hormonal responses in healthy young adult males following an acute bout of intermittent isometric half-squat exercise with and without the superimposition of WBV. It was hypothesized that WBV condition would induce greater force production during maximal isometric unilateral knee extensions (MVC) of the leg extensor muscles, a decrease in cortisol concentration and increase in testosterone concentration; also that the magnitude of effects with WBV would be greater than conventional isometric exercise (Control).

Methods

Seven healthy young adult males voluntarily participated in this study (age 22·3 ± 2·7 years, height 182·9 ± 7·1 cm, body mass 76 ± 8·8 kg). All testing procedures and the training protocol were explained and subjects gave written informed consent prior to participating in the study. Ethics approval was obtained from the Grampian Research Ethics Committee. All subjects were screened for contraindications to VE (i.e. recent fractures, taking supplements, cancer, enrolled in strength training programmes or having metallic plates on their bones) prior to commencement of the study and were asked to replicate their physical activity level and dietary intake, and to refrain from consuming alcohol for both treatment weeks. Subjects completed two familiarization trials to ensure they could execute the correct technique for maximal isometric unilateral leg extensions.

Study protocol

This study consisted of two separate treatment days, which were separated by a washout period of 2 weeks, and the treatments applied using a randomized cross-over design. On the morning of the treatment days and the day after the treatments (24 h post), subjects reported to the laboratory following an overnight fast. Upon arrival, subjects were asked to rinse their mouth thoroughly with water and then sit at rest for 10 min. After providing the first saliva sample (Pre; see Saliva), subjects completed a 5 min standardized warm-up cycling on a cycle ergometer (Monark 824E; Ergomedic, Varberg, Sweden) 2·5 min at 30 W and 2·5 min at 60 W. Pre-treatment MVC were then performed (see Isometric dynamometry). The treatments under investigation were non-VE (Control) and VE. The order the subjects were to receive the two treatments (Control and VE) was randomly assigned. Each treatment session consisted of 10 sets of 60 s each with 60 s seated rest between sets. Subjects removed their shoes during the treatment period to ensure that the soles of the footwear would not dampen the vibrations and affect transmissibility. Each set was performed with subjects in an isometric half-squat position, with body mass distributed over the balls of the feet and heels raised off the vibrating platform to prevent vibrations being transmitted to the head. An upright relaxed seated posture was adopted during the rest period between sets. Immediately upon completion of treatment, a timer was started to monitor the time elapsed for the 1 and 2 h period after the tests. The immediate Post-exercise saliva sample was collected and MVCs were then performed. Subjects sat at rest between Post and 1 h Post tests and 1 h Post and 2 h Post-tests.

On the day after the treatment session (24 h Post) subjects reported to the laboratory in a fasted state at the same time as the previous morning. Testing the subjects at the same time each day negated any effects of circadian rhythm on hormonal status and performance of MVCs. The 24 h Post session consisted of identical procedures to the Pre treatment tests for collection of saliva sample, warm-up and five MVCs. After completing their first randomly assigned bout of exercise testing, subjects returned to the laboratory on the same day exactly 2 weeks later.

Saliva

Saliva samples were collected before treatment (Pre), immediately after the 10th (final) set of squatting (Post), 1 h (1 h Post), 2 h (2 h Post) and 24 h after squatting (24 h Post). Unstimulated saliva samples were collected in 5 ml aliquots when subjects drooled through a straw at each stage of the session. Following this procedure samples were kept on ice until the end of the session and then stored at −20°C until analysed.

Testosterone and cortisol concentration

Salivary testosterone concentration was determined by enzyme immunoassay using a commercially available kit (Salimetrics, salivary testosterone enzyme immunoassay kit, Catalogue No. 1-1402/1-141296; Salimetrics LLC., State College, PA, USA). Salivary cortisol concentration was also determined by enzyme immunoassay again using a commercially available kit (Salimetrics HS-Cortisol kit, Catalogue No. 1-0102/1-011296; Salimetrics LLC.). The manufacturer-reported correlations between serum and saliva were r (30) = 0·93, $P<0{\cdot}001$ for free testosterone and r (17) = 0·960, $P<0{\cdot}0001$ for cortisol. Samples were allowed to thaw completely, vortexed and centrifuged at 1500 **g** (at 3000 r.p.m.) for 15 min prior to assay. Instructions for each competitive immunoassay technique were provided by the manufacturer and these were followed to determine the concentrations of testosterone and cortisol in the saliva samples. A microtitre plate coated with rabbit antibodies to the hormone under investigation (testosterone or cortisol) was used for both assays. Standards and unknowns of each hormone compete with the enzyme conjugate (solution of testosterone or cortisol labelled with horseradish peroxidase) for the antibody-binding sites. The anti-testosterone/anti-cortisol-coated plate was incubated and unbound components were then washed away. The reaction of the peroxidase enzyme on the substrate tetramethylbenzidine measured bound enzyme conjugate. This reaction was stopped with 2 M solution of sulphuric acid in distilled water. The optical density of the plate wells, containing the standards and unknown samples, was read on a standard plate reader (Thomson Wellscan) at 450 nm. Average intra-assay coefficient of variation (CV) was 3·3% and 6·7% for high and low levels of testosterone concentration ($\text{pg}\cdot\text{ml}^{-1}$) respectively. Average inter-assay CV was 5·1% and 9·6% for high and low levels of testosterone concentration (pg ml^{-1}) respectively, (CVs as quoted by the manufacturer). Average intra-assay CV was 3·88% and 7·12% for high and low levels of cortisol concentration ($\mu\text{g 100 ml}^{-1}$) respectively. Average inter-assay CV was 6·69% and 6·88% for high and low levels of cortisol concentration ($\mu\text{g 100 ml}^{-1}$) respectively (CVs as quoted by the manufacturer).

Samples provided by each subject were analysed in the same assay to eliminate any inter-assay variance (Kraemer *et al.*, 2001). Commercially available standards and quality control samples were used for both assays (Salimetrics LLC.).

Isometric dynamometry

Maximal isometric unilateral leg extensions were performed on a Biodex System II (Biodex Medical Systems, Inc. New York, NY, USA). Only the right leg was tested in all subjects, regardless of the dominant limb. Knee and hip were at 90° flexion (where 0° is equal to full extension). The upper body and ankle were secured firmly by straps to restrict any movement (involvement of muscles distant to the leg extensors may assist performance) and prevent injury. The lever arm was adjusted so that the ankle strap was secured just above the medial malleolus. The knee was positioned so that the lateral femoral epicondyle was at the level of the centre of the powerhead shaft of the dynamometer.

Subjects were instructed to perform leg extensions with maximal effort pushing as hard and as fast as they could. They were asked to maintain the maximal contraction until told to relax. Five trials of 5 s MVCs, each separated by 1 min rest, were performed at every test point; verbal encouragement was given throughout. Maximal isometric torque-generating capacity, absolute rate of torque development (RTD) and rate of torque development in the first 200 ms ($\text{RTD}_{200\ \text{ms}}$) were determined from the trial with the maximum torque value and used as measures of performance in repeated trials. Absolute RTD was calculated by dividing the maximum torque prior to plateau by the duration of the initial rapid rise in torque (i.e. the time between the initial deviation from baseline resting torque until the plateau in torque) (Behm *et al.*, 2002). $\text{RTD}_{200\ \text{ms}}$ was calculated by dividing the torque value reached 200 ms after the initial deviation from baseline by 200 ms. Maximal isometric unilateral leg extensions were performed before squatting (Pre), immediately after the 10th (final) set of squatting (Post), 1 h (1 h Post), 2 h (2 h Post) and 24 h after squatting (24 h Post).

Whole body vibration

Subjects were exposed to vertical sinusoidal WBV using the NEMES device (NEMES LC; Ergotest, Rome, Italy). The parameters of the mechanical vibration stimulus were as follows: frequency 30 Hz; peak-to-peak displacement 4 mm; magnitude 3·5 g (where $1\ \text{g} = 9{\cdot}81\ \text{m}\cdot\text{s}^2$). A frequency of 30 Hz has been shown to be the optimal frequency for producing the greatest magnitude of response in EMG activity of vastus lateralis muscle during WBV in an isometric half-squat position (Cardinale & Lim, 2003).

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 (two-way ANOVA) with Bonferroni *post hoc* test was used to identify any statistically significant differences with treatment (Control, WBV) and time (Pre-, Post, 1 h Post, 2 h Post and 24 h Post) as within factors. Where significant differences were identified by two-way ANOVA, a one-way ANOVA with Dunnet's multiple comparison test was used. Unless otherwise stated values given in the text are mean ± standard deviation (SD). The level of significance was set at P<0·05.

Results

Baseline measure of MVC, RTD, $\text{RTD}_{200\ \text{ms}}$, and the salivary concentration of testosterone and cortisol were not statistically significantly (P>0·05) different between treatment conditions (Control, WBV).

Maximal isometric unilateral leg extension

No statistically significant treatment (Control, WBV) effect was observed for MVC (P = 0·07). However, two-way ANOVA revealed that there was a statistically significant main effect of time on MVC (P = 0·0006; Fig. 1). The post hoc repeated-measures ANOVA revealed statistically significant reductions in MVC across time in WBV condition only. MVC torque was significantly depressed immediately after (229·4 ± 53·2 Nm), 1 h (231·6 ± 59·9 Nm) and 2 h (233·0 ± 59·1 Nm) after WBV compared with baseline (252·7 ± 56·4 Nm; P<0·05). However, the 24 h Post MVC was not significantly different from that measured before WBV (P>0·05), showing that MVC had recovered to baseline level 24 h after WBV exposure. No statistically significant differences in MVC were observed between any other time points (P>0·05). There were no statistically significant temporal effects on MVC in Control condition (P>0·05).

Rate of torque development

There was no difference in absolute RTD either between treatments (Control versus WBV) or across time (Pre, Post, 1 h Post, 2 h Post, 24 h Post) (P>0·05; Fig. 2). Similarly, there were no statistically significant treatment (Control, WBV) or temporal (Pre, Post, 1 h Post, 2 h Post, 24 h Post) effects on $\text{RTD}_{200\ \text{ms}}$ (P>0·05; Fig. 3).

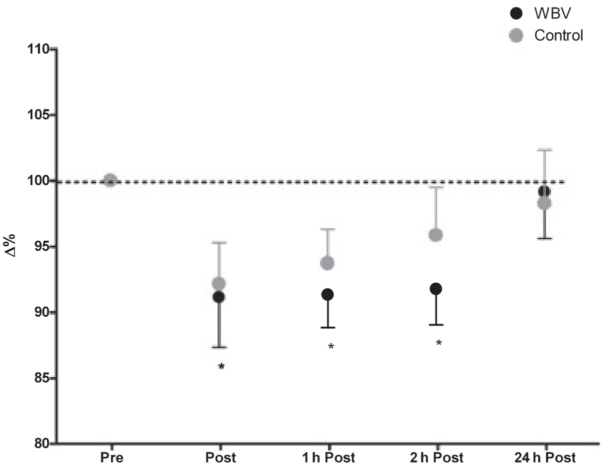

Figure 1 Short-term (treatment day and day after treatment) effects of Control and whole body vibration (WBV) treatments on maximal isometric unilateral leg extension performance (% deviation from baseline). Values shown are mean ± SD. *Statistically significant difference in maximal isometric unilateral knee extension (MVC) torque from baseline Pre MVC torque (P<0·05).

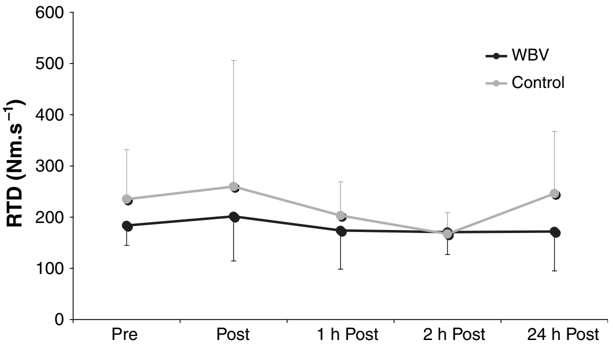

Figure 2 Short-term (treatment day and day after treatment) effects of Control and whole body vibration (WBV) treatments on absolute rate of torque development (Nm.s^{-1}). Values shown are mean ± SD.

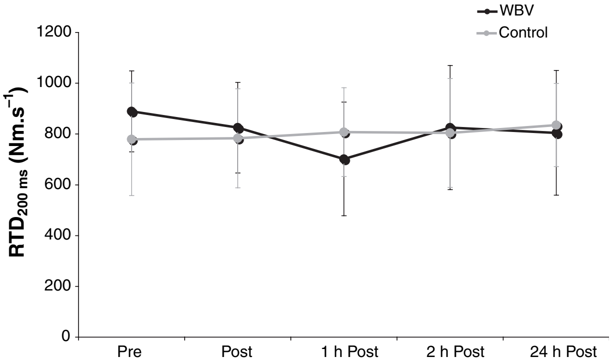

Figure 3 Short-term (treatment day and day after treatment) effects of Control and whole body vibration (WBV) treatments on rate of torque development in the first 200 ms (Nm.s^{-1}). Values shown are mean ± SD.

Hormones (testosterone and cortisol)

There were no statistically significant differences (P>0·05) in salivary testosterone concentration (Fig. 4) either between

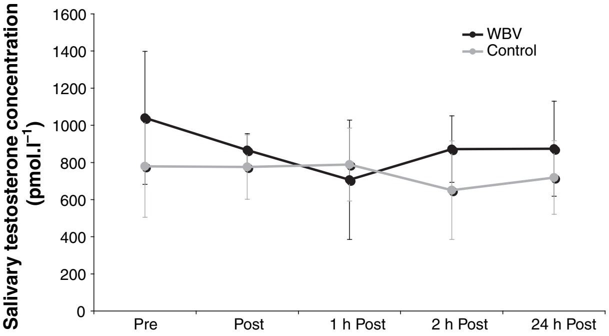

Figure 4 Short-term (treatment day and day after treatment) response of salivary testosterone concentration (ρmol.l^{-1}) to Control and whole body vibration (WBV) treatments. Values shown are mean ± SD.

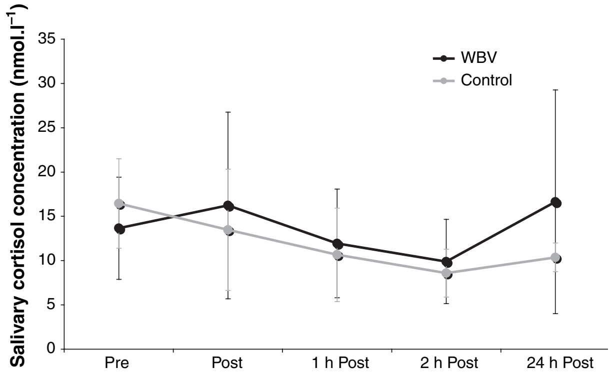

Figure 5 Short-term (treatment day and day after treatment) response of salivary cortisol concentration (nmol.l^{-1}) to Control and whole body vibration (WBV) treatments. Values shown are mean ± SD.

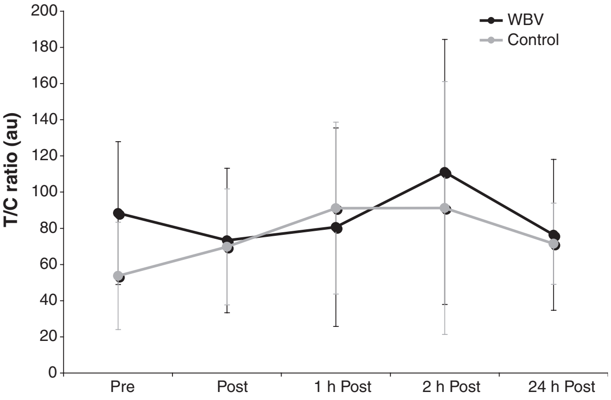

Figure 6 Short-term (treatment day and day after treatment) response of testosterone/cortisol (T/C) ratio to Control and whole body vibration (WBV) treatments. Values shown are mean ± SD.

treatments (Control, WBV) or across time (Pre, Post, 1 h Post, 2 h Post, 24 h Post). There were also no statistically significant differences ($P > 0{\cdot}05$) in salivary cortisol concentration (Fig. 5) either between treatments (Control, WBV) or across time (Pre, Post, 1 h Post, 2 h Post, 24 h Post). However, statistical analysis revealed a trend for salivary concentration of cortisol to increase over time ($P = 0{\cdot}052$) but only with the vibration treatment. There was also no statistically significant differences ($P > 0{\cdot}05$) in the T/C ratio (Fig. 6) either between treatments (Control, WBV) or across time (Pre, Post, 1 h Post, 2 h Post, 24 h Post).

Discussion

It was hypothesized that WBV condition would induce a decrease in cortisol concentration, an increase in testosterone concentration, and greater force production during a maximum isometric leg extension contraction. In addition, it was hypothesized that the magnitude of effects with WBV would be greater than conventional isometric exercise (Control). However, the results obtained do not support this hypothesis. There was no significant change in salivary hormone concentrations (testosterone and cortisol), and leg extensor muscle maximum voluntary isometric torque significantly decreased but only in the first 2 h after WBV treatment.

The results seem to suggest that WBV is not markedly stressful to this type of subject (i.e. young healthy males) while undergoing intermittent short duration bouts of WBV and when the magnitude of vibration is low. A recent study conducted in our laboratory showed that serum anabolic hormone levels were not affected by 20 min of WBV exercise with small amplitudes (Cardinale *et al.*, 2006). These findings support Di Loreto *et al.* (2004) who reported that an acute session of WBV had no effect on the serum concentrations of anabolic hormones such as GH, testosterone and insulin-like growth factor-I (IGF-I).

There was no significant change in the salivary concentration of either testosterone or cortisol following WBV or Control, although a trend ($P = 0{\cdot}052$) for an acute increase in cortisol concentration was observed after the treatment. The trend for an increase in cortisol concentration observed in the 2 h immediately after WBV is indicative of a typical stress response. The response involves activation of the HPA axis and the subsequent release of cortisol (Christiansen, 1998). An elevated salivary cortisol concentration appeared to be only a transient effect as the trend showed a steady decline during the 2 h period after WBV. Previous studies have shown that cortisol responses to vibration and acceleration load are quite marked in humans (Matoba *et al.*, 1985) and animals (Perremans *et al.*, 2001).

A threshold intensity and/or duration must be reached before a hormonal response is elicited (Viru *et al.*, 1996). The WBV stimulus employed in this study was under a threshold intensity to trigger a hormonal response in these subjects. As supportive evidence, the results of Kvorning *et al.* (2006) seem to suggest that in young healthy individuals WBV should be superimposed to high levels of muscle tension in order to elicit a marked hormonal response. In fact, in their study, the combination of squatting and WBV acutely increased both cortisol and testosterone concentrations, whereas WBV alone did not produce such an acute hormonal response (Kvorning *et al.*, 2006). In addition, the duration of WBV exposure may have been insufficient to elicit a physiological significant hormonal response. Whether WBV would impose a greater stress in other subject populations, for example in the elderly who experience some depression in endocrine system function, remains to be determined.

It is difficult to conclude whether the lack of hormonal responses observed in the present study, are typical of WBV exercise. The only randomized-controlled cross-over trials so far published (Di Loreto *et al.*, 2004; Cardinale *et al.*, 2006) have shown that WBV has no significant effect on serum concentrations of GH, IGF-I, free testosterone and total testosterone. The present results seem more in agreement with those of Di Loreto *et al.* (2004); WBV failed to significantly affect the pituitary-adrenal-gonadal axis. As acute hormonal responses reveal the level and type of physiological stress, the metabolic demands of the exercise and changes in metabolic homeostasis (Kraemer, 2000), we can conclude that for healthy fit individuals low acceleration WBV with static exercise does not represent a stressful form of exercise and is probably insufficient in stimulating a significant training effect.

Different vibration parameters can produce different effects in humans. In fact, vibration frequency seems to produce specific EMG responses in muscles (Wakeling *et al.*, 2002; Cardinale & Lim, 2003). However, as vibration amplitude and frequency together determine the acceleration (vibration magnitude) that is transmitted to the body (Cardinale & Wakeling, 2005), it is likely that high magnitudes may be necessary in healthy individuals in order to trigger specific hormonal responses. It has been reported that acceleration stress can produce powerful glucocorticoid and androgen responses (Obminski *et al.*, 1997), with salivary cortisol purported to be a good indicator for acceleration stress (Tarui & Nakamura, 1987). Vibration with an acceleration of 17 g produces the greatest perturbation of the gravitational field and thus represents the most intense stimulus, however it is appropriate to remember that specific ISO guidelines have been developed suggesting that high vibration magnitudes should not be applied to the whole body due to the possibility of negatively affecting the health of the user (for a review see Cardinale & Rittweger, 2006). The only possibility then to change the training load while performing VE seems to be to superimpose VE onto conditions requiring a high level of muscle tension, such as isometric or dynamic squatting with an added load.

Notwithstanding the lack of hormonal responses observed in our study, recent studies provide evidence that mechanical vibration-induced activation of muscle afferents is capable of producing a hormonal response by modulating the release of bioassayable growth hormone in both rats (Gosselink *et al.*, 2004) and humans (McCall *et al.*, 2000; for a review see McCall *et al.*, 2001). This novel muscle afferent-pituitary axis has been suggested to be involved in the maintenance of musculoskeletal integrity (Gosselink *et al.*, 2004) and further studies should explore whether a similar responses can be observed with WBV exercise.

It is evident from the present results and those of other studies that the force-generating capacity of human skeletal muscle can be both acutely and chronically affected by exposure to mechanical vibrations. The significant reduction in maximal isometric unilateral leg extension torque up to 2 h after WBV treatment only seems to suggest that a certain degree of neuromuscular fatigue can occur with certain durations of exposure. de Ruiter *et al.* (2003) in fact reported significant decreases in MVC, maximal force-generating capacity (MFGC) and voluntary activation of knee extensor muscles following five 60 s bouts of WBV (30 Hz; 8 mm). Both MVC and MFGC remained significantly depressed up to 2 h after WBV, but had recovered within the next hour (de Ruiter *et al.*, 2003). A similar effect was observed here with vibrations superimposed onto isometric exercise inducing muscular fatigue over time; an effect which persisted up to 2 h after treatment but had recovered 24 h later. However, this decline in MVC torque production was not observed at any time following Control treatment. Indeed long duration vibration exposure appears to have a negative effect on the ability of muscle to generate force. Thirty minutes of locally applied vibration (30 Hz; 1·5–3·0 mm) of the rectus femoris muscle caused significant decreases in maximal isometric force output, maximal rate of force development (dF/dt_{max}) and iEMG of this muscle (Kouzaki *et al.*, 2000; Jackson & Turner, 2003).

Despite these negative acute effects of vibration exposure, applied both locally and at a whole body level, WBV protocols have in fact been merited for their potential performance-enhancing qualities. Consensus appears to be somewhat lacking regarding the effects of WBV on neuromuscular performance. For example, acute WBV exposure has been reported to significantly increase average force, velocity and power in leg extensor muscles and significantly improve jumping performance (e.g. Bosco *et al.*, 1999, 2000; Torvinen *et al.*, 2002; Cochrane & Stannard, 2005). These findings appear to be in contrast to the present study. Not only was MVC, measured in isometric modality, unchanged but there was also no change in rate of force development (RTD; $RTD_{200\ ms}$) It is quite conceivable then that the performance outcomes following a period of VE are dependent upon the vibration parameters, exposure times, experimental subjects and training principles applied. Furthermore, de Ruiter *et al.* (2003), who applied tetanic stimulation to subjects' knee extensor muscles, observed a significant decline in voluntary activation during the 3 h following WBV. In support of our current findings, de Ruiter *et al.* (2003) reported a significant decrease in maximal voluntary knee extensor force that persisted up to 1 h after WBV.

In light of the present findings, where 10 min of intermittent WBV produced an acute transient reduction in MVC, but had no effect on the salivary concentrations of testosterone and cortisol, it is suggested that WBV with low acceleration does not represent a stressful stimulus for the neuroendocrine system of young healthy individuals. Furthermore, the data suggest that an acute bout of WBV performed in static position at a frequency of 30 Hz and peak to peak displacement of 4 mm does not produce an improvement in force-generating capacity of leg extensor muscles in healthy young men.

Nevertheless, future investigations should focus on determining the precise effects of WBV on neuromuscular performance and hormonal profile, in particular when different WBV magnitudes are applied to muscles producing different levels of tension. WBV represents an interesting form of exercise; potentially more practicable for elderly or disabled/injured individuals who may be unsuited to heavy resistance exercise or treadmill running.

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