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ORIGINAL ARTICLE

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Hormonal responses to whole-body vibration in men

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Abstract The aim of this study was to evaluate the acute responses of blood hormone concentrations and neuromuscular performance following whole-body vibration (WBV) treatment. Fourteen male subjects [mean (SD) age 25 (4.6) years] were exposed to vertical sinusoidal WBV, 10 times for 60 s, with 60 s rest between the vibration sets (a rest period lasting 6 min was allowed after 5 vibration sets). Neuromuscular performance tests consisting of counter-movement jumps and maximal dynamic leg presses on a slide machine, performed with an extra load of 160% of the subjects body mass, and with both legs were administered before and immediately after the WBV treatment. The average velocity, acceleration, average force, and power were calculated and the root mean square electromyogram (EMGrms) were recorded from the vastus lateralis and rectus femoris muscles simultaneously during the leg-press measurement. Blood samples were also collected, and plasma concentrations of testosterone (T), growth hormone (GH) and cortisol (C) were measured. The results showed a significant increase in the plasma concentration of T and GH, whereas C levels decreased. An increase in the mechanical power output of the leg extensor muscles was observed together with a reduction in EMGrms activity. Neuromuscular efficiency improved, as indicated by the decrease in the ratio between EMGrms and power. Jumping performance, which was measured using the counter-movement jump test, was also enhanced. Thus, it can be argued that the biological mechanism produced by vibration is similar to the effect produced by explosive power training (jumping and bouncing). The enhancement of explosive power could have been induced by an increase in the synchronisation activity of the motor units, and/or improved co-ordination of the synergistic muscles and increased inhibition of the antagonists. These results suggest that WBV treatment leads to acute responses of hormonal profile and neuromuscular performance. It is therefore likely that the effect of WBV treatment elicited a biological adaptation that is connected to a neural potentiation effect, similar to those reported to occur following resistance and explosive power training. In conclusion, it is suggested that WBV influences proprioceptive feedback mechanisms and specific neural components, leading to an improvement of neuromuscular performance. Moreover, since the hormonal responses, characterised by an increase in T and GH concentration and a decrease in C concentration, and the increase in neuromuscular effectiveness were simultaneous but independent, it is speculated that the two phenomena might have common underlying mechanisms.

Key words EMG · Growth hormone · Jumping performance · Testosterone · Whole-body vibrations

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Introduction

Recent studies have documented the effect of vibration on the neuromuscular apparatus. Acute treatment with whole-body vibration (WBV) has been shown to increase leg muscle force (F) and power ($\dot{W}$), and movement velocity. After 10 min of vibration treatment the velocity/F and $\dot{W}/F$ curves were shifted to the right (Bosco et al. 1999a). In 12 well-trained boxers, treated with 5 repetitions of 1-min vibration that was applied while their arms were kept in a semi-flexed position, an increase in the mechanical $\dot{W}$ of the arm was observed. The root mean square of the associated electromyogram (EMGrms) did not change following the vibration treatment, but the ratio of EMG/$\dot{W}$ decreased, showing an enhancement of neural efficiency (Bosco et al. 1999b). Apart from these acute effects, vibration may induce chronic adaptation changes in the mechanical behaviour of human skeletal muscles: a daily series of five vertical sinusoidal vibrations lasting 90 s each and imposed for a period of 10 days caused pronounced improvement of jumping performance (Bosco et al. 1998). These results suggest that vibration elicits short-term and long-term neurogenic adaptation. In accordance with this, previous studies have demonstrated a facilitation of the excitability of the patellar tendon reflex by vibration applied to quadriceps muscle (Burke et al. 1996), vibration-induced drive of α-motoneurones via the Ia loop (Rothmuller and Cafarelli 1995), and activation of the muscle spindle receptors (Kasai et al. 1992). However, muscle tissue can also be affected by vibration (Necking et al. 1992). In rats, a vibration-induced enlargement of slow- and fast-twitch fibres has been demonstrated (Necking et al. 1996).

A question arises as to whether vibration effects include adaptive changes and changes in endocrine functions. It has been shown that short-term intensive exercises such as 60-s consecutive jumps (Bosco et al. 1996a), anaerobic cycle exercises (Adlercreutz et al. 1976; Näveri et al. 1985; Buono et al. 1986; Farrell et al. 1987; Brooks et al. 1988; Kraemer et al. 1989; Schwarz and Kindermann 1990) and weight lifting (Kraemer et al. 1990; Schwab et al. 1993) evoke rapid hormonal responses. At the same time, certain relationships seem to exist between plasma concentrations of hormones and short-term performance: athletes with better explosive strength and sprint-running performances have a higher basal concentration of testosterone (T, Kraemer et al. 1995; Bosco et al. 1996b). It has been demonstrated that exercise-induced hormonal responses are significant not only for acute adaptation, but also for triggering long-term training effects (Inoue et al. 1994; Viru 1994; Kraemer et al. 1996). Similarly, the vibration-induced hormonal changes may be significant for chronic improvement of neuromuscular function in repeated exposure to vibration.

The aim of the present study was to test the possibility that WBV induces changes in the plasma concentration of hormones that are known to be associated with the adaptation of muscular activity.

Methods

Subjects

A group of 14 male subjects [mean (SD) age 25.1 (4.6) years, body mass (m_b) 80.9 (12.9) kg, height 177.4 (12.3) cm] voluntarily participated in the study. They were physically active and were engaged in a team sport training program three times a week. Each subject was instructed on the protocol and gave their written informed consent to participate in the experiment, which was approved by the ethical committee of the Italian Society of Sport Science. Subjects with a previous history of fractures or bone injuries were excluded from the study, as were those under the age of 18 years. The protocol consisted of performing jumping and mechanical $\dot{W}$ testing together with electromyographic (EMG) analysis of leg extensor muscles, as well as blood collection for analysis, before and immediately after the 10-min WBV treatment.

Testing procedures

The first blood sample was taken after the measurement of height and m_b. The subjects then performed a 10-min warm-up, consisting of 5 min of bicycling at 25 km/h on a cycle ergometer (Newform s.p.a., Ascoli Piceno, Italy), followed by 5 min of static stretching for the quadriceps and triceps surae muscles.

Jumping measurements

After the warm-up, as well as after the vibration exposure, the subjects performed three trials of a counter-movement jump (CMJ). The flight time (t_f) and contact time (t_c) of each single jump was recorded on a resistive (capacitative) platform (Bosco et al. 1983) that was connected to a digital timer (accuracy ±0.001 s; Ergojump, Psion XP, MA.GI.CA., Rome, Italy). To avoid unmeasurable work, horizontal and lateral displacements were minimised, and the hands were kept on the hips throughout the test. During CMJ the angular displacement of the knee was standardised so that the subjects were required to bend their knee to approximately 90°. The increase in the centre of gravity above the ground (height in m) was measured from t_f (s) by applying ballistic laws:

$$h = t_f^2 \cdot g \cdot 8^{-1}(\mathrm{m}) \quad (1)$$

where g is the acceleration due to gravity (9.81 $\mathrm{m} \cdot \mathrm{s}^{-2}$). The best performance was used for statistical analysis.

Reproducibility of jumping measurements

The reproducibility of the increase in the centre of gravity during CMJ performances was high $r = 0.90$ (Bosco and Viitasalo 1982).

Mechanical $\dot{W}$ measurements

After the jumping test, all of the subjects, who were well accustomed with the exercises, performed maximal dynamic leg-press exercises on a slide machine (Newform s.p.a.) with extra loads of 160% of the subject's m_b, corresponding to 70% of a one-repetition maximum (1RM), with both legs. Five attempts were made with 1-min intervals between each. Since two or three trials were needed to reach a plateau in performance, the last two trials of each set of

measurements recorded were averaged and used for statistical analysis, as recommended by Tornvall (1963) and Bosco et al. (1995). During the test, the vertical displacement of the load was monitored with a sensor (encoder) machine (Muscle Lab – Bosco System, Ergotest Technology, Langensund, Norway) that was interfaced to a PC. When the loads were moved by the subjects, a signal was transmitted by the sensor at every 3 mm of displacement. Thus, it was possible to calculate several parameters, such as average velocity, acceleration, average F, and average power ($\dot{W}$), corresponding to the load displacements (for details see Bosco et al. 1995). However, since it has been shown that $\dot{W}$ is the most sensitive parameter among all of the mechanical variables studied, it was the only one considered for statistical analysis (Bosco et al. 1995).

EMG analysis

The signals from the vastus lateralis and rectus femoris muscles of one leg were recorded during the leg-press measurements, with bipolar surface electrodes (inter-electrode distance 1.2 cm) that were fixed longitudinally over the muscle belly. An amplifier (gain ×600, input impedance 2 GΩ, common-mode rejection ratio 100 dB, band-pass filter 6–1500 Hz; Biochip Grenoble, France) was used. The MuscleLab encoder converted the amplified EMG raw signal to an average root-mean-square (rms) signal via its built-in hardware circuit network (Frequency response 450 kHz, averaging constant 100 ms, total error ±0.5%). The EMGrms is expressed as function of the time (mV or μV). Since the EMGrms signals were used in association with the biomechanical parameters measured with MuscleLab, they were sampled simultaneously at 100 Hz. The subjects wore a skin suit to prevent the cables from swinging and from causing movement artifacts. A personal computer (PC 486 DX-33 MHz) was used to collect and store the data. The values obtained for both the vastus lateralis and rectus femoris muscles were averaged for statistical analysis, as suggested by Bosco and Viitasalo (1982) and Viitasalo and Bosco (1982).

Reliability of the mechanical $\dot{W}$ and EMG measurements

Table 1 gives the mean value, SD, coefficient of correlation (r) and coefficient of variation (CV) of the results from the last two trials (trial 4 and trial 5). The CV showed results ranging from 6 to 12%, while high correlation coefficients were found ($r = 0.90$, 0.92, and 0.94 for $\dot{W}$, EMGrms and EMGrms: $\dot{W}$, respectively; $P < 0.001$).

Hormonal measurements

The first blood samples were drawn at 8.00 a.m. from an antecubital vein after the subjects had fasted for 12 h and rested for 1 day. The second blood sample was obtained right after the end of the vibration treatment. The subjects were asked to sit near to the vibration machine, where an appropriate setup was prepared for blood collection. The blood samples were drawn in the 1 min following the end of the vibration treatment. Serum samples to be used for the hormone determinations were kept frozen at −20 °C until assayed. The assays for serum total T and cortisol (C) were performed by radioimmunoassay (RIA) using reagent kits (Diagnostic Products Corporation, Los Angeles, Calif., USA). Growth hormone (GH) was measured using RIA reagent kits obtained from Radium (Pomezia, Italy). All samples from the tested subjects were analysed using the RIA counter (COBRA 5005, Packard Instruments, Meriden, USA). The Intra-assay coefficients of variation for duplicate samples were 3.63% for T, 5.1% for C and 2.1% for GH.

Table 1 Reliability of two successive trials (trials 4 and 5). Mean (SD) power ($\dot{W}$) expressed as a function of body mass, electromyogram root mean square (*EMGrms*), and the EMG/$\dot{W}$ ratio, measured during leg presses executed with a load of 100% of the subject's body mass ($n = 12$) before vibration treatment. (r Pearson product moment correlation coefficient, CV coefficient of variation for repeated measurements)

Variables	Trial 4	Trial 5	r	CV
$\dot{W}$ ($W \cdot kg^{-1}$)	11.6 (2.5)	11.3 (1.8)	0.90*	6.1
EMGrms (μV)	157.1 (71.5)	145.2 (70.6)	0.92*	12.3
EMGrms: $\dot{W}$ ($\mu V \cdot W^{-1}$)	13.6 (7.8)	12.9 (7.2)	0.94*	11.2

*$P > 0.001$

Treatment procedures

Subjects were exposed to vertical sinusoidal WBV using a device called the NEMES 30 L (KB Ergotest, Mikkeli, Finland). The frequency of the vibrations used in this study was set at 26 Hz (displacement = ±4 mm; acceleration = 17 g). The subjects were exposed ten times for a duration of 60 s, with 60 s of rest between each treatment. After five sets of vibration treatment the subjects were allowed 6 min of rest, and then a second set of five vibration treatments was administered. The WBV was performed with the subjects standing with their toes on the vibration platform; the knee angle was pre-set at 100° flexion. During all of the vibration treatments the subjects were asked to wear gymnastic-type shoes to avoid bruises.

Statistical methods

Ordinary statistical methods were employed, including the calculation of means (x) and SD. The Pearson product moment correlation coefficient (r) was used for test re-test measurement reliability. The SD and CV of test re-test measurements were calculated using the following equation (Thorstensson 1976).

$$CV = \left(200 \times \frac{SD}{\sqrt{2}}\right) \times (x_1 + x_2)^{-1} \quad (2)$$

where x_1 and x_2 are the mean average values of two successive measurements, and SD is the standard deviation of the mean differences between test re-test measurements. Differences between the mean values before and after the vibration treatment were tested for significance using Student's t-test for paired observations. The level of statistical significance was set at $P < 0.05$.

Results

The WBV treatment effected a significant increase in plasma concentrations of T ($P = 0.026$), and GH ($P = 0.014$), while C concentration decreased significantly ($P = 0.03$, Table 2). The mechanical $\dot{W}$ output of the leg extensor muscles, measured while performing maximal leg-press exercise, was significantly enhanced ($P = 0.003$), while the EMGrms detected in the leg extensor muscles reduced during test performance as

Table 2 Acute effects of whole-body vibration on blood concentrations of cortisol, testosterone and growth hormone. Values are given as the mean (SD)

Parameter	Before vibration	After vibration	P, paired t-test
Cortisol ($nmol \cdot l^{-1}$)	682 (255)	464 (257)	0.03
Testosterone ($nmol \cdot l^{-1}$)	22.7 (6.6)	24.3 (6.6)	0.026
Growth hormone ($ng \cdot ml^{-1}$)	6.2 (16.2)	28.6 (29.6)	0.014

Table 3 Average mechanical $\dot{W}$, EMGrms and counter-movement jump (*CMJ*) performances recorded before (*Pre*) and after (*Post*) vibration treatment. Statistically significant differences were analysed using Student's *t*-test for paired observations

Variables	Pre	Post	$P <$
$\dot{W}$ ($W \cdot kg^{-1}$)	11.4 (2.2)	12.2 (2.1)	0.003
EMGrms (μV)	151.8 (48.5)	136.4 (49.7)	0.008
CMJ (cm)	36.1 (5.2)	37.5 (5.1)	0.001

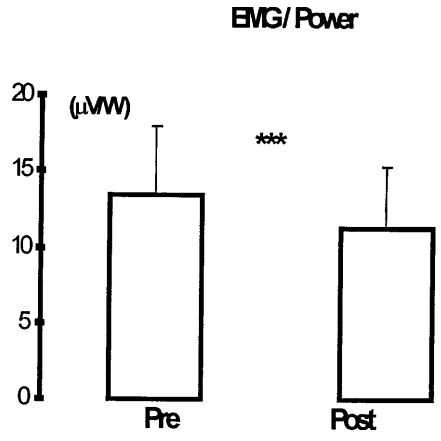

Fig. 1 Electromyogram (*EMG*)/average mechanical power recorded before (*Pre*) and after (*Post*) vibration treatment of the leg extensor muscle during leg-press exercise performed at 160% of the subject's body mass. **Statistically significant differences ($P < 0.001$) between the test performed before and after the treatment period

compared to pre-treatment values (see Table 3; $P = 0.008$). Consequently, the EMGrms: $\dot{W}$ ratio decreased ($P < 0.001$; see Fig. 1). The jumping performance was also positively affected by the vibration treatment, effecting a significant enhancement ($P < 0.001$; See Table 3).

Discussion

The results obtained show that an acute set of WBV treatments induces increased blood concentrations of T and GH. Since the C concentration decreased, the hormonal response to vibration reproduced neither a general stress reaction nor a response that is common for high-intensity exercises (Viru 1994). In exercise, the rapid endocrine activation is triggered by collaterals of the central motor command to the hypothalamic neurosecretory and autonomic centres. The responses are further supported by positive feedback influences from proprio- and metaboreceptors in muscles (see Kjaer 1992). In vibration, although certain cortical influences cannot be excluded (Bosco et al. 1998), the same cortically originating efferent pathways are not used, as has been shown to be in the case when performing voluntary contractions (Burke et al. 1996). Experiments on partially curarized subjects have demonstrated an increased central motor command that is associated with exaggerated activation of the pituitary-adrenocortical and sympatho-adrenal systems, as well as increased production of GH (Kjaer et al. 1987). Small doses of epidural anaesthesia were used to block the thin sensory afferent nerve fibres, leaving the thicker afferent fibres, and consequently the motor function almost intact. The essential role of nervous feedback from working muscles has been shown for corticotrophin and β-endorphin responses, but not for somatotropin, insulin, glucagon and catecholamine responses (Kjaer et al. 1989). Thus, the lack of a C response may be explained by the insufficient stimulation effect of both central motor command and nervous feedback from skeletal muscles. However, the decrease in C concentration allows us to suggest the occurrence of an accompanying inhibitory influence on the hypothalamic neurosecretory centres, probably from the hippocampal serotonergic structures (Knigge and Hays 1963). The pronounced responses of somatotropin and T indicate that there should be differences in the activation of various hypothalamic neurosecretory structures. These facts point to differences in the central control of various endocrine systems during vibration.

The design of this study does not allow us to comment on the metabolic effects of C, GH and T during vibration. Nevertheless, attention should be paid to the effects of vibration on muscle $\dot{W}$ and jumping performances, since the mechanical behaviour of the leg extensor muscles demonstrated a dramatic enhancement after WBV lasting only 10 min. However, a reasonable explanation for this improvement cannot easily be found, considering that the athletes in the present experiments were well accustomed with this type of exercise, and therefore any learning effect of the movement executed could be excluded. Enhancement of the performance of the leg extensor muscles has been observed after several weeks of heavy resistance training (e.g. Coyle et al. 1981; Häkkinen and Komi 1985). Such adaptation effects have been attributed to the improvement in neuromuscular behaviour caused by the increasing activity of the higher motor centres (Milner-Brown et al. 1975). The results of the present experiment suggest that the WBV caused an improvement of the neuromuscular efficiency, as demonstrated by the decrease in EMG activity of the leg extensor muscles associated with the increase in muscle $\dot{W}$ output. Similar observations were recently noted in well-trained boxers who were subjected to five repetitions of 1-min vibration applied to the arm. This treatment resulted in an increase in mechanical $\dot{W}$, and no change in the EMGrms. Consequently, the EMG: $\dot{W}$ ratio decreased (Bosco et al. 1999b). A reduction in EMG activity associated with a given concentration of force production has been noted at the end of a long-term resistance training program (Komi et al. 1978). In athletes trained with submaximal loads ranging from 70%–80% of 1RM, the maximal EMG response decreased at the beginning of the training program (Häkkinen and Komi 1985). Thus, it is likely that WBV treatment elicits a biological adaptation that is connected to the neural potentiation effect, similar to

that produced by resistance and explosive power training. In fact, this suggestion is consistent with the knowledge that the specific neuronal components and their proprioceptive feedback mechanisms are the first structures to be influenced by specific training (Bosco et al. 1983; Häkkinen and Komi 1985). There are several ways in which explosive power training can influence neural activation, such as by increasing the synchronisation activity of the motor units (Milner-Brown et al. 1975). In addition, an improvement in the co-contraction of synergists and increased inhibition of the antagonist muscles cannot be excluded. Whatever is the case, an intrinsic mechanism appears to exist, which enhances neuromuscular activation after specific explosive power training.

On the other hand, the possibility that T influences the nervous structures should not be excluded. Experiments on birds have shown that T has an effect on the up-regulation of acetylcholine receptors in muscle (Bleisch et al. 1984). It has been suggested that this T effect may be connected to the calcium-handling mechanism in skeletal muscles (Rolling et al. 1996). It should be noted that in human experiments, a positive relationship between the basal concentration of T and both sprinting and explosive power performances (evaluated with a CMJ test) has been observed (Bosco et al. 1996). Finally, the duration of the stimulus seems to be important. The adaptive response of human skeletal muscle to simulated hypergravity conditions (1.1 *g*), applied for only 3 weeks, caused a marked enhancement in the neuromuscular functions of the leg extensor muscles (Bosco 1985). In addition, chronic centrifugal force (2 *g*) applied for 3 months (Martin and Romond 1975) induced a conversion of muscle fibre type. In the present experiment, even if the total length of the WBV period was only 10 min, the perturbation of the gravitational field was dramatically high (17 *g*). An equivalent length of training stimulus can be reached only by performing 200 drop jumps from a height of 100 cm, twice a week for 5 months. In fact, the time spent performing each drop jump is about 150 ms, and the acceleration developed would barely reach 5 *g* (Bosco 1992).

In conclusion, we have shown that acute exposure to WBV causes increased plasma concentrations of T and GH, and a decreased plasma concentration of C. The increases in neuromuscular effectiveness and T concentration were simultaneous but independent responses, however the two phenomena may have a common mechanism.

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