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Abstract of the Ph.D. Thesis

The effects of vibration on human performance and hormonal profile

By

Marco Cardinale

Semmelweis University Doctoral School
Faculty of Physical Education and Sport Sciences

Doctoral Program:

Empirical and theoretical issues in sport sciences

Program Director: Prof. Dr. Frenkl Ròbert

Supervisor: Prof. Dr. Carmelo Bosco

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INTRODUCTION

Skeletal muscle is a specialised tissue, which modifies its overall function capacity in response to chronic exercise with high loads (e.g. Mc Donagh and Davies 1984). The adaptation to the training stimulus is related to the modification induced by the repetition of the daily exercise, which are specific for the movement executed (Edington and Edgerton , 1976). Strength training response has been shown to be mediated by both neurogenic and myogenic factors (e.g. Moritani and De Vries, 1979). Intensive prolonged strength training is known to induce a specific neuromuscular (e.g. Sale, 1988) and hormonal (e.g. Guezennec et al ,1986) adaptive responses in the human body in few months ,while the changes in the morphological structure occur later (e.g. Sale,1988). However, the exact mechanism which regulate how the body adapts to the specific demands upon it , is still unknown. In addition , even less knowledge are available in respect to fatigue, relative strength loss and hormonal changes during one acute session exercises (e.g. Hakkinen and Pakarinen 1995). It should be remind, that strength and explosive power training specific programs are based on exercises performed with rapid and violent variation of the gravitational acceleration (Bosco, 1992). Gravity normally provides the major portion of the mechanical stimulus responsible for the development of the muscle structure during everyday life and during training. In this connection, simulation of hypergravity (wearing vests with extra loads) conditions has been utilised for enhancement of human explosive muscle power (Bosco et al., 1984; Bosco 1985). On the other hand, changes of the gravitational conditions can be produced also by mechanical vibrations applied to the whole body. In light of the above observations, it can be assumed that application of whole body vibration and/or locally applied vibrations to physical active subjects could influence the mechanical behaviour of lower and upper limbs' muscles. Vibrations have been extensively studied in occupational medicine and ergonomics. It means that they represent some sort of stimulus to which all of us undergo in daily activities. Literature on vibration is mostly related to the study of vibrations as a diagnostic tool and on their effect on chronical exposure. In fact, most of the work has been carried out in occupational medicine and ergonomics and in animal experiments to be able to understand what is the effect of vibrations on human body. However, even if there is a respectable amount of scientific work on the topic, it is difficult to come to a consensus since different devices have been used and different vibration treatments have been utilised (changing frequency, acceleration and displacement). Moreover, the application of vibrations as an exercise tool is a rather new topic in literature (i.e. Issurin 1994, Issurin et al., 1999). Based upon the literature findings it is possible to affirm that vibrations provide a strong stimulus for the neuromuscular system, the bone and the muscle tissue itself. Not only that, hormonal responses have been identified in human and animal experiments following vibrations treatments (i.e. McCall et al., 2000; Dmitriev & Tropnikova, 1988). The aim of this work was to study the effects of vibrations on human performance and hormonal profile and to provide further information for applying vibration exercise in the athletic setting.

Research Hypotheses

The problem addressed in this series of studies was the effect of vibrations on human performance and hormonal profile. Based upon the literature findings, the following research hypotheses were generated:

1) Prolonged administration of vibration treatments produce enhancement of neuromuscular performance similar to the improvements obtained following explosive jumping training and resistance exercise

2) Acute effects of vibrations treatment modifications of neuromuscular performance and hormonal profile similar to the ones observed following resistance exercise or explosive jumping training

3) Vibration treatment lead to an improvement of neuromuscular efficiency.

METHODS

A total of sixtytwo subjects voluntarily participated to the studies. They were all physically active and involved in regular exercise. Their characteristics are presented in the following table:

Study	Number	Gender	Age (years) ± SD	Height (cm) ± SD	Weight (kg) ± SD
1	14	♂	20.2 ± 0.9	179.5 ± 10.1	72.8 ± 5.9
2	6	♀	19.5 ± 2.1	174.9 ± 3.2	65.1 ± 3.7
3	12	♂	20.1 ± 3.1	173.7 ± 7.2	69.6 ± 21.4
4	14	♂	25.1 ± 4.6	177.4 ± 12.3	80.9 ± 12.9
5	8	♂	30.7 ± 5.3	188 ± 4.7	89.3 ± 7.2
6	8	♂	21.8 ± 2.2	180.1 ± 6.4	81.4 ± 21.5

Anthropometric measures (height and weight) were recorded together with the age of the subjects at the beginning of each study.

Vertical Jumping. The followings jumping tests were performed: counter movement jump (CMJ) and 5s of continuous jumping (5s CJ).The flight time (tf) and contact time (tc) of each single jump were recorded on a resistive (capacitative) platform (Bosco et al., 1983) connected to a digital timer (accuracy ± 0.001s) (Ergojump, Psion XP, MA.GI.CA.Rome, Italy). To avoid un-measurable work, horizontal and lateral displacements were minimised, and the hands were kept on the hips through the test. During CMJ the knee angular displacement was standardised that the subjects were required to bend their knee approximately 90°. The rise of the centre of gravity above the ground (h in meters) were measured from flight time (tf in seconds) applying ballistic laws:

h = tf2 • g • 8-1 (m) [1]

where g is the acceleration of gravity (9.81 m•s-2). During CJ exercises the subject were required to perform the maximal jumping effort minimising knee angular displacement during contact. From the recordings of tf and tc the average mechanical power (AP), average rise of center of gravity (AH) were calculated for the total 5s continuos jumping. From 5s CJ the best jumping performance was selected and maximal mechanical power (PBJ) as well as the highest rise of center of gravity (HBJ) were obtained using the equation introduced by Bosco et al. (1983) :

AP = Tf • T • 24.06 • (Tc)-1 (W • kg bm-1) [2]

where P is the mechanical power per kilogram of body mass, Tf the sum of the total flight time, Tt the total working time (5s), and Tc the sum of the total contact time. The average height during 5s CJ and the HBJ were computed using formula [1]. The reproducibility of the mechanical power test (5s CJ) and CMJ performances were high with respectively r=.95 and r =.90 (Bosco et al., 1983; Viitasalo & Bosco, 1982).

Iso-inertial dynamometry was implemented in study 2,3,4,5 and 6. During the test, the vertical displacements of the loads were monitored with simple mechanics and sensor arrangement (Muscle Lab®, Ergotest Technology A.S., Langensund, Norway). The loads were mechanically linked to an encoder interfaced to an electronic microprocessor (Muscle Lab, Pat. No.1241671). When the loads were moved by the subjects a signal was transmitted by the sensor every 3mm of displacement. Thus it was possible to calculate average velocity (AV), acceleration, average force (AF), and average power (AP), corresponding to the load displacements (for details see Bosco et al., 1995).

The dynamic exercises reproducibility testing gave a test-retest correlation r = 0.95 for the average power (P) (Bosco et al., 1995).

Electromyography. EMG analyses were performed with bipolar surface electrodes (interelectrode distance 1.2 cm) including an amplifier (gain 600, input impedance 2Giga □, CMMR 100dB, band-pass filter 6-1500 Hz; Biochip Grenoble, France) fixed longitudinally over the muscle belly. The MuscleLab converted the amplified EMG raw signal to an average root-mean-square (rms) signal via its built in hardware circuit network (Frequency response 450kHz, averaging constant 100ms, total error ± 0.5%). The EMGrms was expressed in function of the time (millivolts or microvolts). Since the EMGrms signals were used in relation with bio-mechanical parameters measured with MucleLab, they were simultaneously sampled at 100Hz. The subjects wore a skin suit to prevent the cables from swinging and from causing movement artefact. A personal computer (PC 486 DX-33MHz) was used to collect and store the data.

Hormonal measurement. The first blood samples were drawn at 08:00 a.m from an antecubital vein after 12 hours fasting and 1 days resting. 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 hormone determinations were kept frozen at –20°C until assayed. The assay for serum total T and cortisol (C) were performed by radioimmunoassay (RIA) using reagent kits (Diagnostic Products Corporation, Los Angeles California, USA). Growth hormone was measured using RIA reagent kits obtained from radium (Pomezia, Italy). All samples from the tested subjects were analysed using RIA counter (COBRA 5005, Packard Instruments, Meriden, USA). The intra-assay coefficients of variations for duplicate samples were 3.63% for T, 5.1% for C and 2.1% for GH.

Blood lactate measurement. Peak lactate concentration was determined from the subject's ear lobe blood samples before test-1, and 3-5-7 min after 30r-N and 30r-V. The tests were de-proitenezed in ice -cold percloric acid for subsequent analysis of lactic acid (Enzymatic method, Biochimica, Boehring, Mannheim, Germany).

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

$$CV = (200x\frac{SD}{\sqrt{2}})x(x_1 + x_2)^{-1} \qquad [3]$$

where x1 and x2 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. Repeated measures ANOVA was also used in study 6. For all the studies, alpha was set at p<.05.

TREATMENTS. Whole body vibration was delivered to the body by means of vibrating plates (Galileo, Novotec, Germany and Nemes, Ergotest, Greece). Those specially designed machines were able to produce sinusoidal type of oscillations of relatively low amplitude (6 to 10 mm peak to peak). The frequencies used in the experiments were 26Hz and 30Hz. Vibration were locally applied by means of specially designed vibrating dumbbells (Galileo, Novotec, Germany) producing sinusoidal vibrations of relatively small amplitude (4 to 6 mm) and frequency (0-30 Hz).

RESULTS

The first experiment was aimed to analyse the effects of a chronic exposure to vibration exercise for 10 days on vertical jumping ability of physically active subjects. Average jumping height during 5s continuous jumping was shown to be significantly improved by 11.9% in the experimental group. The height of rise of centre of gravity and average power of the best jump recorded during 5s continuous jumping was also shown to improve. No changes were observed in counter movement jump. It was suggested that the adaptive response to vibration exercise was connected to neural factors since no increase in muscle size could be detected in less than 2 weeks of exercise. Also, vibrations were shown to affect stiffness modulation suggesting strong influence of vibration exposure on the Ia loop.

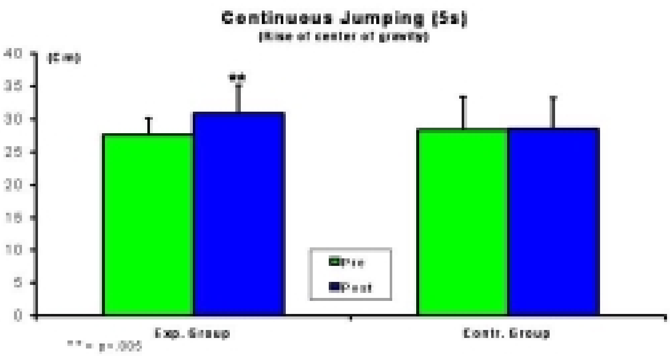


Fig.1. *The effects of 10 days of vibration on the height of rise of C.G. measured during continuous vertical jumps. Asterisk denotes statistically significant differences (p<.05)*

The second experiment was aimed to investigate the acute effects of vibration exercise on the force/velocity relationship of lower limbs. Five minutes exposure to vibration exercise in static position were shown to shift the force/velocity and the power/velocity curve to the right in professional volleyball players. It was suggested that the improvements in F/V and P/V relationship were due to neural factors connected to force generating capacity in human skeletal muscle. Neural adaptations have been quoted to be the main adaptive response leading to an increased force-generating capacity without a concomitant increase in cross-sectional area (i.e. Sale, 1988). Due to the short application of vibration treatment (five minutes) and the early gains observed, the neuromuscular aspects were underlined as predominant in determining the observed response.

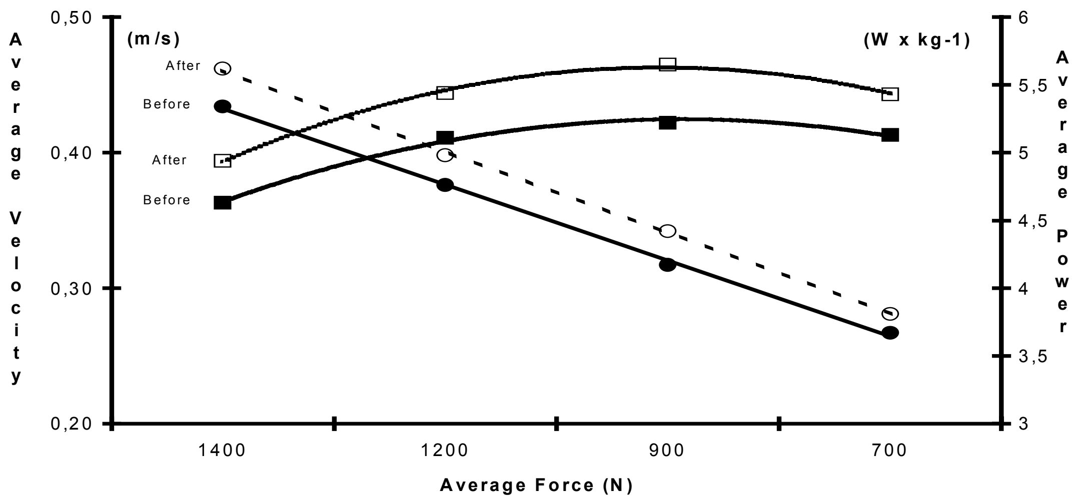
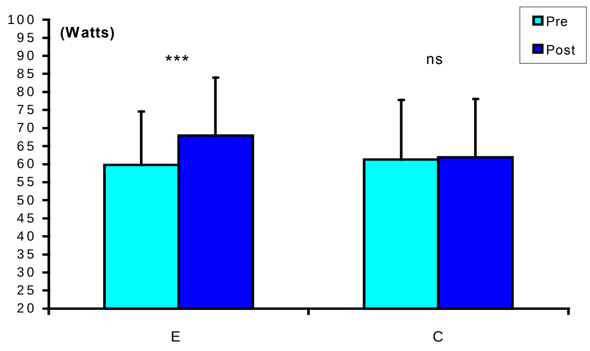


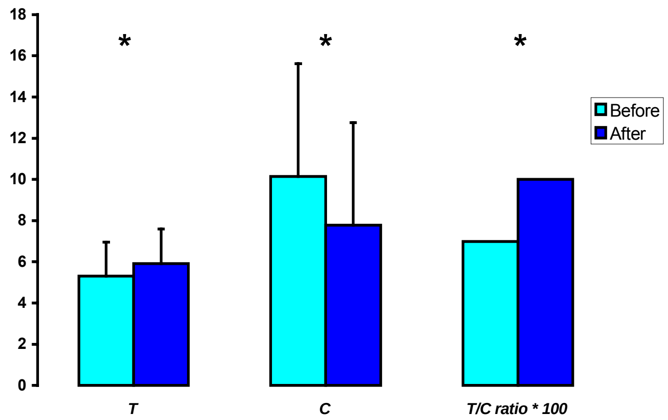
Fig.2. Force/velocity relationship and Power/velocity relationship measured with isoinertial dynamometry with 4 different loads during leg press exercise. All the data are significantly different form pre-treatment values. ($p<.05$).

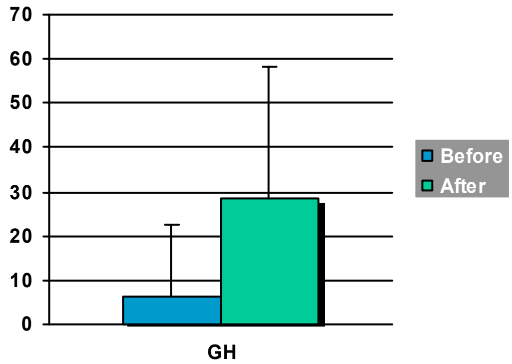
The third experiment tested the efficacy of vibration treatment on the upper limbs of well-trained international level boxers. It was found that five minutes vibrations with a protocol similar to the one used in experiment two were capable of enhancing arm flexors mechanical power by 13 %. EMG analyses showed a reduction in EMGrms activity following vibration exercise concomitant to an increase in average power. This finding suggested an increased neuromuscular efficiency following vibration exposure. EMGrms measured during vibration exposure was found to reach levels higher than 200% of the EMGrms measured in normal conditions, supporting the occurrence of the tonic vibration reflex with vibration exposure. The results supported the idea that acute adaptive responses to vibration exposure were connected to neural factors. In particular, the reduced EMG and the parallel increase in mechanical power suggested an increased efficiency of the□ □ and □ loop leading to an improved joint stiffness modulation.



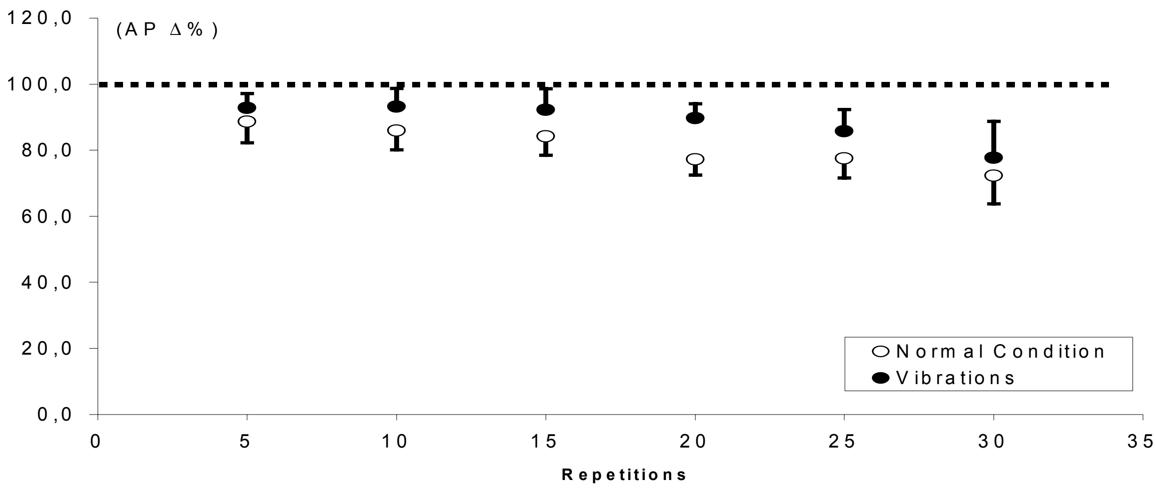
The fourth experiment was conducted in order to verify acute hormonal responses to vibration exposure in well-trained subjects. For this aim, a total of 7 minutes vibrations were administered through a vibrating plate to well-trained handball players. Vertical jumping ability was shown to decrease together with serum testosterone and serum cortisol concentrations. The results suggested that 7 minutes vibration represented a stressful treatment protocol leading to an impaired neuromuscular performance. The parallel decrease in Testosterone and cortisol levels also showed an impaired activity of pituitary-adrenocortical and pituitary-testicular axes with a 7 minute protocol.

The fifth experiment was conducted to analyse the effectiveness of a vibration exercise protocol different from the one used in experiment four on hormonal profile and vertical jumping ability. For this scope, a total of 10 minutes vibration treatment were administered divided in two sets of five sub-sets lasting one minute each, with 6 minutes rest in between sets. Testosterone levels were shown to improve by 7% following the vibration treatment. Growth hormone levels increased by 460% and cortisol levels decreased by 32%. A parallel enhancement of vertical jump was observed (+ 4%), together with an increased mechanical power of lower limbs during leg press exercise (+7%) and a reduced EMG activity of leg extensors muscles (-10%). The results suggested that the physiological responses to vibration exercise can vary depending on the protocol utilised. Moreover, considering the observed hormonal responses and the adaptations in neuromuscular performance, vibration exercise can represent an effective exercise intervention for increasing force-generating capacity and affecting hormonal profile even in well-trained populations.





The final experiment compared the effects of fatiguing exercise protocols with and without superimposed vibrations. From this study it was concluded that dynamic muscle activation with superimposed vibration produced an average power 8% higher than in normal conditions. EMG activity recorded during arm flexion with superimposed vibration was shown to be 14% higher than during the same task performed without superimposed vibrations. Peripheral factors were mainly involved in determining fatigue during the superimposed vibration task as shown by the negative relationship found between power and LA ($r = -.83$; $p < 0.05$). This phenomenon suggested that during superimposed vibrations larger motor units were most probably recruited leading to an increased power performance and to lactate accumulation as compared to the normal condition.



With reference to the current literature, the results of this thesis have confirmed:

1. Vibration exercise can lead to an increase in vertical jumping ability even in well-trained subjects

2. Vibration exercise can lead to an increase in mechanical power of lower limbs
3. Vibration exercise improves force-generating capacity of human skeletal muscles
4. Vibration exercise determines specific hormonal responses based upon the treatment protocol
5. Vibration exercise can improve neuromuscular performance and affect hormonal production based upon the duration and the characteristics of the vibration stimulus

Conclusions

These findings suggest that vibration could represent an effective exercise intervention for enhancing neuromuscular performance in athletes. However, it seems appropriate to consider other applications to the general population. We are convinced that vibration could be an effective exercise intervention for reducing the effects of aging on musculoskeletal structures. The potential influence of vibration on hormonal activity also opens interesting perspectives for its application in training and rehabilitation programs for different pathologies. Due to the enormous potentials of vibration exercise treatments, it is also important to study the effects of long-term vibration exercise programs on different physiological parameters and define safe exercise protocols based upon individual responses to vibration stimuli. Ultimately, the effects of vibration exercise on musculoskeletal interactions need to be analyzed, to verify the effectiveness of this form of exercise on bone remodelling, including the potential effects on osteoporosis.

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