HORMONAL RESPONSES ON THE WHOLE BODY VIBRATION IN MAN

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Introduction

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

A question arises whether vibration effects include adaptive changes also 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 exists between blood level of hormones and short-term performances: athletes with better explosive strength and sprint running performances have a higher basal level of testosterone (Kraemer et al. 1995, Bosco et al. 1996b). It has been demonstrated that exercise-induced hormonal responses have significance not only for acute adaptation but also for triggering long-terms training effects (Viru, 1994, Inoke et al. 1994, Kraemer, 1996). Similarly, the vibration induced hormonal changes may have significance for chronic improvement of neuromuscular function in repeated exposure to vibration.

The aim of the present study is to test the possibility that the whole-body vibration induces changes in blood hormone levels which may be related to acute effects in muscle performance.

Method

Subjects.

A group of fourteen male subjects (age 25.1 ± 4.6 years; weight 80.9 ± 12.9 ; height 177.4 ± 12.3) voluntarily participated to the study, they were physically active and were engaged in team sport training program 3 times a week . Each subject was instructed on the protocol and signed an informed consent, approved by the ethical committee of the Italian Society of Sport Science, to participate to the experiment. Subjects with previous history of fractures or bone injuries were excluded from the study together with the ones under the adult age. The protocol consisted on performing jumping and mechanical power measurements and EMG analysis of leg extensor muscles, as well as blood analysis collection before and immediately after 10-min whole body vibration treatment.

Testing procedures.

Each subject was asked to sign the informed consent before becoming part of the study and was instructed about the experiment. Anthropometric measures (height and weight) were taken together with the age of the subjects. Ten minutes warm up was performed consisting of 5 minutes of bicycling at 25 km/h on a cycle ergometer (Newform s.p.a., Ascoli Piceno, Italy) and five minutes of static stretching for the quadriceps and triceps surae muscles.

Jumping measurements .

After the warm up, the subjects performed three trials of a counter movement jump (CMJ) . 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 unmeasurable 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 center of gravity above the ground (h in meters) in were measured from flight time (tf in seconds) applying ballistic laws:

$$h = tf^2 \bullet g \bullet 8^{-1} \text{ (m)} \qquad (1)$$

where g is the acceleration of gravity (9.81 m .s-2). The best performance was used for statistical analysis.

Reproducibility of jumping measurements.

The reproducibility of the rise of center of gravity during CMJ performances were high r = 0.90 (Bosco and Viitasalo 1982).

Mechanical power measurements .

After the jumping test , all the subjects , well accustomed with the exercises , performed maximal dynamic leg press exercises on a slide machine (Newform s.p.a., Ascoli Piceno, Italy) with extra loads of 160 % of the subject's body mass (m_b) ,corresponding to 70 % of 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 trails of each set of measurements recorded were averaged and used by for statistical analysis as has been 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 A.S., Langensund, Norway), interfaced to a PC . 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 several parameters like average velocity, (V) acceleration, average force (F) , and average power (P) , corresponding to the load displacements (for details see Bosco et al.1995). However , since it has been shown that the P is the most sensitive parameter among all the mechanical variables studied , only the P was considered for statistical analysis (Bosco et al.1995).

EMG analysis.

The signals from the mm. vastus lateralis and rectus femoris of one leg , were recorded during the leg press measurements, with bipolar surface electrodes (interelectrode distance 1.2 cm) including an amplifier (gain 600, input impedance 2Giga Ω, 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 EMG_{rms} 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 artifact. A personal computer (PC 486 DX-33MHz) was used to collect and store the data. The values of both mm. vastus lateralis and rectus femoris were averaged for statistical analysis as suggested by Bosco and Viitasalo (1982) and Viitasalo and Bosco (1982) .

Reliability of the mechanical power and EMG measurements.

Table 1 gives mean value (x) , standard deviation (SD) , coefficient of correlation (r) and coefficient of variation (CV) of last two trails (trail-4 and trail-5) used for statistical analysis . The CV showed results ranging from 6 to 12 % , while the correlation coefficients found were ($r = 0.90$ - 0.94 ; $P<0.001$).

Hormonal measurements.

After 12h of fasting and one day of rest, blood samples were drawn at 8.00 a.m. from the antecubital vein. Serum samples for the hormone determinations were kept frozen at -20 °C until assayed. The assays of serum total testosterone (T) and cortisol (C) were performed by radioimmunoassays using reagent kits (Diagnostic Products Corporation, Los Angeles, California, USA). Growth hormone (GH) was measured using RIA reagent kits obtained from Radium (Pomezia,Italy). All samples of tested subjects were analysed utilising the RIA counter (COBRA 5005, Packard Instruments, Corporation, Meriden, USA). The Intra-assay coefficients of variation for duplicate samples were 3.63 % for T , 5.1% for C and 2.1 % for HG.

Treatment Procedures

Subjects were exposed to vertical sinusoidal whole body vibration (WBV) using the device called 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 60s with 60s of rest between the treatment each. After five times of vibration treatment (VT) it was allowed six minutes rest , before a second set of five VT was administrated .The application was performed in the standing position with the toes on the vibration platform, the knee angle was pre-set at 100° flexion. During all the treatments the subjects were asked to wear gymnastic-type shoes to avoid bruises.

Statistical methods

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

$$CV = \left(200 \times \frac{SD}{\sqrt{2}} \right) \times (x1 + x2)^{-1} \qquad (2)$$

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 .

Results

The whole body vibration resulted in significant increase of blood levels of testosterone (p=0.026) ,and growth hormone (p = 0.014) , while cortisol level decreased significantly (p = 0.03, Table 2). After VT the mechanical power output of the leg extensor muscles showed a significant increase (p=0.003) (fig. 1) , while the EMG_{rms} detected in the leg extensor indicated a reduced electrical activity of muscles (fig. 2) during test performance (p=0.008) . Consequently the ratio EMG_{rms} to power decreased (p<0.001), (fig.3). The jumping performances was also positively affected by the VT , demonstrating a significant enhancement (P <0.001) (fig.4).

Discussion

The results obtained showed that an acute set of whole body vibration induces increased blood levels of testosterone and growth hormone. Since the cortisol level decreased the hormonal response to vibration reproduced neither general stress reaction nor response common for high intensity exercises (Viru, 1992). 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 feed-back influences from proprio - and metabolic receptors in muscles (see Kjaer 1992). In vibration certain cortical influences cannot be excluded (Bosco et al. 1998), however they do not use the same cortically originated efferent pathways, as has been shown to be the case when performing voluntary contractions (Burke et al. 1976). Experiments on partially currarized persons showed that increased central motor command associated with exaggerated activation of pituitary-adrenocortical and sympatho-adrenal systems, as well as increased production of growth hormone (Kjaer et al. 1987). Using small doses of epidural anaesthesia to block the thin sensorial afferent nerve fibers and leaving thicker afferent fibers and, subsequently the motor function almost intact, the essential role of nervous feed-back from working muscles was shown for corticotrophin and ß-endorphin responses but not for somatotropin, insulin glucagon and catecholamine responses (Kjaer et al. 1989) Thus the lack of cortisol response may be explained by the insufficient stimulation effect of both central motor command and nervous feed-back from skeletal muscles. However, the decrease of cortisol concentration allows us to suggest accompanying inhibitory influence on hypothalamic neurosecretory centres, probably from the hippocampal serotonergic structures (Knigge, Hays 1963) . However, despite the suggested mild nervous activation of hypothalamic neurosecretory centres, the somatotropin and testosterone responses were pronounced. These facts point on the differences in the central control of various endocrine systems during vibration. The design of this study does not allow us to judge on the metabolic effects of cortisol, growth hormone and testosterone during vibration . On the other hand, attention should be paid also on the vibration effects on muscle power and jumping performances ,since the mechanical behaviour of the leg extensor muscles demonstrated a dramatic enhancement after VT lasting only ten minutes. However a reasonable explanation for this improvement cannot be easily found, considering that the athletes of the present experiments were well accustomed with this type of exercises and therefore any learning effect of the movement executed could be excluded. Enhancement of leg extensor muscles performances has been observed after several weeks of heavy resistance training (e.g. Coyle et al., 1981; Hakkinen & Komi, 1985). Such adaptation has been attributed to the improvement of the neuromuscular behaviour caused by the increasing activity of the higher motor centre (Milner-Brown et al., 1975). The results of the present experiment , are suggesting that the VT have caused an improvement of the neuromuscular efficiency, as it could be shown by the decrease of EMG activity of the leg extensor muscles associated with increase of P . Similar observation were recently noted in well trained boxers , treated with five repetitions of 1-min vibration applied to the arm . It was found, after VT , increase in mechanical power and no change of the EMGrms, consequently the ratio of EMG / Power decreased , suggesting an enhancement of the neural efficiency (Bosco et al. 1999b). Reduction of EMG activity associated with a given level of force production has been noted at the end of a long -term resistance training programme (Komi et al, 1978) . On the other hand , in athletes trained with sub-maximal loads of 70 %-80 % of 1 RM , it has also been shown decreasing of maximal EMG at beginning of the training programme (Hakkinen and Komi , 1985) . Thus , it is likely that the effect of VT treatment has elicited biological adaptation connected to neural potentiation producing effect similar to those produced by resistance and explosive power training . In fact, this suggestions is consistent with knowledge that mainly the specific neuronal components and its proprioceptive feedback mechanism are the first structure to be influenced by specific training (Bosco et al. 1981, Hakkinen and Komi , 1985). There are several ways in which the explosive power training can influence neural activation, for example by increasing the synchronisation activity of the motor units (Milner- Brown et al., 1975). It cannot be excluded also an improvement of co-contraction of synergist and increased inhibition of antagonist muscles. In any case, what ever it is the intrinsic mechanism which enhance neuromuscular activation after specific explosive power training . On the other side, a possibility for rapid influence of testosterone on nervous structures should not be excluded. Experiments on birds showed the testosterone effect on up-regulation of acetylcholine receptors in muscle (Bleisch et al. 1984). It has been suggested that the testosterone effect may be connected with calcium handling mechanism in skeletal muscles (Rolling et al. 1996) . It should be noted that in human experiments it has been shown positive relationship between basal level of T and both sprinting and explosive power performances evaluated with CMJ test (Bosco et al,1996) . Finally it should not be neglected that even if the intrinsic mechanism ,of both responses of neuromuscular functions and hormonal profile to VT, could not be explained , the duration of the stimulus seems to have relevant importance. Adaptive response of human skeletal muscle, to simulated hypergravity conditions (1.1 *g*), applied for only three weeks, caused a drastic enhancement of the neuromuscular functions of the leg extensor muscles (Bosco ,1985) . In addition chronic centrifugal force (2 *g*) for 3 months (Martin and Romond, 1975) induced conversion of fiber type. In the present experiment , even if the total length of the VT application period was not very high (only 10 minutes), the perturbation of the gravitational filed was dramatically high (17 *g*) . An equivalent length of training stimulus can be reached only by performing 200 Drop Jumps from 100 cm , twice a week for 5 months. In fact the time spent for each Drop Jump is about 150 ms , and the acceleration developed hardly can reach 5 g (Bosco 1992).

In conclusion, acute exposure to whole body vibration causes increased levels of testosterone and growth hormone and decreased concentration of cortisol in blood . On the one hand, even if the increases of neuromuscular effectiveness and testosterone concentration might be simultaneous independent responses, the two phenomenon might have some common mechanism .

Table 1. Reliability of two successive trials (trials 4 and 5) of the average power ($\bar{P}$) expressed in function of body mass ,electromyogram (EMG) and $\overline{EMG/(P)}$ measured during leg press executed with 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*
Power (W · kg $^{-1}$)	Mean	11.6	11.3	0.90*	6.1
	SD	2.5	1.8		
EMGrms (µV)	Mean	157.1	145.2	0.92*	12.3
	SD	71.5	70.6		
EMGrms/Power (µV ·W-^{1})	Mean	13.6	12.9	0.94*	11.2
	SD	7.8	7.2		

* P > 0.001

Table 2. Acute effects of whole body vibration on blood levels of cortisol, testosterone and growth hormone, (mean ± SD)

	Before vibration	After vibration	p in paired t-test
Cortisol (nmol·l $^{-1}$)	**682 ± 255**	**464 ± 257**	**0.03**
Testosterone (nmol·l^{-1})	**22.7 ± 6.6**	**24.3 ± 6.6**	**0.026**
Growth hormone (ng · ml^{-1})	**6.2 ± 16.2**	**28.6 ± 29.6**	**0.014**

Table 3. Average mechanical power , EMGrms), EMGrms / P,and CMJ performances recorded before (pre) and after (post) vibration treatment. Statistical significant differences were analysed using Student's t-test for paired observations.

Variables	**Pre**	**Post**	**P <**
Power (W · kg $^{-1}$)	**11.4 ± 2.2**	**12.2 ± 2.1**	**0.003**
EMGrms (µV)	**151.8 ± 48.5**	**136.4 ± 49.7**	**0.008**
EMGrms / Power (µV ·W^{-1})	**13.5 ± 4.4**	**11.3 ± 4. 0**	**0.001**
CMJ (cm)	**36.1± 5.2**	**37.5 ± 5.1**	**0.001**

Referenced

Adlercreuts H, Härkönen M, Kuoppasalmi K, Kosunen K, Näveri H, Rehunen S (1976) Physical activity and hormones. Adv Cardiol 18:144-157

Bleisch W, Lukie VN, Nottebohm F (1984) Modification of synapses in androgen-sensitive muscle. Hormonal regulation of acetylcholine receptor number in the songbirds syrinx. J Neurosci 4:786-793

Bosco C. (1985). Adaptive responses of human skeletal muscle to simulated hypergravity condition. Acta Physiol Scand 124: 507-513.

Bosco, C. (1992). The effects of extra-load permanent wearing on morphological and functional characteristics of leg extensor muscles. Published Doctoral Thesis, Universitè Jean-Monnet de Saint Etienne,France.

Bosco C,Viitasalo J (1982) Potentiation of myoelectrical activity of human muscles in vertical jumps .Electromyogr Clin Neurophysiol 22 :549-562

Bosco, C., Komi PV, Pulli M, Pittera C, and Montonen H, (1981). Considerations of the training of the elastic potential of the human skeletal muscle. Volleyball IFVB official magazine 2: 22-30

Bosco C,Luhtanen P,Komi PV (1983) A simple method for measurement of mechanical power in jumping. Eur J Apll Physiol 50 :273-282.

Bosco C., Belli A., Astrua M., Tihanyi J., Pozzo R., Kellis S., Tsarpela O., Foti C., Manno R., & Tranquilli C. (1995). Dynamometer for evaluation of dynamic muscle work. Eur J Appl Physiol 70 :379-386.

Bosco C, Tihanyi J, Rivalta L, Parlato G, Tranquilli C, Pulverenti G, Foti C, Viru M, Viru A (1996a) Hormonal responses to strenuous jumping effort. Jpn J Physiol 46:93-98

Bosco C, Tihanyi J, Viru A (1996b) Relationships between field fitness test and basal serum testosterone and cortisol levels in soccer players. Clin Physiol 16:317-322

Bosco C, Cardinale M, Tsarpela O, Colli R, Tihany J, von Duvillard SP, Viru A (1998) The influence of whole body vibration on jumping performance. Biol Sport 15:157-164.

Bosco C, Colli R, Introini E, Cardinale M, Iacovelli M, Tihanyi J, von Duvillard SP, Viru A (1999a) Adaptive responses of human skeletal muscle to vibration exposure. Clin Physiol, in press.

Bosco C, Cardinale M, Tsarpela O (1999b) Influence vibration on mechanical power and electromyogram activity in human arm flexor muscles. Eur J Appl Physiol, 79,4:306-311.

Brooks S, Burrin J, Cheetham ME, Hall GM, Yeo T, Williams C (1988) The response of the catecholamines and ß-endorphin to brief maximal exercise in man. Eur J Appl Physiol 57:230-234

Buono MJ, Yeager JE, Hodgden JA (1986). Plasma adrenocorticotropin and cortisol responses to brief high-intensity exercise in humans. J Appl Physiol 61:1337-1339

Burke JR, Schutten MC, Koceja DM, Kamen G (1996) Age dependent effects of muscle vibration and the Jendrassik maneuver on the patellar tendon reflex response. Arch Phys Med Rehabil 77:600-604

Coyle E., Feirin C., Rotkis T., Cote R., Roby F., Lee W., & Wilmore J. (1981). Specificity of power improvements through slow and fast isokinetic training. J Appl Physiol 51:1437-1442.

Farrell PA, Kjaer M, Bach FW, Galbo H (1987) Beta-endorphin and adrenocorticotropin response to supramaximal treadmill exercise in trained and untrained males. Acta Physiol Scand 130:619-62

Hakkinen K., & Komi P.V. (1985). Effect of explosive type strength training on electromyographic and force production characteristics of leg extensors muscles during concentric and various stretch-shortening cycle exercises. Scand J Sports Sci 7 (2): 65-76.

Milner-Brown H.S., Stein R.B., & Lee R.G. (1975). Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. Elettroenceph Clin Neurophys 38: 245-254.

Kasai T, Kawanishi M, Yahagi S (1992) The effects of wrist muscle vibration on human voluntary elbow flexion-extension movements. Exp Brain Res 90:217-220

Kjaer M (1992) Regulation of hormonal and metabolic responses during exercise in humans. Exerc Sport Sci Rev 20:161-184

Kjaer M, Secher NH, Bach FW, Sheikh S, Galbo H (1989) Hormonal and metabolic responses to exercise in humans: effect of sensory nervous blockade. Am J Physiol 257:E95-E101

Kjaer M, Secher NH, Galbo H (1987) Role of motor center activity for hormonal changes and substrate mobilization in humans. Am J Physiol 253:R687-R697

Knigge KM, Hays M (1963) Evidence of inhibitive role of hippocampus in neural regulation of ACTH release. Proc Soc Exp Biol Med 114:67-69

Komi PV, Viitasalo JT, Rauramaa R, Vihko V. (1978). Effect of isometric strength training of mechanical, electrical, and metabolic aspects of muscle function. Eur J Appl Physiol 40 (1):45-55

Kraemer WJ, Fleck SJ, Evans WJ (1996) Strength and power training: physiological mechanisms of adaptation. Exercise and sports Sciences Reviews 24:363-397

Kraemer WJ, Häkkinen K, Newton RV, Patton J, Harman EA, Dohi K, Bush I, Dziados JE (1995) Factors in various strength and power performance in men. In: Proceeding of the XVthe Congress of the International Society of Biomechanics. Jyväskylä, University of Jyväskylä, pp.508-509

Kraemer WJ, Marchitelli L, Gordon SE, Harman E, Dziados JE, Mello R, Frykman P, McCurry D, Fleck SJ (1990). Hormonal and growth factor responses to heavy resistance exercise protocols. J Appl Physiol 69:1442-1450

Kraemer WJ, Patton JF, Knuttgen HG, Mrachitelli LJ, Cruthirds C, Damokosh A Harman EA, Frykman PN, Dziados JE. (1989) Hypothalamic-pituitary-adrenal response to short durations high-intensity cycle exercise. J Appl Physiol 66:161-166

Martin, W.D., & E.H., Romond (1975). Effects of chronic rotation and hypergravity on muscle fibers of soleus and plantaris muscles of rat. Exp. Neurol. 49: 758-771

Näveri H, Kuoppasalmi K, Härkönen M (1985) Plasma glucagon and catecholamines during exhaustive short-term exercise. Eur J Appl Physiol 53:308-311

Necking LE, Dahlin LB, Frieden J, Lundborg G, Lundstrom R, Thornell LE (1992) Vibration-induced muscle injury. An experimental model and preliminary findings. J Hand Surg 17:270-274

Necking LE, Lundstrom R, Lundborg G, Thornell LE, Frieden J (1996) Skeletal muscle changes after short term vibration. Scand J Plast Reconstr Surg Hand Surg 30:99-103

Rolling GL, Hurst E, Fell RD, Roheleder M (1996) Effects of testosterone proprionate on strength and eccentric induced muscle damage. Med Sci Sports Exerc 28:S113

Rothmuller C, Cafarelli E (1995) Effects of vibration on antagonist muscle coactivation during progessive fatigue humans. J Physiol 485:857-864

Schwab R, Johnson GO, Housh TJ, Kinder JE, Weir JP (1993) Acute effects of different intensities of weight-lifting on serum testosterone. Med Sci Sports Exerc 25:1381-1386

Schwarz L, Kindermann W (1990) ß-endorphin, adrenocorticotropic hormone, cortisol and catecholamines during aerobic and anaerobic exercises. Eur J Appl Physiol 61:165-171

Thorstensson A (1976) . Muscle strength , fiber types and enzyme activities in man . Acta Physiol Scand 98 , [Suppl 443] : 1-45.

Tornvall G (1963) . Assessment of physical capabilities with special reference to the evaluation of the maximal working capacity . Acta Physiol Scand 58 , [Suppl 201] : 1- 101.

Viitasalo, J.T., & C. Bosco, (1982). Electromechanical behaviour of human skeletal muscles in vertical jumps. *Eur.J.Appl.Physiol.* 48: 253-261

Viru A (1994) Molecular cellular mechanisms of training effects. J Sports Med Phys Fitness 34:309-322

Leggend for Figures

Fig. 1 . Average mechanical power (ordinate) recorded before (pre) and after (post) vibration treatment of the leg extensor muscle during leg press exercise performed with 160 % of the subject's b_m.** The asterics denotes statistically significant differences (P<0.01), between the test performed before and after the treatment period.

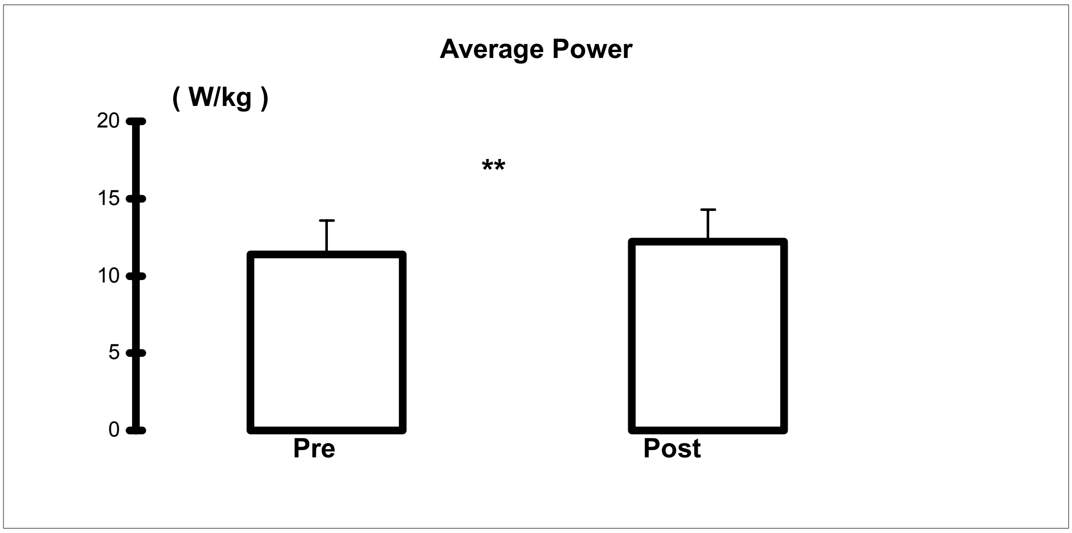
Fig. 2 . Eectromyogram (EMG rms) (ordinate) recorded before (pre) and after (post) vibration treatment of the leg extensor muscle during leg press exercise performed with 160 % of the subject's b_m. .** The asterics denotes statistically significant differences (P<0.01), between the test performed before and after the treatment period.

Fig. 3 . Eectromyogram /Average mechanical power (ordinate) recorded before (pre) and after (post) vibrationtreatment of the leg extensor muscle during leg press exercise performed with 160 % of the subject's b_m. .*** The asterics denotes statistically significant differences (P<0.001),between the test performed before and after the treatment period.

Fig. 4 . Rise of the center of gravity reached during Counter movement jump (ordinate) recorded before (pre) and after (post) vibrationtreatment of the leg extensor muscle during leg press exercise performed with 160 % of the subject's b_m. .*** The asterics denotes statistically significant differences (P<0.001),between the test performed before and after the treatment period.

Fig. 1

11.4 12.2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(W/kg)
20
15
10
5
0
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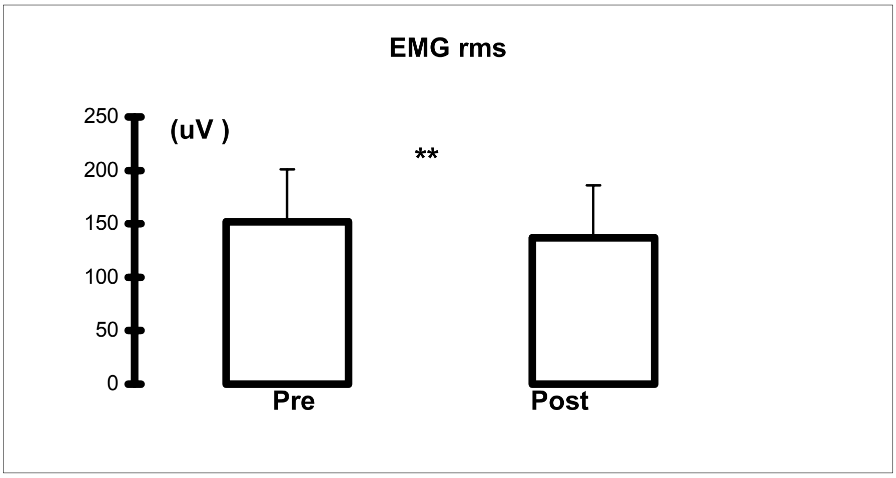
Pre
Post

Fig.2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250
200
150
100
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Pre
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Fig. 3

13,5 11,3

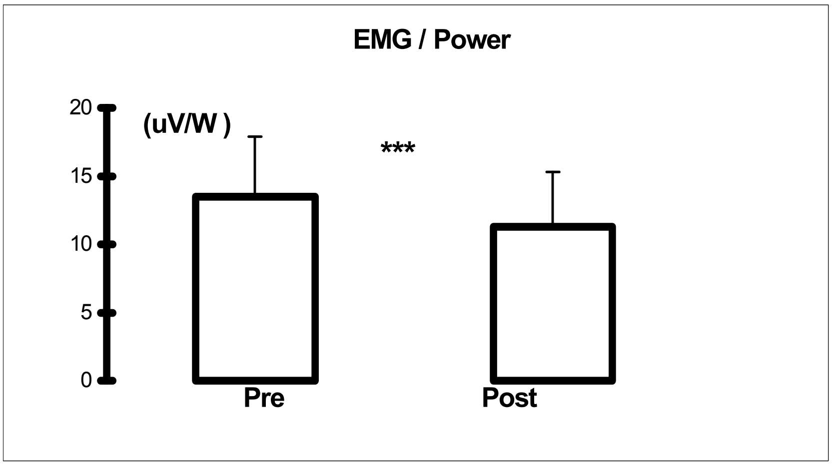

Fig. 4

36.1 37.5