
Short Communication

Adaptive responses of human skeletal muscle to vibration exposure

C. Bosco^{1,2,3}, R. Colli⁴, E. Introvini⁴, M. Cardinale⁵, O. Tsarpela¹, A. Madella⁶, J. Tihanyi³ and A. Viru⁷

¹University of Rome – Tor Vergata, Fondazione 'Don Gnocchi', Rome, Italy

²Department of Biology of Physical Activity, University of Jyväskylä, Finland

³Department of Biomechanics, Hungarian University of Physical Education, Budapest, Hungary

⁴Research and Study Center, Italian Cycling Federation

⁵Research and Study Center, Italian Handball Federation

⁶Italian Olympic Committee

⁷Institute of Exercise Biology, University of Tartu, Estonia

Received 24 February 1998; accepted 13 November 1998

Correspondence: C. Bosco, c/o Società Stampa Sportiva, Via G. Guinizzelli, 56, 00152 Rome, Italy

Summary

The aim of this study was to investigate the effects of whole-body vibrations (WBV) on the mechanical behaviour of human skeletal muscle. For this purpose, six female volleyball players at national level were recruited voluntarily. They were tested with maximal dynamic leg press exercise on a slide machine with extra loads of 70, 90, 110 and 130 kg. After the testing, one leg was randomly assigned to the control treatment (C) and the other to the experimental treatment (E) consisting of vibrations. The subjects were then retested at the end of the treatment using the leg press. Results showed remarkable and statistically significant enhancement of the experimental treatment in average velocity (AV), average force (AF) and average power (AP) ($P < 0.05$ – 0.005). Consequently, the velocity–force and power–force relationship shifted to the right after the treatment. In conclusion, it was affirmed that the enhancement could be caused by neural factors, as athletes were well accustomed to the leg press exercise and the learning effect was minimized.

Keywords: force/velocity, muscle mechanics, vibration.

Introduction

Skeletal muscle is a specialized tissue that modifies its overall function capacity in response to chronic exercise with high loads (e.g. McDonagh & Davies, 1984). Intensive prolonged strength training is known to induce a specific neuromuscular (e.g. Sale, 1988) and hormonal (e.g. Guezennec *et al.*, 1986) adaptive response in the human body in a few months, whereas changes in morphological structure occur later (e.g. Sale, 1988). However, the exact mechanism that regulates how the body adapts to the specific demands upon it is still unknown. Even less knowledge is available in respect of fatigue, relative strength loss and hormonal changes during one acute session of exercises (e.g. Hakkinen & Pakarinen, 1995; Bosco *et al.*, 1998). It should be remembered that specific programmes for strength and explosive power training are based on exercises performed with rapid and violent variation of the gravitational acceleration (Bosco, 1992). In this connection, it should also be borne in mind that changes in gravitational conditions can be produced by mechanical vibrations applied to the whole body. Whole-body vibration applied for 10 min during a

10-day treatment period induced an enhancement in explosive power performances in physically active subjects (Bosco *et al.*, 1998). After the latter experiment, the present study was conducted to observe how human skeletal muscle responded to a single session of 10-min application of whole-body vibration in well-trained athletes.

Methods

Six female volleyball players of national level (age 19.5 ± 2.1 years; weight 65.1 ± 3.7 kg; height 174.9 ± 3.2) participated in the study voluntarily. They were physically active and were engaged in a team sport training programme five times a week. Each subject was instructed on the protocol and gave informed consent to participate in the experiment. Subjects with a previous history of fractures or bone injuries were excluded from the study. The study design was approved by the ethical committee of the Italian Society of Sport Science.

Procedures

Ten minutes warm up was performed consisting of 5 min of bicycling at 25 km h^{-1} on a cycle ergometer (Newform, Ascoli Piceno, Italy) and 5 min of static stretching for the quadriceps and triceps surae muscles. After the warm up, all the subjects, well accustomed to the exercises, performed maximal dynamic leg press exercises on a slide machine (Newform) with extra loads of 70, 90, 110 and 130 kg. One leg per time was used for each load. The best trial of three measurements for each load was used for statistical analysis. During the test, the vertical displacements of the loads were monitored with a simple mechanics and sensor arrangement (Ergopower; Ergotest Technology, Langensund, Norway). The loads were linked mechanically to an encoder interfaced to an electronic microprocessor (Muscle Lab, patent no. 1241671). When the loads were moved by the subjects, a signal was transmitted by the sensor for every 3 mm 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).

Reproducibility of the measurements

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

Treatment procedures

Subjects were exposed to vertical sinusoidal whole-body vibration (WBV) using a device called Galileo 2000 (Novotec, Pforzheim, Germany). The frequency of the vibrations used in this study was set at 26 Hz (displacement = 10 mm; acceleration = 54 m s^{-2}). The subjects were exposed to the vibrations 10 times for a duration of 60 s with a 60-s rest between each treatment.

Type of treatment used

The application was performed in the standing position with the toes of one leg on the vibration platform, the knee angle was preset at 100° flexion, while the other was raised from the ground. During all the treatments, the subjects were asked to wear gymnastic-type shoes to avoid bruises. The leg exposed to vibration was assigned to E group, while the other not exposed was assigned to C group. Thus, in each subject, one leg was exposed to vibration (E) and the other was considered as a control (C). The leg randomly assigned to the E or C groups demonstrated similar mechanical behaviour before the vibration (VT) exposure (Table 1). Testing procedures were administered at the beginning (pre) and immediately after (post) the VT period.

Statistical methods

The Kolmogorov-Smirnov adapted test (D. Somers) was performed on account of the small sample to verify the possibility of using parametric statistics. All data except AV at 90 kg in the E group and 90 kg and 130 kg in the C group were normally distributed, and then differences were evaluated using Student's *t*-test. The above-mentioned data, not normally distributed, were analysed using the Wilcoxon test. Conventional statistical methods, including mean and standard deviation, were also performed. The level of significance was set at $P < 0.05$.

Table 1 Mean values (\bar{X}) \pm standard deviation (SD) of the average power (AP) per kg of body weight, average velocity (AV) and average force (AF) measured during leg press performances executed with progressive extra loads, before and immediately after WBV treatment, in the experimental leg and in the control leg.

Load (kg)		AP ($W \times kg^{-1}$)		AV ($m s^{-1}$)		AF ($m s^{-1}$)	
		Before	After	Before	After	Before	After
Experimental leg							
70	X	4.63	4.94**	0.434	0.462*	735	737
	SD	0.46	0.44	0.025	0.015	6	5
90	X	5.11	5.44**	0.376	0.398***	936	941*
	SD	0.44	0.43	0.011	0.003	8	9
110	X	5.22	5.65***	0.317	0.342***	1134	1138*
	SD	0.54	0.52	0.018	0.015	14	15
139	X	5.13	5.43***	0.267	0.281***	1324	1327*
	SD	0.66	0.7	0.028	0.027	20	19
Control leg							
70	X	4.6	4.6	0.431	0.436	737	736
	SD	0.5	0.3	0.032	0.010	5	5
90	X	5.05	5.3	0.371	0.387	937	937
	SD	0.4	0.4	0.016	0.022	11	12
110	X	5.4	5.4	0.327	0.328	1136	1137
	SD	0.5	0.5	0.019	0.013	5	15
139	X	5.2	5.4	0.272	0.279*	1324	1328
	SD	0.6	0.5	0.03	0.025	14	17

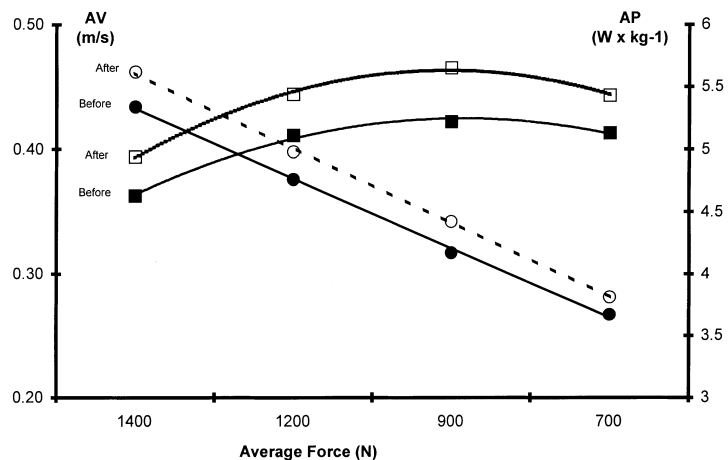
Significant difference before and after treatment: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Results

Before the VT period, no significant differences were found in the mechanical behaviour between the E and C legs in the parameters studied (AF, AV and AP) for all loads used (70, 90, 110 and 130 kg) (Table 1). After the VT period, the legs affected by vibration (E) showed statistically significant improvement (pre vs. post) of the AF, AV and AP developed with all loads used ($P < 0.05$ – 0.005) (Table 1). As a result, the veloc-

ity–force (V–F) and the power–force (P–F) curves (Fig. 1), established by the variables shown in Table 1, were shifted to the right after the VT period. Only the AF developed with 70 kg remained unchanged after the VT period. In contrast, the mechanical behaviour of the C legs demonstrated no changes in mechanical variables studied by the pre- and post-test analysis (Table 1). Only the AV developed with 130 kg showed a statistically significant improvement (near 3%) in the post-evaluation test ($P < 0.05$).

Figure 1 Average velocity (AV) and average power (AP) developed during leg press exercise performed with various loads (70, 90, 110 and 130 kg) are shown according to the average force (AF) before (filled symbols) and after (open symbols) the VT period. The statistical differences for AF, AV and AP values together with the different loads used are showed in Table 1.



Discussion

As expected, the pre- vs. post-test analysis performed for the C legs did not show any modification in the mechanical properties studied. This is not a surprising finding as, in half-squat exercises performed with extra load (100% of the subject's body mass), no change was observed in 12 female and male throwers during same day (Bosco *et al.*, 1995). However, the AV developed with 130 kg showed a statistically significant improvement in the post-evaluation test of the C leg ($P < 0.05$). A reasonable explanation for this improvement cannot easily be found, considering that the athletes in the present experiments were well accustomed to this type of exercise and, therefore, any learning effect of the movement executed could be excluded. The mechanical behaviour of the E legs demonstrated a dramatic alteration in the V-F and P-F relationships after VT lasting only 10 min. Changes in and shifting to the right of the force-velocity (F-V) relationship have been observed after several weeks of heavy resistance training (e.g. Coyle *et al.*, 1981; Hakkinen & Komi, 1985). The improvement in the F-V relationship has been attributed to the enhancement of neuromuscular behaviour caused by the increasing activity of the higher motor centre (Miller-Brown *et al.*, 1975). Thus, it is also likely that the VT caused a dramatic enhancement of the neural traffic regulating neuromuscular behaviour (Bosco *et al.*, 1998).

During vibration of the body, skeletal muscles undergo small changes in muscle length. Facilitation of the excitability of the spinal reflex has been elicited through vibration to the quadriceps muscle (Burke *et al.*, 1996). Lebedev & Peliakov (1991) pointed out the possibility that vibration may elicit excitatory flow through short spindle-motoneuron connections. Burke *et al.* (1976) suggested that the vibration reflex operates predominantly or exclusively on alpha motoneurons and does not use the same cortically originating efferent pathways as are used in the performance of voluntary contractions. However, a facilitation of voluntary movement cannot be excluded. In the present study, no neurogenic potentiation has been demonstrated, as no EMG recordings were performed. Nevertheless, enhancement of the mechanical behaviour strongly suggests that a neurogenic adaptation may have occurred in response to

the vibration treatments. Therefore, even if the intrinsic mechanism contributed, the adaptive response of neuromuscular functions to VT could not be explained by it. 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 3 weeks, caused a drastic enhancement of the neuromuscular functions of the leg extensor muscles, shifting the F-V relationship to the right (Bosco, 1985). In the present experiment, even if the total length of the VT application period was only 10 min, the perturbation of the gravitational field was consistent (5.4 g). An equivalent length and intensity of training stimulus can be reached only by performing 150 leg press or half-squat exercises with extra loads of three times the body mass twice a week for 5 weeks (Bosco, 1992).

References

- 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, Université Jean-Monnet de Saint Etienne, France.
- 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., COLLI R., BONOMI R., VON DUVILLARD S. P. & VIRU A. (1999) Monitoring strength training. Neuromuscular and hormonal profile. *Med Sci Sport Exerc*, (in press)
- BOSCO C., CARDINALE M., COLLI R., TIHANYI J., VON DUVILLARD S. P. & VIRU A. (1998) The influence of whole body vibration on jumping ability. *Biol Sport*, **15**, 157-164.
- BURKE J. R., RYMER W. Z. & WALSH H. V. (1976) Relative strength of synaptic inputs from short latency pathways to motor units of defined type in cat medial gastrocnemius. *Neurophysiology*, **39**, 447-458.
- BURKE J. R., SCHUTTEN M. C., KOCEJA D. M. & 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.

- GUEZENNEC Y., LEGER L., LHOSTE F., AYMUNOD M. & PESQUIES P. C. (1986) Hormone and metabolic response to weight-lifting training sessions. *Int J Sports Med*, **7**, 100–105.
- HÄKKINEN 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**, 65–76.
- HÄKKINEN H. & PAKARINEN A. (1995) Acute hormonal responses to heavy resistance exercise in men and women at different ages. *Int J Sports Med*, **16**, 507–513.
- LEBEDEV M. A. & PELIAKOV A. V. (1991) Analysis of the interference electromyogram of human soleus muscle after exposure to vibration (in Russian). *Neirofiziologia*, **23**, 57–65.
- MCDONAGH M. J. N. & DAVIES C. T. M. (1984) Adaptative response of mammalian skeletal muscle to exercise with high loads. *Eur J Appl Physiol*, **52**, 139–155.
- MILNER-BROWN H. S., STEIN R. B. & LEE R. G. (1975) Synchronization of human motor units: possible roles of exercise and supraspinal reflexes. *Electroenceph Clin Neurophys*, **38**, 245–254.
- SALE D. G. (1988) Neural adaptation to resistance training. *Med Sci Sports Exerc*, **20**, 135–145.