THE INFLUENCE OF WHOLE BODY VIBRATION ON THE MECHANICAL BEHAVIOUR OF SKELETAL MUSCLE

Bosco C. 1,2,3, M. Cardinale, 4, R. Colli 5, J. Tihanyi 3, S.P. von Duvillard 6, A. Viru 7

1 University of Rome -Tor Vergata, Fondazione “Don Gnocchi”, Rome, Italy
2 Department of Biology of Physical. Activity, University of Jyvaskyla, Finland
3 Department of Biomechanics, Hungarian University of Physical Education, Budapest, Hungary
4 Research and Study Center, Italian Handball Federation
5 **Research and Study** Center Italian Cycling Federation
6 Department of HPER, University of North Dakota, Grant Forks, USA
7 Institute of Exercise Biology, University of Tartu, Estonia

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Correspondence

Carmelo Bosco Ph.D.
C /o Societa Stampa Sportiva
Via G.Guinizzelli,56
00152 Roma,Italy
Phone+39335283024;+393482680265
Fax : + 39 6 5806526
E-mail : C.Bosco@ **Quipo.it**

ABSTRACT

The aim of this study was to investigate the effects of whole body vibrations on the mechanical behaviour of human skeletal muscles. For this purpose, fourteen physically active subjects were recruited and randomly assigned to an experimental (EG) and a control group (CG). The EG was treated fur ten days with 5 sets of vertical sinusoidal vibrations lasting up to two minutes each, for a total volume of ten minutes per day. The subjects of CG were asked to maintain their normal activity and avoid strength or jumping training. Subjects were tested at the beginning and at the end of the treatment with specific jumping tests performed on a resistive platform. Results showed remarkable and statistically significant enhancement in the EG of the height of the best jump (1.6 %, $P<O.5$), the mechanical power of the best jump (3.3 %, $P<O.5$) and the average jumping height during 5s Cj (12 %, $P<0.01$). In contrast, no statistically significant variations were noted in the CG. Consequently, it was suggested that the effect of WBV treatment elicit fast biological adaptation connected to neural potentiation.

INTRODUCTION

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 **[12].** Strength training response has been shown to be mediated by both neurogenic and myogenic factors [22]. The first phase of adaptation is characterised by an improvement of neural factors, while the myogenic factors becomes more important as the adaptations continues over several months (e.g. [20]. Enhancement of explosive power performance (e.g. jumping abilities) **and** the corresponding biological adaptations to a specific training stimulus are still not understood. Gravity normally provides the major portion of the mechanical stimulus responsible for the development of the muscle structure during everyday life and during training. 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 [8]_ In this connection, simulation of hypergravity (wearing vests with extra loads) conditions has been utilised for enhancement of human explosive muscle power [5,6], On the other hand, changes of the gravitational conditions can be produced also by mechanical vibrations applied to the whole body. Thus, in light of the above observations, it was assumed that application of whole body vibration to physical active subjects could influence the mechanical behaviour of the leg extensor muscles

METHODS

Fourteen subjects voluntarily participated to the study, they were physically active and were engaged in team sport training program 3 times a week. The subjects were not engaged in strength and explosive power training but participated regularly for tactical and technical training program according to the discipline practised (handball and water polo). They were equally divided into two groups: an experimental group (EG) and a control group (CG). 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. Table 1 presents physical characteristics of the subjects.

Procedures: Anthropometric measures (height and weight) were recorded together with the age of the subjects. Following this phase a ten minutes warm up was performed consisting of 5 minutes of bicycling at 25 kmh-1 on a cycle ergometer (Newform s.p.a., Ascoli Piceno, Italy) and five minutes of static stretching for the quadriceps and triceps surae muscles. After the warm up, the subjects peformed the followings jumping exercises: counter movement jump (CMJ) and 5s of continuous jumping (5s CJ).The flight time (tf) and contact **time** (t_c) of each single jump were recorded on a resistive (capacitative) platform [4] 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 gravity above the ground (h in meters) in were measured from flight time (t_f in seconds) applying ballistic laws:

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

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 t_f and t_c the average mechanical power (AP), average rise of center of gravity (AH) were calculated for the total 5s continues 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 [4] :

$$AP = T_f \bullet T \bullet 24.06 \bullet (T_c)^{-1} \quad (W \bullet kg \, bm^{-1}) \qquad (2)$$

where P is the mechanical power per kilogram of body mass, T_f the sum of the total flight time, T_t the total working time (5s), and T_c the sum of the total contact time. The average height during 5s CJ and the HBJ were computed using formula 1.

Reproducibility of *measurements:* The reproducibility of the mechanical power test (5s CJ) and CMJ performances were high with respectively r =.95 and r =,90 [4,27]

Statistical methods: Conventional statistical methods used included mean, standard deviation and paired Student’s t-test. The level of significance was set at p<.O5.

Treatment Procedures: Subjects were exposed to vertical sinusoidal whole body vibration (WBV) using the device called GALiLEO 2000 (Novotec, Pforzheim, tiermany) . The frequency of the vibrations used in this study was set at 26 Hz (displacement = 1 Omm; acceleration = $27 \, m \cdot s^{-2}$). The subjects were exposed five times for a duration of 90s with 40s of rest between the treatment each. This procedure was repeated for ten days, each day five seconds were added for each treatment up to a total of 2 minutes per position. Following the ten days the subjects of both groups were again tested and data were statistically analysed.

Type of treatment employed: The first applicaticm was performed in the standing position with the toes on the vibrations platform. The second bout was performed with the subject in the half squat position. The third application was realised with the feet rotated externally on the vibration platform. The knee angle was pre-set at 90° flexion. The fourth treatment was performed with the subjects standing on the leg on the right side of the vibration platform with the knee at 90° flexion. Finally the fifth application was given while the subjects standing on another leg on the left side of the vibration platform with the knee at 90° flexion. During the 4th and 5th treatment subjects were allowed to keep themselves in balance with the aid of a bar mounted on the platform. During all the treatments the subjects wear gymnastic-type shoes to avoid bruises. The E group was treated with WBV for ten days, the C group was not treated during the project and was asked to maintain their typical activities. Testing procedures were administered at the beginning and at the end of the experiments for both E and C groups.

RESULTS

After almost two weeks of regular technical and tactical training program, the subjects of the C group, as expected, failed to showed changes in any of the mechanical or anthropometric parameters studied ($P>0.05$). The jumping height in

CMJ remained the same in E group after 10 days of WBV (Table 2). This treatment, in contrast, produced remarkable and statistical significant ($P < 0.05$) enhancement of the HBJ (Fig. **1)** and the PBJ (Fig. 2). In addition, the average height during 5s CJ was also improved in E group, demonstrating a statistical significant difference of $P < 0.01$ (Table 2). On the other hand, the average power developed during 5s CJ failed to demonstrate statistically significant change after the treatment (Table 2).

DISCUSSION

Less than two weeks of regular tactical and technical training programme, as expected, did not induce any modification in the mechanical properties and anthropometric profile of the control subjects_ This is not a surprising findings, since no changes, in jumping performances, was noted after four weeks either in physical active subjects [14], or in volleyball players [2]. In contrast, a remarkable improvement of the neuromuscular characteristics studied was observed after the WBV period in the E subjects. Significant enhancement was noted for the HBJ (Fig. 1), PBJ (Fig. 2) and the average jumping height during 5s CJ (Table 2). On the other hand, no changes were noted for the AP during 5s CJ. It should be remind that, during the continues jumping test [4], the average jumping height possessed higher significance and sensitivity than AP in differentiating athletes [28] or in revealing the effect of creatine supplementation [9]. In addition no changes in CMJ were noted after the vibration treatment in E group. Apparently these are contradictory results. However, a reasonable explanation **can** be found analysing the mechanical behaviour of the leg muscles during CMJ and 5s CJ. In fact, both exercises are characterised by the so called stretch- shortening cycle (SSC). This means that, before the concentric work (pushing phase), leg extensor muscles are actively stretched (eccentric phase) in both exercises. Nevertheless, the neuromuscular activation in CMJ is different than that found in 5s CJ. The CMJ is characterised by large angular displacement and slow stretching speed (3-6 rad • s-l) [3], while 5s CJ are performed with fast stretching speed (1 O-12 rad • s-l) and small angular variation [7]. This means that, only in 5s CJ the leg extensor muscles experience fast stretching which may elicit a concurrent gamma dynamic fusimotor input that would enhance primary afferent discharge. This notion is supported by the studies of Bosco, et al. [3], who showed that during eccentric phase of drop jumping exercises (similar to 5s CJ), EMG activity was high and comparable to maximal concentric ballistic movements. Thus there is a possibility of enhanced neural potentiation either via spinal or cortical reflex. On the other hand, it is likely that CMJ is not a suitable activity to elicit stretch reflex, since high EMG activity has not been recorded during the stretching phase (e.g. [3]).

On the background of these considerations it is likely that the effect of WBV treatment elicits a biological adaptation connected with neural potentiation. Thus, it can be argued that, the biological mechanism produced by vibration treatment is similar to the effect produced by explosive power training (jumping and bouncing exercises). 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 [2,14].

Training with high stretching loads may improve stretch-reflex potentiation and increase the threshold of firing for the Golgi tendon organs (GTO). The latter one, would then improve the possibility to recruit greater amount of motor units during eccentric phase [2]. Furthermore, 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 [21]. 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, it is likely that, the vibration treatment have to improve the proprioceptors' feedback mechanism, since it is filly operating and elicited during 5s GJ performance, which was enhanced after WBW. On the other hand, the lack of modifications observed in GMJ test after the VBV treatment suggests that the proprioceptors' feedback mechanism is not strongly operating in CMJ. In fact, this exercise is strongly influenced by the voluntary recruitment capacity and by the fiber type composition of leg extensor muscles [1]. However, there is no doubt that stretch reflex play an important role in stiffness regulation [IS], and that muscle spindles and GTO operate actively in the control of muscle length and tension [16]. Consequently, it can be suggested that **WBV** treatment may affect dramatically the neuromuscular functions and properties which are regulating muscle stiffiess through the control of length and tension.

During vibration the body and the skeletal muscle undergo to small changes in muscle length. Facilitation of the excitability of spinal reflex has been elicited through vibration to quadriceps muscle [11). The idea that vibration may elicit excitatory flow through short spindle - motoneurons connections in the overall motoneuron inflow has been suggested also by Lebedev and Peliaksv [IX] pointed on the possibility. It has been shown also that vibration drives alpha-motoneurons via la loop, producing force without descending motor drive [25]. Burke et al. [**101,** suggested that vibration reflex operates predominantly or exclusively on alpha motoneurons and that it does not utilise the same cortically originating efferent pathways as are in the performance of voluntary contractions. In addition, the results of Kasai et al. [17] are consistent with vibration induced activation of muscle spindle receptors not only in the muscle where vibration is applied, but also to the nearest muscles. Mechanical vibration (10 - 200 Hz) applied to the muscle belly or the tendon can elicit a reflex muscle contraction (e.g.

[13]). This response has been named tonic vibration reflex (TVR). It is not known wheather it can be elicited by low WBV frequency (1-30 Hz), even if it has been suggested to occur [26].

Finally, it should be remind that not only nervous tissue, but also muscle tissue can be affected by vibration [23]. In fact, 5 hours daily for 2 days of vibration exposure at two different frequencies were sufficient to induce enlargement of slow and fast fibers in rats [24].

In the present study, no neurogenic potentiatian or modification in the morphological structure of the muscles was demonstrated since neither EMG recordings nor muscle biopsy sampling were performed. However enhanced mechanical behaviour during 5 s CJ, strongly suggests that a neurogenic adaptation have occurred in response to the vibration treatments. Even if the intrinsic mechanism of the adaptive response of neuromuscular functions to WBV could not be explained, the effectiveness of the stimulus seems to have relevant importance. Adaptive response of human skeletal muscle, to simulated hypergravity conditions (1.1g), applied for only three weeks, caused a drastic enhancement of the neuromuscular functions of the leg extensor muscles [6]. Chronic centrifugal force (2 g) for 3 months [19] has initiated conversion of fiber type. In the present experiment, the total length of the WBV application period was not very long (only 100 minutes), the perturbation of the gravitational filed was rather consistent (2.7 g) An equivalent length and intensity of training stimulus can be reached only by performing 200 drop jumps from 60 cm, twice a week for 12 months. In fact, the time spent for each drop jump is less than 200 ms, and the acceleration developed can hardly reach 2.7 g [8]. This means to stimulate the muscles for 2 min / week for the total amount in one year of 108 minutes, which is almost the total time of vibration applied to the E subjects.

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