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THE INFLUENCE OF WHOLE BODY VIBRATION ON JUMPING PERFORMANCE

C.Bosco[1,2,3], M.Cardinale[4], O.Tsarpela[1], 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]Dept. of Biology of Physical Activity, University of Jyväskylä, Finland; [3] Dept. of Biomechanics, Hungarian University of Physical Education, Budapest, Hungary; Research and Study Center, Italian [4] Handball and [5] Cycling Federations, Italy; [6] Dept. of HPER, University of North Dakota, Grant Forks, USA; [7] Institute of Exercise Biology, University of Tartu, Estonia

The effects of whole body vibrations on the mechanical behaviour of human skeletal muscles were studied in 14 physically active subjects randomly assigned to the experimental (E) or control (C) group. Group E was subjected to 5 sets of vertical sinusoidal vibrations lasting up to 2 min each, for 10 min daily, for a period of 10 days. The control subjects were requested to maintain their normal activity and to avoid strength or jumping training. The subjects were tested at the beginning and at the end of the treatment. The test consisted of specific jumping on a resistive platform. Marked, significant improvements were noted in Group E in the power output and height of the best jump (by 6.1 and 12 %, respectively; $P<0.05$) and mean jump height in continuous jumping for 5 s (by 12%, $P<0.01$). In contrast, no significant variations were noted in Group C. It was suggested that the effect of whole body vibration elicited a fast biological adaptation associated with neural potentiation.

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Introduction

The adaptation to a training stimulus is related to the modification induced by the repetition of the daily exercise, which are specific for the movement executed [11]. Strength training response has been shown to be mediated by both neurogenic and myogenic factors [21]. The first phase of adaptation is characterised by an improvement of neural factors, the myogenic ones gaining importance with the adaptation continuing for several months (e.g. [19]). The improvement of explosive power (e.g. jumping abilities) and the accompanying adaptations to a specific training stimulus are still poorly understood. Gravity normally provides the major portion of the mechanical stimulus responsible for the development of muscle structure in everyday life and in training. It should be remembered, that specific programs for strength- and explosive power-training employ exercises performed with fast, abrupt variations of the gravitational acceleration [8]. There-

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Reprint requests to: Prof. Carmelo Bosco, c/o Societá Stampa Sportiva, Via G.Guinizzelli 56; 00152 Roma, Italy

fore, simulation of hypergravity (wearing vests with extra loads) has been utilised for improving explosive muscle power [5,6]. On the other hand, changes of 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 the application of whole body vibration to physically active subjects could influence the mechanical behaviour of the leg extensor muscles.

Material and Methods

Fourteen physically active subjects volunteered to participate in the study. They were not engaged in strength or explosive power training but participated regularly in tactical and technical training in handball or waterpolo 3 times a week. They were randomly divided into two groups: experimental (E) and control (C). Each subject was familiarised with the experimental protocol and signed an informed participation consent, approved by the Ethical Committee of the Italian Society of Sport Science. Subjects with previous history of fractures or bone injuries and those underage were excluded from the study. Table 1 presents physical characteristics of the subjects.

Group	Experimental	Control
n	7	7
Age (years)	20.4±1.1	19.9±0.7
Body height (cm)	179.3±10.1	179.7±7.9
Body mass (kg)	74.8±8.2	70.9±3.7

Table 1

Mean (±SD) age, body height and mass of subjects studied

Procedures: After the body height and weight were recorded, a 10-min warm-up was applied consisting of ergometer (Newform, Ascoli Piceno, Italy) cycling at a rate of 25 $km \cdot h^{-1}$ for 5 min and static stretching of the *quadriceps* and *triceps surae* muscles. Next, the subjects performed a counter-movement jump (CMJ) and 5 s of continuous jumping (5 s CJ). The flight time (t_f) and contact time (t_c) of every single jump were recorded on a resistive (capacitative) platform [4] connected to a digital timer (Ergojump, Psion XP, MA.GI.CA. Rome, Italy) with an accuracy of ±0.001 s. To avoid unmeasurable work, horizontal and lateral displacements were minimised and hands were kept on the hips throughout the test. During CMJ, the knee angular displacement was standardised as the subject was to bend the knee at approximately 90°. The rise of the body centre of gravity above the ground (h) was determined from the flight time (t_f) by applying ballistic law:

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

where g is the gravity constant ($9.81\ m \cdot s^{-2}$).

During CJ exercise, the subjects were requested to perform the maximal jumping effort minimising knee angular displacement during contact. From the recorded values of t_f and t_c, average mechanical power (AP) and average rise of center of gravity (AH) were calculated. Furthermore, the best jump was selected for which the maximal mechanical power (PBJ) and highest rise of the center of gravity (HBJ) were obtained using the equation below [4]:

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

where P is the mechanical power output, T_f - sum of the total flight times, T_t - total working time (5 s), and T_c - sum of the total contact times. The average height during 5 s CJ and HBJ were computed using Formula 1.

Reproducibility of measurements: The reproducibility of the mechanical power test (5 s CJ) and CMJ were high, the respective test-retest correlations being equal to $r = 0.95$ and 0.90 [4,26].

Statistical methods: Conventional statistical methods were used, the differences between means being assessed by paired Student's t-test. The level of significance was set at $P \leq 0.05$.

Treatment procedures: Subjects were exposed to vertical sinusoidal whole body vibration (WBV) using the GALILEO 2000 device (Novotec, Pforzheim, Germany). The vibration frequency was set at 26 Hz (displacement = 10 mm; acceleration = 54 $m \cdot s^{-2}$). The subjects were exposed to 5 series of vibrations, 90 s each, separated by 40 s intermissions. This procedure was continued for 10 days, the duration of vibration series being extended by 5 s every consecutive day up to a total of 2 min per position. Following the 10 day period, all subjects were tested again.

Type of treatment employed: The first series of vibrations was applied in standing position with the toes on the vibration platform. Series 2 was performed with the subject in half-squat position, Series 3 - with feet rotated externally on the vibration platform. The knee was flexed at 90°. Series 4 was applied while standing on one leg on the right side of the vibration platform, the knee bent at 90°. Finally, Series 5 was applied while standing on the other leg on the left side of the vibration platform, the knee bent at 90°. During the 4th and 5th series, the subjects were allowed to maintain balance with the aid of a bar mounted on the platform. The subjects were wearing gymnastic-type shoes to avoid bruises throughout the session. Group E was treated with WBV for 10 days, subjects from Group C were untreated and requested to maintain their typical activities. Testing procedures were administered at the beginning and at the end of the experiments for both groups.

Results

After almost 2 weeks of regular technical and tactical training, the subjects from Group C showed no changes in any of the mechanical parameters studied. Jumping height in CMJ remained the same in Group E after 10 days of WBV (Table 2). In contrast, this treatment produced remarkable and significant (P<0.05) enhancement of the HBJ (Fig. 1) and PBJ (Fig. 2). In addition, the average height during 5 s CJ was also significantly improved in Group E (P<0.01; see Table 2). On the other hand, the average power developed during 5 s CJ did not change significantly after the treatment (Table 2).

Table 2
Mean values (±SD) of jump parameters before and after whole body vibration treatment

Group Variable	Experimental (n=7) Pre	 Post	Control (n=7) Pre	 Post
Counter-movement jump				
Jump height (cm)	36.5±6.1	37.1±5.5	36.7±4.8	36.6±4.8
Continuous jumping for 5 s				
Mean power output ($W \cdot kg^{-1}$)	42.1±5.8	43.4±7.8	44.6±4.7	44.1±4.4
Mean jump height (cm)	27.6±2.6	30.9±4.3**	28.3±5.1	28.5±4.1

* Significantly different from the respective initial (Pre) value (P<0.05)

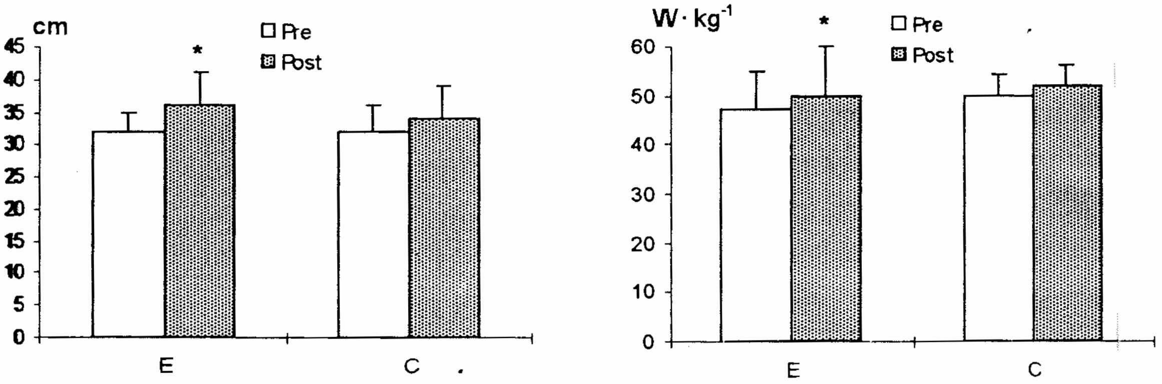

Fig. 1
Height of rise of the centre of gravity (left) and average mechanical power output (right) in the best jump from continuous jumping for 5 s recorded in the experimental (E) and control (C) groups before (empty bars) and after (shaded bars) a 10 day experimental period (means ±SD)
* Significantly different from the respective initial (pre) value (P<0.05)

Discussion

As expected, less than two weeks of regular tactical and technical training programme, did not induce any changes in the mechanical properties of control subjects. No change in jumping performance was noted after 4 weeks either in physical active subjects [13], or in volleyball players [2]. In contrast, a remarkable improvement was observed after the WBV period in E subjects regarding HBJ (Fig. 1), PBJ (Fig. 2) and the average jumping height during 5 s CJ (Table 2). On the other hand, no changes were noted for AP during the 5 s CJ. It should be emphasised that average jumping height recorded in the continuos jumping test [4] was more significant and sensitive than AP in differentiating athletes [27]. In addition, no changes in CMJ were noted after the vibration treatment in Group E. These apparently contradictory results can be reasonably explained by the mechanical behaviour of leg muscles during CMJ and 5 s 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 5 s CJ. The CMJ is characterised by a large angular displacement and slow stretching speed (3-6 rad $\cdot$ s^{-1}) [3], while 5 s CJ is performed at fast stretching speed (10-12 rad $\cdot$ s^{-1}) and small angular variation [7]. This means that only in the 5 s CJ the leg extensor muscles experience fast stretching which may elicit a concurrent gamma-dynamic fusimotor input that would enhance primary afferent discharge. This is supported by our earlier studies [3] which showed that during the eccentric phase of drop-jumping exercise (similar to 5 s CJ), the 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 a high EMG activity has not been recorded during the stretching phase (e.g. [3]).

Taking this into account it is likely that WBV elicits a biological adaptation associated with neural potentiation. 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 exercises). In fact, this suggestion is consistent with the knowledge that mainly the specific neuronal component and its proprioceptive feedback mechanism are the first structure to be influenced by specific training [2,13].

Training at 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 increase the possibility to recruit greater numbers of motor units during the eccentric phase [2]. Furthermore, there are several ways in which the explosive power training can influence neural activation, e.g. by increasing the synchronisation activity of motor units [20]. Moreover, an improved co-contraction of synergistic muscles and increased inhibition of the antagonistic ones cannot be ruled out. Irrespectively of the nature of the intrinsic mechanism which enhances neuromuscular activation after a specific explosive power-training, it is likely that vibration improves the proprioceptor feedback mechanism as it was fully operating and elicited in the WBV-enhanced 5 s CJ performance. On the other hand, the lack of modifications observed in CMJ 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 fibre type composition of leg extensor muscles [1]. However, there is no doubt that stretch reflex play an important role in stiffness regulation [14], and that muscle spindles and GTO operate actively in the control of muscle length and tension [15]. Consequently, it can be suggested that WBV treatment may affect dramatically the neuromuscular functions and properties which are regulating muscle stiffness through the control of length and tension.

During vibration, the length of skeletal muscles changes slightly. Facilitation of the excitability of spinal reflex can be elicited by vibration applied to *quadriceps* muscle [10]. 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 Peliakov [17]. It has been also shown that vibration drives α-motoneurons via the Ia loop, producing force without descending motor drive [24]. Burke *et al.* [9], suggests that vibration reflex operates predominantly or exclusively on α-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.* [16] are consistent with the vibration-induced activation of muscle spindle receptors, not only in the muscle to which vibration is applied, but also of the neighbouring muscles. Mechanical vibration (10 - 200 Hz) applied to the muscle belly or the tendon can elicit a reflex contraction (e.g. [12]). This response has been named the 'tonic vibration reflex' (TVR). It is not known whether it can be elicited by low WBV frequency (1-30 Hz), even if it has been suggested to occur [25].

Finally, it is to be remembered that not only the nervous but also muscle tissue can be affected by vibration [22]. In fact, 5 hours daily for 2 days of vibration exposure at two different frequencies were sufficient to induce enlargement of slow and fast fibres in rats [23].

In the present study, no neurogenic potentiation or changes in the morphological structure of muscles were demonstrated since neither EMG nor muscle biopsy were performed. However, the enhanced mechanical behaviour during 5 s CJ, may suggest that neurogenic adaptation took place in response to the vibration treatment. 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 muscles to simulated hypergravity conditions (1.1 *g*), applied for only 3 weeks, caused a pronounced enhancement of neuromuscular functions of leg extensor muscles [6]. Chronic centrifugal force (2 *g*) applied for 3 months [18] initiated the conversion of fibre type. In the present study, the total duration of WBV was relatively short (only 100 min), the perturbation of the gravitational force being rather constant (5.4 *g*). An equivalent length and intensity of training stimulus can be attained 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 3.0 g [8]. This means that exercising drop jumps for 2 min weekly would make 108 min in a year which is close to the total time of vibration applied to subjects from Group E.

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