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Acute changes in neuromuscular activity in vertical jump and flexibility after exposure to whole body vibration

Giuseppe Annino, PhD[a,b,c,*], Ferdinando Iellamo, MD[e], Francesco Palazzo, PhD[a], Augusto Fusco, MD[c,d], Mauro Lombardo, MD[c], Francesca Campoli, PhD[a,c], Elvira Padua, PhD[a,c]

Abstract

This study was aimed to investigate the neuromuscular activity after 10 minutes of exposure to a whole body vibration (WBV) session.

Twenty male young adults (24.8 ± 2.5 year olds) were randomized and divided into 2 groups: the vibration group (VG) was exposed to 10 minutes of WBV at 35 Hz; performed 10 minutes of WBV at 35 Hz (displacement = 5 mm; magnitude = 5 g); the nonvibrated group (NVG) was the placebo group that maintained the same position on the plate but without exposure to any type of vibration. Subjects were evaluated with counter movement jump (CMJ) and muscular flexibility by means of electromyographic (EMG) analysis recorded on the vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), and gastrocnemius lateralis (LG).

The 10 minutes of WBV showed an increase in muscular flexibility, associated with a decrease of EMG activity in BF ($P < .01$) and jump height. The latter was associated with a reduction of EMGs activity in BF ($P < .01$). The control group did not show any significant difference in all considered parameters.

These results support the hypothesis that 10 minutes of WBV had effects on flexibility and explosive strength performance influencing neuromuscular behavior through inhibitor effects on antagonist muscles more than the stretch reflex activity on agonist muscles.

Abbreviations: Δ Flex = difference in flexibility, Ag = agonist, ANOVA = analysis of variance, Ant = antagonist, Ant/Ag = antagonist/agonist, BF = biceps femoris, BH = body height, BM = body mass, CMJ = counter movement jump, Hz = hertz, LG = lateral gastrocnemius, mV = milliVolts, NVG = no vibration group, RMS = root mean square, sEMG = surface electromyography, sEMG-RMS = surface electromyography - root mean square, Tcon = concentric time, Tecc = eccentric time, Tf = flight time, VG = vibration group, VL = vastus lateralis, VM = vastus medialis, WBV = whole body vibration.

Keywords: flexibility, jump, lower limb, strength, stretch reflex, vibration

1. Introduction

The training of muscular strength is characterized by neuromuscular and hormonal changes, which may improve the efficiency of physical performance.[1] Resistance training protocols are designed in terms of work load, intensity, exposure time, and rest time, in order to favor biological reactions inducing specific adaptations.[2,3]

Sinusoidal vertical mechanical vibrations have been introduced in muscular strength training to facilitate and accelerate this physical activity.[4,5] Use of whole body vibration (WBV) has shown to be an effective and easy training method to increase physical performance.[6] Currently, segmental and/or WBVs are used in different fields, ranging from not only training of elite athletes[7,8] or into the rehabilitation of individuals with anterior cruciate ligament reconstruction[9] but also as treatment for osteoporosis[10,11] and chronic low back pain[12,13] or in neurologic rehabilitation for reducing spasticity.[14]

Nevertheless, the extensive use of vibrations is still contrasting. In fact, even if many studies have reported remarkable improvements in muscle strength after acute and chronic vibration exposure,[4,6,15–17] other authors did not find any significant effects.[18–22] A possible reason of this conflicting results could be due to the use of different protocols. In fact, several factors such as type of application, amplitude, frequency, and time exposure of vibrations may influence the acute, residual, and chronic effects on neuromuscular performance.[23]

In physical training, temporary positive effects on jump height, force-velocity relationship, and muscular flexibility of the lower limbs are obtained after a few minutes (~10 minutes) of mechanical vibration.[6,7,15,16,24] At the same time, it was observed that a prolonged exposure to vibrational treatments induces fatigue in muscle spindle with consequent reduction in reflex activity and decrease in muscular performance.[25]

How a vibratory stimulus acts on neuromuscular system in muscular performance remains unclear. In fact, it is known as the vibrational stimulus applied to muscle bell or tendon causes an involuntary muscle reflex contraction called "tonic vibration

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[a] Movement Science Institute, [b] Department of Systems Medicine, Faculty of Medicine and Surgery, Tor Vergata University of Rome, [c] Department of Human Sciences and Promotion of the Quality of Life, San Raffaele Roma Open University, [d] Clinical Laboratory of Experimental Medicine, Fondazione Santa Lucia IRCCS, [e] I.R.C.C.S. San Raffaele Pisana, Rome, Italy.

[*] Correspondence: Giuseppe Annino, Movement Science Institute, Faculty of Medicine and Surgery, Tor Vergata University of Rome, via Montpellier, 1 00133, Rome, Italy (e-mail: g_annino@hotmail.com).

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reflex."[26,27] This neuromuscular adaptation is mediated by the stimulation of muscle spindle fibers that activates the reflex response of the α-motoneuron of the agonist muscle. This neuromuscular activation has been suggested to be related to the increase in muscular performance.[5,28] Subsequently, Colson et al[29] did not find any changes in voluntary agonist muscle activation after acute vibration intervention. Probably, it is possible that this increment of the muscle power output could be due to the effect of mechanical vibration on antagonist muscles. Even if it has been clearly shown as the mechanical vibration applied to the skeletal muscles induces a simultaneous inhibitory effect on their direct antagonist muscles,[30,31] surprisingly poor studies have been focused on the antagonist behavior.

This study was aimed to investigate the effect of a single bout of 10 minutes of WBV on neuromuscular jump pattern activation and neuromuscular hamstring behavior during a muscular flexibility test. We hypothesized that the acute effects of 10 minutes of exposure times of WBV could affect muscular performance (strength and flexibility) through changes in neuromuscular patterns.

2. Methods

2.1. Subjects

Twenty healthy young college students (age 24.8 ± 2.5 years, height 172.1 ± 6.9 cm, weight 74.9 ± 4.7 kg) agreed voluntarily to participate in this experimental trial. In order to be included in the study, participants had to possess an official medical clearance. None of the subjects was active smoker or suffering by nutritional and physical disturbances; no subject took drugs that could affect physical performance and none was involved in a regular exercise program.

Before each testing session, the subject's body mass (BM) was measured to the nearest 0.5 kg (Seca Beam Balance 710, Hamburg, Germany) with subjects lightly dressed and barefooted. Standing height (body height, BH) was measured to nearest 0.5 cm (Seca Stadiometer 208, Hamburg, Germany). Table 1 reports all the physical features of the enrolled subjects for the different groups.

The study was approved by the ethical committee of the Movement Science Institute, Faculty of Medicine and Surgery, "Tor Vergata" University of Rome. Subjects were fully informed of possible discomforts associated with the protocol. All subjects gave their written consent.

2.2. Protocol

Subjects were randomly assigned into 2 groups. The experimental group (VG) was exposed to vertical sinusoidal WBV (Nemes LC; Boscosystem, Rieti, Italy) for 10 minutes. The vibration frequency was set at 35 Hz (displacement = 5 mm; magnitude = 5 g) in order to stimulates leg extensor muscles.[32]

Table 1

Mean ± SD of age, body height, and mass of subjects in VG (vibration group) and in NVG (no vibration group).

Anthropometrics data	VG Mean ± SD	NVG Mean ± SD
Age, y	24.2 ± 3.6	23.8 ± 2.3
Body height, cm	170.2 ± 8	173.3 ± 6
Body mass, kg	73.8 ± 4.9	76.1 ± 5.1

The vibration protocol consisted of 2 sets of five 60-second repetitions separated by 60 seconds of passive recovery with resting periods between sets of 5 minutes (10 minutes of WBV, 25 minutes all session). WBV was carried out with the subject standing on the vibration platform with bent legs. Second group performed the same protocol of VG, without any use of vibration (NVG). Hence, subjects stood on the vibration platform, switched-off, in the half squat position for all the duration of the protocol (10 minutes of squat position, 25 minutes all session).

2.3. Outcome measures

Tests were performed at the beginning and at the end of vibration in the same order. Before the beginning of the experimental trial, subjects familiarized with the testing and training procedures in 2 sessions in the preceding week.

After BM and BH measurements, participants performed a standardized general warm-up protocol immediately followed (1~2 minutes) by jumping and muscular flexibility measurements. General warm-up consisted of stationary cycling (5 minutes) on a computerized cycle-ergometer (Technogym, Gambettola, Italy) followed by 5 minutes of dynamic stretching of the quadriceps and calf muscles.

2.4. Countermovement jump test (CMJ)

Subjects were evaluated with a counter movement jump (CMJ) test by means of performing maximal vertical jumps (with arms rested on a light wooden bar of 0.25 kg fixed on the shoulders) on a switch mat connected to a computer (Ergojump; Boscosystem, Rieti, Italy). Before the test, each subject preformed some submaximal CMJ and 1 minute after performed 3 maximal CMJs. During CMJs, performance was asked to subjects, as previously familiarized, from upright starting position to bend their knees at approximately 90°. The rise in the center of mass after take-off (h) was measured with the following ballistic formula[33]:

$$h = tf^2\, g\, 8^{-1}$$

where tf is the flight time (from take-off to landing) and g is the gravitational constant (9.81 m/s^2). The best jump height was used for statistical analysis.

In order to evaluate the eccentric and concentric phases during the CMJ, the vertical displacements of the wooden bar were monitored with a linear encoder (Muscle Lab; Ergotest Technology, Langensund, Norway). The sensor was interfaced with an electronic device. When the bar was moved, a signal was transmitted by the sensor at every displacement of 0.3 mm. Thus, it was possible to discriminate the negative and positive time during CMJ performance. The linear encoder was synchronized with surface electromyographic (sEMG) signal.

2.5. Hamstrings flexibility

The muscular flexibility was assessed with the common fingertip-to-floor test. The test was performed at the beginning in the standing position on a 25 cm high step with both knees held straight by a tester. Subjects rolled their head downward and slowly slid a rigid marker along a ruler as far down as possible, holding the greatest stretch for 3 seconds. The test was repeated 3 times and the best score was recorded. This test was conditioned by the flexibility of the lower back and extensibility of hamstring muscles. All measurements were taken by the same pair of testers: one with the responsibility to hold the subject's knees straight and the other one to record the measurements. In this test, the EMG-RMS signals of all muscles were processed in the last 3 seconds of the greatest stretch.

2.6. Surface electomyographic (sEMG) analysis

Finally, a sEMG analysis was also performed. Signals by vastus lateralis (VL, 2/3 of the distal distance between the anterior spina iliaca superior and the lateral side of the patella), vastus medialis (VM, 80% of the distal distance between the anterior spina iliaca superior and the joint space in front of anterior border of the medial ligament), biceps femoris (BF, 50% of the distance between ischial tuberosity and the lateral epicondyle of the tibia), and lateral gastrocnemius (LG, on the most prominent bulge/calf of the muscle, approximately parallel to muscle fibers) according to the SENIAMs recommendation[34] were positioned on the preferred leg and recorded during CMJ performance with bipolar surface electrodes (contact diameter = 11 mm, interelectrode, center-to-center, distance = 20 mm). The surface electrodes connected with an amplifier (gain 600, input impedance 2 GW, Common-Mode Rejection Ratio 100 dB) and a pass band filter (6–1500 Hz; Biochip, Grenoble, France), fixed longitudinally over the muscle belly in a parallel arrangement over the pennation angle for the entire period of the experimental trials, from pre to post assessment test. Before the placement of the gel-coated self-adhesive electrodes (Dri-Stick Silver Circular sEMG Electrodes AE—131; NeuroDyne131; NeuroDyne Medical, Cambridge, MA), the skin was shaved, washed with alcohol, and abraded to prevent the cables from swinging and from causing movement artifacts.

EMG signals were used in combination with biomechanical parameters measured with the linear encoder (Muscle Lab; Ergotest Technology, Langensund, Norway). They were simultaneously sampled at 100 Hz on a personal computer via a 16bit A/D converter (AD637); thus, all EMG recordings were root mean square (RMS) converted with a time-averaging period of 100 ms via an electronic converter. The average RMS was integrated and expressed as a function of time expressed in millivolts (mVs). The EMG analyses from the leg extensor muscles were averaged because of the great similarity in their activity pattern and used as the denominator in the antagonist/agonist (Ant/Ag) muscle ratio.[1,35] Pattern activation analysis of jump test performed before and after vibration was processed during eccentric and concentric phase activation. The average of sEMG-RMS signals was analyzed from the onset of the eccentric phase to the onset of the concentric phase (negative displacement velocity equal to zero), and from the onset of concentric movement (velocity equal to zero), to maximum positive displacement velocity before take-off. The obtained values for both VL and VM muscles were averaged. The neuromuscular efficiency was determined via the Ant/Ag muscle ratio (averaged VM and VL/BF) during the concentric phase. In the fingertip-to-floor test, the sEMG signals of all muscles were processed in the last 5 seconds of the greatest stretch and the average RMS for this period was used for statistical analysis.

Means and standard deviations (SDs) of the eccentric and concentric times (T_{ecc}, T_{conc}) in 2 successive CMJ trials performed before the experimental session were T_{ecc}, = 0.428 ± 0.042 seconds in trial 1 and 0.436 ± 0.043 seconds in trial 2 (r = 0.97, $P < .001$) and T_{conc} = 0.197 ± 0.037 seconds in trial 1 and 0.204 ± 0.037 seconds in trial 2 (r = 0.91, $P < .001$). For the reproducibility of related sEMG, we considered the sums of the 4 muscles, which on T_{ecc}, were 0.606 ± 0.245 mV in trial 1 and 0.595 ± 0.243 mV in trial 2 (r = 0.95, $P < .001$) and on T_{conc} 1.496 ± 0.317 mV in trial 1 and 1.575 ± 0.444 mV (r = 0.91, $P < .001$) in trial 2, as previously performed.[36,37]

2.7. Statistical analyses

The results are expressed as mean ± SD. Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity.[38] A mixed between-within subject analysis of variance (ANOVA) was conducted to assess the impact of 2 different training program (VG and NVG) on participants' scores on the performance variables across 2 time periods (pre-intervention, post-intervention). Bonferroni-adjusted 1-tailed paired t tests post hoc analyses were used to locate the differences between the vibration protocols if a significant main effect between the latter was found. The effect size (η^2) was calculated to assess meaningfulness of differences. Effect sizes values of 0.01, 0.06, and 0.14 were considered small, moderate, and large, respectively. The corresponding P values are provided for each analysis. IBM - SPSS 20.0 for Windows (SPSS, Inc., Chicago, IL) was used for statistical analysis. Statistical significance was set at $P < .05$.

3. Results

3.1. CMJ measurement

CMJ test was statistically different between groups (Table 2). The VG showed a statistically significant increase in jump height (4.10 ± 4.1%, $P < .01$, $\eta^2 = 0.19$), while no significant changes were observed in the NVG (-2.01 ± 3.92%, $P = .32$, $\eta^2 = 0.01$). In the eccentric phase, no statistical difference was found between group in each muscle activity analyzed in this study. There was a statistically significant change in Tecc ($P < .05$) and in EMG activity for only the VG in the pre- and post-treatment (Table 2) in the LG ($P = .04$) and BF ($P = .04$). In the concentric phase, BF exhibited a significant difference between the pre- and post-treatment in VG ($P = .03$) and between groups ($P < .01$, $\eta^2 = 0.018$). Moreover, in the concentric phase, we observed a significant decrease in the post-treatment, compared with the baseline values for the Ant/Ag ratio in the VG (Table 2, Fig. 1), with a significant intergroup difference ($P < .01$, $\eta^2 = 0.021$)

In terms of time in jump performance, the VG showed a significant decrease in Tconc after vibration ($P = .03$). No changes were observed between groups ($P = .11$). No statistical changes within and between groups was observed in VL, VM, and Ag muscles (averaged VM and VL) in eccentric and concentric phases of CMJ.

3.2. Flexibility measurement

Statistically significant modifications were observed in the fingertip-to-floor test in VG ($P < .001$, $\eta^2 = 0.027$) (Table 3). No changes were observed in the NVG ($P = .45$, $\eta^2 < 0.01$). A significant decrease within and between groups was observed in the EMG-RMS of the BF muscle (−62.22%, $P < .05$, $\eta^2 =$ 0.023) in VG, whereas no changes were recorded in the NVG (-3.32%) (Table 3). No changes were observed in any groups for the other analyzed muscles.

Table 2

Mean ± SD of timing, sEMG-RMS, and rise of center of gravity of best counter-movement jump (CMJ) performance recorded in the VG (vibration group) and NVG (no vibration group) before and after (pre and post) the respective training protocol performed.

	VG		NVG	
	Pre	Post	Pre	Post
CMJ eccentric phase				
Contraction time, s	0.488 ± 0.078	0.426 ± 0.057*	0.541 ± 0.116	0.502 ± 0.154
Down position, m	0.293 ± 0.05	0.271 ± 0.07	0.291 ± 0.09	0.279 ± 0.06
VM, mV	0.261 ± 0.164	0.193 ± 0.088	0.169 ± 0.091	0.184 ± 0.085
VL, mV	0.185 ± 0.096	0.161 ± 0.074	0.181 ± 0.103	0.166 ± 0.077
AG, mV	0.223 ± 0.121	0.177 ± 0.078	0.175 ± 0.089	0.175 ± 0.062
BF, mV	0.063 ± 0.037	0.035 ± 0.020*	0.060 ± 0.073	0.045 ± 0.036
LG, mV	0.098 ± 0.052	0.057 ± 0.031*	0.078 ± 0.093	0.072 ± 0.123
CMJ concentric phase				
Contraction time, s	0.218 ± 0.021	0.188 ± 0.027‡	0.234 ± 0.068	0.214 ± 0.043
VM, mV	0.585 ± 0.226	0.549 ± 0.210	0.591 ± 0.284	0.485 ± 0.175
VL, mV	0.505 ± 0.202	0.471 ± 0.146	0.541 ± 0.267	0.538 ± 0.257
AG, mV	0.545 ± 0.189	0.510 ± 0.166	0.566 ± 0.244	0.512 ± 0.167
BF, mV	0.135 ± 0.103	0.082 ± 0.027*,‡	0.199 ± 0.150	0.185 ± 0.120
LG, mV	0.332 ± 0.137	0.307 ± 0.094	0.324 ± 0.095	0.318 ± 0.064
ANT/AG ratio	0.262 ± 0.154	0.178 ± 0.088†,§	0.278 ± 0.215	0.262 ± 0.188
CMJ performance				
Jump high, m	0.337 ± 0.068	0.350 ± 0.067†,‡	0.331 ± 0.035	0.324 ± 0.030
Progress (%)		4.10 ± 4.1†,‡		−2.01 ± 3.92

Ag = agonist, Ant/Ag = antagonist/agonist, BF = biceps femoris, CMJ = counter movement jump, LG = lateral gastrocnemius, VL = vastus lateralis, VM = vastus medialis.
Significant difference within group *$P<.05$; †$P<.01$.
Significant difference between groups ‡$P<.05$; §$P<.01$.

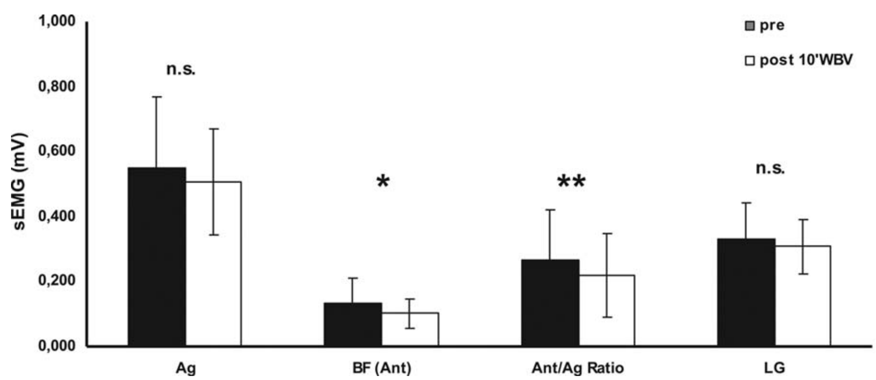

Figure 1. Changes in surface electromyography (sEMG) measurements of AG (Agonist) muscles (averaged vastus medialis and lateralis), BF (biceps femoris, antagonist muscle), Ant/Ag (antagonist/agonist) ratio, LG (lateral gastrocnemius) in concentric phase before and after 10 minutes of WBV (10'WBV) in the VG. Data are presented as mean ± SD. Significant difference within group *$P<.05$; †$P<.01$.

Table 3

Mean ± SD of the sEMG-RMS and downward displacement measured during flexibility test performance executed before and after the protocol treatment in the VG (vibration group) and NVG (no vibration group).

	VG		NVG	
	Pre	Post	Pre	Post
VM, mV	0.039 ± 0.024	0.052 ± 0.075	0.052 ± 0.044	0.054 ± 0.036
VL, mV	0.051 ± 0.042	0.062 ± 0.063	0.056 ± 0.038	0.062 ± 0.047
BF, mV	0.045 ± 0.024	0.017 ± 0.011†,§	0.032 ± 0.023	0.033 ± 0.027
LG, mV	0.027 ± 0.010	0.020 ± 0.012	0.016 ± 0.007	0.017 ± 0.011
ΔFlex, cm		2.38 ± 1.06‡,§		−0.80 ± 1.05
ΔFlex (%progress)		6.40 ± 2.68‡,§		−2.19 ± 3.57

ΔFlex (Difference in flexibility) between pre and post 10 min of WBV in VG shows a statistical improvement in absolute and in percentage values compared to the baseline values.
BF = biceps femoris, LG = lateral gastrocnemius, VL = vastus lateralis, VM = vastus medialis.
Significant difference within group †$P<.01$; ‡$P<.001$.
Significant difference between groups §$P<.05$.

4. Discussion

The aim of this study was to analyze the effects of vibrational stimulus on the neuromechanical parameters associated with jump performance and muscular flexibility. The increase in jump performance after a vibratory stimulus has been well investigated by many authors. Several studies have observed as while a subject stand in the half squat position on a vibration plate, the sEMG of quadriceps and calf muscles increase about twice more with respect to the same position without vibration.[8,5,32] How this phenomenon influences jump performance and muscular flexibility of the lower legs remains unclear.

Our results show an increase in jump performance after only the 10 minutes of WBV protocol. Exposure to WBV seems to reduce LG and BF muscles intervention during the eccentric phase and a decrease in BF activity and Ant/Ag ratio during concentric contraction before the take-off of the jump.

In according with Colson et al,[29] in the present study, the posteffect of vibration stimulus seems not to produce changes on the agonist muscles but on the antagonist muscle (BF) only, reducing its activity. The reduction observed in the duration of eccentric and concentric phases could be related to the better joint stability mediated by an increase in ligament and tendon efficiency as a consequence of better mechanoreceptor activity generated by vibration.[20] The joint system efficiency could be also mediated by increased tissue temperature resulting from transferability of ascending vibration waves.[39] At the same time, a greater tendon-ligament efficiency could better counteract the forward sliding of the knee joint during the eccentric phase reducing the stabilizing calf intervention.[40] In our study, the lower hamstring activity of the concentric phase was involved in a decrease in Ant/Ag muscle ratio correlated with an increase in jump performance.

Previous studies have associated jump performance with associated several mechanisms, including increased neural activity on the agonist muscles[41] and changes in muscle elasticity and neuromuscular adaptations as a reduced level of antagonist activity[42,43] that could also influence the neural plasticity.[31,44] Our data support the hypothesis related more to an inhibitory effect of vibration on antagonists rather than to an excitatory effect on agonists. In fact, vibration stimulus is not sufficient to improve maximal isometric force in which antagonist muscles seem not have any influence.[21,22,29]

Moreover, our results suggest that enhanced hamstring flexibility is associated with a significant reduction in their sEMG activity. Consistent with the literature,[15,45] our data show that an exposure to 10 minutes of WBV seems enough to improve hamstring flexibility. It is conceivable that flexibility and strength performance could be related to the reduced antagonist activity as a consequence of the same vibratory stimulus.

These results are interesting at the light of the physical training. In traditional training regimens, it is hard to simultaneously improve both strength and flexibility. Use of vibrations may offer the advantage of greater strength and flexibility, contemporarily. Hence, vibration may modify the corticomotor excitability via spinal reflexes. Probably, the tonic vibration reflex, observable in the agonist muscles during vibration treatment, could have a post prolonged inhibitory effect on the antagonist muscles,[46] resulting in an increase in muscle flexibility as well, in the speed of contraction in explosive movements.

In future studies, it will be necessary to investigate how the application of supporting techniques and determining parameters of their using will be a target to optimize physical training, also identifying the subjects who could be helped. In fact, the correct definition of the correct setting of use of technology is crucial in many fields of medical and physical treatments.[47]

These results could be analyzed at the light of their limits. One of the main limitations of our study is the reduced sample size, which suggests caution in our conclusions. However, it has to be noted that the number is consistent with literature. Moreover, the presence of many studies with different parameter values with several outcome measures limited the comparisons with other studies. At the same time, the presence of a control group reduces the potential bias about the obtained results.

In conclusion, our results show as vibration influences muscular performance through the action of the antagonist more than agonist muscles.

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