The acute effects of different training loads of whole body vibration on flexibility and explosive strength of lower limbs in divers

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ABSTRACT: The purpose of this study was to examine the acute effects of different vibration loads (frequency and amplitude) of whole-body vibration (WBV) on flexibility and explosive strength of lower limbs in springboard divers. Eighteen male and female divers, aged 19 ± 2 years, volunteered to perform 3 different WBV protocols in the present study. To assess the vibration effect, flexibility and explosive strength of lower limbs were measured before (Pre), immediately after (Post 1) and 15 min after the end of vibration exposure (Post 15). Three protocols with different frequencies and amplitudes were used in the present study: a) low vibration frequency and amplitude (30 Hz/2 mm); b) high vibration frequency and amplitude (50 Hz/4 mm); c) a control protocol (no vibration). WBV protocols were performed on a Power Plate platform, whereas the no vibration divers performed the same protocol but with the vibration platform turned off. A two-way ANOVA 3 x 3 (protocol × time) with repeated measures on both factors was used. The level of significance was set at $p < 0.05$. Univariate analyses with simple contrasts across time were selected as post hoc tests. Intraclass coefficients (ICC) were used to assess the reliability across time. The results indicated that flexibility and explosive strength of lower limbs were significantly higher in both WBV protocols compared to the no vibration group (NVG). The greatest improvement in flexibility and explosive strength, which occurred immediately after vibration treatment, was maintained 15 min later in both WBV protocols, whereas NVG revealed a significant decrease 15 min later, in all examined strength parameters. In conclusion, a bout of WBV significantly increased flexibility and explosive strength in competitive divers compared with the NVG. Therefore, it is recommended to incorporate WBV as a method to increase flexibility and vertical jump height in sports where these parameters play an important role in the success outcome of these sports.

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INTRODUCTION

Diving, and especially springboard diving, is a dynamic aquatic sport that combines skill, coordination, flexibility and muscular power of lower limbs [1,2] and requires large range of motion (ROM) movements in order to execute unusual or unique body positions and skills of artistic nature [3]. Additionally, excessive muscular strength of the lower body compared to the upper body in springboard divers is an obvious necessity that needs to be achieved via specific strength training [4]. A variety of means and training methods have been used in order to improve these abilities. Whole body vibration (WBV) training has been claimed to produce superior results in flexibility, muscular strength, neuromuscular stimulation, and jumping ability [5-10] compared to other types of training. Several studies have shown positive effects of vibration on flexibility and explosive strength [11-14], while others showed a decrease [15] or no changes [14]. The conflicting results in these studies may have been attributable to the variations in the frequency, amplitude, and duration of the WBV applied, as well as variations in samples tested.

Bosco et al. [16] found that a single vibration bout resulted in a significant temporary improvement in lower limb muscle strength in female volleyball players.

It has been shown that the acute effects of WBV depend on the vibration characteristics (amplitude, frequency, acceleration magnitude) [11, 17]. Torvinen et al. [9] found a 2.5% improvement in vertical jump height after a 4-min WBV session (25-35 Hz) with 2 mm amplitude, whereas the 4 mm amplitude produced no improvements. In addition, Marshall and Wyon [18] reported that WBV training has the potential to increase jump height by 5.7% and active ROM by 15%-17% in young trained dancers without increasing thigh and calf circumferences after a four-week intervention programme.

Other studies have revealed an acute increase in strength, counter movement jump (CMJ) height and power after 4-10 min WBV exposure [9,19], and these improvements depended on the duration of the exposure time and on the time elapsed between the WBV and testing [14]. In contrast, Cochrane et al. [20] found no significant changes in CMJ after 9 WBV sessions (5 static exercises, 2 × 1 min, total exercise 10 min) in non-elite athletes. These discrepancies might be due to the variations in the applied vibration frequencies, which ranged from 15 to 35 Hz [9, 12, 15], and to the applied amplitudes, which ranged from 2 to 8 mm [8,9,12]. Previous studies showed that low frequencies and amplitudes are most effective in improving muscular performance [8,9,12,14]. However, there are controversial results with regards to the effect of high frequency and amplitude on explosive strength of lower limbs. Cardinale and Lim [11] reported a statistically non-significant reduction in squat jump (SJ), CMJ and flexibility [11], in contrast to other studies [12,21,22] reporting a significant improvement in CMJ using high amplitude and high frequency vibration exposure. Specifically, Cronin, Nash and Whatman [23] revealed that a vibration frequency of 44 Hz produced significant improvements in leg ROM compared to lower frequencies (24 Hz, 34 Hz), which did not produce any significant increment in ROM. Bazett-Jones et al. [24] reported that a single bout of different WBV frequencies and loads (40 Hz, 2-4 mm; and 50 Hz, 4-6 mm) produced no effects in men, whereas they improved CMJ performance in untrained women. Furthermore, according to Di Giminiani et al. [25] individualized vibration frequency (20, 25, 30, 35, 40, 45, 50, and 55 Hz) seems to produce greater improvement in SJ performance compared to fixed frequency of 30 Hz after 8-week WBV exposure in 33 physically active male and female participants. Turner et al. [26] examined the influence of different frequencies (0, 30, 35, and 40 Hz) in recreationally trained men and found that a 40 Hz WBV frequency produced greater improvements in CMJ performance compared to the lower applied frequencies. In another study, Ritzmann, Gollhofer and Kramer [27] demonstrated that 30 Hz with an extra load produced the greatest neuromuscular activation during WBV compared to lower frequencies. Additionally, Sands et al. [28] reported that a vibration exposure of 45 s, with 30 Hz frequency and 2 mm amplitude, significantly increased the flexibility of the forward leg split position by 27.5% compared to 13.7% increase of no vibration exposure. All the aforementioned studies examined untrained or physically trained participants or subjects from different sports who were assigned to different groups. However, these findings contradicted the results of Cronin et al. [29], who found that a combination of vibration (34 Hz, 2 mm) and passive knee flexor stretching did not improve hamstring ROM compared to static stretching only, which revealed an improvement by 2.1%. According to our knowledge, there is no study that examines the effects of a bout of WBV intervention with different vibration loads (frequency and amplitude) on flexibility and explosive strength of lower limbs in the same group, especially in athletes characterized by high levels of flexibility and lower limb strength. Furthermore, the selection of trained athletes would answer the question whether there can be further improvement in this particular type of trained athletes. Therefore, the purpose of this study was to examine the acute effect of different WBV loads on flexibility and explosive strength of lower limbs in competitive divers.

MATERIALS AND METHODS

Subjects. Eighteen competitive divers (age: 17.94 ± 2.36 years, body mass 52.83 ± 10.36 kg, body height 163.78 ± 9.06 cm, % body fat 14.76 ± 3.53%), ten males (age: 18.50 ± 2.79 years, body mass 56.10 ± 11.79 kg, body height 164.30 ± 12.13 cm, % body fat 14.63 ± 4.06%) and eight females (age: 17.25 ± 1.58 years, body mass 48.75 ± 6.88 kg, body height 163.12 ± 2.99 cm, % body fat 14.92 ± 3.02%) volunteered to participate in this study (Table 1). Because there were no gender differences the data for male and female divers were pooled and analyzed together. All divers were of competitive level and had been in training 6 days per week, 2-3 hours per day and had no previous experience with WBV training. The subjects were informed extensively about the experiment procedures and the possible risks or benefits of the project, and written consent was obtained. The study was approved by the local institutional Review Board, and all procedures were in accordance with the Helsinki declaration of 1975 as revised in 1996.

TABLE 1. Mean ± SD and level of significance of dependent variables (anthropometrical data, flexibility and explosive strength tests) for male and female divers

	Male	Female	p-value
Age	18.50 ± 2.79	17.25 ± 1.58	NS
Body mass (Kg)	56.10 ± 11.79	48.75 ± 6.88	NS
Body height (cm)	164.30 ± 12.13	163.12 ± 2.99	NS
Body fat (%)	14.63 ± 4.06	14.92 ± 3.02	NS
S & R (cm)	36.80 ±7.89	35.00 ± 6.39	NS
SJ (cm)	31.66 ± 6.74	28.62 ± 3.76	NS
CMJ (cm)	34.86 ± 7.56	30.30 ± 2.84	NS
RL (cm)	17.46 ± 3.36	14.77 ± 2.51	NS
LL (cm)	18.19 ± 5.23	15.06 ± 2.73	NS

Note: S&R: Sit and Reach; SJ: Squat Jump; CMJ: Counter Movement Jump; RL: Right Leg; LL: Left Leg; NS - statistically not significant.

Protocols

A familiarization session on a Power Plate ® Next Generation WBV platform (Power Plate North America, Northbrook, Illinois), and measurements of anthropometric characteristics were performed one week before testing. Three protocols with different frequencies and amplitudes were designed and applied 1 week apart on three separate days, randomly. The first protocol (VG1) was characterized by low vibration frequency and amplitude (30 Hz – 2 mm), the second protocol (VG2) included high vibration frequency and amplitude (50 Hz – 4 mm), whereas in the control protocol (NVG) all the exercises were executed on the vibration platform but with no vibration. The total time of vibration exposure in all protocols was 2 min (4 × 30 s, with 30 s rest between sets). The four exercises (30 s each) performed on the vibration platform were a static squat at a knee angle of 120°, a dynamic squat at a tempo of 2 s up and 2 s down at a knee angle ranging from 120° to 180°, and two lunges (one on each leg) with the "working-vibrated" leg on the platform and the other leg on the ground. A battery of tests was used to evaluate flexibility (sit and reach – S&R) and explosive strength of lower limbs SJ, CMJ, single leg jump for right leg (RL) and left leg (LL)) with 2 min rest between tests, all tests being performed randomly. The measures of single leg jumps were chosen in order to evaluate each leg's power due to the fact that divers in most diving skills execute the preparatory phase of take-off from the springboard with one leg. These tests were performed as baseline tests (Pre tests), immediately after the end of the vibration intervention (Post 1) and 15 min after the end of each intervention (Post 15) for each of the three protocols (three evaluation measurements for each protocol on each day). The participants were informed about the test procedures and were asked to perform all tests at maximum intensity. All testing sessions were conducted at the same time of day (11:00 to 14:00) with no warm-up. Verbal encouragement was given throughout testing trials. During all the interventions participants wore gymnastics shoes to standardize the damping of the vibration caused by foot wear.

Measurements

Flexibility – Sit and reach test (S&R)

Flexibility was assessed using the S&R test using a flex-tester box (Cranlea, UK). Participants were instructed to remove their shoes and sit with their legs extended in front of them against the box. The subjects then placed one hand over the other and stretched forward slowly as far as possible along the top of the box until they could stretch no further, holding this position for 2 s [8]. The test was repeated twice with a rest period of 10 s [12], and the best trial of the two was recorded to the nearest 1.0 cm for further analysis.

TABLE 2. Intraclass coefficients (ICC) across time (time 1, 2 and 3) for each protocol and dependent variable.

Protocol	S & R	SJ	CMJ	RL	LL
VG 1	0.996	0.951	0.965	0.912	0.952
VG 2	0.948	0.974	0.968	0.958	0.948
NVG	0.994	0.981	0.987	0.953	0.956

Explosive strength

Explosive strength of lower limbs was assessed using three different jump tests (SJ, CMJ, RL and LL) using a switch mat [30]. Two trials were performed and the best score was considered for statistical analysis. The height of rise of the centre of mass in all jump tests was determined by the flight time according to the method of Asmussen and Bonde-Petersen [31] and used in order to analyze the explosive strength characteristics of the leg muscles as reported elsewhere [16].

Jump height, h, was calculated using $h = g\, t_f^2/8$, Where t_f is the flight time and g is the acceleration due to gravity ($9.81\ m \cdot s^{-2}$).

Statistical analysis

A two-way ANOVA 3 x 3 (protocol × time) with repeated measures on both factors was used. The level of significance was set at $p<0.05$. Effect size is also reported though eta-squared (η^2). Univariate analyses with simple contrasts across time were selected as post hoc tests. The intraclass coefficients (ICC) assess the reliability across time (time 1, 2 and 3) for each protocol and dependent variable. Percent changes in all examined variables after the vibration protocols from baseline (pre) tests were calculated.

RESULTS

The reliability was assessed across time with the intraclass coefficient (ICC). The reliability findings are presented in Table 2.

The mean scores of tests for various measurements are presented in Table 3.

There was a significant protocol × time interaction with respect to S&R ($F=8.035$, $p=.001$, $\eta^2=.697$). Univariate analysis with simple contrast revealed significant differences between: a) baseline (Pre) and Post 1 ($F=26.496$, $p=.001$, $\eta^2=.609$) and b) baseline and Post 15 ($F=39.170$, $p=.001$, $\eta^2=.697$), for VG1; between: a) baseline (Pre) and Post 1 ($F=18.287$, $p=.001$, $\eta^2=.518$) and

TABLE 3. Mean ± SD of S&R, SJ, CMJ, RL, and LL at the Pre, Post 1, and Post 15 measurements for the VG1, VG2 and NVG protocols.

	VG 1			VG 2			NVG		
Tests	Pre	Post 1	Post 15	Pre	Post 1	Post 15	Pre	Post 1	Post 15
S&R (cm)	36.00±7.12	37.39±7.39#	37.61±7.26#	36.83±6.87	38.22±6.92#	38.94±6.74#	35.55±6.85	35.78±6.78	35.83±7.05
SJ (cm)	30.31±5.68	32.68±6.87#	31.21±6.89	32.23±7.15	34.11±7.75#	33.03±7.62	31.49±7.51	31.59±7.67	31.27±8.14
CMJ (cm)	32.83±6.25	34.19±7.44#	33.40±7.31	34.44±7.41	35.44±8.26	34.69±7.55	33.59±7.66	33.85±8.02	33.44±7.89
RL (cm)	16.27±3.23	16.80±3.49	16.79±3.67	16.41±3.67	17.12±3.85#	17.04±3.43#	16.43±4.18	15.68±4.15	16.03±3.76
LL (cm)	16.80±4.49	16.82±4.27	16.94±4.31	16.67±3.87	17.25±3.88#	17.11±4.32	16.56±3.98	16.51±4.42	16.12±4.15

Note: VG1: Low vibration Frequency and Amplitude; VG2: High vibration Frequency and Amplitude; NVG: No Vibration; S&R: Sit and Reach; SJ: Squat Jump; CMJ: Counter Movement Jump; RL: Right Leg; LL: Left Leg. # Significantly different from Pretest

b) baseline and Post 15 (F =10.509, p=.005, η^2=.382), for VG2. No significant differences were found for a) NVG baseline (Pre) and Post 1 (F =2.125, p=.163, η^2=.111) and b) baseline and Post 15 (F =1.735, p=.205, η^2=.093), for NVG.

A significant protocol × time interaction (F=6.457, p=.004, η^2=.648) in SJ was found. Univariate analysis with simple contrast revealed significant differences between: a) baseline (Pre) and Post 1 (F =19.631, p=.000, η^2=.536) but not for baseline and Post 15 (F =2.743, p=.116, η^2=.135), for VG1; and b) baseline (Pre) and Post 1 (F =20.431, p=.000, η^2=.546), but not for baseline and Post 15 (F =3.805, p=.068, η^2=.183), for VG2. No significant differences were found in NVG a: baseline (Pre) and Post 1 (F =0.301, p=.590, η^2=.017) and b: baseline and Post 15 (F =0.279, p=.604, η^2=.016).

No significant protocol × time interaction (F=1.322, p=.310, η^2=.274) in CMJ was found. Further, the time main effect was not significant as well (F=1.958, p=.174, η^2=.197). The protocol main effect however was significant (F=7.277, p=.015, η^2=.300), and univariate analyses with Bonferroni adjustment (.05/2) revealed no significant differences between VG1and NVG (F=.116, p=.738, η^2=.007). The differences between VG2 and NVG approached significance (F=3.458, p=.080, η^2=.169), and examination of the respective mean scores revealed that VG2 had the highest mean score (M=34.86, SD=1.81), compared to NVG (M=33.63, SD=1.84).

There was a significant protocol × time interaction with respect to single leg jump on RL (F=4.345, p=.017, η^2=.554). Univariate analysis with simple contrast revealed significant differences between: a) baseline (Pre) and Post 1 (F =7.977, p=.012, η^2=.319), and b) baseline and Post 15 (F =7.586, p=.014, η^2=.309) for VG2; between: a) baseline (Pre) and Post 1 (F =12.203, p=.003, η^2=.418), but not for baseline and Post 15 (F =1.452, p=.245, η^2=.079), for NVG. No significant differences were found for VG1 between a) baseline (Pre) and Post 1 (F =3.798, p=.068, η^2=.183) and b) baseline and Post 15 (F =2.293, p=.148, η^2=.119).

No significant protocol × time interaction (F=.866, p=.508, η^2=.198) in single leg jump on LL was found. Further, main effects were not significant for protocol (F =1.181, p=.332, η^2=.129) and time (F=.923, p=.418, η^2=.103), and therefore no post hoc analyses were conducted.

DISCUSSION

The results of the present study indicated that a single bout of WBV that generates sinusoidal vibration improves flexibility and explosive strength in the lower limbs in competitive springboard divers, whereas the NVG protocol had no effect on the examined parameters. Specifically, three important findings are reported in the current study. First, both vibration loads (low frequency/low amplitude and high frequency/high amplitude) are effective in improving flexibility of the lower back and knee flexors. The second finding was that both vibration loads produce significant improvement in explosive strength of lower limbs, and finally that the improvement that appeared in SJ performance was greater than that for CMJ. This latter finding contradicts the logic that improvement that usually appears in CMJ performance is greater because the stretch reflex evoked in this jump would increase motor neuron excitability, and hence jump height [32].

The improvement that appears in flexibility in the vibration groups (VGs) is in agreement with previous findings that revealed improvements of 4.7-13.5% [11,12]. However, the improvement that appeared in VG2 contradicts the results of Cardinale and Lim [11], who found a reduction of 3.3% after WBV with a frequency of 40 Hz.

The improvements in flexibility by 3.86% in VG1 and those of VG2 by 3.77% are in agreement with previous findings that revealed improvements of 4.7-13.5% [11,12]. However, the improvement of 3.77% that appeared in VG2 is in contrast to the results of Cardinale and Lim [11], who found a reduction of 3.3% after WBV with a frequency of 40 Hz. In addition, our findings support previous results [3,28,33] that revealed improvements in flexibility following acute local vibration simultaneously with stretching applied directly to the limb. The characteristics of the WBV intervention programme (loading parameters, body position on the platform and training method) and type of vibration platform may be the causal factors for those differences and the magnitude of the effects among these studies. According to the present findings, the improvement in S&R that was maintained for 15 min after the end of the vibration protocol extended other findings that reported an improvement after 3 to 6 min [34,35]. From the physiological point of view it has been hypothesized that vibration improves the stretch reflex loop through the activation of the main endings of the muscle spindle, which influences the agonist muscle contraction while the antagonist is simultaneously inhibited (Rothmuller and Cafarelli [36]. Additionally, vibration might raise the muscle temperature due to the friction between the vibrating tissue, increase the blood flow, which could in turn enhance the extensibility of the muscle and ROM and change the pain threshold [37]. Further, the great improvement of the VGs compared to NVG suggests that the vibration exposure may have activated the Ia inhibitory interneurons of the antagonist muscles. This in turn may have caused changes to intramuscular coordination to reduce the braking force around the hip and lower back joints and potentiate the flexibility score [38].

The WBV in this study had a positive effect on SJ performance. Specifically, the improvements of 7.82% and 5.83% in Post 1 immediately after VG1 and VG2 , respectively were significantly greater by 0.28% than those observed for the NVG. The improvement that appeared in VG1 in the present study extends data of Cardinale and Lim [11], who found that 5 min of WBV training with a low frequency -20 Hz had a significant effect on SJ performance (3.9%), and those of Di Giminiani et al. [25], who reported a benefit of 11.0% for the individualized-vibration group compared with the 3.0% increment of the fixed-vibration (30 Hz) group that comprised physically active males and females. Conversely, the improvement of 5.83% in VG2 contradicts the finding of Cardinale and Lim [11] of a reduction of 4% in SJ performance after WBV with a frequency of 40 Hz. A similar improvement in SJ was observed in both VGs 15 min after (Post 2) the intervention protocols (2.97% and 2.51%, respectively). These findings contradicted those of Gerodimos et al. [39], who found no significant effects of amplitude on SJ performance in all four protocols.

In the present study a WBV loading induced a percentage increase in CMJ by 4.14% and 2.90% immediately after the end of vibration (Post 1) for both VGs, supporting previous findings reporting increases of 0.7 to 9.0% [8, 9, 11,12, 18, 24, 40]. Furthermore, the present findings confirm previous data by Turner et al. [26], who revealed a significant difference from the pre- to post-vibration average, with a 6.9% increase. In addition, although VG2 maintained the Pre test values 15 min after the end of vibration, it did not show significant improvements (0.81%). From a physiological point of view, as Nordlund and Thorstenson stated [41], the exact mechanisms responsible for the improvements in neuromuscular performance after WBV are not fully known. However, according to Eklund and Hagbarth [42], vibration induces rapid changes in muscle length that evoke the Tonic Vibration Reflex (TVR), which may cause an improvement of -motor neuron inflow and enhancement of the Ia neuron stretch-reflex loop [38]. In addition, the present findings support the results of Cormie et al. [43], who found that applying low frequency (30 Hz) and low amplitude (2.5 mm) WBV for 30 seconds significantly increased CMJ height immediately after treatment. These improvements are significantly greater than the results of Cardinale and Lim [11], who recorded mean reductions in performance by 3.8% and 3.2% for 20 and 40 Hz respectively. It has been reported that acute and short-term vibration exposure improved muscle activity, force and power [44,45], and possibly differentiated spinal excitability. However, these increases in muscle performance could be due to neurogenic potentiation, which is based on the tonic vibration reflex [46].

The above findings, with respect to the SJ and CMJ, support the effect of the intervention programme on the single leg jumps (RL, LL). The reported improvement, evident in each leg separately, has not been established in the literature previously. The present study is the first one known to report this finding, and the results may not be generalized without caution.

WBV exposure from 4 to 10 min has been shown, as an acute effect, to induce a transient increase in strength, CMJ height [9,18] and power [18]. According to Jackson and Turner [47] and Kihlberg et al. [48], a vibration frequency between 30 Hz and 50 Hz may have a greater acute effect in vibration training. Also, the present results extend the findings of Bosco et al. [19], who reported that a single session o f 5 to 10 min, divided into sets, improved vertical jump performance. However, the different WBV frequencies in the present study caused different acute effects on vertical jumping ability, a finding that supports the results of Cardinale and Lim [11], who stated that 5 min WBV training with a low frequency of 20 Hz has a significant effect on SJ of 3.9% but has no significant difference on CMJ (2.3%).

CONCLUSIONS

In conclusion, this study presents evidence that a single bout of WBV may increase flexibility and explosive strength in competitive divers, extending previous results supporting that the benefits from WBV apply to untrained participants [49,50] or trained individuals [51, 52, 53]. Therefore, it is recommended to incorporate WBV as a method to increase flexibility and vertical jump height for both legs or either leg in sports where these parameters play an important role in the outcome. Further research is warranted to examine whether longer exposure to a vibration stimulus might have a positive effect in maintaining or increasing the baseline values of the athletes' flexibility and explosive strength after vibration rest more than 15 min.

Practical applications

As mentioned by other researchers [19, 54], WBV exercises used for warm-up before competition have been shown to improve explosive strength. Therefore, WBV may prove an effective warm-up method before training or competition where power is a dominant factor. The fact that both intervention loads (30 Hz – 2 mm and 50 Hz – 4 mm) were equally effective indicates that coaches may apply such loads to improve parameters such as flexibility and explosive strength of lower limbs.

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