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Effect of Whole Body Vibration Training on Lower Limb Performance in Selected High-Level Ballet Students

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ABSTRACT. Annino, G., E. Padua, C. Castagna, V. Di Salvo, S. Minichella, O. Tsarpela, V. Manzi, and S. D'Ottavio. Effect of whole body vibration training on lower limb performance in selected high-level ballet students. *J. Strength Cond. Res. 24(1): 1072–1076. 2007.*—The aim of this study was to examine the effects of 8 weeks of whole body vibration (WBV) training on vertical jump ability (CMJ) and knee-extensor performance at selected external loads (50, 70, and 100 kg; leg-press exercise) in elite ballerinas. Twenty-two (age, 21.25 ± 1.5 years) full-time ballerinas were assigned randomly to the experimental (E, $n = 11$) and control (C, $n = 11$) groups. The experimental group was submitted to WBV training 3 times per week before ballet practice. During the training period, the E and C groups undertook the same amount of ballet practice. Posttraining CMJ performance significantly increased in E group (6.3 ± 3.8%, $p < 0.001$). Furthermore, E group showed significant ($p < 0.05$–0.001) posttraining average leg-press power and velocity improvements at all the external loads considered. Consequently, the force-velocity and power-velocity relationship shifted to the right after WBV training in the E group. The results of the present study show that WBV training is an effective short-term training methodology for inducing improvements in knee-extensor explosiveness in elite ballerinas.

KEY WORDS. strength, power, vertical jump, force-velocity, ballerina

INTRODUCTION

Ballet is considered mainly as an aesthetic activity (17, 22). Recent findings, however, have shown dance to be a physically demanding exercise mode (17). Due to its highly complex, multidirectional movement requirements, dance may be considered as a high-intensity intermittent exercise (26).

Body composition, joint mobility, cardiovascular fitness, and muscular strength have been reported as limiting factors in ballet performance (19). Dance requires quick bursts of energy interspersed with low-intensity activities (9), and strength level is an important component of ballet performance (19, 27). Additionally, strength has been suggested as an effective strategy for injury prevention in ballet (16, 22). Nevertheless, dancers see themselves as artists rather than athletes and only rarely undertake structured physical conditioning, particularly strength training (16, 17, 19, 27, 32, 33).

The few studies that have addressed the issue of strength training in ballet reported significant improvements from pretraining strength levels, without any detrimental effect on actual and perceived physical appearance (19, 27).

Despite the reported encouraging effect of strength training on ballet performance, the protocols that have been suggested are time-consuming and require moderate to high skill to be performed. Furthermore, they necessitate training facilities that are very often difficult to implement in a ballet academy due to economic or logistical reasons. Consequently, these protocols, usually involving free-weight exercises or weight-training machines, may have little applicability to the ballet population.

Recently, whole body vibrations (WBV) have been proposed as a training intervention to develop strength and flexibility (7, 15). The major documented benefit of WBV is explosive strength performance, usually considered as vertical jump height (2, 12, 29–31). This result is of particular interest, because vertical jump performance is considered to be related to ballet performance (19, 27). Additionally, WBV training protocols require only a limited amount of time and very limited, if any, specific skills to be performed (7).

The aim of this study was to examine the effects of a short-term WBV training intervention on dynamic strength and vertical jump performance in a selected population of elite-level classical ballerinas. It was hypothesized that WBV intervention may result in explosive strength and dynamic strength improvements in professional ballerinas if provided as a supplement to the usual dance training routine.

METHODS

Experimental Approach to the Problem

The strength training protocols that used ballerinas as subjects considered weight-machine and free-weight exercises (19, 27). Furthermore, the strength training protocols involved progressive loads exceeding 70% of 1 repetition maximum (1RM) during 3–4 exercises in 5–6 sets with up to 8 repetitions each (19, 27). Although these training protocols are widely used by athletes of different sports, they require proper facilities, good weight-training apparatus, and professional supervision (10). Additionally, those successful protocols require extensive resistance training over 50–90 minutes (19), an amount of time that may be intolerable given the often-busy dance practice routines of professional dancers. Moreover, strength training is felt by ballerinas to have potentially detrimental effect on actual and perceived physical appearance (19, 27).

With respect to this, WBV may grant several advantages (7). In fact, WBV has been reported to exert a positive effect on both explosive and maximal strength, requiring only a small amount of time per session (2, 3, 12, 30, 31). Furthermore, the WBV training exercise needs very limited familiarization and supervision (12, 30, 31) and can be performed without frequenting well-equipped weight training facilities. Additionally, there is no need to progressively adjust training loads with each testing session, being time of treatment an effective way to implement increments into training stimulus (30, 31). Finally, unlike the reported successful strength protocols (19, 27), WBV does not involve exercising to failure, a condition that may exacerbate the likelihood of a pernicious condition of overreaching that, over a long training period, may lead to an overtraining status (18).

This study used a randomized, fully controlled experimental design to examine the effect of WBV on a group of classical ballerinas. Ballerinas' countermovement vertical jump height (CMJ) and maximal strength and power at selected loads (50, 70, and 100 kg) were considered as dependent variables in this study. These variables had not been addressed previously in training studies despite being considered as limiting factors in ballet performance (17, 19, 27).

Recent research has shown that dance training routines provide few stimuli for physical performance improvement, suggesting the need for supplemental conditioning (17, 19, 27, 32, 33). However, usual ballet training routines involve plyometric-type exercises (17, 27) that may improve jumping ability as a synergistic effect of ballet practice. In this regard, Newton et al. (21) showed that if proper training stimuli are provided, vertical jump performance may be improved further in female athletes who are already highly trained in the jump. In this study we used WBV as a training stimulus for inducing improvement in vertical jump and dynamic strength, because such training has been shown to enhance this neuromuscular performance domain (12, 23).

The working hypothesis was that in non–strength-trained but potentially highly trained individuals who jump, WBV may induce significant improvements in various aspects of functional strength performance using nonspecific movements (2, 7, 20).

Subjects

Twenty-two well-trained ballerinas (age, 21.25 ± 1.25 years; body mass, 50.8 ± 3.7 kg; height, 165.7 ± 5.6 cm), full-time students of the National Ballet School, volunteered for the present study. At the time of the investigation, all of the subjects had at least 8 years of dance experience and no previous history of fractures or muscle-bone injuries. In order to be included in the study, participants had to possess official medical clearance at the beginning of the season, according to the law. None of the subjects were active smokers or suffered nutritional disturbances, and no medication or drug that would have been expected to affect physical performance was being taken by the ballerinas during the course of this investigation. Furthermore, none of the ballerinas had been involved in strength or explosive-power training prior to the commencement of the training study.

Ballerinas were assigned randomly into an experimental group (E, $n = 11$) or control group (C, $n = 11$). Throughout the 8-week training intervention, the E and C groups undertook the same amount of ballet training (5 session per week), equated in terms of intensity and volume. Ballet training was performed 5 times a week (Monday–Friday), each session lasting 60–90 minutes. The typical training session consisted of barre technical exercises, center choreography exercises, and ballet jump exercises.

Table 1. Mean ± standard deviation of age, body height, and mass of subjects studied.

Anthropometric data	Experimental group	Control group
	Mean ± *SD*	Mean ± *SD*
Age (y)	21.0 ± 1.3	21.2 ± 1.6
Body height (cm)	165.7 ± 7.0	165.6 ± 5.0
Body mass (kg)	50.7 ± 4.1	51.0 ± 2.8

Unlike the C group, the E group also undertook a specifically designed WBV training 3 times per week. No other form of conditioning, apart from those considered for this study, were allowed or were performed by participants during the study duration.

Full advisement was given to the volunteers regarding the possible risks and discomfort that might be associated with the testing and training procedures used in this study. Prior to the training study and after a detailed written and verbal explanation as to the nature of the procedure involved in this study, all the subjects gave their written informed consent. The study was approved by the Institutional Review Board of the Italian Society of Sport Science. Table 1 presents the physical characteristics of the subjects.

Testing Procedures

Testing procedures were administered at the beginning and the end of the training intervention using the same order. Posttraining assessments were accomplished 3 days after the last training session to avoid the acute effects of WBV and to allow recovery in both groups. Prior to the commencement of the training study, subjects became accustomed to the testing and training procedures with 2 familiarization sessions that took place during the preceding week. Familiarization procedures were performed on an individual basis until subjects appeared to be fully accustomed to the testing and training procedures involved with this study. The first 2 authors of this study supervised the familiarization sessions.

Before each testing session, the ballerinas' body mass was measured to the nearest 0.5 kg (Seca Beam Balance 710, Hamburg, Germany) with subjects lightly dressed and barefooted, and standing height was measured to nearest 0.5 cm (Seca Stadiometer 208). After body mass and body height were measured, ballerinas undertook a standardized general warm-up protocol that preceded the jumping and mechanical power measurements. The general warm-up comprised stationary cycling (5 minutes) on a computerized cycle ergometer (Technogym, Gambettola, Italy) followed by 5 minutes of static stretching of quadriceps and calf muscles.

Countermovement Jump Height Testing

Countermovement jump height was assessed with subjects performing maximal vertical jumps (with hands on hips) on a switch mat connected to a computer (Ergojump; Boscosystem, Rieti, Italy), according to the procedures reported by Bosco et al. (6). Prior to testing, each subject performed 3 submaximal CMJs with 1 minute of recovery between repetitions, followed by 3 maximal CMJs paced with similar recovery time. During CMJs, knee flexion was standardized, allowing subject to bend their knee at approximately 90°. According to Bosco et al. (6), the rise of center of mass after the takeoff (h) was measured applying the following ballistic formula:

TABLE 2. Height of rise of center of gravity of best countermovement jump performance (CMJ) and progress (%) recorded in the experimental group (E) and control group (C) before and after the 2-month experimental period (mean ± *SD*).

	Experimental group		Control group	
	Before	After	Before	After
CMJ (cm)	26.7 ± 2.7	28.5 ± 3.5*	28.8 ± 2.8	28.5 ± 2.9
CMJ (% progress ± *SD*)		6.3 ± 3.8*		−1.1 ± 4.67

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

where g is the gravity pool constant (9.81 $m \cdot s^{-2}$). The best h was used for statistical analysis. The reproducibility of the CMJ testing procedure here used has been reported to be high (1, 12, 24).

Mechanical Power Measurements

Following CMJ testing, the mechanical power of subjects' knee extensors was assessed using a horizontal leg-press machine (Technogym, Gambettola, Italy). After a brief, specific warm-up of approximately 10 minutes, consisting of 3 sets with increasing loads (40, 60, and 70 kg with 10, 6, and 3 repetitions, respectively) separated by 2–3 minutes of passive recovery, each subject performed maximal dynamic leg-press exercises with 50, 70, and 100 kg until exhaustion. During leg-press exercises, knee flexion was standardized at 90° and only the repetitions that matched the selected angular displacement were used for calculations. Knee flexion was monitored using an electronic goniometer (Muscle-Lab, Ergotest Technology, Langesund, Norway) worn by subjects on their nondominant leg and interfaced with a laptop computer. In order to improve measurement reliability, horizontal leg-press seat position was modified according to subjects' lower limb length and was recorded for posttraining testing reconsideration. Magnitude and rate of load displacement were assessed with a computerized system (Muscle-Lab, Ergotest Technology, Langesund, Norway) according to Bosco and colleagues' (1) procedures. As suggested by Bosco et al. (1), average knee-extensor power was considered as a variable representing lower limb mechanical power.

Subjects performed 3 trials of each load and the best measures were considered for calculations.

The reliability of this testing procedures and measurements reported as an intraclass correlation coefficient has been reported to be $r = 0.95$ (1).

Vibration Treatment Procedures

Subjects were exposed to vertical sinusoidal WBVs using the Nemes LC device (Boscosystem, Rieti, Italy). Vibration frequency was set at 30 Hz according to Cardinale et al. (8) (5-cm displacement; magnitude = 5 g) to maximize WBV training effects. During each training session, the subjects in the E group were exposed to WBV treatment before their usual ballet lesson with C group. Whole body vibration treatment consisted of five 40-second repetitions separated by 60 seconds of passive recovery and was provided 3 times a week (Monday, Wednesday, and Friday). The total training intervention comprised 24 WBV sessions over 8 weeks. Whole body vibrations were applied with the subject standing on the vibration platform in a half-squat position (approximately 100°) with feet and knee rotated externally (i.e., demi-plié position). In order to avoid bruises, E group ballerinas wore dancer-type shoes throughout the WBV session.

Statistical Analyses

Data are shown as mean and standard deviation. Paired *t*-tests were used for within-group comparisons. The level of significance was set at $p \leq 0.05$. Unpaired *t*-tests with Bonferroni adjustment were used for between-group comparisons, with a resulting *p* value of 0.025. In order to assess meaningfulness of pre- to posttraining changes, the effect size (ES) was calculated according to Thomas et al. (28). Effect sizes of 0.8 or greater, around 0.5, and 0.2 or less were considered as large, moderate, and small, respectively (28).

RESULTS

The E and C groups differed at pretraining only for average velocity (AV) and average power (AP) during the 50-kg condition ($p > 0.05$). The E group showed significant CMJ performance improvement after training ($p < 0.001$) (Table 2). Effect size for CMJ was medium (0.67).

Results of the mechanical variables of interest are showed in Table 3. The E group showed significant ($p < 0.05$–0.001) pre- to posttraining improvements in all the mechanical parameters (average force, AP, and AV) for the 70- and 100-kg conditions. Effect sizes ranged from medium to large (0.33–1.8). In the 50-kg condition, only AP and AV showed pre- to postintervention improvements in the E group (0.89 and 1.00, respectively). These results shifted the force-velocity and power-velocity curves to the right (Figure 1). No significant change in any of the mechanical variables was observed in the C group.

DISCUSSION

This is the first training study that investigated the effects of WBV on vertical jump and lower limb dynamic muscular strength and power in elite-level ballerinas.

The main finding of this investigation is that WBV training positively affected vertical jump performance in well-trained elite ballerinas. This result is of particular interest, because vertical jump performance is considered to be related to ballet performance (19, 27). The pre- to postintervention improvement in CMJ performance found in this study is similar (6.3 vs. 7.6%) to that reported by Delecluse et al. (12) for age-matched, untrained female subjects submitted to WBV treatment. However, in the Delecluse et al. (12) study, the WBV treatment was undertaken for 12 weeks using higher WBV frequencies (35–40 vs. 30 Hz) but with a similar vibration platform displacement (5 mm) and magnitude (5 g). Furthermore, WBV training loads were adjusted (vibration frequency, repetition number, and duration) over the intervention duration in order to provide progressive overloads (12).

The few studies that addressed the issue of strength training in ballerinas reported significant improvement in isometric and isokinetic strength (19, 27). Although those studies analyzed the effect of free-weight and weight-training machines on ballet performance using re-

TABLE 3. Mean ± *SD* of the average force (AF), average power (AP), and average velocity (AV) measured during leg-press performance executed with progressive loads, before and after the experimental period in both groups.

Load (kg)	AF (N) Before Mean ± *SD*	AF (N) After Mean ± *SD*	AP (W) Before Mean ± *SD*	AP (W) After Mean ± *SD*	AV ($m \cdot s^{-1}$) Before Mean ± *SD*	AV ($m \cdot s^{-1}$) After Mean ± *SD*
Experimental Group						
50	519.0 ± 4.0	529.0 ± 3.0	258.7 ± 24.7	280.7 ± 21.7†	0.50 ± 0.04	0.54 ± 0.04†
70	718.0 ± 9.0	735.0 ± 5.0*	323.1 ± 45.9	340.4 ± 32.6*	0.45 ± 0.06	0.47 ± 0.04*
100	986.0 ± 16.0	1,035.0 ± 12.0*	271.5 ± 79.2	320.4 ± 66.8†	0.27 ± 0.07	0.34 ± 0.66‡
Control Group						
50	522.0 ± 4.0	520.0 ± 2.0	282.8 ± 15.5	277.7 ± 26.3	0.54 ± 0.03	0.53 ± 0.05
70	724.0 ± 6.0	726.0 ± 7.0	356.0 ± 46.9	376.6 ± 92.5	0.49 ± 0.06	0.52 ± 0.10
100	1,016.0 ± 16.0	1,015.0 ± 12.0	352.4 ± 100.3	385.4 ± 56.4	0.35 ± 0.09	0.38 ± 0.05

* $p < 0.05$.
† $p < 0.01$.
‡ $p < 0.001$.

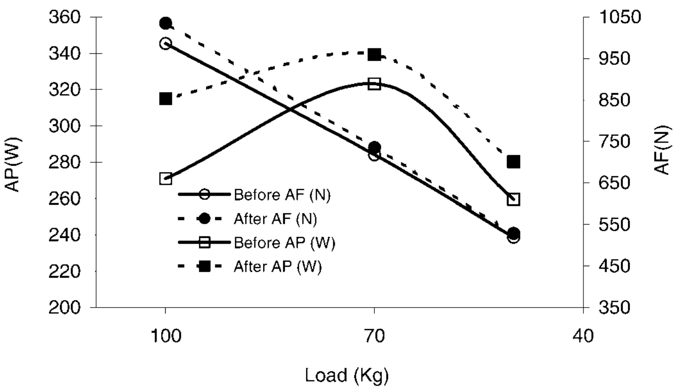

FIGURE 1. Average power (AP) and average force (AF) developed during leg press exercise performed with progressive loads (50, 70, and 100 kg) are shown before (open symbol) and after (filled symbol) the WBV training. The statistical differences of mechanical parameters used are showed in Table 3.

peated-jumping ballet simulation protocols, they did not study CMJ performance. In this regard, Delecluse et al. (12) reported no CMJ improvement in a population of untrained young female subjects using strength-training protocols similar to those used for ballerina training studies (19, 27).

Providing 40-Hz vibrations during squat training (6–10RM), Rønnestad (24) reported significant improvement in CMJ (9%) and squat 1RM performance (32.4%) as a consequence of a 5-week WBV training in male resistance-trained subjects. Interestingly, the control group, which comprised resistance-trained individuals who performed the same strength training protocol without added vibration stimuli, reported no significant improvements in CMJ performance.

In light of these considerations, it may be argued that WBV or explosive strength training (14) should be considered for ballerinas in order to improve vertical leap performance. However, transfer of CMJ height improvements to dance performance should be assessed with sound performance analysis.

In this study, the WBV training determined significant improvement of AP. The major effects of WBV were observed at the 100-kg load with an average AP improvement of 25% (ES = 0.62). This AP improvement was due mainly to a concomitant AV increment of 26% (ES = 1.0).

As a consequence of WBV training, a general shift of force and power profiles to the right was observed (see Figure 1). Training-induced improvements (i.e., shift to the right) of force-power profiles (11, 13) may be caused by several factors such as motor unit synchronization, cocontraction of synergistic muscle, or increased inhibition of the antagonist muscles (25). From this we can infer that WBV training probably was effective in causing an alteration of the neural traffic that regulates muscle stiffness (2, 7). Interestingly, WBV intervention induced force-power profile improvements similar to those reported in studies involving heavy-load strength training (11, 13).

According to Bosco et al. (4), stimuli duration seems to be important in inducing neuromuscular adaptation. In the present study, the total duration of WBV intervention was short (only 24 minutes), with a constant gravitational perturbation of 5 g. This means that in order to induce similar training loads using leg-press or half-squat exercises, 150 repetitions with extra loads of approximately 3 times body mass should be provided over the same training period (4) twice a week.

The mechanisms mediating the effects of WBV on the neuromuscular system are not completely understood (7, 20). However, current knowledge of WBV effects determinism are considered to be related to neuromuscular, hormonal mechanisms, or both (5, 7). In the present study, no neural extra excitatory inflow or hormonal changes have been demonstrated, because neither electromyographic recordings nor blood samples were collected. Nevertheless, enhancement of mechanical power in leg press performance and the improvement in the CMJ height strongly suggest that a neural adaptation occurred in response to the vibration training in the subjects of the experimental group.

These findings are of particular interest because maximal anaerobic power is highly involved in ballet performance (17). However, as suggested for CMJ, the actual effects of AP and AV improvements on ballet performance should be investigated with proper performance analysis.

The successful WBV protocol used in this training study was devised specifically to be as nonintrusive as possible to the usual dance routine. However, use of this training protocol obtained very limited improvements in dynamic strength in the E group at the selected external loads (1–3%, $p < 0.05$). It can be speculated that if periodized and progressive WBV training programs (12) are used, further improvements in strength, explosive strength, and CMJ performance could be achieved.

Practical Applications

According to previous research (18, 19, 27), this study reported that ballet practice is ineffective in promoting significant strength improvements in well-trained ballerinas.

Whole body vibration training may be considered as an effective and safe training strategy for improving muscular power in well-trained ballerinas. In this regard, a 30-Hz vibration frequency should be used for inducing muscular adaptation throughout the muscular strength-power spectrum. Whole body vibration stimuli should be provided in the form of 3–5 repetitions of 40 seconds. Recovery time between repetitions should be no less than 60 seconds.

In this study, no significant ($p > 0.05$) variations in body mass were found to result from the WBV treatment. Furthermore, the WBV group reported a perceived increase in physical appearance and technical efficacy during ballet performance (a multi-response questionnaire was submitted at the end of the training intervention). Whole body vibration training studies that used similar or even higher training loads for a longer duration also reported no variation in body mass (12, 30, 31). Although this study did not provide detailed information about the variations in body composition that may have occurred as consequence of WBV, it can be suggested that WBV might increase muscular performance without significantly affecting body appearance. Finally, it is difficult to say if increasing dynamic and explosive muscular strength can increase ballet performance, but it can help the dancers be safer and prevent muscle injures related to their highly intense plyometric activity.

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