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COMPARING THE PERFORMANCE-ENHANCING EFFECTS OF SQUATS ON A VIBRATION PLATFORM WITH CONVENTIONAL SQUATS IN RECREATIONALLY RESISTANCE-TRAINED MEN

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ABSTRACT. Rønnestad, B.R. Comparing the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. *J. Strength Cond. Res. 18(4):000-000. 2004.*—The purpose of this investigation was to compare the performance-enhancing effects of squats on a vibration platform with conventional squats in recreationally resistance-trained men. The subjects were 14 recreationally resistance-trained men (age, 21–40 years) and the intervention period consisted of 5 weeks. After the initial testing, subjects were randomly assigned to either the "squat whole body vibration" (SWBV) group ($n = 7$), which performed squats on a vibration platform on a Smith Machine, or the "squat"(S) group ($n = 7$), which performed conventional squats with no vibrations on a Smith Machine. Testing was performed at the beginning and the end of the study and consisted of 1 repetition maximum (1RM) in squat and maximum jump height in countermovement jump (CMJ). A modified daily undulating periodization program was used during the intervention period in both groups. Both groups trained at the same percentage of 1RM in squats (6–10RM). After the intervention, CMJ performance increased significantly only in the SWBV ($p < 0.01$), but there was no significant difference between groups in relative jump height increase ($p = 0.088$). Both groups showed significant increases in 1RM performance in squats ($p < 0.01$). Although there was a trend toward a greater relative strength increase in the SWBV group, it did not reach a significant level. In conclusion, the preliminary results of this study point toward a tendency of superiority of squats performed on a vibration platform compared with squats without vibrations regarding maximal strength and explosive power as long as the external load is similar in recreationally resistance-trained men.

KEY WORDS. whole body vibration, resistance training, strength adaptations, squat, CMJ

INTRODUCTION

Lately, it has been hypothesized that mechanical vibration at a low amplitude and high frequency of the whole body can positively influence muscle performance (8–10, 15, 49, 55, 57–59). Nazarov and Spivak (38) were among the first to highlight the association between strength and power development and whole-body or segment-focused vibration training. They assumed that repetitive, eccentric vibration loads with small amplitudes would effectively enhance strength, because of a better synchronization of motor units. In the last decade, remarkable enhancements in strength and power after vibration training have been presented. A single vibration bout has been shown to result in acute and temporary effects when it comes to muscle power and/or strength of the lower extremities (8, 9, 57) and arm flexors (7, 27, 33).

The mechanisms mediating this acute effect of vibration on neuromuscular performance are not entirely understood. The mechanical action of vibration mediates fast and short changes in the length of the muscle-tendon complex. This may induce a nonvoluntary muscular contraction termed the "tonic vibration reflex" (TVR). TVR is believed to depend upon the excitation of the primary muscle spindle (Ia) fibers (11, 18, 35, 47). Thus, potential extra excitatory inflow during vibration stimulation is partly related to the reflex activation of the α-motoneuron. Accordingly, researchers have reported an increase of the root mean square EMG (EMG_{rms}) of the biceps brachii muscle in boxers exercising with a vibrating dumbbell that was twice as high as a voluntary arm flexion with a load equal to 5% of the subject's body mass (7). Also, Torvinen et al. (57) found an increase in EMG_{rms} in the calf muscles during whole body vibration (WBV). In accordance with the latter, studies have demonstrated a facilitation of the excitability of the patellar tendon reflex by vibration applied to the quadriceps muscle (12), vibration induced drive of α-motoneurons via the Ia neuron loop (48), and activation of the muscle spindle receptors after applying vibrations (30). However, if muscle spindles are stimulated for a long period of time by vibration, they will finally fatigue (6). This, in turn, is seen as reduction in EMG activity, motor-unit firing rates, and muscle contraction force. It is possible that the ideal vibration period to achieve acute strength/power gains is individual, thus fatigue may explain why some of the studies find no positive effect after one acute bout of vibration (16, 45, 58). However, a confounding explanation exists. Vibrations also seem to depress some monosynaptic spinal reflexes (e.g., H-reflex) (17, 34). The decrease in the reflex is primarily related to a presynaptic inhibitory mechanism, involving a depolarization of Ia afferents (21). The practical effects of these reflexes regarding resistance training are unclear.

Some studies have examined the effect of WBV training on muscle performance over a longer period. Bosco et al. (8) studied the effect of a 10-day training program with daily series (5 × 90 seconds) of vertical sinusoidal vibrations at a frequency of 26 Hz on subjects who had no previous experience with resistance training. They found significant improvement in the height and mechanical power during a 5-second continuous jumping test. However, a period of 10 days is too short to determine the long-term effects of WBV. Runge et al. (49) presented gains of 18% in chair-raising time in fit elderly persons after 8 weeks of WBV training (3 times a week at 27 Hz). Recently, Torvinen et al. (59) presented a study of 8-month WBV (4 minutes per day, 3–5 times per week, with 25–45 Hz). The subjects were young and healthy nonathletic adults. They found a significant 7.8% improvement in vertical jump height in the vibration group. On the isometric extension strength of the lower extremities, grip strength, shuttle run, and postural sway the vibration intervention had no effect. Similar results have been presented after 4 months of WBV training with an identical training protocol (58).

Neither of the studies mentioned above compared the performance-enhancing effects of WBV with those of conventional resistance training, so we cannot tell if there is a difference in strength improvement between the two training methods. However, other studies have compared these 2 training methods for a longer period (6–12 weeks), and have concluded with similar and significant improvement in strength regarding WBV and conventional resistance training with moderate intensity (15, 55). Both these studies included only untrained subjects, and untrained people improve their strength dramatically in the beginning of a strength-training period (40). Thus, if there are any differences in strength gain between the WBV training and conventional resistance training, it is difficult to detect it in previously untrained subjects. Regarding conventional resistance training, studies indicate that training at an intensity similar to 80–90% of 1 repetition maximum (1RM) is best for improving strength (4, 64). The studies of Delecluse et al. (15) and Schlumberger et al. (55) did not carry out conventional resistance training in this intensity zone, so it can be claimed that it was not an optimal strength training regime. Issurin et al. (26) took the latter into consideration when they studied the effects of "vibratory stimulus training" on strength, using a "sitting bench-pull apparatus" with 44 Hz vibration frequency 3 times per week for 3 weeks with men who had not previously trained on resistance exercises. A control group performed exactly the same training protocol except from the vibration stimulus (6 sets of sitting bench-pulls with the load gradually increasing from 80 to 100% of 1RM). The group using vibration showed an increase in maximum strength of 49.8%, whereas the group using conventional resistance training without vibration showed an improvement of 16.1%.

In the latter study, the vibration training induced significant greater strength improvement compared with conventional resistance training. Because WBV training is used by professional athletes (9, 27, 33, 36), it is of great interest to repeat the study of Issurin et al. (26) on resistance-trained subjects. Thus, the purpose of this study was to compare the effects of squats performed on a vibration platform (VP; NEMES-LC, Ergotest, Rome, Italy) with conventional squats without vibrations on 1RM and countermovement jump ([CMJ]; a measurement of explosive strength after stretch shortening of the muscles), in resistance-trained men during a 5-week overreaching period of peaking. Both groups trained with a load equal to 6–10RM. With the results of Issurin et al. (26) in mind, it was hypothesized that squats performed on a VP are superior to conventional squats when the subjects are training with the same external load on the Olympic bar.

Figure 1. Squat performed on a vibration platform.

Methods

Experimental Approach to the Problem

To address the question of whether squats performed on a VP are superior to conventional squats without vibrations in resistance-trained men, the effects of 5 weeks with squat training on 1RM and CMJ were compared. Both groups trained at the same intensity (number of RM); the only difference was that 1 group performed the squats on a vibration platform (Figure 1). The subjects carried out all squats (both testing and training), in both groups, on a Smith Machine (Gym Bo, Gelsenkirchen, Germany) to avoid a balance problem on the VP during the squats.

Subjects

Sixteen men (age, 21–40 years; height, 177.8 ± 6.5 cm; weight, 76.2 ± 8.8 kg) served as subjects. Two subjects withdrew before completion of the study, due to causes unrelated to the study. All subjects had participated regularly in resistance training (minimum 3 times a week during the last year) and completed at least 1 bout of squats each week. To be included in the study, the lifters had to lift at least 2.2 times their body weight in a 1RM squat. To make sure there were no differences in training periodization, the subjects provided written information about their training regimen during the last year. Full advice was given to the subjects regarding the possible risk and discomfort that might be involved, and the subjects gave their written informed consent. The study was

TABLE 1. Training regime for both the SWBV and S groups*

Week	Bout 1	Bout 2	Bout 3
1	3 × 10 × max†	3 × 10‡	4 × 10 × max†
2	4 × 10‡	4 × 8 × max†	
3	4 × 8 × max†	3 × 8‡	4 × 8 × max†
4	3 × 8‡	4 × 6 × max†	
5	4 × 6 × max†	3 × 6‡	4 × 6 × max†

* SWBV = squat whole body vibration; S = squat.

†Maximal sets.

‡Submaximal sets (90% of max). Training volume and intensity throughout the intervention period are identical for both groups.

approved by the Regional Ethics Committee of the Norwegian Research Council for Science and Humanities.

Subjects were randomly divided into 2 different training groups. The "squat whole body vibration" (SWBV) group ($n = 7$) trained squats on the VP on a Smith Machine. The "squat" (S) group ($n = 8$) trained conventional squats (without a VP) on a Smith Machine.

Testing was administered at the beginning and at the end of the 5-week training intervention. Because all the subjects had completed at least 1 bout of squats per week during the last year, we did not spend time on familiarization with the squat exercise. The order of tests was similar before and after the training intervention. The posttests were accomplished at approximately the same time of the day as the pretests, 3 days after the last workout to avoid acute effects of WBV and to reassure proper recovery after the last workout. All subjects completed at least 91% of the workouts.

Training

The 5-week training period consisted of 3 workouts during the first, third, and fifth weeks, and 2 workouts during the second and fourth weeks. The subjects completed 13 workouts on nonconsecutive days (Table 1). Each subject performed a standardized 10-minute aerobic warm-up before each workout; 2–3 warm-up sets of squat were also performed with gradually increased weight. All subjects were supervised by the investigator at every workout during the first 2 training weeks, and thereafter at least once a week.

Training volume (total reps performed) and intensity (RM) were altered similarly for the 2 groups. During the first week, both groups performed 3 sets of 10RM in each bout of exercise, during the second and third training week they completed 4 sets of 8RM, and during the last 2 weeks they trained with 4 sets with 6RM (Table 1). Subjects were encouraged to continuously increase their RM loads during the intervention. Subjects were allowed assistance on the last rep. However, to achieve a modified daily undulating periodization, the subjects were told to reduce their load on the Olympic bar by 10% approximately every third workout (this was coordinated between the 2 training groups). Daily undulating periodization is characterized by frequent alterations in the intensity and volume (43, 44). This program seems to place considerably stress on the neuromuscular system, because of the rapid and continuous change in program variables (44), and thus elicits greater strength gains than a linear periodized program. The subjects in SWBV group performed their squats on a VP with a frequency of 40 Hz. Subjects were prohibited from performing any other strength-building exercises on the legs during the 5-week training intervention.

Testing

We used 1RM as a measure of pretraining strength in squats. Squat testing and training was performed on a Smith Machine. The pre- and posttesting was done on the same equipment with identical subject-equipment positioning overseen by the same trained investigator.

Jumping Measurements

The subjects performed a 10-minute warm-up, consisting of cycling at a workload of 60–70 W. Thereafter they performed 4 trials of CMJ. The flight time of each single jump was recorded using an infrared light mat (Muscle Lab, Ergotest Technology A.S, Langesund, Norway), interfaced to a personal computer. To avoid immeasurable work, horizontal and lateral displacements were minimized, and the hands were kept on the hips throughout the jumps. During CMJ, the angular displacement of the knees was standardized so that the subjects were required to bend their knees to approximately 90°. The obtained flight time (t) was used to estimate the height of the rise of body center of gravity (h) during CMJ (i.e., $h = gt^2/8$, where $g = 9.81\ \mathrm{m \cdot s^{-2}}$). The coefficient of variation regarding test-retest reliability for a similar test has been found to be 4.3 % (63). The best performance was used for statistical analysis.

1RM Measurement

Before the 1RM squat test, subjects performed a standardized warm-up consisting of 3 sets with a gradually increasing load (40, 75, and 85% of expected 1RM) and decreasing number of reps (12, 7, and 3). The knee-angle during the 1RM squat had to be 90° to be accepted. To assure similar knee angle in the pre- and posttest for all the subjects, the subjects' squat depth was individually marked at the pretest depth of the buttock on a list. Thus, the subject had to reach his individual depth (touch his list with the buttock) in the posttest to get his lift accepted. The first attempt in the test was performed with a load approximately 5% below the expected 1RM load. After each successful attempt, the load was increased by 2–5% until failure in lifting the same load in 2–3 consecutive attempts. The rest period between each attempt was 3 minutes. The coefficient of variation for test-retest reliability for this test has been found to be <2% (41).

Statistical Analyses

All values given in the text, figure, and tables are mean ± *SD*. Paired t-tests were used for within-groups comparisons, and unpaired t-tests were used to compare the relative changes in strength and jump height between groups. Bonferroni adjustments were made to account for tests of 2 variables. Thus, p values of 0.025 were used for each of the 2 variables (1RM and CMJ).

RESULTS

1RM test

There was no significant difference between the groups at the pretest in 1RM. In both groups, 1RM squat increased during the training intervention ($p < 0.01$, Table 2). Although there was a trend toward a greater relative strength increase in the SWBV group compared with the

Table 2. One repetition maximum loads in squat and counter-movement jump performances recorded before (pretraining) and after (posttraining) the 5-week training intervention.

Variables	Groups SWBV†		Group S†	
	Pretraining‡	Posttraining	Pretraining	Posttraining
1RM (kg)	165.0 ± 34.5	217.1 ± 2.4 (32.4 ± 9.0)*	150.0 ± 15.3	186.4 ± 21.9 (24.2 ± 3.9)*
CMJ (cm)	36.5 ± 7.3	39.7 ± 6.6 (9.1 ± 5.5)*	34.7 ± 3.9	36.1 ± 3.4 (4.2 ± 4.2)

* Marks significant increase within the groups ($p < 0.01$).
† SWBV = squat whole body vibration; S = squat
‡ Values are mean ± *SD* (% progress ± *SD*).

S group (32.4 ± 9.0% vs. 24.2 ± 3.9%, respectively; $p = 0.046$), it did not reach a significant level when Bonferroni adjustments were made (Table 2).

CMJ test

There was no significant difference between the groups at the pretest. Only the SWBV group significantly improved their jump height ($p < 0.01$, Table 2), but there was no significant difference between groups in relative jump height increase ($p = 0.088$).

Discussion

This is the first study on resistance-trained subjects that compares the effects of WBV training and conventional resistance training on 1RM in squats and maximal CMJ, where the external load is similar between 2 groups. The preliminary results of this study point toward a trend in which squats performed on a VP is superior to conventional squats regarding maximal strength and explosive power. It seems that this advantage depends on heavy external loading in addition to WBV. Both groups increased their 1RM in squats during the training intervention, and the relative strength increase was greater in the SWBV group than the S group (32.4 ± 9.0% vs. 24.2 ± 3.9%, respectively; $p = 0.046$). The jumping performance, CMJ, was significantly improved in the SWBV groups, but there was no significant difference between the groups ($p = 0.088$). It may be speculated that the lack of significant differences between the groups is related to the fact that this study contains only 7 subjects in each group and the intervention lasted only 5 weeks.

Several other studies have found positive effects of WBV on CMJ (8, 15, 56, 58, 59). In contrast to the present study, Delecluse et al. (15) found in untrained subjects that WBV training is superior to conventional resistance training when it comes to improvement in CMJ. However, in the latter study, there was a significant higher CMJ performance recorded in the conventional resistance group compared with the other groups in the pretest condition. Thus, it may be argued that the potential for progression in CMJ was smaller for this group.

The first adaptation mechanism of a skeletal muscle to resistance training is believed to be neural change, due to an almost immediate increase in strength at the onset of training and the absence of (measurable) hypertrophy (3, 13, 51). The exact mechanism by which resistance training can improve neuromuscular activation is not known, but there are several possible explanations which could cause this enhancement (e.g., increase in motor unit synchronization, co-contraction of the synergistic muscles or increased inhibition of the antagonist muscles [52]). These explanations have also been used to explain the effects of WBV on jumping performance (7, 15, 58, 59). All these studies were accomplished with subjects who had no previous resistance training, and neural adaptation seems to dominate in the early adaptation phase of resistance training (51, 53). The present study was carried out with resistance-trained men, with whom the neural adaptation phase should have reached a plateau. However, neural adaptation can not be ruled out, because of the specificity principle: a change in the training program, such as different exercises and/or intensity, could trigger a transient burst of neural and muscular adaptations (52). The modified daily undulating periodization training regime and the introduction of vibration training could potentially result in neural adaptations. This is supported by the relatively great improvement in 1RM strength in both the S and SWBV groups (24.2 ± 3.5 and 32.4 ± 8.9%, respectively). In line with this, Häkkinen et al. (24, 25) found increased integrated EMG activity in elite weightlifters, indicating the importance of neural adaptations in experienced strength and power athletes.

The trend toward superiority of the SWBV group regarding 1RM strength in this study is in accordance with earlier results with untrained subjects. Issurin et al. (26) found that, with previously untrained subjects, applying vibrations (44 Hz) while training with a load 80–100% of 1RM, is superior to training with the same external load without vibrations. However, Delecluse et al. (15) and Schlumberger et al. (55) compared conventional resistance training with WBV training and found no differences regarding strength improvement. This result may have been caused by the lack of external load in the WBV group. Other studies have not found improvement in maximum strength after WBV interventions (16, 54, 58–60). The reason is unclear, but the lack of external load in all these studies may indicate that this is important to achieve strength gains after WBV training.

The mechanisms mediating the apparently superior effect of performing squats on a VP vs. conventional squats, regarding 1RM strength, are not fully understood. An increase in isometric contraction strength induced by TVR has been well documented after local vibratory stimulation applied to the tendon or muscle (1, 18, 29). Armstrong et al. (2) found similar results when subjects were holding a cylindrical handle vibrating at 40 Hz, resulting in 52% increase in grip strength. The TVR may have contributed to the results of Bosco et al. (7), who found an increase of the EMG_{rms} of biceps brachii muscle in boxers who were exercising with a vibrating dumbbell twice as high as a voluntary arm flexion, with a load equal to 5% of the subject's body mass. Also, Torvinen et al. (57) found an increase in EMG_{rms} in the calf muscles during vibration. In accordance with the latter, studies have demonstrated a facilitation of the excitability of the patellar tendon reflex by vibration applied to quadriceps muscle (12), vibration induced drive of α-motoneurons via the Ia loop (47), and vibration activation of the muscle spindle receptors (30). Rittweger et al. (46) also found significantly greater EMG mean frequency over the vastus lateralis after exercise with vibrations than without vibrations. These studies indicate that exercising with vibrations achieves superior excitation of the motoneurons to exercising without vibrations. Sale (50) suggested that full activation of the muscle may lead to motor unit fatigue, and due to this training effect, may increase the strength. The motor units in the SWBV group did perhaps get more fatiguing stimulus because of increased TVR, and thus superior gains in 1RM compared with the S group.

The α-motoneuron is the final point of summation for all the descending and reflex inputs, and the net membrane current of this motoneuron determines the discharge pattern of the motor unit and thus the muscle activity (37). De Gail (14) states that TVR is able to cause an increase in recruitment of the motor units through activation of muscle spindles and polysynaptic pathways. In addition, the WBV waves propagate from the distal links to muscles located proximally and activate a greater number of muscle spindles. Their discharge activates a larger fraction of the motor pool and recruits many previously inactive motor units into contraction (27). This increased activity of motor units may enable the SWBV group to train with heavier loads than the S group, and thereby optimize the stimulation of higher recruitment threshold motor units and muscle tissue mass with each workout (42).

Another possible explanation concerns the difficulty in achieving full muscle activation by voluntary effort during dynamic exercise, when large muscle groups are involved (28). It is likely that the vibrations may cause partial activation of the muscles, and their mobilization at the beginning of the effort will be faster. Thus it is possible that the group which trained with vibrations could train with heavier loads and get a better stimulus for strength increase. Evidence also indicates that voluntary activation is a limiting factor in force production, and that improvements in force generated per unit cross-sectional area are responsible for the initial gain in strength (20). The possibility of enhanced capacity of the muscle to perform work when vibrations are applied simultaneously with external load was demonstrated by Liebermann and Issurin (33). The 1RM in isotonic elbow flexions for Olympic athletes increased significantly (8.3%) while applying vibrations (44 Hz) to the maximum lift, compared with conventional maximum lift without vibrations. Similar results were presented by Issurin and Tenenbaum (27). They found significant increase in mean and maximal power in elite athletes when vibration was applied (44 Hz). This is in accordance with the result of this study, where the SWBV group tended to train with a higher percent of their 1RM, compared with the S group, although this difference was not significant (data not shown). Thus, it seems as the vibrations increases the intensity of the lift rather than reduce it.

Although not measured in this study, a certain degree of hypertrophy may be expected after 5 weeks of intensive resistance training (56). In rats, a vibration-induced enlargement of slow- and fast-twitch fibers has been demonstrated (39). Thus it is possible that the vibrations gave an extra hypertrophy stimulus. Another potential explanation is that the vibrations resulted in greater stretch/tension on the contractile elements (either directly through the TVR itself, or by increased capacity to lift heavier loads via the TVR). Stretch/tension seems to be an essential stimulus for muscle growth (22, 32, 62).

Another stimulus for muscle growth is the androgen hormone testosterone. Testosterone is able to affect muscle growth via increased amino acid uptake and protein synthesis in the muscle cells (5, 19, 23, 61). Bosco et al. (10) found that acute exposure to WBV causes increased plasma concentrations of testosterone. The same acute testosterone response is also seen after a single bout of resistance exercise when the workout involves large muscle groups, relative heavy resistance (85–95% of 1RM), moderate to high volume of exercises, and short rest intervals between the sets (31). Whether the addition of vibrations in the SWBV group induced a larger testosterone response than the S group is not known.

It may be argued that differential psychological factors due to training on the VP might affect the motivation, and because of that promote greater effort in each single session in the SWBV group compared with the S group. This study did not control for psychological factors, but the results of Delecluse et al. (15) indicate no placebo effect of vibration training.

The study design makes it impossible to answer the reasons behind the tendency of difference in 1RM gain between the 2 groups, because no neurogenic enhancement or changes in the morphological structure of the muscles could be demonstrated (neither EMG recordings nor muscle biopsies were performed).

In conclusion, this preliminary study on recreationally resistance-trained men indicates that CMJ height was significantly increased only by the squats performed on the VP. Both training interventions led to a significant improvement regarding 1RM in squats. There was a tendency toward superior 1RM improvement in the SWBV group, compared with the S group, but this did not reach a statistically significant level ($p = 0.046$). Possible explanations for this tendency toward differences in training adaptations may be related to neural adaptation, TVR, or a more favorable hormone milieu regarding muscle growth during the SWBV strength-exercise protocol.

The above-noted findings suggest that vibration is a potentially efficient training stimulus. Future studies should include a sufficient number of subjects and focus on comparing the long-term effects of WBV with external loads to conventional resistance training to explore the mechanisms behind these apparent differences.

PRACTICAL APPLICATIONS

This study indicates that when recreationally resistance-trained men perform squats with the same external load, there is a tendency toward superiority of squats performed on a VP compared with conventional squats without vibrations regarding 1RM in squat and maximal CMJ height. Consequently, it seems as though optimal strength gains in resistance-trained subjects are achieved by adding vibration to the conventional resistance training. This superior effect of vibrations on strength seems to depend on relatively heavy external resistance (6–10RM). Therefore, instructions from a qualified instructor are advised before adding the relatively heavy external load needed to optimize strength gains.

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