Effects of a 6-Week Periodized Squat Training Program With or Without Whole-Body Vibration on Jump Height and Power Output Following Acute Vibration Exposure

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Abstract

Lamont, HS, Cramer, JT, Bemben, DA, Shehab, RL, Anderson, MA, and Bemben, MG. Effects of a 6-week periodized squat training program with or without whole-body vibration on jump height and power output following acute vibration exposure. *J Strength Cond Res* 23(8): 2317–2325, 2009—The purpose of this study was to examine the effects of a 6-week, periodized squat training program with (SQTV) or without (SQT) whole-body low-frequency vibration (WBLFV) on acute improvements in jump height and power output over 3 separate testing occasions. Participants ranged in age from 18 to 30 years and were randomized into 1 of 3 groups (CG, or control group, $n = 6$; SQTV, $n = 13$; or SQT, $n = 11$). SQTV and SQT performed Smith machine back squat training twice per week with 3 to 5 sets of 55 90% of the 1-repetition maximum (1RM). The SQTV group also received WBLFV (50 Hz; 2–6-mm amplitude) during the 6-week training period before training (30 seconds, 2–4-mm amplitude) and between sets (3 bouts lasting 10 seconds each). Two 30-cm depth jumps and two 20-kg squat jumps were performed after an acute vibration protocol during weeks 1, 3, and 7. Jump height (cm), peak power (Pmax), peak power per kilogram of body mass (Pmax/kg), and mean power (Pav) were recorded for the depth and squat jumps. Although there were no group by trial interactions, percent change in Pmax for the squat jump was greater ($p < 0.01$) for the SQTV group than for the SQT group post WBLFV. In addition, the percent change scores for jump height and Pmax/kg for the depth jump were greater ($p < 0.05$) for SQTV than for SQT following WBLFV exposure. WBLFV during the 6-week squat training program resulted in greater acute improvements in power output and jump height for both jump conditions compared to SQT alone.

Key Words periodized resistance training, jump performance, post-activation potentiation

Introduction

Resistance training interventions aimed at increasing lower-body power have produced varying results. Increased descending cortical drive, increased alpha motor neuron input, increased motor unit firing rates, preferential motor unit synchronization, and decreased activation threshold for Type II motor units have been cited as central and peripheral adaptations to resistance training (3,8,11,16,26,27,29,37). Resistance training has also been shown to increase the probability and frequency of short interspike doublets prior to the initiation of ballistic actions leading to enhanced power production (1,2,16,40). Because power is the product of force and velocity, resistance training methods aimed at increasing muscle power development have focused on improving both factors (3,20,22,28,30). However, maximal power expression within the lower extremities is dependent on training status, the jump task performed (SSC vs. no SSC), and the load expressed relative to back squat 1RM (3,20,22,24,26,28,37). In addition, improvements in lower-body power that are transferable to ballistic tasks, such as vertical jumps, may be dependent on the training load, volume, velocity, movement intent, and specificity of the exercise to the jumping task (3,20,22,24,26,28,37).

Periodized resistance programs using "mixed method" regimens such as heavy load (greater than 80% of 1RM) resistance training utilizing maximal movement intent combined with moderate to lighter load (15 to 70% of 1RM) resistance exercises performed in a ballistic manner may be effective at increasing jump power (3,20,22,24,30,32). Harris

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et al. (20) evaluated a mixed methods training regimen vs. a heavy load and lighter load regimen over a 9-week training period and reported that the mixed method design resulted in greater scores on a wider range of power tests when compared with more conventional power training methods.

In addition to traditional resistance training, other techniques have been used to elicit acute increases in power output (5,6,9,13,14,17–19,32,34). For example, maximal voluntary contractions (MVCs) prior to jumping tasks have resulted in a potentiation of jump height (17–19). This potentiation in performance after an MVC has been termed "postactivation potentiation" or PAP. Similar recent studies have also suggested that whole-body low-frequency vibration (WBLFV) may elicit a PAP response to improve performance (5,6,9,11,14,32). If these findings can be validated, WBLFV may be an attractive modality by which to improve performance, rather than with the use of more difficult MVCs.

WBLFV has been shown to stimulate both mono- and polysynaptic reflex pathways leading to acute and chronic adaptations that are similar to moderate-load resistance training (5,6,9,10,11,14,15,25,28,32,33,36). Combining resistance training and WBLFV methods in an attempt to improve both acute and chronic adaptations to resistance training is a growing research area. For example, Ronnestad (32) examined the effects of a 5-week, periodized Smith machine back squat training regimen, with or without imposed WBLFV, on 1RM back squat and countermovement vertical jump performance. Both groups significantly ($p < 0.05$) increased 1RM Smith machine back squat strength; however, only the WBLFV group improved vertical jump performance. Contrasting results were reported by Kvorning et al. (25), who compared squatting on a vibration platform to squatting alone and vibration alone over a 9-week training period (6 sets at 8–10 RM, 1–3 workouts per week). Results indicated isometric strength increased similarly for both squat-trained groups, but only squat training without vibration had a significant improvement in jump height and peak power. The addition of vibration to resistance training did not appear to afford any additional advantage over resistance training alone. It is possible that the addition of vibration to the resistance training (20–25 Hz; 4-mm amplitude) initially improved average force/power output during the first 2 sets but then led to fatigue over successive sets, ultimately reducing the total work performed over the 6 sets.

Potentially, the use of WBLFV in between sets of resistance training rather than during resistance training itself may be useful for increasing high-threshold motor unit recruitment to prepare for high load resistance while minimizing fatigue potential. The 6-week training period selected as the resistance training intervention was a specialized extended mesocycle focusing on high force generation then transitioning to higher power and dynamic rates of force development. Such a design was utilized because it was believed by this author that such a specialized training block would lead to significant improvements in peak force and rates of force production, which would have a degree of transferability to the jump tests used. Therefore, the purpose of this study was to examine the chronic effects of a 6-week, per iodized squat training program with (SQTV) or without (SQT) WBLFV between sets on jump height and power output recorded following an acute vibration protocol on weeks 1, 3, and 7. It was hypothesized that a group performing squat training while receiving vibration will respond more favorably to an acute vibration stimulus than groups not receiving vibration as a result of adaptations within both the CNS and PNS.

METHODS

Experimental Approach to the Problem

Subjects were randomly assigned to 1 of 3 groups: (1) control group (CG); (2) squat training with vibration (SQTV); or (3) squat training (SQT). Following an orientation period, the SQT and SQTV groups engaged in a 6-week periodized squat training program, whereas the CG did not perform any training. In addition to the training, the SQTV group experienced WBLFV immediately prior to the training sessions for 30 continuous seconds and then between sets intermittently for 3 bouts of 10 seconds. To test for power output and jump height prior to, and then following, acute WBLFV exposure, all groups (CG, SQTV, and SQT) performed several 30-cm depth jumps and 20-kg squat jumps during week 1 (pre-training), week 3 (mid-training), and week 7 (post-training).

Subjects

Thirty-six men between the ages of 18 and 30 years were informed of the experimental risks before completing

TABLE 1. Physical characteristics of each subject at baseline by group ($n = 30$).

Group	1 ($n = 6$)	2 ($n = 13$)	3 ($n = 11$)
Age (years)	22.8 ± 0.9†	24.1 ± 0.9†	23.2 ± 0.9†
Height (cm)	177.7 ± 3.5†	182.0 ± 1.9†	179.3 ± 2.0†
Weight (kg)*	87.2 ± 5.8†	83.8 ± 3.4†	73.9 ± 2.3‡*
% Fat	15.2 ± 3.5†	15.1 ± 1.4†	15.7 ± 1.6†

All values presented mean as ± *SE*.
*Significant $p < 0.05$. (*Post hoc revealed no significant differences $p > 0.05$)
†Denotes statistically similar ($p > 0.05$).
‡Significantly different ($p < 0.05$) (posthoc revealed no significant differences $p > 0.05$)

TABLE 2. Loading progression throughout the 6-week periodized Smith machine training program.

Week	Sets	Repetitions	% of 1RM	
			(W1)	(W2)
1	4*	5	(85%)	(70%)
2	3	4	(88%)	(75%)
3	3*	3	(90%)	(80%)
4	3	5	(85%)	(70%)
5	4	5	(75%)	(60%†)
6	4	6	(65%†)	(55%†)

1RM = 1 repetition maximum; W1 = first workout of the week; W2 = second workout of the week.

*Denotes reduced volume of sets performed during W1 on weeks 1 and 3 resulting from 1 repetition maximum assessment.

†Denotes squats performed as speed squats.

a written informed consent form, which had been approved by the University of Oklahoma's Institutional Review Board, concerning experimentation with human subjects. However, only 30 participants completed the entire protocol (CG = 6; SQTV = 13; and SQT = 11). Of the 6 subjects who were dropped from the final analysis, 1 left because of an unrelated injury, 3 left for personal reasons, and 2 failed to complete the minimum required amount of training sessions. The physical characteristics of the subjects are presented in Table 1. The subjects' prior training status was assessed using a questionnaire, self-reported training experiences, and the Smith machine 1RM squat ability. The training study was carried out between the months of March and May in a temperature-controlled environment within the Applied Neuromuscular Physiology laboratory at the University of Oklahoma. The subjects were deemed to be recreationally resistance trained with at least 6 months of resistance training experience but not performing more than 3 workouts per week. Self reported training histories and pre-participation health screening and physical activity questionnaires were used to establish resistance training status. Table 1 outlines the physical characteristics of all subjects ($N = 30$) by groups (CG; $N = 6$, SQTV; $N = 13$., SQT; $N = 11$) at baseline.

Procedures

Subjects were required to attend 2 familiarization sessions (at least 48 hours apart) during which Smith machine back squat exercises, 30-cm depth jumps, 20-kg squat jumps, and WBLFV were performed. Over the 6-week training period subjects were required to complete 12 workouts of 3 to 5 sets at 55 to 90% 1RM. Testing was performed during weeks 1 (pre-training), 3 (mid-training), and 7 (post-training) and consisted of height (cm), mass (kg), 1RM Smith machine squat (reported in a separate manuscript), 30-cm depth jumps, and 20-kg squat jumps. The Sayers mathematical peak power nomogram (35) was used to estimate depth jump and squat jump peak power (Pmax) using the subject's body mass (kg) and jump height. Jump height was calculated from flight time (ms) using a Just Jump (Probotics, Birmingham, Alabama, USA.) switch mat. Also, during the depth jump the subjects rested a broom handle across their upper trapezius and shoulders as to mimic a "high bar" squat position; attached to this was a Fitrodyne (Fitronic, Bratislava, Slovakia) linear accelerometer. For the squat jump the same device was attached to 1 end of a 20-kg Olympic standard-sized barbell instead of a broom handle. The Fitrodyne provided mean power (Pav; W) during the upward, concentric phase of the jumps.

Depth jumps were performed by dropping from a 30-cm box onto the switch mat with a 2-foot landing, minimizing the

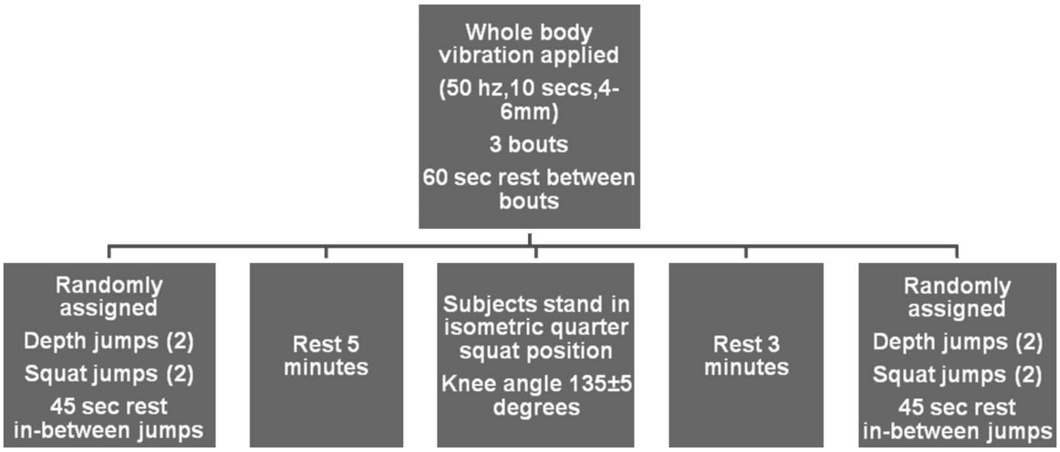

Figure 1. Acute vibration protocol carried out on weeks 1, 3, and 7.

Table 3. Baseline jump data by group.

30-cm depth jump	Group 1 ($n = 6$)	Group 2 ($n = 13$)	Group 3 ($n = 11$)
1. Height (cm)	1. 48.8 ± 2.9* (37.85 – 60.33)	1. 49.8 ± 2.8* (34.04 – 74.93)	1. 43.3 ± 1.8* (32.51 – 51.69)
2. Peak power (W)	2. 4877.8 ± 162.4*[a] (4398.17 – 5497.05)	2. 4753.6 ± 239.2* (3046.09 – 5981.35)	2. 3960.2 ± 146.7† (3310.18 – 4716.22)
3. Peak power per kilogram (W/kg)	3. 56.3 ± 2.4* (47.39 – 66.17)	3. 57.0 ± 2.2* (45.46 – 77.68)	3. 53.1 ± 1.6* (44.21 – 63.34)
4. Mean power (W)	4. 1505.0 ± 80.1* (1286.50 – 1871.50)	4. 1485.2 ± 66.9* (1070.50 – 1850.00)	4. 1205.9 ± 57.6† (959.00 – 1492.50)
20-kg squat jump	**Group 1 ($n = 6$)**	**Group 2 ($n = 13$)**	**Group 3 ($n = 11$)**
1. Height (cm)	1. 35.1 ± 2.4* (29.34 – 44.45)	1. 35.5 ± 2.3* (21.21 – 54.36)	1. 28.9 ± 1.2* (22.35 – 36.70)
2. Peak power (W)	2. 4951.2 ± 204.4* (4571.82 – 5901.97)	2. 4792.0 ± 241.4* (3173.49 – 6289.24)	2. 3992.3 ± 140.2† (3392.20 – 4658.61)
3. Peak power per kilogram (W/kg)	3. 57.0 ± 2.2* (50.88 – 65.42)	3. 57.3 ± 1.7* (47.37 – 73.23)	3. 53.4 ± 1.0* (48.15 – 59.31)
4. Mean power (W)	4. 1402.0 ± 74.0* (1276.00 – 1767.00)	4. 1360.9 ± 61.0* (921.00 – 1799.00)	4. 1064.6 ± 80.8* (595.50 – 1432.00)

All values presented as mean ± *SE*.
*Denotes statistically similar ($p > 0.05$).
†Significant difference (ANCOVA used when significant differences seen between groups at baseline).

ground contact time, rebounding as high as possible, and then landing again with 2 feet on the switch mat. Two depth jumps were performed with 45 seconds of rest between trials. The average of the 2 trials was used for analyses.

Subjects were instructed to step on the mat, squat to a 90-degree knee joint angle, hold this position for 3 seconds, jump as high as possible, and land with both feet on the mat. The 3-second hold was implemented to minimize the contribution of the series elastic component. Two squat jumps were performed with 45 seconds rest between trials, and the average of the 2 trials was used for analyses.

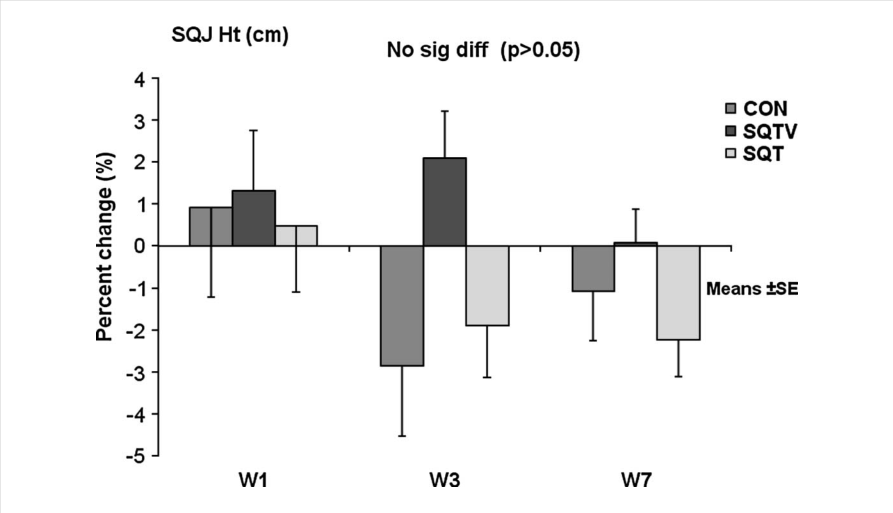

Figure 2. Percent change (%Δ) in squat jump height (cm) following vibration by group at weeks 1, 3, and 7. No significant Group *Trial interaction or group differences ($p > 0.05$). No significant within-group differences ($p > 0.05$), Expressed as means ± *SE*.

Training Procedures. The periodized 6-week training program focused on strength development during the first 3 weeks and power development over the final 3 weeks (Table 1) based on previous studies (20,28,37). Smith machine back squat exercises were performed twice per week, each separated by 72 hours. Loading ranged from 55 to 90% of the subjects' predetermined 1RM between weeks 1 and 3 and from 55 to 85% 1RM during weeks 4 to 6. During weeks 4 to 6, the load was reduced to improve the potential for increased bar velocity and rate of force development. Also during the second sessions of weeks 4 to

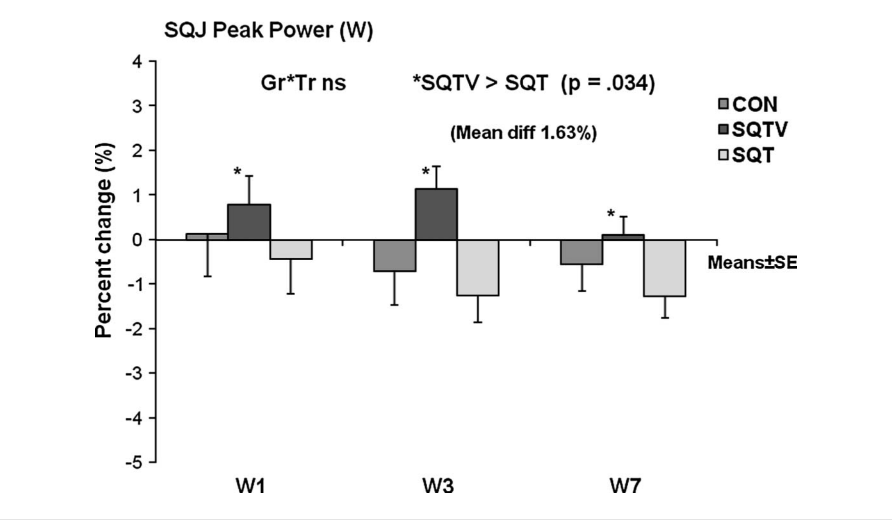

Figure 3. Percent change (%Δ) in squat jump peak power (W) following vibration by group at weeks 1, 3, and 7 (covaried by week 1 squat jump peak power). No significant Group *Trial interaction ($p > 0.05$). *SQTV significantly greater than SQT ($p < 0.05$). No significant within-group differences ($p > 0.05$). Expressed as means ± *SE.*

6, subjects were instructed to perform "speed squats" by continuing the squat movement upward, rising up onto their toes using a strong contraction of the plantar flexor muscles. Subjects were verbally encouraged to push as forcefully as possible throughout the full range of motion of the Smith machine squat exercise. Four minutes of rest were allowed between sets. Table 2 outlines the periodized training progression over the 6-week period.

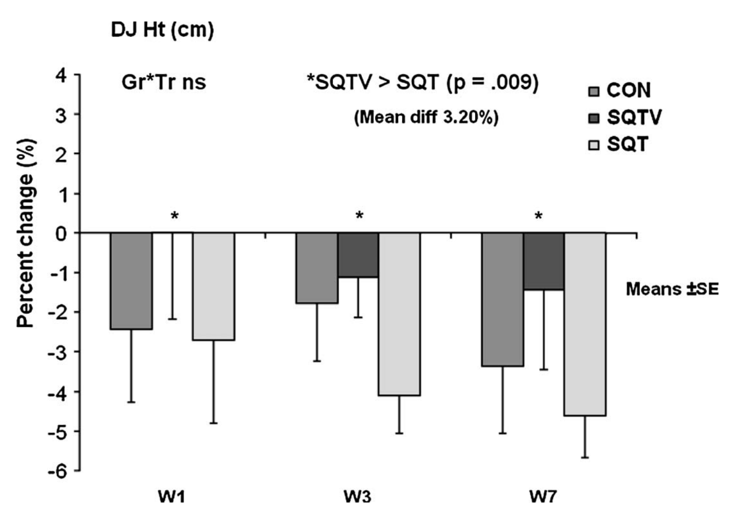

Figure 4. Percent change (%Δ) in depth jump height (cm) following vibration by group at weeks 1, 3, and 7. No significant Group *Trial interaction ($p > 0.05$). *SQTV significantly greater than SQT ($p < 0.05$). No significant within-group differences ($p > 0.05$). Expressed as means ± *SE.*

WBLFV Exposure. WBLFV was applied using a Power Plate, Next Generation vibrating platform (Power Plate USA, Northbrook, Illinois, U.S.A.). The plate's action is action is Tri-Planer, but the majority of the vibration is directed up and down within the Z plane. The acceleration imparted on the body is a result of the combination of the frequency (30, 35, 40, and 50 Hz) and amplitude ("low" 2–4 mm, "high" 4.1–6.0 mm) used. While holding onto the handles, subjects stood on the platform in a quarter squat position with the feet shoulder-width apart (similar to the Smith machine back squat position). A 50-Hz low-frequency vibration was applied for 30 seconds with an amplitude of 2 to 4 mm prior to the first set of the squat exercise. Three minutes of rest was allowed after the vibration, prior to the first set. The same frequency but a higher amplitude setting (4–6 mm) of vibration was then applied intermittently with 10-second bouts at 60, 120, and 180 seconds into the rest periods between squat sets. When subjects were not receiving vibration, they were instructed to sit in a chair with their legs elevated on a wooden box. The group not receiving vibration (SQT) sat down for the entire 4-minute rest period between squat sets.

Acute WBLFV Protocol. The acute response to intermittent WBLFV (50 Hz; amplitude 4–6) was also tested at weeks 1, 3, and 7. Subjects first performed a 5-minute warm-up on a Monarch 828E cycle ergometer (Monarch Ergometers, Sweden) at a cadence of 60 to 70 revolutions per minute with a 0.5-kg load placed on the fly wheel. After a 3-minute rest and 2 practice jumps, baseline jump performance was assessed with two 20-kg squat jumps and two 30-cm depth jumps (4 total jumps) performed in random order with 45 seconds rest between jumps. Following a 5-minute rest period subjects

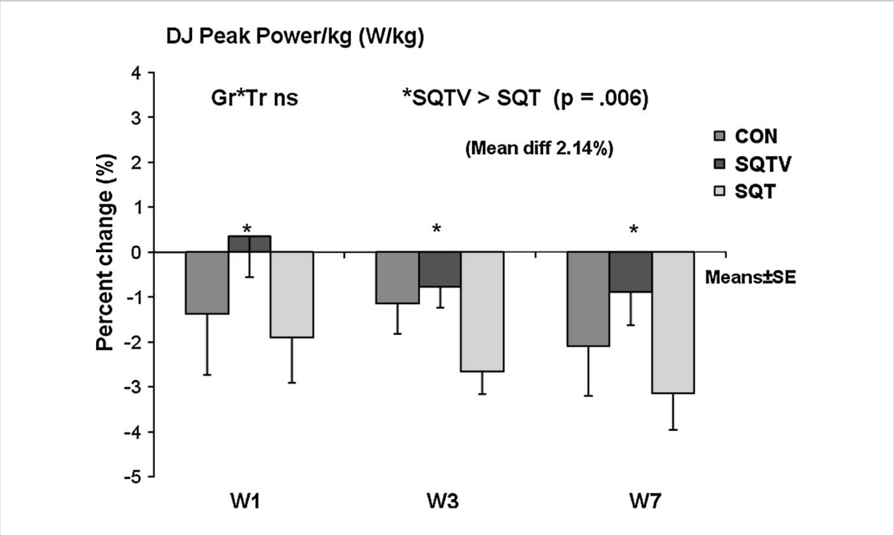

Figure 5. Percent change (%Δ) in depth jump peak power per kilogram of body mass following vibration by group at weeks 1, 3, and 7. No significant Group *Trial interaction ($p > 0.05$). *SQTV significantly greater than SQT ($p < 0.05$). No significant within-group differences ($p > 0.05$). Expressed as means ± *SE.*

underwent three 10-second vibration bouts separated by 60 seconds with the same body position, frequency, and amplitude described earlier. Subjects rested for 3 minutes after the vibration and then repeated the squat and depth jump procedures. Figure 1 outlines the acute WBLFV protocol performed on weeks 1, 3, and 6.

Statistical Analyses

Statistic analyses were performed using SPSS for Windows (Version 15.0, SPSS, Inc., and Chicago, Illinois, U.S.A.). Using data from a similar study, the sample sizes in the present study were deemed to be adequate based on the calculated effect sizes (ES = [Post-measurement mean – pre-measurement mean]/pooled standard deviation) (32) and a minimum statistical power of 0.80. The intraclass correlation coefficient (ICC) reliability coefficients (R) for depth jump variables included height ICC = 0.937, peak power ICC R = 0.972, mean power ICC R = 0.953, and peak power/kg of body mass ICC R = 0.936. The ICC Rs for squat jump variables included height ICC R = 0.924, peak power ICC R = 0.977, mean power ICC R = 0.910, and peak power /kg of body mass ICC R = 0.910.

Each parameter that had multiple trials was subject to 1-way repeated measures analysis of variance (ANOVA) to produce the most stable representation for that parameter. Bonferroni pairwise comparisons were used as a post hoc analysis if significant differences were found ($p < 0.05$). The initial analysis included a 1-way ANOVA to explore baseline (pretest) values for each parameter of interest. If there was a significant group effect, then a Bonferroni pairwise comparison was utilized as a post hoc analysis. Repeated measures (Group*Time point, percent change) analysis of covariance (ANCOVA) performed on percent change values were used if significant group differences were found at baseline for any of the jump parameters to allow for relevant covariates to be added to the analysis.

Because the depth jump and squat jump parameters (height [cm], peak power [W], peak power/kg [W/kg], and mean power [W]) were assessed pre–post vibration at weeks 1, 3, and 7, 2-way ANOVA or ANCOVA was used to compare group percent changes in these variables. Percent change was calculated as ([[Post value – pre value]/pre value] × 100). Bonferroni corrections were used when multiple comparisons were calculated to account for inflation of alpha. Statistical significance was set at $p < 0.05$. Significant group differences ($p < 0.05$) were observed at baseline for both depth jump and squat jump Pmax and Pav values, meaning that ANCOVAs were subsequently used to assess percent change following vibration at weeks 1, 3, and 7. ANOVAs were used to analyze percent change values for Pmax/kg (W/kg) and jump height (cm).

RESULTS

A 1-way ANOVA revealed no significant differences between subjects' age, weight, and height ($p > 0.05$). Table 3 outlines measures of absolute (Pmax; W), relative power peak (Pmax/kg,W), and average power out (Pav,W) and jump height (cm) for both jump conditions at baseline.

Two-way ANOVA of percent change (post-vibration) analysis of squat jump height revealed no significant differences between groups ($p > 0.05$). Within-group analysis revealed no significant differences between testing time points for any of the groups ($p > 0.05$) (Figure 2). A 2-way ANCOVA (covariate, week 1 squat jump Pmax) performed on squat jump Pmax percent change on weeks 1, 3, and 7 revealed no significant group by time point interaction ($p > 0.05$). Significant group differences were seen for Pmax with SQTV significantly greater than SQT ($p = 0.034$, mean difference 1.63%, $1 - \beta = 0.67$, ES = 0.24). A significant main effect was seen for the covariate, week 1 squat jump Pmax for SQTV ($p = 0.035$). No significant within-group changes were seen over the 3 testing time points ($p > 0.05$). Figures 2 and 3 outline percent change (%) in SQj height (cm) and SQj Peak power (W) following WBLFV exposure on weeks 1, 3, and 7 by group.

Analysis of squat jump Pmax/kg of body mass percent change data revealed no significant interaction or within- or between-group differences ($p > 0.05$). An ANCOVA of squat jump Pav percent change (covariate, squat jump Pav at week 1) revealed no significant interaction or within- or between-group differences ($p > 0.05$).

A 2-way ANOVA of percent change in depth jump height revealed no significant group by time point interaction ($p > 0.05$). A significant main group effect was seen, with SQTV significantly greater than SQT percent change ($p = 0.009$, mean difference 3.20%, $1 - \beta = 0.80$, ES = 0.28). Figure 4 depicts percent change (% Δ) in Dj height (cm) following acute WBLFV exposure by group at weeks 1, 3, and 7.

Furthermore, 2-way ANCOVA analysis for depth jump Pmax percent change revealed no significant group by time point interaction ($p = 0.865$). A significant group effect was seen with SQTV > SQT (mean difference 2.53%), but post hoc revealed no significant differences ($p > 0.05$). A 2-way ANOVA analysis for depth jump Pmax/kg revealed no significant group by time point interaction. A significant main effect was seen for group with SQTV > SQT ($p = 0.006$, mean difference = 2.14%, $1 - \beta = 0.83$, ES = 0.30). Figure 5ow depicts percent change (%Δ) in Dj Peak power/Kg of body mass following WBLFV exposure, by group at weeks 1, 3, and 7.

No significant within-group differences were found ($p > 0.05$). A 2-way ANCOVA analysis for depth jump Pav percent change revealed no significant group by time point interaction or main effects for group.

DISCUSSION

The results from the current study suggest that squat jumps and depth jumps responded differently to the WBLFV stimulus with greater responsiveness seen within the 20-kg squat jump. Furthermore, baseline jump performance at week 1 appeared to have a significant impact on a subject's ability to produce PAP.

Although significant group differences were not seen for squat jump height achieved at any of the testing points, a trend was seen favoring SQTV > CG and SQT. During week 3, squat jump testing resulted in SQTV PAP equal to 2.1%, whereas CG (−2.8%) and SQT (−1.90) exhibited PAD. The chronic exposure of WBLFV to SQTV during resistance training may have resulted in a facilitated neuromuscular adaptation leading to greater relative jump performance post-vibration, although high intersubject variability may have negated significant group differences.

Post-activation depression (PAD) within SQT coupled with slight PAP within SQTV could account for the near significant difference ($p = 0.056$) between the 2 groups at week 3. The PAD seen for both CG and SQT may have arisen as a result of pre-synaptic and post-synaptic inhibition of Type 1a afferents. Reduced neurotransmission between the sensory afferent (in this case primarily Type 1a afferents) and the target cell at the axonal terminal (alpha motor neuron) may have accounted for the former, with a decrease in excitability of an entire alpha motor neuron possibly accounting for the latter (7,9,31). Reduced attenuation of initial stretch reflex and Hoffman reflex depression may have occurred during vibration application for SQTV producing a more favorable environment for super compensation of both the stretch reflex and Hoffman reflex. This supported mechanism is speculative because both reflex types were not recorded prior to or following vibration exposure.

Such a phenomenon may have accounted for the significant group differences seen for squat jump peak power favoring SQTV > SQT. Although not directly tested during this study, facilitation or inhibition of select cutaneous receptor inputs to the spinal cord and somatosensory cortex could have accounted for some of the variability between the groups. A possible "resetting" of Renshaw cell sensitivity within SQTV may have elevated the level of alpha motor neuron discharge attainable before post-synaptic inhibition set in. This, coupled with a slowing in the rate of adaptation to the vibration stimulus at phasic cutaneous (Meissner corpuscles, Pacinian Corpuscles) sensory receptors, could have offset potential disruptions to proprioceptive feedback previously reported following exposures at higher vibration frequencies (7,9,10,23,29).

Training status has previously been suggested to affect responsiveness to an intended PAP stimulus (5,9,10,15,19), which, in this instance, may partly explain the PAD, rather than PAP, seen with SQT. It could also be argued that because SQT did not receive chronic exposure to the vibration stimulus, they were not acclimated to the vibration as SQTV appeared to be. However, the control group at week 1 was found to be significantly stronger than SQTV and SQT but still exhibited post-activation depression during weeks 3 and 7. The extent of the PAD was not as great as that seen for SQT, which suggests that their background training status prevented excessive attenuation in squat jump performance. Previous research has suggested resistance training may increase the action potential firing threshold attained within Type 1b afferents before inhibitory post-synaptic potentials (IPSP) are relayed via interneurons to the alpha motor neurons of the targeted musculature (1,2,7,31).

It is possible that the vibration frequency (50 Hz) coupled with the high amplitude (4–6 mm) was too strong a stimulus for the groups not chronically exposed to the vibration stimulus leading to GTO-mediated reductions in alpha motor neuron firing discharge.

The acute responses of the 3 groups to vibration applied between trials of depth jumps produced interesting data. For the measure of depth jump height, all groups exhibited PAD at all testing time points, which suggests that the acute vibration protocol resulted in fatigue rather than potentiation. However, SQTV showed the least amount of attenuation in DJ height (cm), Pmax (W), and Pmax/kg (W/kg), suggesting a preferential adaptation to the vibration stimulus in this group. As already alluded to elsewhere, Renshaw cell-mediated alpha motor neuron firing inhibition may have been pushed back to a higher activation frequency as a result of the chronic exposure to vibration. Although SQT completed the specialized squat training regimen with significant chronic adaptation with regard to strength and power (results presented in a separate manuscript), their responsiveness to the acute vibration exposure worsened over time, albeit nonsignificantly ($p > 0.05$). A similar trend was seen for the control group, which at week 1 exhibited minor (0.10–0.60%) nonsignificant PAP for jump height, Pmax, and Pmax/kg followed by nonsignificant PAD on weeks 3 and 7.

High individual variability in response to vibration exposure may in part account for the nonsignificant group differences. The differences between jump conditions is interesting because this author believed potentiation would be more readily seen during depth jumps as a result of the greater reliance on reflex-induced contraction (39). The potential disruption to proprioceptive sense in response to high vibration frequency may have been more detrimental to depth jump performance because such a jump requires a high degree of intermuscular and intramuscular coordination and a pronounced stretch–shortening cycle (4,12,21,39).

Other factors may have included disruption to concentric impulse generation during the depth jump as a result of a decreased eccentric/concentric coupling (amortization phase), The net result of this would be a decreased ability to maintain, and then transfer, the high eccentric forces produced during the initial impact with the ground to the start of the concentric phase of the jump. Presynaptic inhibition of Type 1a afferents and increased IPSPs relayed via Type 1b GTO afferents could have reduced neuronal firing rates. This potentially reduced reflex contribution to the depth jump could have reduced the amount of force generated prior to the concentric phase of the jump. A reduction in the resultant concentric impulse generation following vibration along with disrupted proprioceptive feedback from the lower extremities could account for the reduced jump performance. Because the squat jump condition was not performed with a stretch–shortening cycle, concentric impulse was less likely to be affected by attenuated Type 1a afferent feedback.

In conclusion, the majority of subjects did not respond favorably to the vibration protocol used. This was most evident for the individuals who have had the least resistance training at the lower limits of the inclusion criteria for the study. Nonsignificant ($p > 0.05$) PAD was seen for all groups for the depth jumps, whereas significant and nonsignificant PAP were seen for squat jumps for SQTV. States of PAD rather than the hypothesized PAP likely arose as a result of increased presynaptic inhibition at Type 1a afferents and GTO-mediated force inhibition (31).

It would appear that the addition of vibration to resistance training for SQTV led to a chronic adaptation above that afforded by resistance training alone, resulting in a more favorable acute response to the vibration stimulus. The use of both a high frequency (50 Hz) and amplitude (4–6 mm) during the present study was based on pilot data collected by these researchers using countermovement vertical jumps. Such a protocol produced significant improvements in jump height when compared to similar protocols utilizing lower (30-Hz) vibration frequencies. It is possible that the significant PAD seen for the depth jump condition rather than the significant PAP seen for countermovement vertical jumps was a result of the greater contribution from reflex action during the stretch–shortening cycle imposed during the depth jump condition. Disruption to such reflex-induced muscle activity would appear to be more detrimental to depth jump performance. Future research directions could focus on optimal combinations of frequency, amplitude, and time course of exposure relative to gender, background resistance training status, and jump type. Larger sample sizes and longer training interventions may lead to greater delineation between treatment conditions.

PRACTICAL APPLICATIONS

The addition of WBLFV prior to, and then in between, sets of resistance exercise does appear to have some practical merit. However, prior resistance training experience appears to play a strong role regarding individuals responsiveness to vibration applied at higher amplitudes and frequencies. Therefore, background training status and fatigue state should be taken into consideration prior to applying WBLFV. Individuals who are less heavily resistance trained may benefit from vibration applied at a lower frequency and amplitude.

It may prove more practical to "periodize" the vibration exposure starting at lower frequencies and amplitudes before progressing to higher frequencies and amplitudes for shorter exposure times. Such a gradual increase in the intensity of the vibration exposure may lead to greater habituation, allowing for acute modification of the spinal stretch reflex response. Such adaptations could be helpful to strength/power athletes wanting to maximize dynamic rates of force development and power generation during both heavier load and lighter load ballistic resistance training exercises.

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