EFFECTS OF A 6-WEEK PERIODIZED SQUAT TRAINING WITH OR WITHOUT WHOLE-BODY VIBRATION UPON SHORT-TERM ADAPTATIONS IN SQUAT STRENGTH AND BODY COMPOSITION

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ABSTRACT

Lamont, HS, Cramer, JT, Bemben, DA, Shehab, RL, Anderson, MA, and Bemben, MG. Effects of 6 weeks periodized squat training with or without whole-body vibration upon short-term adaptations in squat strength and body composition. *J Strength Cond Res* 24(x): 000–000, 2011—The purpose of this study was to examine the effects of a 6-week, periodized squat training program, with or without whole-body low-frequency vibration (WBLFV), applied before and between sets to 1RM squat strength and body composition. Thirty men aged between 20 and 30 years with at least 6 months of recreational weight training experience completed the study. Subjects were randomly assigned to either 1 of 2 training groups or to an active control group (CON). Group 1 (CON; $n = 6$) did not participate in the training protocol but participated only in testing sessions. Group 2 (SQTV, $n = 13$) performed 6 weeks of squat training while receiving WBLFV (50 Hz), before, and in-between sets. The third group (SQT, $n = 11$) performed 6 weeks of squat training only. Subjects completed 12 workouts with variable loads (55–90% one repetition maximum [1RM]) and sets (3–5), performing squats twice weekly separated by 72 hours. The RM measures were recorded on weeks (W) 1, 3, and 7. During the second workout of a week, the load was reduced by 10–15%, with "speed squats" performed during the final 3 weeks. Rest periods in between sets were set at 240 seconds. The WBLFV was applied while subjects stood on a WBLFV platform holding an isometric quarter squat position (knee angle 135 ± 5°). Initially, WBLFV was applied at 50 Hz for 30 seconds at low amplitude (peak–peak 2–4 mm). A rest period of 180 seconds followed WBLFV exposure before the first set of squats. The WBLFV was then applied intermittently (3×10 seconds) at 50 Hz, high amplitude (peak–peak, 4–6 mm) at time points, 60, 120, and 180 seconds into the 240-second rest period. Total body dual x-ray absorptiometry scans were performed at W0 (week before training) and W7 (week after training). Measures recorded included total body mass (kg), total body lean mass (TLBM, kg), trunk lean mass (kg), leg lean mass (kg), total body fat percentage, trunk fat percentage, and leg fat percentage (LF%). Repeated-measures analysis of variance and analysis of covariance revealed 1RM increased significantly between W1–W3, W3–W7, and W1–W7 for both experimental groups but not for control ($p = 0.001$, effect size [ES] = 0.237, $1 - \beta = 0.947$). No significant differences were seen for %Δ ($p > 0.05$). Significant group by trial and group effects were seen for TLBM, SQTV > CON at W7 ($p = 0.044$). A significant main effect for time was seen for LF%, W0 vs. W7 ($p = 0.047$). No other significant differences were seen ($p > 0.05$). "Practical trends" were seen favoring "short-term" neuromuscular adaptations for the SQTV group during the first 3 weeks ($p = 0.10$, ES = 0.157, $1 - \beta = 0.443$, mean diff; SQTV week 3 4.72 kg > CON and 2.53 kg > SQT). Differences in motor unit activation patterns, hypertrophic responses, and dietary intake during the training period could account for the trends seen.

KEY WORDS whole-body low frequency vibration, potentiation, maximal dynamic strength, fat free mass

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0(0)/1–10

Journal of Strength and Conditioning Research

INTRODUCTION

Resistance training interventions aimed at increasing lower body strength and hypertrophy via central and peripheral mechanisms (12,13,14,19,24,28–30,36,42,47) have produced

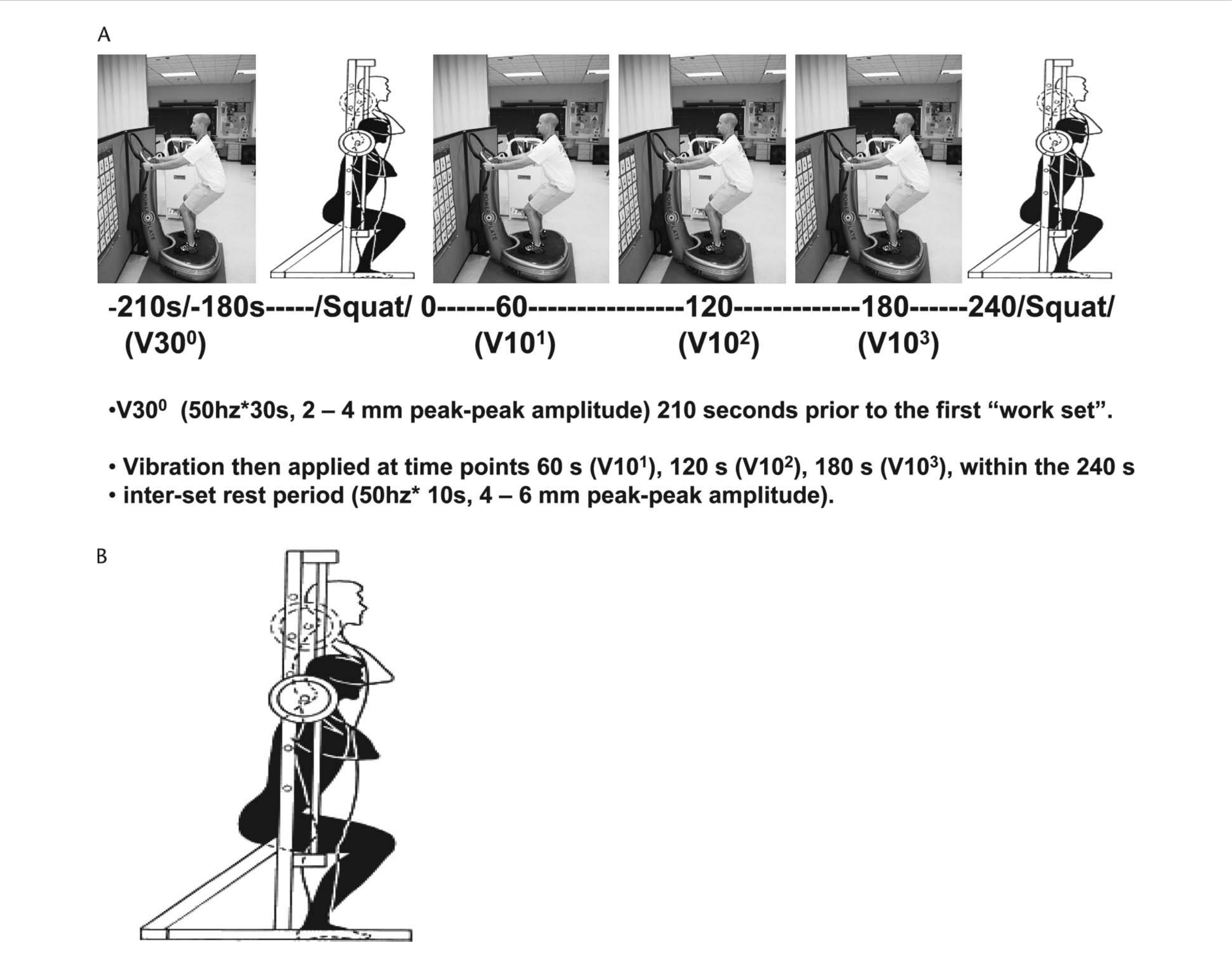

Figure 1. A) Whole-body low-frequency vibration (WBLFV) protocol applied before (50 Hz 2- to 4-mm peak–peak amplitude (3.08 G), 30 continuous seconds) and in-between (50 Hz 4- to 6-mm peak–peak amplitude (5.83 G), 3 bouts of 10 seconds) sets of squats. B) Smith Machine Squat setup, heels touching marker 2.

a wide range of outcomes, including increases in cortical drive, alpha motor neuron input, motor unit recruitment, firing rates, synchronization, doublet discharge (1–3,10,25,45), muscle coactivation, muscle cross-sectional area, and angle of pennation (1,2,10,19,26,42), coupled with decreases in activation threshold for type 2 motor units and Golgi Tendon Organ sensitivity (1,10,19,22,25,28,45)

Previous training studies have varied from 4 to 24 weeks in length using progressive overload or varying periodized plans (2,12,23–26,28,29,35,36). Aagaard et al. (2) found significant increases in maximal voluntary contractions (MVC) force and rate of force development (RFD) after 14 weeks of resistance training using heavy load resistance (80%> 1RM) with previously untrained men. Harris et al. (24) reported a "mixed methods" approach using heavier and lighter loads produced the greatest improvements in dynamic strength, power, and RFD over the widest range of the loading spectrum in trained men. Newton et al. (36) reported similar improvements for measures of strength and power in younger and in older men. The use of high relative loads (80% >1RM) for 1–8 repetitions, and moderate to long rest periods (90–300 seconds) within a periodized model appears to produce the greatest increases in strength with a moderate degree of muscle hypertrophy (2,24–28,36,42,47) within " recreationally" trained men. Short-term adaptations in muscle size and strength within the lower body have previously been reported in as little as 4 weeks (42). The use of 1RM assessment for dynamic strength, and dual x-ray absorptiometry (DXA) to track changes in lean body mass helps discern neuromuscular (1–3,7,24,45) and muscle cross sectional adaptations (1,2,10,19,26,42) to resistance exercise.

In recent years, a number of "acute" techniques have been used with the aim of increasing force and power output during resistance exercise or ballistic tasks (11,19,21,22,23,38,41,45). The MVCs and heavy load dynamic actions performed before jumping tasks have resulted in postactivation

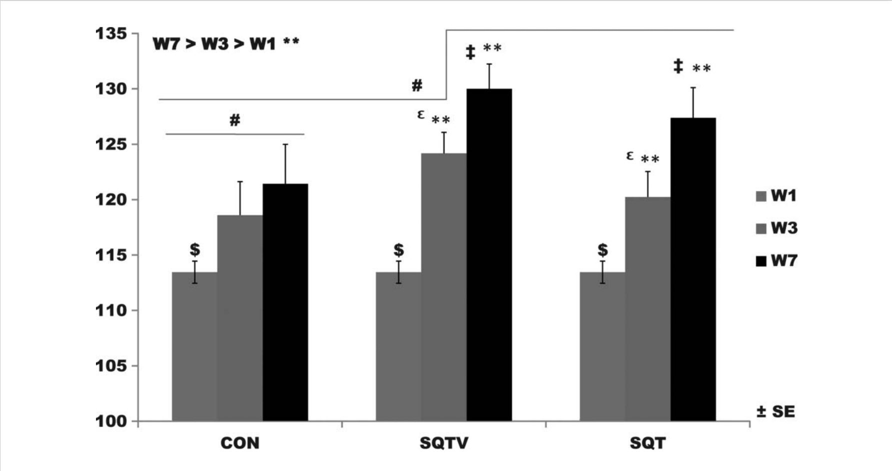

Figure 2. Within- and between-group differences for 1-repetition maximum (1RM) squat measures recorded at weeks 1, 3, and 7 (CON = control, SQTV = squat + vibration, SQT = squat only) ($n = 30$). Significant differences found at week 1 (baseline). $Denotes covariate adjusted week 1 squat 1RM value = 113.45 kg (baseline) for all groups. Within-group measures; Significant within group differences seen for SQTV ($p = 0.017$, effect size (ES) = 0.311, $1 - \beta = 0.753$) and SQT ($p = 0.007$, ES = 0.422, $1 - \beta = 0.855$). ‡ Denotes measures at week 7 significantly greater than at weeks 3 and 1. ε Denotes week 3 > week 1 (**significant at level ≤ 0.001). # Denotes no significant within-group differences. Measures at week 7 > week 3 > week 1 collapsed across groups ($p = 0.001$, ES = 0.237. $1 - \beta = 0.947$). Between-group measures; # Denotes no significant between-group differences ($p > 0.05$). Data are expressed as mean ± *SE*.

potentiation (PAP) of jump performance (11,19,21,22,23,38,41,45). The PAP also may be seen after whole-body low-frequency vibration (WBLFV) (4,7,8,15,16,28,29,33,40) via mono and polysynaptic reflex pathways triggering a "Tonic Vibration Reflex", arising from net "mixed" (facilitatory and inhibitory) afferent input from muscle spindle afferents, joint mechanoreceptors, dermal and epidermal proprioceptors, and nociceptors (4,5,7–9,15,16,18, 20,27–29,33,34,37,39,40). Initial upregulation in musculotendinous stiffness (within 1–3 seconds) results in high oscillatory accelerations within the musculature proximal to the plate, resulting in reflex activation of Alpha motor neurons leading to increased motor unit activation, firing frequency, and possible motor unit synchronization (4–8,15,16,18,27–29,37, 40,46). Residual effects appear to be dependent upon frequency, amplitude, exposure time, muscle length and preactivation, training status, and platform type (4,5,7,16,28,29, 31,33,37,40,46).

Combining resistance training and WBLFV in an attempt to facilitate chronic adaptations to resistance training is a novel but growing area of research. Ronnestad (39) saw significant improvements in 1RM after 5 weeks of Smith machine back squat training, with or without WBLFV applied concurrently (40 Hz). More recently, Ronnestad (40) found applying WBLFV at 50 Hz (high amplitude) during 1RM Smith Machine Squat assessment significantly increased 1RM ($p < 0.05$). Kvorning et al. (27) compared squatting on a WBLFV platform to squatting alone or WBLFV alone over a 9-week period and saw significant increases in MVC for both squat trained groups.

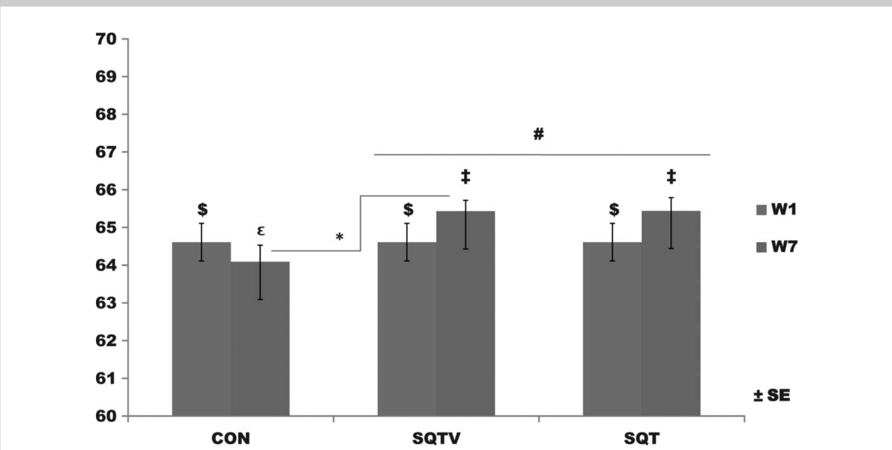

Figure 3. Within- and between-group differences for change in total lean body mass (TLBM; dual x-ray absorptiometry [DXA]) between weeks 0 and 7. Significant differences seen at week 0 (baseline). $ Denotes covariate adjusted value at week 0 = 64.61 kg (CON = control, SQTV = squat + Vibration, SQT = squat only) ($n = 30$). No significant within-group differences ($p > 0.05$). ‡ Denotes SQTV and SQT statistically similar at week 7 ($p > 0.05$); ε denotes SQTV > CON week 7 ($p = 0.038$, effect size = 0.222, $1 - \beta = 0.627$). Data are expressed as mean ± *SE*.

Applying WBLFV intermittently between sets may be more appropriate, potentially facilitating H-flex activity, which has been shown to be depressed after multiple sets of resistance exercise (1,10,19, 22,25,41). However, McBride et al. (33) found increased MVC within the tricep surae post WBLFV exposure at

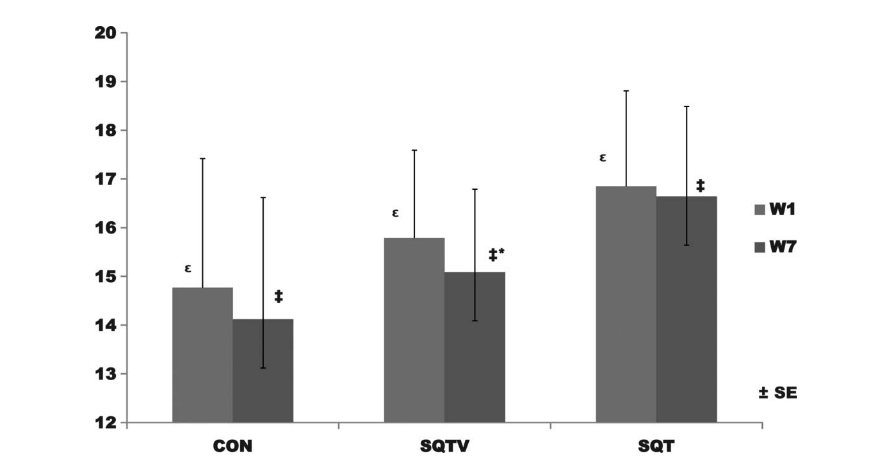

Figure 4. Within- and between-group differences for change in leg fat percentage (LF; dual x-ray absorptiometry) between weeks 0 and 7. (CON = control, SQTV = squat + vibration, SQT = squat only) ($n = 30$). No significant differences at baseline (week 0). Week 0 measures collapsed across groups > week 7 measures ($p = 0.047$, effect size (ES) = 0.138, $1 - \beta = 0.518$). *Denotes week-7 values significantly less than week 0 ($p = 0.039$, ES = 0.310, $1 - \beta = 0.569$) within the SQTV group. No significant within-group differences seen for CON or SQT groups ($p > 0.05$) Data are expressed as mean ± *SE*.

30 Hz and high amplitude using Powerplate®, with no change in motor neuron excitability suggesting mechanisms other than reflex potentiation. Rhea and Kern (37) saw a 5.2% increase in P_{av} during squats at 75% of 1RM after WBLFV applied while performing dynamic body weight squats. Da Silva-Grigoletto et al. (15) looked at acute and cumulative effects of inter-WBLFV rest periods upon select measures of dynamic performance and found the greatest PAP of jump height and P_{av} using 120 seconds of rest. However, after 12 WBLFV training sessions (3 per week for 4 total weeks) 60 seconds was most effective suggesting a chronic adaptation to WBLFV exposure. Facilitation, and increased sensitivity at type 1a and type 2 afferents over successive sets may affect; average acceleration (A_{av}), average force (F_{av}), RFD, and average power output (P_{av}) (4,6,7,10,19,22,25,28,34,37,45, 46). Increased myosin light chain phosphorylation, reciprocal inhibition, neuromuscular efficiency, or intramuscular temperature (4,6,7,8,10,16,17, 19,20,22,23,27–29,37,40) may also be seen.

The appropriate use of WBLFV has come under scrutiny because chronic long-term exposure may lead to decreased performance and structural damage (46); therefore, using the "least effective dose" would seem advisable (28,29,46). The mode of WBLFV application is also important with different manufactures using vertical, horizontal, or pivot-based platforms with variable results (46). Therefore, the purpose of this study was twofold: first, to test the efficacy of applying WBLFV using Powerplate® before, then intermittently between sets, with the aim to potentiate, then maintain measures of A_{av}, F_{av}, and P_{av} over successive repetitions and sets, and second, to look at the chronic impact of such hypothesized effects upon chronic adaptations in Squat 1RM and body composition compared to no squatting and squat training without WBLFV.

Methods

Experimental Approach to the Problem

This study used a longitudinal design where subjects were randomly assigned to either 1 of 2 training groups, resistance

Table 1. Six-week periodized squat training protocol.*

			%1RM load		
Week	Sets	Reps	Workout 1	Workout 2	Adjusted volume
1†	4	5	85	70	2 × 5 (workout 1)
2	3	4	88	75	
3†	3	3	90	80	1 × 3 (workout 1)
4	3	5	85	70	
5	4	5	75	60‡	
6	4	6	65‡	55‡	

*Data expressed as means ± *SE*.
†1RM assessment incorporated into the workout.
‡Performed as speed squats. Four minutes of rest was taken between all sets.

Table 2. Baseline anthropometric data for all subjects by group.*†

Group	CON (n = 6)	SQTV (n = 13)	SQT (n = 11)
Age (y)	22.8 ± 0.90	24.1 ± 0.87	23.2 ± 0.86
Height (cm)	177.67 ± 3.53	181.98 ±1.89	179.27 ± 2.02
Weight (kg)	87.15 ± 5.81	83.83 ± 3.44	73.86 ± 2.27
BF (%)	15.15 ± 3.53	15.10 ± 1.41	15.65 ± 1.58

*CON = control; SQTV = squat + vibration; SQT = squat only; TBM = total body mass; TLBM = total lean body mass; TLM = total leg mass; LLM = leg lean mass; TBF% = total body fat percentage; TRF% = trunk fat percentage; LF% = leg fat percentage.
†Data expressed as means ± *SD*.

training only (SQT; n = 14) or resistance training plus vibration (SQTV; n = 14), or an active control group (CON; n = 8). WBLFV was applied before (50 Hz, 2- to 4-mm peak–peak amplitude (3.08 G) 30 seconds), and then in between sets (50 Hz, 4- to 6-mm peak–peak amplitude (5.83 G), 3 bouts of 10 seconds with 1-minute rest in between sets) of variable load Smith Machine Squats over a 6-week period.

Over the 6-week training period, subjects were required to complete 12 squat workouts with variable loads (55–90% 1RM) and sets (3–5). Testing sessions were carried out during weeks (W) 0, 1, 3, and 7 and consisted of 1RM smith machine squat measures at W1, W3, and W7 and DXA body composition assessment at W0 and W7. W0 and W7 corresponded to the week before and after the 6-week training period, respectively. Loads were based upon relative percentages of 1RM at W1 and then adjusted to reflect any changes at the beginning of W3 after reassessment of 1RM (see Table 1).

Subjects

Initially 36 men aged between 18 and 30 years with at least 6 months of recreational weight training were informed of the experimental risks before completing a written informed consent form, which had been approved by the Institutional Review Board concerning experimentation with human subjects. Self-reported training histories and preparticipation health screening and physical activity questionnaires were used to establish resistance training status. All subjects were familiar with the back squat exercise and had previously incorporated it in their personal workout plans before taking part in the study. Sample sizes were adequate to attain a statistical power of at least 0.80 based on effect size (ES = post measurement mean − pre-measurement mean/pooled *SD*) calculated from a similar study (37). A total of 30 men completed all training and testing requirements of the study (CON; n = 6, SQTV; n = 13, and SQT; n = 11).

Subjects were randomly assigned to either of 2 training groups or to an active control group. No statistically significant differences were found between groups at baseline for age, height, weight, and percent body fat ($p > 0.05$). Group 1 (CON, n = 6) acted as an active control continuing their own physical activity, participating only in testing sessions. Group 2 (SQTV, n = 13) performed 6 weeks of squat training while receiving WBLFV (50 Hz), before, and in-between sets. The third group (SQT, n = 11) performed 6 weeks of squats only. Subjects were required to attend 2 familiarization sessions (at least 48 hours apart) during which squats (3 sets of 10 repetitions with 120-second rest at a load deemed to be "moderate") and WBLFV (exposures to 50-Hz low amplitude for 30 seconds and 50-Hz high amplitude for 3 bouts of 10 seconds with 60-second rest between exposures) exercises were performed. This session served a dual purpose: (a) to familiarize subjects with exercises and timing patterns used and (b) to induce a degree of muscle soreness in an attempt to convey a "neuromuscular protective effect" before starting the study at high relative loads (≥80 of 1RM) (see Table 2).

Training Protocol

Over the 6-week training period, subjects completed 12 workouts with variable loads (55–90% 1RM) and sets (3–5) with rest periods held constant at 240 seconds. Loading during the first 4 weeks ranged between 70 and 90% of 1RM and was then reduced to between 55 and 75% of 1RM during the final 2 weeks. Emphasis was placed upon maximal acceleration and force generation during the first 4 weeks, then RFD and power generation during the final 2 weeks. The final 2 weeks also acted as a "taper" in relative intensity with the aim to allow for potential supercompensatory adaptation to occur (12,36,43,44). Previous work has supported such a "mixed methods" design when attempting to increase force and power measures across the widest load spectrum (12,24,28,29,36).

Squats were performed twice weekly separated by 72 hours. One repetition maximum (1RM) measures were recorded during W1 and W3, during the first workout of the week, and then after completion of the study during W7. The 1RM measures recorded during the first workout of W1 were performed 120 hours after the final familiarization session to allow for any residual soreness to dissipate. During the second workout of a week, the load was reduced by 10–15%, with "speed squats" performed during the final 3 workouts of the training program. Subjects were verbally encouraged to use "maximal movement intent" during all lifts in an attempt to maximize motor unit: recruitment and discharge rates, and acceleration force and RFD. Rest periods were set at 240

TABLE 3. Baseline 1RM data (kg), actual vs. covariate adjusted values (covariate value appearing as 113.45 kg at baseline).*

Group	Actual	Covariate corrected
CON (kg)	138.29 ± 14.79†	113.45
SQTV (kg)	120.22 ± 7.41†	113.45
SQT (kg)	91.36 ± 5.68‡	113.45

*CON = control, SQTV = squat + vibration, SQT = squat only.
†Denotes statistically similar.
‡Denotes significantly less than †.

seconds between sets, with the WBLFV protocol incorporated within this period for the SQTV group.

Whole-Body Low-Frequency Vibration Application

The WBLFV was applied using a Power Plate, Next Generation® vibrating platform (Power Plate® USA, Northbrook, IL, USA). Its action is TriPlaner, but the majority of the vibration is vertical (*Z* plane) making it quite distinct from the Galileo and Nemes Bosco vibration platforms (28,29,46). Such a plate produces a continual sinusoidal wave form at a fixed frequency and amplitude depending upon settings selected. Other plates use pivot mechanisms using lower frequencies but greater peak-peak amplitudes (46). The acceleration imparted upon the body is a result of frequency (30, 35, 40, and 50 Hz) and amplitude ("low" 2–4 mm, "high" 4.1–6 mm, peak–peak amplitude) (27,28,46). The WBLFV was applied while subjects stood on a WBLFV platform holding an isometric quarter squat position (knee angle 135 ± 5°) with their feet a little wider than shoulder width apart. Foot position was standardized for all subjects. Initially, WBLFV was applied at 50 Hz for 30 seconds at low amplitude (2–4 mm peak–peak; 3.08 G), followed by 180 seconds of rest before the first "work set." The WBLFV was then applied intermittently (3 × 10 seconds) at 50 Hz, high amplitude (4–6 mm peak–peak; 5.83 G) at 60, 120, and 180 seconds into the 240-second rest period. When subjects were not receiving WBLFV, they sat in a chair with their legs elevated on a wooden box. The group not receiving vibration (SQT) sat for the entire 240-second rest period between sets (see Figure 1).

Procedures

One-Repetition Maximum Smith Machine Squat. The IRM Smith Machine back squat was performed during the first workout day on W1 and W3 and then at the beginning of W7 (week after training) using a Cybex free standing Smith Machine (Cybex International, Medway, MA, USA). The starting position required subjects to position their heels on a taped off line (marker 2) at a set distance forward of a line parallel to the bar. Subjects positioned the bar in a "high bar" position, resting across the upper trapezius at T2–T3 level. The arms were positioned with hands gripping the bar equidistant from the midline of the torso to add stability and symmetry to the lift. Subjects were instructed to take a deep breath and hold during the descent phase and then to move forcefully upwards with "maximal movement intent" while exhaling once they had attained a bottom position where their upper thighs were parallel with the floor. Such an instruction was given in an attempt to maximize acceleration, F_{av}, and motor unit recruitment throughout the lift (22,28,29,40,47). After a standardized warm-up, subjects were allowed up to 5 attempts to find their 1RM. Two experienced spotters were used at either end of the bar for safety purposes The subject's 1RMs were deemed to be the last successfully completed attempt in accordance with the criteria outlined elsewhere (see Table 3).

TABLE 4. Baseline DXA data for all subjects.*†

	CON (n = 6)	SQTV (n = 13)	SQT (n = 11)
Body weight (kg)	87.15 ± 14.24	83.83 ± 12.39	73.86 ± 7.53
TBM (DXA) (kg)	84.14 ± 13.70‡	80.05 ± 12.27‡	70.47 ± 7.45§
TLBM (kg)	69.90 ± 3.73‡	67.09 ± 8.69‡	58.81 ± 6.31§
TLM (kg)	34.77 ± 2.46‡	32.17 ± 4.56‡	28.49 ± 3.29§
LLM (kg)	21.26 ± 1.40‡	21.60 ± 2.78‡	18.78 ± 2.59§
TBF (%)	15.15 ± 8.64	15.10 ± 5.08	15.65 ± 5.25
TRF (%)	17.33 ± 8.79	17.08 ± 6.13	17.28 ± 5.83
LF (%)	14.77 ± 9.20	15.79 ± 5.65	16.85 ± 5.76

*CON = control; SQTV = squat + vibration; SQT = squat only; DXA = dual x-ray absorptiometry; TBM = total body mass; TLBM = total body lean mass; TLM = trunk lean mass; LLM = leg lean mass; TBF = total body fat; TRF = trunk fat; LF = leg fat.
†Data expressed as mean ± *SD*.
‡ Denotes data statistically similar.
§ Denotes significantly less than ‡.

Body Composition Analysis Using Dual X-Ray Absorptiometry

Total body scans were performed using a GE Lunar Prodigy enCORE, software version 10.50.086. (Madison, WI, USA). Total body mass (TBM, kg), total body lean mass (TBLM, kg) (total body, fat free, bone-free lean tissue), trunk lean mass (TLM, kg), leg lean mass (LLM, kg), total body fat percentage, trunk fat percentage, and leg fat percentage (LF%) were used for data analysis. Standard calibration procedures were performed before the beginning of each testing session by the same technician (31,32). Coefficients of variation for total body lean mass and fat mass have previously been calculated as 1.4 and 1.7%, respectively. (31). Larger relative variations were found by the same authors for fat free mass (FFM) and fat mass (FM) for the trunk and legs (range 1.3–2.8%) (see Table 4).

Statistical Analyses

Statistical analyses were performed using SPSS for Windows (V.15.0). Descriptive statistics were used to describe the physical attributes and 1RM measures on W1 as mean ± *SE*. The initial analysis included a 1-way analysis of variance (ANOVA) to explore baseline (W1) values for each parameter of interest with a Bonferroni pairwise comparison used as a post hoc analysis. Repeated-measures analysis of covariance (ANCOVA; Group [3] × Trial [3]) was used to control for the initial differences found between groups for 1RM Squat values. Subjects respective baseline 1RM values were collapsed and weighted across groups ($n = 30$) and then acted as the covariate variable for repeated-measures ANCOVA analysis. A similar analysis was then performed with the data set sorted by group to assess potential within group differences. Univariate ANCOVA was used to compare group's percent change in variables between W1–W3, W3–W7, and W1–W7. A Bonferroni correction was applied to all multiple comparisons. For body composition measures, a series of 2-way repeated measures (Time point × Group) ANOVA and ANCOVAs (covariate; respective W1 measures for TBM, total body lean mass (TLBM), TLM, and LLM collapsed across groups, $n = 30$) were used to compare between- and within-group differences from W0 to W7. A Bonferroni correction was applied to all multiple comparisons. The level of significance was set at $p \leq 0.05$.

Results

Training-Induced Changes in One-Repetition Maximum Squat Strength

Significant differences were found between groups for 1RM at baseline, so repeated-measures ANCOVAs were used using respective W1 subject values as covariates (covariate adjusted W1 1RM = 113.34 kg for all groups). There were no significant within-group changes for the control group ($p >$ 0.05). Significant within-group differences seen for both the SQTV ($p = 0.017$, ES = 0.311, $1 - \beta = 0.753$) and SQT ($p =$ 0.007, ES = 0.422, $1 - \beta = 0.855$) groups. Measures at W7 were significantly greater than those at W3 and W1 for both SQTV and SQT groups (p significant at level ≤0.001 and <0.05, respectively). Measures at W7 were greater than at W3, which were greater than at W1, when data were collapsed across groups ($p = 0.001$, ES = 0.237. $1 - \beta =$ 0.947). There were no significant between-group differences or Group × Week interaction ($p > 0.05$). Data were expressed as mean ± *SE*. Measures of percent change (%Δ) in 1RM between W1–W3, W3–W7, and W1–W7 revealed no significant between-group differences ($p > 0.05$). However, strong trends with regard to percent change in 1RM over the first 3 weeks of training ($p = 0.063$) were seen for the SQTV group (+10.10 ± 6.1% *SD*) over W1 values (see Figure 2).

Training-Induced Changes in Body Composition Assessed Using Dual X-Ray Absorptiometry

Analysis of select measures of body composition recorded at W0 and W7 using a 2-way repeated-measures ANCOVA (Time (2) × Group (3)) using respective W1 values as covariates revealed significant group by trial ($p = 0.038$, ES = 0.222, $1 - \beta = 0.627$) and group effects ($p = 0.038$, ES = 0.222, $1 - \beta = 0.627$) for TLBM. Pairwise comparisons for groups revealed that SQTV was significantly greater than CON ($p = 0.043$, mean diff = 0.673 kg). Bonferoni post hoc revealed SQTV measures at W7 (65.43 kg) were significantly greater than CON measures at W7 (64.09 kg) ($p = 0.038$, mean diff = 1.34 kg). No significant within-group differences were seen ($p > 0.05$). No significant differences were seen between SQTV and SQT groups ($p > 0.05$).

Repeated-measure ANOVAs were used to analyze measures of The TBM percentage change (TBM %Δ), total fat percent change (TF %Δ), and leg fat percent change (LF %Δ) between W0 and W7. Analysis revealed a significant main effect for time for LF%, with W1 < W7 ($p = 0.047$, ES = 0.138, $1 - \beta = 0.518$). Within-group analysis revealed W7 values to be significantly less than W0 values ($p = 0.039$, ES = 310, $1 - \beta = 0.569$) for the SQTV group. No significant within-group differences were seen for CON or SQT groups ($p > 0.05$). No other significant differences were seen ($p > 0.05$); however, a practical trend favoring greater relative %Δ in LLM was seen for the SQTV group (+2.54% ± 1.7*SD*, $p = 0.18$) between groups. Data are expressed as mean ± *SE* (see Figures 3 and 4).

Discussion

This study found that WBLFV did not enhance 1RM squat strength above squat training alone; however, trends were seen favoring WBLFV application during the first 3 weeks with the largest "actual" %Δ seen for SQTV (10.0 ± 6.1%*SD*). From W3–W7, SQTV improved at a slower rate (4.82%). These large increases after only 3 weeks of training (4 workouts) are considerable but not uncommon (2,39).

Training adaptations during the first 4 weeks are commonly attributed to "neuromuscular adaptations" (1–3,10,19,25,36,42); however, such "early phase" adaptations are normally seen in previously untrained subjects, whereas the current studies subjects were 'recreationally trained.' The term "Short-term" adaptation is more appropriate for recreational and advanced trainers. Potentially, facilitated motor unit recruitment and discharge rates resulting from WBLFV application may have increased the overall training stimulus.

The application of WBLFV after W3 may have partially impeded maximal strength improvement. A slowing in the relative increase in 1RM was expected because of the shift to lighter relative loads, but the reduction was greater for SQTV than for SQT. Loading during the first 3 weeks ranged from 70 to 90% of 1RM and 55 to 85% for the final 3 weeks. The WBLFV "dose" used may have had a greater impact at high loads (70–90%) with decreased or negative impact at lighter loads (55–85%). These results agree with those of Ronnestad (40) who found that Smith Machine Squat 1RM was facilitated by WBLFV added concurrently at 50 Hz, 3-mm peak–peak amplitude in untrained and recreationally trained men and women. The mode of application was different however; WBLFV applied during Squats vs. WBLFV applied before, then in between sets of Squats, the former classified as concurrent potentiation (CP), the latter PAP. McBride et al (34) suggested that vibration may lead to increased synchronization of motor units, increasing performance during ballistic movements, and movements performed with maximal movement intent. However, CP may initially facilitate F_{av}, A_{av}, RFD, and P_{av} but then results in greater overall fatigue over successive sets. A potentially reduced volume load (mass lifted × repetitions × sets), may negatively affect the chronic training adaptation (12,24,26,30,35,36,43,44). If maximal strength is the desired outcome, asynchronous motor unit recruitment during high load and force tasks may be more efficient over multiple repetitions and sets than WBLFV stimulus driven MU synchronization (1–3,10,12,28,33,34,40,44). Greater motor unit synchronization may be more important if high dynamic RFD and submaximal ballistic forces are needed over short time periods, potentially resulting in a leftward shift in the force–time curve (11,19,21–23,25,30,33,38,43,45,47). The relatively short time frame to complete a 1RM attempt (3–6 seconds total, concentric–eccentric phases) may reduce the potential for MU synchronization induced fatigue, resulting in CP. A hybrid of the 2 methods may lead to the greatest chronic adaptations in 1RM strength within recreationally trained men.

Loading during the first 3 weeks' dictated movements be performed at relatively low bar velocities using a "slow" SSC, less reliant upon reflexive force production. During the final 3 weeks, loads were reduced, and "speed squats" performed in a "cyclic" manner during the final 3 workouts. Such movements were performed to maximize movement velocity while minimizing transition time between repetitions. The SSC used would be classified as "slow-moderate" but relies more upon reflexive force production. If WBLFV during the final 3 weeks lead to PAD rather than to PAP, possible presynaptic inhibition at type 1a afferents and increased type 1b golgi tendon organ (GTO) inhibitory afferent discharge may have led to a degree of "uncoupling" between the eccentric and concentric phases of squats over successive sets.

Week 7 analysis revealed no group differences for %Δ with SQT and SQTV improving at similar rates. The 15.43% increase in 1RM for SQTV between W1 and W7 was substantial but not as great as that reported by Ronnestad (39) (32.4%) who used a 5-week periodized Smith Machine training protocol with and without WBLFV applied during squat exercise. Differences in the modes of exposure and 1RM assessment protocols (range of motion, being able to use a weightlifting belt) could have resulted in greater relative improvements in 1RM.

Changes in body composition from W1 to W7 assessed by DXA revealed an increase in TLBM for SQTV compared to CON, which may be attributed to the addition of WBLFV. However, because dietary intake was not controlled for, it is difficult to comment on the differences with true authority. Because both training groups significantly increased TLBM, it could be argued that a favorable anabolic hormonal environment was produced (4,5,17,35). However, only the SQTV group W7 measures were significantly greater than similar measures for the CON, which suggests that there was less variability within the SQTV compared to within the SQT group. Because no blood hormone samples were taken during this study, only speculative claims can be made concerning acute hormonal responses. Such hormonal analysis, similar to that carried out by Kvorning et al. (27) could form the basis of future combined resistance training + WBLFV studies.

The significant reduction in LF% within group, between W1 and W7 seen for SQTV (0.7%) may be because of the larger total work performed and possible greater EPOC leading to greater total fat use. Similarly, the greatest nonsignificant change in LLM (2.54% ± 1.7%*SD*) was seen for SQTV suggesting a "practical" benefit of adding WBLFV. Again, possible changes in the anabolic environment in response to WBLFV application may have occurred but could not be corroborated during this study.

In conclusion, adaptations for both experimental groups, although of a similar magnitude, appear to have affected neuromuscular function differently. Although WBLFV application did not afford any additional training adaptation in1RM after 6 weeks of training, "short-term" adaptations and total body muscle hypertrophy were "practically" facilitated. The RFD rather than F_{max} may have been preferentially affected by WBLFV (26). Future studies using variable frequencies, amplitudes, exposure times, training status, both genders, and greater training durations may lead to significant delineation between groups. More combined resistance training and WBLFV studies are needed to find the "least effective" dose CP and PAP use; electromyography, reflex activation techniques, kinetic and kinematic measurements, would provide valuable mechanistic data.

Practical Applications

This study supports practical merit to intermittently applying WBLFV before and between sets of resistance exercise with regards maximal dynamic strength adaptation during the first few weeks of exposure in recreationally trained male subjects. However, caution should be exercised to use the "least effective dose" to minimize fatigue and reduce injury potential. Modification of WBLFV "dose" based upon the trainees background and resistance training experience would also seem appropriate. Applying WBLFV during resistance exercise when "apparent fatigue" is noted may help athletes push through sticking points (CP) and be valuable if combined with WBLFV applied intermittently between sets (PAP). Whether training for increased strength or power, the use of a linear position transducer or tri-axial accelerometer attached to a barbell may be a practical way of assessing fluctuations in force, velocity, and power output to give the coach or researcher a quantitative means of monitoring fatigue during successive repetitions and sets.

Acknowledgments

This project was funded by internal funds allocated by the College of Arts and Sciences at the University of Oklahoma. The results of this study do not constitute endorsement of the Power Plate Next Generation® whole-body vibration platform by the authors or by the National Strength and Conditioning Association.

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