

Comparison of the effects of whole-body vibration squat exercises applied at different loads on reactive strength and leg stiffness

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Abstract:

Whole-body vibration (WBV) exercises have been widely recognized for decades as a popular exercise method known to have an impact on athletic performance. However, there is a clear lack of consensus in the existing literature regarding the effects of WBV squat exercises performed at different loads on jump performance, reactive strength index, and leg stiffness associated with this performance. To address this gap, our study aimed to compare the effects of whole-body vibration squat exercises applied at different loads on reactive strength and leg stiffness. For this purpose, we recruited twenty trained male athletes (age: 22.05±3.2 years, height: 177.1±6.5 cm, body mass: 74.5±10.6 kg, training experience: 9.2±3.33 years, training volume: 9.8±6.67 hours per week) to participate in the study. The participants underwent three different test sessions: T1 (sham intervention), T2 (25 Hz, 2 mm), and T3 (50 Hz, 4 mm). These sessions involved squat exercises performed on a whole-body vibration platform for 5 sets of 1 minute each, with 30-second intervals. The squat exercises were conducted at an approximate knee flexion angle of 110°. The three test sessions were spaced 72 hours apart. Immediately after each intervention, the participants' reactive strength index, leg stiffness, ground contact time, and jumping height were examined. The statistical analyses, including one-way repeated measures ANOVA and/or Friedman tests, revealed that there were no statistically significant differences observed between any of the pairs concerning the variables investigated in the study. The study found no statistically significant effect of WBV when applied at various amplitude and frequency combinations on variables such as reactive strength index, leg stiffness, ground contact time, and jumping height. Despite WBV exercises being a well-known training concept, there is still a lack of consensus regarding the optimal parameters, including amplitude, frequency, body position, set, and volume configuration, among others. Replication studies are necessary to further investigate and clarify the effectiveness of WBV exercises on athletic performance.

Keywords: whole-body vibration, reactive strength index, jump height, leg stiffness

Introduction

The utilization of whole-body vibration (WBV) exercises on vibration platforms has gained popularity as an exercise and rehabilitation method in sports and health-related fields for several decades (Rittweger, 2010). The popularity of vibration stems from its effectiveness in enhancing various aspects of physical performance. Research has shown that vibration exercises can help individuals increase their strength and power (Tsuji et al., 2014; Osawa, Oguma, and Ishii, 2013; Jacobs and Burns, 2009), influence hormone levels (Moreira-Marconi et al., 2020; Paineiras-Domingos et al., 2017; Kvorning et al., 2006; Cardinale and Pope, 2003), elicit cardiovascular responses (Aoyama et al., 2019; Sa-Caputo et al., 2018), impact electromyographic activity (Arora et al., 2021; Marin and Cochrane, 2021), modulate neuromuscular reflexes (Ritzmann et al., 2013; Cardinale and Lim, 2003a), improve postural control and balance (Piri et al., 2022; Fort et al., 2012), enhance reactive strength (Washif, 2019; Cloak et al., 2014; Di Giminiani, 2009), and influence leg stiffness (Constantinos and Dallas, 2021; Paradisis et al., 2021; Hobara et al., 2011).

The vibration effect observed in this study is attributed to the stimulation of mechanoreceptors, such as the muscle spindle, located within the muscles of the athletes. When exposed to vibration, these mechanoreceptors become activated, initiating a reflex activation of the α motor neuron and leading to improved recruitment of motor units (Washif, 2019). This effect, occurring involuntarily within the athlete's muscles, is then transmitted to the whole body through the vibration platform, which generates sine waves.

In the last two decades, whole-body vibration training (WBVT) emerged as an alternative exercise modality for strength training (Zago et al., 2018). Vibrations mechanically generate rapid variations in the length of the muscle-tendon complex (Cardinale and Bosco, 2003), stimulating repetitive eccentric-concentric muscular work and reflexive muscle contractions. Sprinting, jumping and throwing are key components of athletic motor skill competencies that are important for success in most sports (Radnor et al., 2018; Lloyd et al., 2015). These

movements utilize the stretch-shortening cycle (SSC), which is characterized by an eccentric ‘stretching’ action prior to a subsequent concentric ‘shortening’ action (Nicol, Avela, and Komi, 2006). Recently, the reactive strength index (RSI) and leg stiffness have been used in the practical strength and conditioning setting as well as in the exercise science literature as a means to quantify SSC performance. RSI is defined as the ability of the muscle-tendon complex to produce greater force during concentric contraction immediately after a rapid eccentric contraction (Beattie et al., 2017). On the other hand, leg stiffness is described as the lower-limb resistance to deformation, which is calculated as the ratio of force to length, and reflects the integration of muscles, tendons, and ligaments as a simple spring to store and recoil elastic energy (Butler et al., 2003).

The sine waves generated by the vibration platform contribute to a training load that affects neuromuscular performance, incorporating four fundamental components: frequency (the number of vibration repetitions per unit of time, measured in Hz), amplitude (the displacement of the wave, measured in mm), acceleration (the speed of vibration that generates reactive forces in the human body), and duration (Cochrane, 2011; Rittweger, 2010; Cardinale and Erskine, 2008). Despite numerous studies on whole-body vibration treatment (WBV), there is currently no consensus in the literature regarding the optimal combination of vibration components that would create the most effective training load for improving functional performance (Alam, Khan, and Farooq, 2018).

Washif (2019) reported that two 30-s (60-s total duration) WBV interventions on a vibration platform in a quarter-squat position and administered at a frequency of 40 Hz and a vertical displacement of 6.0 mm did not elicit an increase in RSI performance of highly-trained sprinters. Furlong and Harrison (2009) reported that WBV vibrations at 30 Hz $\pm$ 4 mm with 60 seconds rest between each exposure on a Vibrogym platform increased RSI and musculotendinous stiffness in trained males. The findings in WBV research have been mixed, and further investigation is needed to determine the ideal configuration of vibration parameters for achieving desired outcomes.

The main objective of this study was to investigate whether whole-body vibration squat exercises with different frequencies and amplitudes (50 Hz, 4 mm, and 25 Hz, 2 mm) could lead to acute improvements in reactive strength index (RSI), leg stiffness (K_{leg}), ground contact time (GCT), and jump height (JH) compared to a sham intervention (0 Hz, 0 mm) in trained male athletes. The study hypothesis posited that performing static squat exercises with high frequency and amplitude vibration would result in significant enhancements in RSI, K_{leg} , GCT, and JH compared to low-frequency and low-amplitude vibration or no vibration (sham intervention).

Material & methods

Participants

Twenty recreationally active men (age: 22.05 ± 3.2 years, height: 177.1 ± 6.5 cm, body mass: 74.5 ± 10.6 kg, training experience: 9.2 ± 3.33 months, training volume: 9.8 ± 6.67 hours per week) from various sports, including soccer, basketball, wrestling, swimming, track and field, and softball, participated in the study. According to the study conducted by Turner, Sanderson, and Attwood in 2011, with an effect size of $d = 0.66$ and significance levels of $\alpha = 0.05$ and $1-\beta = 0.80$, G*Power 3.1.9.2 indicated that a sample size of 10 subjects should be recruited for the study. The inclusion criteria were as follows: being ≥ 18 years old, possessing a player license for the 2021-2022 game season, and having a minimum of two years of experience in a sport. Participants with a history of ongoing injury or sports-related injuries, as well as those using performance enhancers, doping agents, or ergogenic aids, were excluded from the study. Each participant provided informed consent after receiving an explanation of the study protocol, including the potential risks and benefits. Participants were instructed to maintain their regular daily routines, refrain from making any changes to their physical activity and dietary habits, and avoid engaging in exhaustive exercise or consuming substances for two days before each experiment. All aspects of the study protocol were verbally communicated to the participants, who provided informed consent prior to their involvement. The study received approval from the Medical Ethics Committee of the Medical Faculty of Trakya University (Protocol number: TÛTF-GOBAEK 2022/120) in compliance with the Declaration of Helsinki.

Table 1. Descriptive characteristics of the athletes.

	Mean $\pm$ SD		
Age (year)	22.05	$\pm$	3.24
Height (cm)	177.1	$\pm$	6.52
Body mass (kg)	74.50	$\pm$	10.60
Training age (years)	9.20	$\pm$	3.33
Training volume per week (hour)	9.80	$\pm$	6.67

SD: Standard deviation.

Procedures

Participants underwent three different test sessions spaced 72 hours apart. In the first session, the athletes in the sham group began with a warm-up by walking on a treadmill with no incline at a speed of 6 km/h for 5 minutes. Following the warm-up, the athletes performed squat exercises on a vertical sinusoidal whole-

body vibration (WBV) platform (Power Plate® Next Generation PRO 5, 2×1A, 2010, USA). The WBV platform was set to 0 Hz and 0 mm. The athletes completed 5 sets of 1-minute squats with 30-second intervals between each set. The squat position was maintained at approximately 110° knee flexion, which was measured using a plastic goniometer (Lafayette Instrument Europe, Richardson Products, INC., Sammons Preston J00240, 12-inch). Subsequently, we conducted the jump-plyometric test following the methodology outlined in the study by Laffaye et al. (2016) to assess K_{leg} , RSI, JH, and GCT. Firstly, we measured the body mass of the participants. Then, we attached the device to their belts and secured it in a vertical position.

The participants were instructed to perform five consecutive hops in place, aiming to achieve maximum height while minimizing ground contact time (GCT). The instructions given were as follows: “Upon hearing the acoustic signal, perform five hops in place, maintaining minimal knee flexion and maximizing jump height (JH). After the final hop, return to a vertical standing position and await the final acoustic signal” (Laffaye et al., 2016). Once the final signal was given, the jump-plyometric test was completed, and the device automatically calculated RSI, K_{leg} , GCT, and JH. This entire procedure was repeated twice, with a 3-minute rest period in between. For statistical analysis, we selected the best scores obtained from the two trials. The Myotest Pro system, which has been previously validated for measuring these parameters (Choukou, Laffaye, and Taiar, 2014), was utilized to determine the aforementioned values. In the second session, which took place 72 hours after the control session, participants followed the same warm-up protocol as before. After the warm-up, they performed squat exercises on the WBV platform, which was set to 25 Hz and 2 mm amplitude.

The squat exercises were conducted with 110° knee flexion, and participants completed 5 sets of 1-minute squats with 30-second intervals. Immediately after the squat exercises, the maximum jump height (JH), ground contact time (GCT), reactive strength index (RSI), and leg stiffness (K_{leg}) values were determined using the same methodology as in the control session. In the third session, occurring 72 hours after the second session, participants followed the same warm-up routine. However, during the squat exercises, they were exposed to high-frequency and high-amplitude WBV effects. The WBV platform was set to 50 Hz and 4 mm amplitude. Similar to previous sessions, participants performed 5 sets of 1-minute squats with 30-second intervals and maintained a squat position with 110° knee flexion. Subsequently, the JH, GCT, RSI, and K_{leg} values were assessed using the established methodology. Throughout all the squat exercises, participants were instructed to adopt the most comfortable squat position and keep their hands on their waists.

Warm-up: 5 min jogging at 6 km/h, 0% slope on a treadmill		
2 min passive rest		
Session 1: Sham intervention 0 Hz + 0 mm	Session 2: Low load 25 Hz + 2mm	Session 3: High load 50 Hz + 4 mm
2 min passive rest		
Static squat exercise at 110° knee angle on a Power Plate® Next Generation PRO 5		
5 × 1 min with 30-sec interval		
2 min passive rest		
5 vertical reactive jumps using Myotest Pro system		
3 min passive rest		
5 vertical reactive jumps using Myotest Pro system		

Figure 1. Research protocol

Statistical Analysis

Statistical analysis was conducted using IBM SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). The data are presented as mean ± standard deviation (SD) or median and interquartile range (25th and 75th percentiles) for parametric and non-parametric tests, respectively. The normality of the data was assessed using the Shapiro-Wilk test, and the assumption of sphericity was examined using Mauchly’s test of sphericity. To compare the variables between the mean scores of the three different measures (sham: T1 - 0 Hz and 0 mm, vibration exercise treatments: T2 - 25 Hz and 2 mm, T3 - 50 Hz and 4 mm), either one-way repeated measures ANOVA or the Friedman test was employed based on the normality test results. Descriptive statistics are presented as median [25th percentile - 75th percentile] for non-parametric values in Table 2. The effect sizes of the differences are also reported using r for the Wilcoxon signed-rank test (where 0.1 indicates a small effect size, 0.3 indicates a medium effect size, and 0.5 indicates a large effect size) and Cohen’s effect size for ANOVA (where 0.2 indicates a small effect size, 0.5 indicates a medium effect size, and 0.8 indicates a large effect size). A p-value of <0.05 was considered statistically significant.

Results

All participants successfully completed all the experimental procedures of the study. The results of our investigation into the effects of whole-body vibration squat exercises at different loads on jump height (JH), ground contact time (GCT), reactive strength index (RSI), and leg stiffness (K_{leg}) indicate that there were no

statistically significant differences observed in any of the pairwise comparisons of the relevant variables (Table 2). The RSI values did not exhibit a statistically significant change when compared to the sham intervention. Notably, the mean values of the two separate pairwise comparisons between the control measurement and different whole-body vibration (WBV) loads (T1 vs T2: 0.21 m/s; T1 vs T3: 0.19 m/s) were found to be very similar. The largest difference between the pairwise comparisons was observed between T2 and T3. However, none of these paired comparisons yielded a statistically significant difference (Table 2). The statistical analysis conducted for K_{leg} demonstrated that there were no statistically significant differences observed in any of the pairwise comparisons.

Interestingly, the difference between the mean values of the pairwise comparisons of K_{leg} , measured immediately after the squat exercises without vibration (T1) and under the highest vibration effect applied in our study (T3) (T1 vs T3: $-0.267 \text{ kN}\cdot\text{m}^{-1}$), was numerically quite small. However, when comparing the other pairwise comparisons (T1 vs T2: $5.05 \text{ kN}\cdot\text{m}^{-1}$ and T3 vs T2: $5.32 \text{ kN}\cdot\text{m}^{-1}$), it can be observed that the statistical differences in the mean values were very similar (Table 2). Based on the results of K_{leg} , it can be inferred that the impact of a very high and non-existent vibration load on K_{leg} during squats is comparable. The statistical analysis performed on the GCT and JH values revealed that the distribution was non-normal, and no statistically significant differences were observed in any of the pairwise comparisons of the mean values for these variables. Based on these results, it can be concluded that the effects of the 25 Hz, 2 mm and 50 Hz, 4 mm vibration loads, as well as the non-vibration load, on K_{leg} during squats are similar in terms of GCT and JH values.

Table 2. Results of pairwise comparisons of reactive strength index, leg stiffness, jumping height, and ground contact time values.

Reactive Strength Index ($\text{m}\cdot\text{s}^{-1}$) (n=20)					Leg Stiffness ($\text{kN}\cdot\text{m}^{-1}$) (n=20)			
M $\pm$ SD					M $\pm$ SD			
T1	T2	T3			T1	T2	T3	
2.81 $\pm$ 1.00	2.60 $\pm$ 1.08	2.63 $\pm$ 1.01			33.7 $\pm$ 22.0	28.6 $\pm$ 19.3	33.9 $\pm$ 22.4	
MD	SE	p	ES		MD	SE	p	ES
T1 – T2	0.21	0.16	0.215	0.4 ^d	5.05	3.14	0.124	2.1 ^d
T1 – T3	0.19	0.12	0.149	1.8 ^d	– 0.267	3.45	0.939	0.1 ^d
T2 – T3	– 0.25	0.17	0.889	0.2 ^d	– 5.32	3.90	0.189	0.7 ^d
Ground Contact Time (s) (n=20)					Jumping Height (cm) (n=20)			
M $\pm$ SD					M $\pm$ SD			
T1	T2	T3			T1	T2	T3	
225.8 $\pm$ 119.0	244.0 $\pm$ 133.8	236.7 $\pm$ 132.4			32.7 $\pm$ 6.41	32.9 $\pm$ 5.30	31.6 $\pm$ 7.47	
M [Min Max]	Z	p	ES		M [Min Max]	Z	p	ES
T1 – T2	– 4.5 [–172.0 – 99.0]	–0.8	0.401	0.1 ^r	0.75 [–21.1 – 13.9]	–0.6	0.550	0.03 ^r
T1 – T3	– 9.5 [–284.0 – 214.0]	–1.1	0.286	0.2 ^r	0.20 [–20.2 – 13.8]	–0.7	0.490	0.1 ^r
T2 – T3	8.0 [–231.0 – 157.0]	–0.6	0.575	0.1 ^r	1.00 [–16.9 – 15.3]	–0.8	0.422	0.1 ^r

T1: Treatment 1 (Sham intervention with no vibration); T2: Treatment 2 (25 Hz frequency with 2 mm amplitude); T3: Treatment 3 (50 Hz frequency with 4 mm amplitude); M: mean; SD: standard deviation; MD: mean difference; SE: standard error; M: median, Min: minimum, Max: maximum; ES: unbiased effect size (Cohen's d for repeated measures ANOVA; Hedge's g for Mann-Whitney U test).

*p<0.05

Discussion

The main objective of this study was to investigate whether whole-body vibration squat exercises with high frequency and amplitude (50 Hz, 4 mm) or low frequency and amplitude (25 Hz, 2 mm) would lead to acute improvements in RSI, K_{leg} , GCT, and JH. However, the results of the study revealed that none of the vibration loads showed a significant advantage over the sham intervention (0 Hz, 0 mm). This means that the hypothesis of the study, which proposed that high-frequency and high-amplitude WBV would have a greater impact on RSI, K_{leg} , GCT, and JH compared to low-frequency and low-amplitude WBV or the sham intervention, was not supported by the findings.

Although Cardinale and Bosco (2003) suggested that low-amplitude, low-frequency mechanical stimulation of the human body is a safe and effective way to improve muscle strength, there is no consensus regarding the application of whole-body vibration (WBV) to enhance athletic performance or improve health

(Cochrane and Stannard, 2005; Luo, McNamara, and Moran, 2005). However, a recent study by Van Heuvelen et al. (2021) has been attempting to establish guidelines for WBV in fitness participants, athletes, or workers.

The effectiveness of WBV treatment may vary depending on several factors, including the characteristics of the vibration sources (local or WBV, horizontal or vertical, etc.), the selection of exercises during vibration treatment (static, dynamic, etc.), the vibration load (amplitude, frequency, rest time between treatments, duration of mechanical exposures to the subject, etc.), the physical or fitness characteristics of the subjects (inactive, recreationally active, athlete, obese, etc.), the health status of the subject (healthy or suffering from any chronic disease), and the gender and age of the subjects (male or female, young, elderly, etc.) (Van Heuvelen et al., 2021; Karatrantou et al., 2019; Martínez-Pardo et al., 2013; da Silva-Grigoletto et al., 2011; Rogan et al., 2011; Turner et al., 2011; Gerodimos et al., 2010; Bullock et al., 2008; Luo, McNamara, and Moran, 2005; Cardinale and Lim, 2003b).

Nordlund and Thorstensson (2007) reported that the effects of WBV are strongly dependent on the magnitude of vibration, including factors such as amplitude, frequency, duration, and mode. According to Da Silva et al. (2006), the most ideal vibration parameters for eliciting jump performance are a vibration frequency of 30 Hz and an amplitude of 4 mm, as compared to 20 Hz + 4 mm and 40 Hz + 4 mm vertical sinusoidal vibrations. Additionally, Da Silva et al. (2006) found that jump performance decreased after applying a 40 Hz + 4 mm WBV load. In terms of lower body 1RM strength and power, Da Silva et al. (2006) reported that performance increased after a 20 Hz frequency, but that there was a slight decrease in performance after 30 Hz and 40 Hz loads. However, Turner, Sanderson, and Attwood (2011) argued that a vibration load of 40 Hz and 8 mm peak-to-peak vertical displacement significantly enhanced explosive jumping performance compared to 30 Hz + 8 mm and 35 Hz + 8 mm vibration loads. Turner, Sanderson, and Attwood (2011) explained that performance increases after 40 Hz vibration treatment may be due to an increase in vibration frequency leading to proportional muscle tension, and that lower frequencies might be insufficient to enhance performance.

A study conducted by Cardinale and Lim (2003b) found that low-frequency WBV stimulation (20 Hz + 4 mm) increased squat jump performance, while high-frequency WBV stimulation (40 Hz + 4 mm) decreased squat jump and countermovement jump performance. In contrast to the findings of Turner, Sanderson, and Attwood (2011), Cardinale and Lim (2003b) argued that high-frequency vibration treatment (>40 Hz) induces a strong tonic vibration reflex (TVR), leading to increased neuromuscular activation of the lower limbs to dampen the vibratory waves transmitted to the body. According to Rittweger, Mutschelknauss, and Felsenberg (2003), frequencies below ~20 Hz induce muscle relaxation, while frequencies above ~50 Hz may result in severe soft tissue soreness in untrained subjects. Based on the studies mentioned above, it can be concluded that the optimal WBV frequency may fall somewhere between 20 Hz and 40 Hz.

We encountered limited studies that specifically examined the effect of vibration amplitude on performance or health during our literature search. However, one relevant study by Krol et al. (2011) investigated the effects of different vibration frequencies and amplitudes on the myoelectric activity of the vastus medialis and vastus lateralis muscles. The study involved 29 female sports sciences department students who participated in eight different sessions using a peak-to-peak vertical vibration platform. The sessions included various combinations of vibration frequencies (20 Hz, 40 Hz, and 60 Hz) and amplitudes (2 mm and 4 mm).

According to Krol et al. (2011), the study found that the highest myoelectric activity was observed when using a vibration frequency of 60 Hz and an amplitude of 4 mm. Additionally, Krol et al. (2011) reported that when the same vibration frequency (60 Hz) was applied at different amplitudes (2 mm and 4 mm), significant myoelectric activity was observed at the 4 mm amplitude. In another study conducted by Gerodimos et al. (2010), the researchers aimed to explore the effect of different vibration amplitudes while keeping the frequency constant at 25 Hz (25 Hz + 4 mm, 25 Hz + 6 mm, 25 Hz + 8 mm, and a control protocol). They used a side-to-side alternating vertical sinusoidal vibration platform and assessed flexibility and squat jump (SJ) performance. The findings of Gerodimos et al. (2010) indicated that side-to-side WBV with frequencies ranging from 15 to 30 Hz and amplitudes of 4 to 8 mm resulted in similar improvements in flexibility. However, they found that a single bout of side-to-side WBV did not affect SJ performance.

In a study conducted by Dallas et al. (2015), the researchers investigated the effects of different amplitudes of whole-body vibration (WBV) on the flexibility and explosive strength of springboard divers' lower limbs. They compared a low amplitude and low frequency (30 Hz + 2 mm) of WBV to a high amplitude and high frequency (50 Hz + 4 mm) of WBV using a Power Plate WBV platform, similar to the setup in this study. The findings of the study indicated that both vibration loads (30 Hz + 2 mm and 50 Hz + 4 mm) were effective in improving the flexibility and explosive strength of the divers' lower limbs. However, the study did not find any superiority of one vibration load over the other in terms of increasing flexibility and explosive strength in the divers' lower limbs.

Indeed, the differences in results between the study by Dallas et al. (2015) and the current study highlight the complex nature of whole-body vibration (WBV) and the various factors that can influence its effects on athletic performance. Factors such as the characteristics of the vibration sources, exercise selection, vibration load, physical or fitness characteristics of the subjects, health status, and gender and age of the subjects all play a role in determining the outcomes of WBV studies. The variations in these factors could have contributed to the differences in the observed results. Additionally, there might be other factors, not mentioned in

the previous sentence, that could have influenced the outcomes. Therefore, it is challenging to pinpoint the specific factors that led to the different findings in these studies without a more comprehensive analysis and comparison of the study designs, methodologies, and participant characteristics. To gain a better understanding of the effects of WBV on athletic performance, further research is needed with controlled experimental designs, larger sample sizes, and consideration of multiple factors that can influence the outcomes.

The combination of vibration frequency and amplitude has been a topic of interest in the field of whole-body vibration (WBV) research. It is generally believed that a combination of low frequency and low amplitude or high frequency and high amplitude might be more effective in enhancing performance (Adams et al., 2009). However, Adams et al. (2009) reported that the combination of low amplitude and high frequency (specifically, 50 Hz with 2-4 mm amplitude) did not result in performance enhancement in healthy young untrained subjects. This suggests that different combinations of frequency and amplitude may have varying effects on performance outcomes, and further research is needed to better understand the optimal combination for specific populations and performance goals.

The duration of vibration exposure is indeed an important factor to consider when studying the effects of vibration training. According to Adams et al. (2009), the duration of vibration exposure can vary within the range of 30 to 60 seconds. Da Silva-Grigoletto et al. (2011) found that a protocol consisting of a frequency of 30 Hz and a peak-to-peak displacement of 4 mm, with 6 sets of 60 seconds each, was optimal for enhancing squat jump (SJ) and countermovement jump (CMJ) performance in healthy physically active men. However, in the current study, despite implementing a similar protocol, there was no observed enhancement in reactive strength index (RSI), leg stiffness (K_{leg}), ground contact time (GCT), and jump height (JH). It is important to note that the effects of vibration training can vary depending on multiple factors, including individual differences, specific performance measures, and the physiological response of the participants. Bazett-Jones et al. (2008) proposed that a short duration of WBV exposure, specifically less than 60 seconds, may induce increased neural potentiation known as post-activation potentiation (PAP). On the other hand, a long-duration stimulus could potentially lead to fatigue and decreased muscle performance. These findings highlight the need for further research to explore the optimal duration and timing of vibration exposure to maximize the desired performance outcomes while avoiding potential negative effects such as fatigue.

According to Da Silva-Grigoletto et al. (2011), the majority of studies that have shown positive short-term effects of vibration exposure typically did not exceed a total exposure time of 10 minutes. These studies commonly utilized divided sets, with each set lasting between 30 and 90 seconds. This suggests that shorter durations of vibration exposure within a session may be more effective in eliciting positive outcomes on performance measures. However, it is important to note that the optimal duration and frequency of vibration exposure may vary depending on various factors, including the specific population, training goals, and individual responses. Further research is needed to explore the optimal duration and frequency parameters for different performance outcomes and populations.

There is currently no consensus on the effectiveness of whole-body vibration (WBV) training on the performance response of both trained and untrained athletes to vibration stimulus. The results obtained from acute or chronic treatments of WBV make it challenging to interpret the findings regarding the relationship between the training status of the subjects and the effectiveness of WBV (Martínez-Pardo et al., 2013; Preatoni et al., 2012; Turner, Sanderson, and Attwood, 2011; Bullock et al., 2008; Delecluse et al., 2005).

Bullock et al. (2008) and Delecluse et al. (2005) argued that performance enhancement, particularly in speed-strength activities, through whole-body vibration (WBV) is more subtle in well-trained athletes compared to untrained individuals. This issue can be explained by the fact that well-trained athletes, particularly those who are accustomed to high-intensity stretch-shortening type activities, have already maximized the performance potential of their fast-twitch muscle fibers. These athletes often possess high levels of reflex sensitivity, fast-twitch fiber recruitment, and motor neuron excitability, leaving little room for further improvement (Bullock et al., 2008; Delecluse et al., 2005). Furthermore, the greater stiffness of muscle-tendon units in athletes compared to untrained individuals could be another factor contributing to the lack of improvement. The increased stiffness of these units minimizes muscle length changes during whole-body vibration (WBV), resulting in reduced transmission of the vibratory stimulus to other body parts and a lower load of WBV (Bullock et al., 2008; Delecluse et al., 2005; Ross, Leveritt, and Riek, 2001; Delecluse, 1997). In line with this, Wilcock et al. (2009) argued that WBV training may offer a slight benefit to maximal strength and power in trained athletes. However, the enhancement of speed does not appear to be significantly influenced by WBV.

However, it is worth noting that Nordlund and Thorstensson (2007) found no significant differences in performance enhancement following chronic whole-body vibration (WBV) between trained and untrained subjects. On the other hand, Rønnestad (2009) suggested that untrained subjects experienced a greater increase in their one-repetition maximum (1RM) half squat compared to recreationally trained subjects after acute WBV exercise. This result could be explained by the notion that vibration may have a more pronounced effect in untrained subjects due to their limited ability to fully activate all high-threshold motor units during coordination-demanding dynamic exercises such as squats (Shield and Zhou, 2004).

Thus, there may be a larger potential in untrained subjects for reducing inhibition signals or increasing excitatory stimulus to the motoneuron pool and thereby increase muscle activation and muscle force production (Rønnestad, 2009; Shield and Zhou, 2004).

Kubo et al. (2002) reported that there is a distinction in muscle response between well-trained and untrained subjects. The disparity in response may be attributed to the heightened sensitivity of muscle receptors and the central nervous system in elite athletes to additional stimulation (Issurin, Liebermann, and Tenenbaum, 1994). Although the participants in this study had a training volume of nearly 9 hours per week, they cannot be classified as well-trained athletes due to their amateur status. Given the training status of the participants, the study did not observe any performance improvements following three different loading sessions. Additionally, discrepancies in the whole-body vibration (WBV) program, including factors such as vibration frequency, amplitude, type of exercises, duration of vibration exposure, and other variables, could contribute to the inconsistent results observed in previous WBV studies involving trained, untrained, and recreationally physically active individuals. These variations in the WBV protocols make it challenging to draw definitive conclusions regarding the effectiveness of WBV across different populations and training statuses.

The athletes in this study were recruited from different sports, which may have influenced the results obtained. It is important to note that different sports have varying demands, training protocols, and performance characteristics. These factors can contribute to variations in how athletes respond to the whole-body vibration (WBV) intervention. Therefore, if athletes from the same sport were recruited, it is possible that the results could differ, even when using the same research design. Sport-specific factors and individual variations among athletes within a particular sport can influence the effectiveness of WBV training on performance outcomes.

Conclusion

Based on the study conducted using acute vertical 5×1 min with 30-sec interval static squat WBV exercises, it was found that neither the 25 Hz + 2 mm nor the 50 Hz + 4 mm vibration loads were effective in improving variables such as reactive strength index (RSI), leg stiffness (K_{leg}), ground contact time (GCT), and jump height (JH) in trained male athletes. Even though there was no performance enhancement observed after completing whole-body vibration squat exercises, as none of our subjects reported any whole-body vibration-related complaints, WBV training can still be considered as an alternative training modality to help alleviate training monotony. Therefore, further research is needed to identify and design optimal vibration loading protocols that can enhance the performance of trained male athletes.

Conflicts of interest - The authors declare no conflict of interest

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