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original research

A Comparison of Whole-Body Vibration and Resistance Training on Total Work in the Rotator Cuff

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Context: Whole-body vibration machines are a relatively new technology being implemented in the athletic setting. Numerous authors have examined the proposed physiologic mechanisms of vibration therapy and performance outcomes. Changes have mainly been observed in the lower extremity after individual exercises, with minimal attention to the upper extremity and resistance training programs.

Objective: To examine the effects of a novel vibration intervention directed at the upper extremity as a precursor to a supervised, multijoint dynamic resistance training program.

Design: Randomized controlled trial.

Setting: National Collegiate Athletic Association Division IA institution.

Patients or Other Participants: Thirteen female student-athletes were divided into the following 2 treatment groups: (1) whole-body vibration and resistance training or (2) resistance training only.

Intervention(s): Participants in the vibration and resistance training group used an experimental vibration protocol of 2 × 60 seconds at 4 mm and 50 Hz, in a modified push-up position, 3 times per week for 10 weeks, just before their supervised resistance training session.

Main Outcome Measure(s): Isokinetic total work measurements of the rotator cuff were collected at baseline and at week 5 and week 10.

Results: No differences were found between the treatment groups ($P > .05$). However, rotator cuff output across time increased in both groups ($P < .05$).

Conclusions: Although findings did not differ between the groups, the use of whole-body vibration as a precursor to multijoint exercises warrants further investigation because of the current lack of literature on the topic. Our results indicate that indirectly strengthening the rotator cuff using a multijoint dynamic resistance training program is possible.

Key Words: isokinetic testing, shoulder, upper extremity

Key Points

- We found no difference in strength gains between the whole-body vibration and resistance training and the resistance training–only groups.
- It may be possible to indirectly strengthen the rotator cuff using a multijoint dynamic resistance training program.
- Research on whole-body vibration is in its infancy and should continue so that we can learn if this technique is a useful precursor to resistance training.

Whole-body vibration is a technology that was first developed by scientists in the second half of the 20th century as a way to reduce bone density loss and muscle atrophy in astronauts exposed to zero-gravity conditions.[1–5] Also known as indirect vibration, whole-body vibration (WBV) consists of exposing an individual to repetitive oscillations of a given amplitude and frequency that are produced by a mechanical device in the form of sinusoidal waveforms. Within the past 2 decades, vibration platforms designed specifically for commercial use are finding their way into performance centers and universities throughout the United States. As a result, researchers in athletic training and sport performance have begun to explore the use of WBV in a trained population.

Investigators have studied numerous mechanisms that may explain any effects experienced while using vibration. Possible mechanisms for documented responses include, but are not limited to, the tonic vibration reflex,[6–10] angiogenic factors (outgrowth of new capillaries from preexisting vessels) such as matrix metalloproteinases and vascular endothelial growth factor,[11–14] testosterone and growth hormone,[15] and activation of stem cells.[16]

To date, most literature[7,17–19] regarding muscular performance has focused on the lower extremity, with minimal work exploring the upper extremity. Although authors[18,20,21] have examined the characteristics associated with individual finger, wrist, and elbow flexors, none have tested the rotator cuff using WBV. Also, review articles[6,22] of vibration studies have demonstrated that previous researchers have used different settings and produced different results.

Additionally, previously published data[7,23] indicate that the effect of WBV on strength measures is comparable with that of resistance training. One of the most common methods of resistance training involves multijoint dynamic movements, including the push-up, overhead press, and seated pull-down. This training mode has resulted in a peak torque increase in the rotator cuff after 6 weeks, without the use of the single-plane exercises that are often associated with shoulder rehabilitation.[24]

The aim of our study was to compare isokinetic output of the rotator cuff resulting from various training methods in the National College Athletic Association Division I athletic setting. Specifically, this study was designed to address the following question: Will the additional use of WBV augment the rotator cuff performance gains typically experienced when using a multijoint dynamic resistance training program alone? Based on previous reports of increased muscular performance during activities with vibration versus those without vibration[17,21] and with vibration training alone compared with resistance training alone,[7,18] we were interested in examining the influence of vibration immediately preceding a workout session. Because the effect of WBV on the upper extremity is not completely understood and because the most beneficial settings, if any, have yet to be determined, our findings may help guide professionals in the athletic setting concerned with performance and rehabilitation.

METHODS

Participants

Thirteen volunteer female athletes (age = 21.2 ± 1.1 years, mass = 64.8 ± 8.8 kg) from Division I varsity soccer, lacrosse, and volleyball teams were randomized into 2 groups. One group received a WBV protocol before its resistance training sessions, and the second group only participated in its resistance training sessions, which took place 3 days per week over the course of 10 weeks. Participants were required to complete a health questionnaire before the initiation of the study. Exclusion criteria included pre-existing upper extremity injury, recent fracture, and neurologic or vascular conditions. All procedures were approved by the university's institutional review board.

Multijoint Dynamic Resistance Training Program

All volunteers participated in the program, which was prescribed and supervised by a certified strength and conditioning coach who was a member of the university's staff. The program consisted of pulling, squatting, and pushing exercises that progressed in load, coordination, and speed to address all major muscle groups. Pulling activities involved full-body–extension barbell exercises, such as the clean pull, high snatch pull, and power snatch and clean. Additional basic strength pulling exercises included pull-ups, pull-downs, pull-overs, and various forms of rows. Squatting activities incorporating shoulder fixation included the overhead squat and the overhead lunge using barbells and dumbbells. Pushing exercises consisted of a variety of overhead presses using barbells and dumbbells, progressing to full-body–extension barbell pushes (eg, push presses, push jerks, and jerks). Basic strength pushing included push-ups with various hand and foot placements, weighted push-ups, instability push-ups, and drop push-up progressions. Various forms of seated and lying barbell and dumbbell presses were also included.

Ballistic exercises in the form of multiple tosses, passes, and throws with medicine balls (ranging from 2–10 lb [0.91–4.54 kg]) were also used throughout the training process. Gymnastic work, consisting of crawling techniques, handstands, hand walking, and cartwheels, was performed on a consistent basis throughout the training period.

Training during the first 3 weeks of this study included general preparatory movements and speed foundations. Weeks 4 through 7 focused on strength build-up and speed development, and the last 3 weeks implemented power and speed conversion. Participants were not allowed to perform prophylactic isolation exercises that mimicked the testing motion, such as internal rotations, external rotations, and rotator flies, but they did remain active in all National College Athletic Association–sanctioned activities, as appropriate for their respective sports' off-seasons, while this study was in progress.

Figure 1. Experimental setup for whole-body vibration in a modified push-up position.

WBV

The vibration platform used in this study was a WAVE Pro (WAVE Manufacturing Inc, Windsor, Ontario, Canada). The self-calibrating machine had a 36 × 30–in (91.44 × 76.20–cm) platform, variable frequencies adjustable in 1-Hz increments from 20 to 50 Hz, variable amplitude from 2 to 4 mm, and variable time from 30 to 90 seconds. Participants in the experimental vibration group were placed in a modified push-up position with their hands in the middle of the platform, shoulder width apart, elbows slightly flexed, and with their lower extremities supported by kneeling on the floor to ensure safety. Instructions were given to concentrate on keeping the abdominal and gluteal muscles tight and the scapulae slightly pinched toward the spine, while pressing firmly against the vibration platform with their hands (Figure 1). They used the vibration platform no more than 15 minutes before their weight-training session for the day. The vibration protocol included 2 sets of 60 seconds, at 4-mm amplitude and 50-Hz frequency, with a rest of 30 seconds between sets. Between sets, volunteers remained kneeling but upright and removed from contact with the platform. The protocol was the same throughout the study and was performed 3 days per week for 10 weeks with no progression. All participants in the vibration and resistance training group signed log sheets to record every session.

Measurements

We used the Biodex System 3 (Biodex Medical Systems, Shirley, NY) isokinetic dynamometer to measure total work by the rotator cuff of the nondominant arm.

B

Test Period	Arm	Speed (°/s)	Sets	Repetitions
Baseline		Upper body ergometer warm-up (3 min)	1	
	Dominant	120	1	8
		60	1	5
	Nondominant	120	1	8
		60[a]	1	5
Week 5		Upper body ergometer warm-up (3 min)	1	
	Nondominant	120	1	8
		60[a]	1	5
Week 10		Upper body ergometer warm-up (3 min)	1	
	Nondominant	120	1	8
		60[a]	1	5

Figure 2. A, Modified-neutral testing position and B, isokinetic protocol for all participants. Only data from testing at 60°/s on the nondominant arm were analyzed (represented by [a]).

Volunteers performed a 3-minute warm-up on an upper body ergometer in an effort to reduce the incidence of injury while testing. Each participant was placed in a seated, modified neutral shoulder position of approximately 30° of shoulder abduction, 30° of shoulder flexion, and no more than 90° of elbow flexion. Each chair and dynamometer position was recorded in the subject profile of the Biodex program and on a separate form retained by the researchers and was duplicated for each testing period to increase reliability. Volunteers were stabilized in the chair with the torso, waist, and thigh straps. They were instructed and encouraged to work as hard and as fast as possible while viewing the computer monitor that displayed visual feedback. Total work measurements over a shoulder range-of-motion arc of approximately 60° of internal rotation and 30° of external rotation were used for data analysis at 60°/s. A warm-up set of 8 repetitions at 120°/s preceded the data-collection set. (A detailed representation of the isokinetic protocol is shown in Figure 2 and the Table.) Isokinetic testing was performed at the beginning of the study (baseline), at week 5, and at week 10 to assess short-term and long-term changes. Testing at weeks 5 and 10 was only performed on the nondominant arm, and 5-week intervals were selected to reduce the possibility of a learning effect.[24]

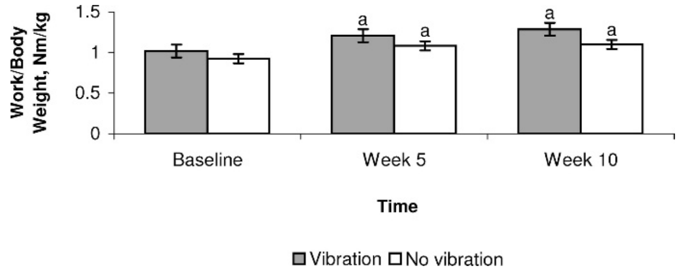

Figure 3. Group means for work/body mass at baseline, week 5, and week 10. No differences were noted between groups from week 5 to week 10. [a] Greater than baseline ($P < .05$).

Data Analysis

The Biodex System 3 software was used to calculate total work of concentric internal rotation, concentric external rotation, and window data in order to eliminate artifacts at end range of motion. The internal and external rotation data for each participant were combined and averaged across the set of 5 repetitions to produce a more accurate representation of the overall performance of the rotator cuff. These data were further normalized to individual body weight. The SPSS software (version 16.0; SPSS for Windows, SPSS Inc, Chicago, IL) was used for data analysis. A 2-way, mixed-effects analysis of variance was calculated to compare differences between groups and across time. The Mauchly test of sphericity was computed with the analysis of isokinetic measurements and was found to be tenable; the α value was set at $P = .05$ for all analyses. A post hoc power analysis revealed a power of 0.21.

RESULTS

Volunteers in the vibration and resistance training and the resistance training–only groups did not perform differently over the course of the study based on isokinetic measures ($F_{1,11} = 1.61$, $P = .231$). No difference was noted for treatment intervention ($F_{2,22} = 0.37$, $P = .697$), but both groups did improve over time ($F_{2,22} = 8.94$, $P = .001$). The Bonferroni procedure was used to control familywise type I error for the pairwise comparisons of the isokinetic measurements over time. Furthermore, both groups improved from the baseline test (mean $= 0.97 \pm 0.17$ Nm/kg) to week 5 (mean $= 1.15 \pm 0.20$ Nm/kg) and from the baseline to week 10 (mean $= 1.19 \pm 0.29$ Nm/kg, $P < .05$), but there was no difference between weeks 5 and 10 ($P > .05$; Figure 3). Individual participant data are found in the Table.

DISCUSSION

Regardless of whether a vibration platform was used before performing resistance exercises, no difference was evident between groups. However, an increase in rotator cuff strength was seen in both groups over the duration of this study, supporting the findings of a previous 6-week study.[24]

Other authors[7,25] have demonstrated the effects of vibration training. Bosco et al[18] found that electromyography of the elbow flexors revealed increased neural activity with the vibration stimulus that was up to more than twice the baseline values. We did not verify the stimulus with electromyographic (EMG) analysis in our study and do not know whether their findings are also applicable to the shoulder complex.

The size of intersubject SDs has not been addressed by authors of previous vibration studies but may be due to the normal variation in anatomical structures and joint laxity of the participants. Two groups[26,27] have proposed theories of variation in joint structure and laxity that may be experienced bilaterally or unilaterally. Also, total work performed by 1 volunteer in the vibration and weight-training group declined approximately 23% during the study. Although we do not have a definitive explanation for this outcome, it did reduce the group mean, which was higher in the vibration and weight-training group, by 7%. Consequently, the unexpected decrease in total work by this or any other participant may have affected the statistical analysis.

We chose the experimental protocol based on a critical review of published literature and the capabilities of the vibration platform. The vibration platform was used for 2 sets of 60 seconds, with a rest of 30 seconds between sets, because previous researchers[28] indicated that exposure to vibration lasting longer than 4 minutes may induce muscle fatigue. Other authors[29] have also reported decreased EMG activity and maximal voluntary contractions as early as 2 minutes into prolonged vibration. Several authors[22,30–32] recommended that frequencies between 20 and 120 Hz and amplitudes between 1 and 4 mm be used to avoid possible tissue damage. In experiments conducted with nearly identical methods which differed only in amplitude, EMG activity and strength measurements increased, with a 4-mm amplitude compared with a 1-mm amplitude.[28,30] Martin and Park[20] demonstrated greater muscle activation at a 50-Hz frequency. Therefore, we set the vibration sessions at an amplitude of 4 mm and a frequency of 50 Hz. We believed that vibration exposure 15 minutes before training would result in persistent adaptations because investigators[30] noted improvements in strength measurements up to 60 minutes postvibration. A 15-minute window between the vibration protocol and training sessions would also allow all participants adequate time to complete the protocol at the same time of day.

Typically volunteers are placed on a vibrating platform in positions such as standing, squatting, or sitting.[7,18,22,33,34] We used a protocol of indirect WBV in a static, modified–push-up position. No previous authors have used this exact position, but some[21,35] have safely transmitted vibration through the upper extremity via handles. We chose this position for several reasons. The magnitude of vibration stimulus decreases with distance from the point of origin of the vibration as a result of attenuation.[30,32] Changes in joint stability with muscle contraction may play a role in the transmission of mechanical vibration.[36] Furthermore, exposure to vibration during isometric contractions has resulted in greater strength gains than have been noted with concentric or eccentric contractions.[17] The concept of proximal stability for distal mobility has long been used in rehabilitation programs, and the relationships among scapular and shoulder stabilization and shoulder pain have been well documented.[37–39] In the context of this study, muscular co-contraction was also emphasized to the participants while they were positioned on the vibration platform. Although metabolically costly, co-contraction can increase joint stability and motor unit recruitment.[40] Multiple authors[41,42] have documented increased joint stability during coactivation of antagonist muscles around a joint due to increased stiffness. We considered these principles when placing volunteers in the described position, which should have allowed the most effective exposure of the rotator cuff musculature to the stimulus. Despite the paucity of literature on vibration and the upper extremity, we found

Table. Isokinetic Measurements of Total Work/Body Weight (Nm/kg) Computed as an Average of Total Work Over 5 Repetitions, Participant % Change from Baseline to Week 10, and Group Mean Change

	Participant	Baseline	Week 5	Week 10	% Change (Baseline to Week 10)
Vibration and resistance training group	1	0.82	0.95	1.03	26
	2	1.07	1.15	1.49	40
	6	0.95	1.29	1.25	32
	8	1.01	1.37	1.64	61
	9	1.13	0.96	0.87	−23
	12	1.13	1.52	1.44	28
					Group mean = 27.33
Resistance training–only group	3	1.1	1.25	1.56	41
	5	0.66	0.83	0.76	14
	10	1.16	1.2	1.19	3
	11	0.76	0.83	0.77	2
	13	0.91	1.09	1.18	30
	14	0.77	1.19	1.2	56
	16	1.11	1.19	1.04	−5
					Group mean = 20.14

it plausible that the upper extremity might react similarly to the lower extremity.[7,17,19]

The isokinetic protocol of the modified neutral shoulder test position was used for several reasons. First, it has been reported[43] that this position places the bony, ligamentous, and muscular components of the glenohumeral and scapulathoracic joints in relationships to optimize congruency, reduce impingement, and enhance length-tension forces. Second, we chose this position in an effort to accommodate our population. Participants were active in various sports, which did not all require overhead dominant activities. Therefore, we avoided the position of 90° of glenohumeral abduction because it may be more specific to muscular function during overhead activities.[44] Similar, but not identical, protocols have been used by other researchers.[45,46] Additionally, shoulder internal-external rotation strength may provide a better measurement of global shoulder strength development than does abduction-adduction or flexion-extension strength. In a recent isokinetic study, improvements were seen in all shoulder motions after strengthening only internal and external rotation, whereas strengthening of flexion, extension, abduction, and adduction resulted in improvements specific to the motions trained.[47]

We decided to augment a strength and conditioning program because it is an integral part of collegiate athletics in today's society, and this approach has not been documented in the previous literature. Programs comprising multijoint dynamic resistance exercises are among the most popular forms in the athletic setting. Examples of these exercises include the pull-up, seated overhead pull-down, dead lift, push-up, squat, and overhead press. Variations of these exercises, including push-up progressions, diagonal proprioceptive neuromuscular facilitation patterns, core strengthening exercises, and others, are often used in the rehabilitation process.

Previous authors have produced results that indicate the possible beneficial nature of vibration for bone density,[14,48] body composition,[16] hormonal effects,[15,46] blood flow,[49] neuromuscular activation,[17] strength,[30] power,[18,21] and oxygen uptake,[50] but we did not examine any of those areas. Our study was unique in comparing a complete resistance training program and an equivalent program using vibration as an additional tool just before training. Although the vibration intervention did not produce a statistical difference, we believe that the protocol as outlined and the use of a vibration platform in this real-life context deserve further investigation. It would be sensible to continue to explore this technology further to identify risks and rewards associated with its use as it becomes more widespread and popular in athletic facilities.

LIMITATIONS

We acknowledge certain limitations of this study, beginning with the small participant population, which decreased the power needed for significant findings. The lack of a vibration-only group, a sham vibration group, and a control group did not allow us to examine the effects of the novel vibration protocol, sustained isometric modified push-ups, and any learning effect that may have resulted from the isokinetic protocol. Also, we did not inquire about ligamentous laxity, fatigue, or soreness levels before testing, which may have affected performance for any given vibration or testing period, but we attempted to reduce these potential problems with a health questionnaire and by allowing adequate warm-up. Additionally, EMG analysis was not used to determine the amount of stimulus that reached the target muscle group. Finally, the percentage of each volunteer's body weight that was transferred through the upper body to the vibration platform was not measured.

FUTURE RESEARCH

As mentioned previously, research on this topic is in its infancy, and the incorporation of WBV as a precursor to resistance training in athletics may offer promise. We focused on the rotator cuff because of its role as a stabilizer. Although motion analysis was not part of this study, if WBV is shown to affect rotator cuff performance, examination of its effect on scapula kinematics may also be justified. We believe that future authors should consider studying larger populations, proprioception outcomes, ligamentous laxity, joint stress measurements, and possibly functional magnetic resonance imaging to investigate any implications of vibration therapy. Vibration intervention warrants further investigation over the course of a longer, prospective study; in addition, long-term follow-up is warranted to help us understand if any side effects are associated with this modality.

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