Journal of Strength and Conditioning Research, 2005, 19(2), 459–466

Brief Review

Vibration Training: An Overview of the Area, Training Consequences, and Future Considerations

Matthew J. Jordan,[1] Stephen R. Norris,[2] David J. Smith,[2] and Walter Herzog[2]

[1]Canadian Sport Centre-Calgary, University of Calgary, Calgary, Alberta T2N 1N4, Canada;
[2]Faculty of Kinesiology, Canadian Sport Centre-Calgary, University of Calgary, Calgary, Alberta T2N IN4, Canada.

Abstract. Jordan, M.J., S.R. Norris, D.J. Smith, and W. Herzog. Vibration training: an overview of the area, training consequences, and future considerations. *J. Strength Cond. Res. 19(2):459–466. 2005.*—The effects of vibration on the human body have been documented for many years. Recently, the use of vibration for improving the training regimes of athletes has been investigated. Vibration has been used during strength-training movements such as elbow flexion, and vibration has also been applied to the entire body by having subjects stand on vibration platforms. Exposure to whole-body vibration has also resulted in a significant improvement in power output in the postvibratory period and has been demonstrated to induce significant changes in the resting hormonal profiles of men. In addition to the potential training effects of vibration, the improvement in power output that is observed in the postvibratory period may also lead to better warm-up protocols for athletes competing in sporting events that require high amounts of power output. These observations provide the possibility of new and improved methods of augmenting the training and performance of athletes through the use vibration training. Despite the potential benefits of vibration training, there is substantial evidence regarding the negative effects of vibration on the human body. In conclusion, the potential of vibration treatment to enhance the training regimes of athletes appears quite promising. It is essential though that a thorough understanding of the implications of this type of treatment be acquired prior to its use in athletic situations. Future research should be done with the aim of understanding the biological effects of vibration on muscle performance and also the effects of different vibration protocols on muscle performance.

Key Words. effects of vibration training, contraindications with vibration training

Introduction

The effects of vibration on the human body have been documented for many years. In fact, a drive along a rough road was once prescribed for individuals suffering from kidney stones due to the therapeutic effects of the bumpy ride (23). Many positive effects of vibration on the human body have also been reported in physiotherapeutic and clinical settings in which vibration has been used for pain management and to elicit muscle contractions in spastic and paretic muscles (2, 28, 30). At present, research is being performed examining the use of whole-body vibration in the treatment and prevention of osteoporosis (40).

Recently, the use of vibration for improving the training regimes of athletes has been investigated (5, 6, 7, 8, 26, 27, 30, 36, 40). Vibration has been used during strength-training movements such as elbow flexion (6), and vibration has also been applied to the entire body by having subjects stand on vibration platforms (5, 8, 36). In these instances, the vibratory wave is propagated from distal to proximal links of muscle groups and the subjects are often required to perform voluntary muscle contractions throughout the vibration exposure (26, 27, 36). The application of vibration in this method has been shown to increase electromyogram (EMG) activity during the exposure to vibration (40). Vibration applied to the upper extremities during a 3-week training period has been shown to enhance gains in maximal strength in the seated row (26, 30) and in the postvibratory period, vibration applied to the elbow flexors resulted in increased power output during elbow flexion (6).

Exposure to whole-body vibration has also resulted in a significant improvement in power output in the postvibratory period and has been demonstrated to induce significant changes in the resting hormonal profiles of men (8). In addition to the potential training effects of vibration, the improvement in power output that is observed in the postvibratory period may also lead to better warm-up protocols for athletes competing in sporting events that require high amounts of power output. All of the above observations provide the possibility of new and improved methods of augmenting the training and performance of athletes through the use of vibration training.

In contrast with the literature on the positive effects of vibration training, the negative effects of vibration on the human body are also well documented and are most often observed in the work place through exposure to large vibration loads or chronic exposure to vibration (21, 22, 43, 46). In this environment, exposure to vibration has been shown to damage several biological structures, including peripheral nerves, blood vessels, joints, and perceptual function. Studies investigating the effects of vibration on animals also report changes in endocrine function, cardiovascular function, respiratory responses, central nervous system (CNS) patterns, and metabolic processes (23). Based on research from the workplace studying the physiological hazards of vibration load, standards have been developed to limit exposure to harmful vibration (23, 24). However, although exposure standards exist for the workplace, there are no standards to limit exposure to vibration in the athletic environment, yet sports such as alpine skiing, sailing, in-line skating, and horse-back riding are known to have a significant vibration load (36). While it appears that exposure to vibration may be more harmful than beneficial, it must be mentioned that the biological reaction to vibration is depen-

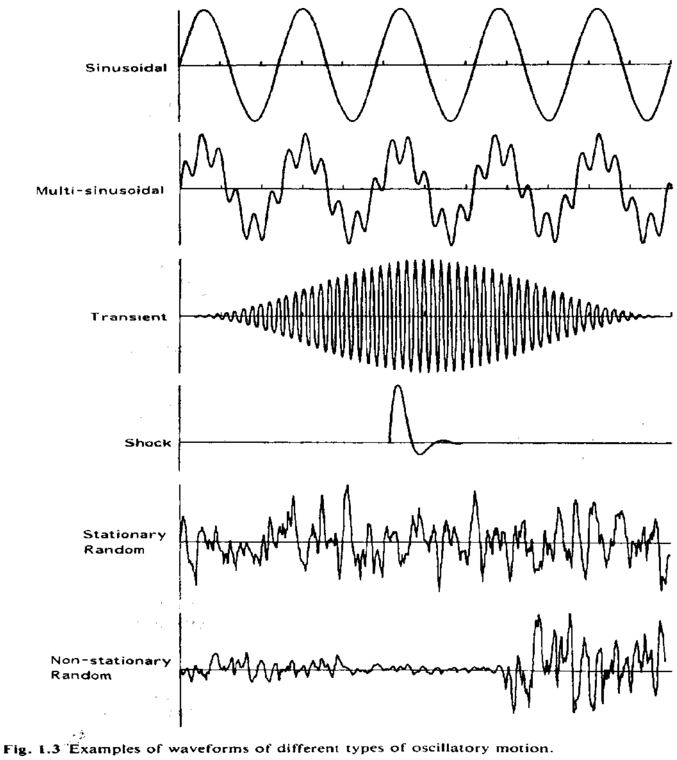

FIGURE 1. Different vibration waveforms (23, p. 6).

dent on the frequency, magnitude, duration, and type of vibration (23).

While vibration may be a potent stimulus for the neuromuscular apparatus, it is crucial that coaches and physiologists have a general understanding of the effects of vibration on the human body. The purpose of this review, therefore, is to provide a general framework of understanding concerning the major factors and implications surrounding vibration training.

AN OVERVIEW OF VIBRATION

Vibration is defined as oscillatory motion and the study of human vibration is "a multi-disciplinary subject involving knowledge from disciplines as diverse as engineering, ergonomics, mathematics, medicine, physics, physiology, psychology, and statistics" (23). In the human environment, whole-body and or hand-transmitted vibration occurs in several instances, including motorized vehicles (e.g., cars, trucks, motor cycles), marine ships (e.g., boats, submarines), aircraft, buildings, and from industrial equipment (e.g., cranes, fork lifts). When an individual is exposed to vibration in these settings, the sensation that is experienced varies considerably. In the above-mentioned settings, the characteristics of the vibration also varies. Vibration can vary according to the magnitude, which is determined by the size of the oscillation, and by the frequency, which is determined by the repetition rate of the vibration. The waveform may be of a deterministic or random form. Examples of different waveforms of oscillatory motion are presented in Figure 1.

Typically in sport situations, vibration is of a random form (e.g., the vibration experienced by an alpine skier during a downhill event). In contrast, during whole-body vibration training using commercially available vibration platforms, the resultant vibration transmitted to the subject is of a deterministic, sinusoidal waveform. That is, this form of vibration can be predicted from knowledge of prior oscillations and it is repeated in an identical time interval.

The frequency of vibration is measured in Hertz (Hz) and is the main factor determining the biological effect of the vibration (23). The magnitude of vibration can be represented either as the acceleration (i.e., g or $m \cdot s^{-2}$) or as the displacement (i.e., mm, cm, m). Finally, the duration of the exposure must be considered when evaluating the potential effects of vibration on the human body (23).

BIOLOGICAL INTERACTION WITH VIBRATION

Exposure to vibration affects several physiological systems, including the neuroendocrine, cardiovascular, musculoskeletal, and sensory systems (23). For example, vibration ranging from 1 to 20 Hz can cause blurry vision, whereas vibration at frequencies between 20 and 70 Hz can result in resonance of the eye (23). Vibration between 2 and 20 Hz may elicit a cardiovascular response similar to that of mild exercise, and vibration at 120 Hz results in an increase in fetal heart rate (23).

While vibration may have the potential to elicit a substantial training effect, it must be clearly understood that exposure to vibration can have serious negative physiological effects. However, the different characteristics of a vibration waveform, including the amplitude, frequency, and type of vibration, make it difficult to predict the exact physiological response (23). The response also depends on the intrasubject and intersubject variability. Some of the factors that affect the intrasubject variability include the orientation of the subject (e.g., sitting in moving vehicle while facing forwards vs. facing sideways), the body position (e.g., sitting vs. standing), and the body posture (e.g., stiff posture vs. relaxed posture). The intersubject variability is affected by the size of the individual (e.g., children vs. adults), body dynamics (e.g., the amount of power that can be absorbed by the body), age, gender, and the psychological preparedness of the individual.

A review of all the different biological reactions that occur in response to vibration is beyond the scope of this document. In order to review the consequences of vibration training, it is more suitable to focus on the effects of vibration on skeletal muscle and some of the potential hazards associated with exposure to vibration.

Effects of Vibration on Skeletal Muscle

Vibration of a muscle stimulates the primary endings of the muscle spindle (Ia afferents), which excites α-motoneurons, causing contraction of homonymous motor units, and this results in a tonic contraction of the muscle, referred to as the tonic vibration reflex (2, 3, 10, 11, 14, 28, 32, 36). Electromyogram data have revealed that the tonic vibration reflex has both a monosynaptic and a polysynaptic component (2). Further evidence demonstrating the complexity of the tonic vibration reflex can be observed in a decerebrate cat, as even in this condition, the tonic vibration reflex can be elicited. The response of the tonic vibration reflex is also dependent on the frequency of vibration, the level of precontraction of the muscle, and the position of the body (32, 38, 42).

During an exposure to vibration, the stretch reflex and the Hoffman-reflex (H-reflex) are inhibited, and this has been referred to as the vibration paradox—vibration induces the tonic vibration reflex but inhibits the stretch reflex and the H-reflex (17, 18, 34). This is due to presynaptic inhibition of the Ia afferents of the muscle spindle, which permits excitation of the pathways relating to vibration and inhibition of the pathways responding to stretch (18). The depression of the H-reflex has been shown to be greater than the depression of the stretch reflex, although the exact mechanism for this difference has been difficult to identify. In the postvibratory period, the stretch reflex displays a marked potentiation in contrast with the H-reflex that displays a gradual recovery up to normal values over a period of about 100 seconds (1, 39). The depression of the H-reflex during exposure to vibration is greater as the amplitude of the vibration increases at a constant frequency, but the depression remains unchanged if the amplitude is constant as the frequency of vibration increases (1).

Research also indicates that vibration compensates for the reduction in motor output in a fatigued state when the exposure is preceded by a prolonged maximal voluntary contraction (i.e., 4 minutes) (3). It has been hypothesized that, in a fatigued state, vibration compensates for the decreased γ-motoneuron drive by exciting the Ia afferents and this results in the reflexive excitation of the α-motoneurons and greater force output.

The effects of vibration on skeletal muscle described above are well documented. However, these effects do not necessarily account for the benefits that are observed following acute and chronic administration of vibration training. While these effects provide insight into the possible mechanisms that may explain these benefits, further research must be performed to determine the physiology underlying the effects of vibration training.

Physiological Hazards Associated With Vibration Exposure

There is substantial evidence regarding the negative effects of vibration on the human body (23). The specific physiological effects of vibration can be considered under the following categories: (a) cardiovascular function, (b) respiratory function, (c) endocrine and metabolic function, (d) motor processes, (e) sensory processes, (f) CNS, and (g) skeletal changes. In animal studies in which high magnitudes of vibration have been used, there are reports of lung damage, gastrointestinal bleeding, and heart hemorrhage causing death in the exposed animals. Some reports on the more serious adverse affects from exposure to large vibration loads include severe chest pain and gastrointestinal bleeding in an individual exposed to vibration of 10 and 25 Hz ranging from $\pm 3\ g$ to $\pm\ 10\ g$ (23). Vibration-induced pathology also includes hypertrophy of blood vessel walls, resulting in a narrowing of the arteriole lumen, damage to joints and bones, and neurological disorders (20, 24).

Research from the workplace provides evidence on the physiological hazards resulting from certain types of vibration exposure. In these instances, workers may be exposed to vibration for long durations or to large magnitudes of vibration for short periods of time. An example of vibration-induced pathology is hand-arm vibration syndrome (HAVS), a disorder associated with excessive exposure to vibration. HAVS is common in miners who operate jack-leg-type drills (46). In these instances, miners can be exposed to vibration for up to 3 hours per day. Patients exhibiting HAVS present with neurological dysfunction in the hands and, in later stages of this disease, vascular dysfunction can occur. The incidence of disease from exposure to vibration is a function of exposure time (37). A study examining the prevalence of vibration-induced pathology in a group of 266 chain-saw operators found that subjects with less than 2,000 hours of exposure reported symptoms of tingling, numbness, and mild pain; those with 2,000–5,000 hours of exposure displayed circulatory dysfunction, including Raynaud's syndrome; and those workers with over 8,000 hours of exposure to vibration suffered severely from functional and organic changes (e.g., vertigo, irritability, sleeplessness, and other autonomic disturbances) (37).

Along with damage to biological tissues, exposure to vibration has also been shown to hinder proprioception (15). It has been well documented that vibration applied to tendons or muscles results in segmental kinesthetic illusions (41). Immediately following an exposure to vibration, spindle responsiveness is diminished. The postvibratory depression of spindle sensitivity lasts for only a few seconds following vibration, but the disturbance in proprioception can persist for up to a few minutes.

Several physiological hazards have also been associated with whole-body vibration (20, 22, 23). Whole-body vibration has been shown to alter sensory motor control, postural regulation, spinal reflexes, and cardiac and respiratory rhythms (33). For example, whole-body vibration below a frequency of 1 Hz has been shown to induce motion sickness in humans due to sensory mismatch (43).

Biomechanical models have also been developed to describe the effects of vibration stress on the human body (19). Short-term exposure to whole-body vibration and vibration exposure over several years may contribute to low-back pain and other musculoskeletal injuries. Epidemiological studies provide evidence for an increased risk of injury and disease mainly to the lumbar spine and the connected nervous system as a result of long-duration exposure to high-intensity, whole-body vibration (20). Whole-body vibration of the type and magnitude produced by motor vehicles, airplanes, and construction have been linked to low-back pain, and studies on animals have suggested that vibration-induced changes in the neurons of the dorsal root ganglion may be partially responsible for vibration-induced low-back pain (35).

Given the many risks associated with vibration exposure, prudence is required when integrating vibration training into the programs of athletes. While the exposure time during vibration training is quite low in comparison with workplace exposures to vibration, most vibration platforms are capable of exposing athletes to frequencies and amplitudes of vibration that could result in serious injury. In summary, the main factors that must be considered to ensure the safety of the athletes engaging in vibration training are the magnitude of vibration (frequency and amplitude), the duration of exposure, and the body position during the exposure. Careful prescreening measures for injuries that may be exacerbated by vibration training should also be included in vibration-training protocols.

VIBRATION TRAINING

Vibration Training, Equipment, and Parameters

Vibration training has been performed during upper-body movements using pulley systems and during lower-body movements using vibration platforms and vibration leg

FIGURE 2. Example of vibration training.

presses (5–8, 16, 26, 27, 30, 45). The investigations that have evaluated the effects of vibration on the upper extremities have used pulley systems, whereby the cable connected to the weight stack passed through a mechanical system designed to impart a vibration onto the cable (26, 27, 30). Investigations evaluating the effects of vibration on the upper body are less common, and this may be due to the fact that vibration-training devices for the upper extremities are not readily available for purchase.

Reports evaluating the use of vibration platforms are more common in the scientific literature and, to the author's knowledge, vibration platforms are more widely used in the strength and conditioning programs of athletes (5–8, 16, 36, 40, 45). Squatting-type movements are often performed on the vibration platform and this has been referred to as whole-body vibration training. An example of whole-body vibration training is illustrated in Figure 2. Whole-body vibration training may require the subject to maintain an isometric squat in varying positions (5–8) or the subject may perform squatting- and jumping-type exercise with additional load (36).

Laboratory vibration platforms are often powered with the use of a hydraulic apparatus that enables the researcher to carefully control the vibration characteristics (36). Most commercially available vibration platforms are motor-driven systems that cause vibration with the use of eccentric discs or off-centered motors. While the mechanically driven vibration platforms are more affordable than the hydraulic systems, problems may exist with the ability to tightly control the vibration amplitude and frequency. This may pose experimental problems for scientific investigations using commercially available platforms.

Most commercially available vibration platforms have a control mechanism for the vibration frequency and amplitude, which allows the vibration characteristics to be adjusted. Typically, the vibration characteristics during vibration training involve relatively low vibration frequencies and small amplitudes of vibration. The scientific literature reports ranges in vibration frequency from 25 to 44 Hz and ranges in amplitude from 2 to 10 mm. It must be mentioned that, at the present time, the effects of different vibration-loading parameters are not clearly understood. This is reflected in the wide range of frequencies, amplitudes, and durations of exposure used in different scientific investigations.

BENEFITS OF VIBRATION TRAINING IN THE GENERAL POPULATION

The interaction of the human body with vibration is complex and, despite a risk for serious injury, certain types of vibration possess healing effects and health benefits. Vibration is used to help clear the lungs in patients with respiratory problems, to improve mobility and muscle function in athletes, to help those suffering from rheumatoid arthritis, to treat the stumps of amputated limbs, and to improve muscle function in spastic and paretic individuals (2, 23).

An excellent example of the potential benefits of vibration on the health of the general population is the increase in bone mass that is observed after long-term exposure to whole-body vibration, an effect that may be important in preventing osteoporosis (18, 25). A study evaluating the effects of whole-body vibration on the bone mineral density of ovariectomized rats indicated that mechanical stimulation in the form of low-intensity, whole-body vibration was effective in reducing postovariectomy bone loss in rats (18). This observation may lead to benefits for humans who are at risk for bone loss. Some of these populations include postmenopausal women and astronauts who are subject to zero-gravity conditions for prolonged periods of time.

Effects of Vibration Training on Athletic Performance

In currently accepted training methodology, the development of the physiological qualities that relate to the expression of muscle force has been accomplished using different types of strength-training protocols (31). This involves the use of jumps, sprints, and exercises with added resistance. It is possible that vibration training may be an additional method for the development of the physiological qualities related to muscle force production (5–8, 26–28, 36, 40).

Vibration training can be performed by applying vibration to a limb or extremity using specially designed pulley machines, but more commonly, it is used in the form of whole-body vibration training. It has been postulated that vibration affects several factors related to intramuscular coordination (30). As previously described, vibration of a muscle activates the tonic vibration reflex, which is evidenced by an increase in EMG of the vibrated muscle during the exposure to vibration (36, 40). It is possible that the tonic vibration reflex may enhance voluntary muscle contractions and, when used in conjunction with strength-training protocols, vibration may improve neuromuscular training in athlete populations. An increase in motor-unit synchronization is one of the explanations offered in an attempt to account for the increase in muscle force observed during vibration of a muscle. Vibration training is also thought to increase the neural drive to muscles and to recruit previously inactive motor units (27). The increased recruitment of motor units is thought to occur because of several neuromuscular changes that occur during exposure to vibration, and through the recruitment of these additional motor units, vibration training may be beneficial in the development of muscle power and maximal strength.

Vibration training does not appear to elicit a significant cardiovascular response. A study comparing the effects of exhaustive whole-body vibration exercise in a group of 40 healthy subjects with exhaustive cycle ergometry demonstrated that there was a significantly smaller increase in heart rate during vibration training (40). Maximal oxygen uptake was also significantly lower during vibration exercise compared with maximal cycling and the mean blood lactate concentration was significantly lower after the exhaustive vibration exercise. It was concluded that exhaustive vibration exercise did not have a significant cardiovascular effect and did not result in a stimulating effect on the cardiovascular control system.

Acute Effects of Vibration Training

Vibration training may be useful in an acute setting as a neuromuscular warm-up in preparation for explosive athletic events. Vibration training applied to the arms of 12 international-level boxers during elbow-flexion exercise resulted in increased EMG during the exposure to vibration and a significant increase in mechanical power following the exposure to vibration, despite a concomitant decrease in EMG (6).

In an acute setting, whole-body vibration training resulted in a significant improvement in average force, average velocity, and average power during leg press in a group of 6 female volleyball players (7). This effect was also noted in a group of 14 male subjects, who displayed a significant improvement in leg power and a concomitant decrease in EMG after a 10-minute treatment with whole-body vibration (8). In this investigation, whole-body vibration also elicited a change in hormonal profiles. Following the 10-minute vibration treatment, there was a significant increase in growth hormone and testosterone and a significant decrease in cortisol over resting values.

In contrast with the reports of acute improvements in performance following vibration, other investigations report a decrement in performance or a negligible improvement in performance (16, 45). De Ruiter and coauthors performed an investigation evaluating the acute effects of whole-body vibration training (16). It was found that acute exposure to vibration did not improve performance during the voluntary and involuntary muscle contractions. In fact, there was a 7% decline in force production during the maximal voluntary contraction 90 seconds following the vibration treatment. The decline in force in the maximum voluntary contraction was relatively larger than the decline in force observed during the involuntary contraction. This was reflected in a decrease in voluntary activation from 95 to 90%. This finding indicates a decline in neural activation (44).

Chronic Effects of Vibration Training

Vibration-training research to date suggests that this modality of training may have the potential to elicit a long-term training effect on strength and power (5, 26, 27, 36). A 21-day training block of whole-body vibration training resulted in substantial gains in strength and leg power in a well-trained alpine skier (36). Following the 21-day training block, force production measured on the isometric leg press increased by 43% over the initial value and vertical jump also increased from 38.9 to 47.8 cm. Lieberman and Issurin evaluated the effects of vibration applied to the upper extremities and found that a 3-week training period of vibration during the seated row resulted in an average increase of 49.8% in strength compared with a 16.1% increase in strength for the training group not exposed to vibrations (30). Finally, a 10-day block of whole-body vibration training resulted in an improvement in vertical jumping ability in 14 physically active subjects (5). The subjects exposed to the 10-day vibration treatment displayed a significant increase in jump height during 5 seconds of continuous jumping and a smaller improvement in jump height for the countermovement jump. The control group did not show improvement in jumping ability for either the 5 seconds of continuous jumping or the countermovement jump.

Evidence for the greater overload on the neuromuscular apparatus that occurs as a result of vibration training was observed in a study examining the acute effects of vibration during elbow flexion (30). Vibration applied during elbow flexion resulted in a significant increase in the 1 repetition maximum and subjects perceived their effort to be less during the exposure to vibration compared with the no-vibration condition. In addition to the increased neuromuscular activation resulting from the tonic vibration reflex, evidence also suggests that the increased load lifted for a 1 repetition maximum during exposure to vibration was obtained in part by the sensation that the load being lifted was lighter than when not subject to vibration. A possible explanation for the decreased sensation of effort during a 1 repetition maximum in elbow flexion observed in this study is that, during the exposure to vibration, the increased activity of the Ia afferents may have reduced the central feedforward element making the force produced during exposure to vibration feel like less force than during a normal contraction (12, 13). The problem in making this conclusion is that it is difficult to quantify the degree to which the feedforward element affects the perception of force during maximal voluntary force production.

Based on the above findings, it is clear that vibration training has the potential to elicit a training effect over a 10–21-day mesocycle. The benefits to vibration training may be a result of positive changes in neuromuscular mechanisms (e.g., improved synchronization of firing of the motor units and improved cocontraction of synergist muscles), and an increased discharge from Ia afferents and subsequent increase in EMG that occur during the period of vibration. These effects on the neuromuscular system may provide a greater overload than conventional training alone, and thus vibration training may provide a superior training effect over the long term.

Current Deficits in Vibration-Training Literature

Currently, the scientific evidence on the benefits of vibration training is mixed. Evidence does exist in support of

TABLE 1. A comparison of vibration characteristics between different vibration training investigations.

Author	Frequency (Hz)	Amplitude	Movement	Timing of measurement	Loading parameters
Bosco et al. (7)	26	10 mm	Isometric squat on 1 leg	Immediate	10 × 1 min/1min rest
Bosco et al. (8)	26	4 mm	Isometric squat	Immediate	10 × 1 min/1min rest
Rittweger et al. (40)	26	15 g	Exhaustive exercise with additional load and isometric squat	Immediate	Continuous to voluntary failure
Torvinen et al. (45)	25–40	2 mm	Multidirectional squatting movements	2 and 50 min after treatment	4 min
De Ruiter et al. (16)	30	8 mm	Isometric squat	1.5, 30, 60, and 180 min after treatment	5 × 1 min/1 min rest

the acute and chronic benefits of vibration training (5–8, 36), and there is also evidence demonstrating a negligible training effect following vibration training and perhaps even a decrement in performance (16, 40, 45). There are several factors that must be considered in the interpretation of the scientific evidence evaluating vibration training. Two important factors that have the potential to affect the outcome of vibration-training experiments include the vibration protocol and the specific movements that are tested following the vibration treatment.

VARIABILITY IN VIBRATION PROTOCOLS

The variability in the vibration-training protocols used by different investigators may be an important reason for the inconsistent results that are reported in the scientific literature. The vibration protocols can vary in the vibration characteristics (i.e., frequency and amplitude) that are used, the movement performed during the exposure to vibration, the duration of the exposure, and the length of time between the cessation of the vibration treatment and the posttreatment measurements. Table 1 provides a brief summary of some of the differences in the vibration-training protocols reported in the scientific literature used in investigations evaluating the acute effects of vibration on performance.

As with all types of exercise designed to improve strength qualities, the exact loading parameters must be carefully determined, applied, and then controlled in order to ensure that the desired training effect occurs. It is likely that different vibration protocols would elicit different physiological effects and, as a result, the exact vibration characteristics are of paramount importance when evaluating and interpreting the results of an investigation on the effects of vibration training.

Evidence in support of the need to account for interprotocol differences in the vibration treatment can be obtained in the basic science literature on vibration. First, the position of the body during the exposure to vibration and the degree of muscle contraction can affect the biological response to vibration (23, 29). The EMG response in the shoulder muscles during exposure to vibration has been shown to vary according to the position of the arm and the level of muscle contraction (42). Second, the biological response, and specifically the tonic vibration reflex, is highly dependent on the frequency of the vibration (23, 32). Third, the duration of the vibration exposure can greatly affect muscle function. Evidence from an investigation on the effects of prolonged exposure to vibration suggests that, during a sustained maximal voluntary contraction of the dorsiflexors muscles, vibration counteracted fatigue in the initial phase of its application but prolonged vibration accentuated fatigue as evidenced by a large decrease in EMG activity (4).

In summary, based on the parameters represented in Table 1, it is clear that vibration protocols used by investigators have varied according to the frequency, amplitudes, duration of exposure, the type of exercise during the exposure to vibration, and the timing of the posttreatment measurements. It is also clear that all of these parameters have the capacity to greatly affect the biological response to vibration and therefore the effects of vibration training on performance.

Movement-Specific Effects of Vibration

In addition to the large potential that exists for the vibration protocol to affect the outcome of vibration-training studies, it is also possible that vibration may elicit movement-specific effects. While several investigations have demonstrated a postvibratory improvement in dynamic and explosive activities (5, 7, 8), other studies have demonstrated a deterioration or negligible improvement in performance during isometric maximal voluntary contractions (16, 40, 45).

While accurate comparisons between the results of these different investigations may be troublesome due to the large interprotocol variability that exists in the vibration treatment, it may be possible that the posttreatment effects of vibration treatment would augment performance only in explosive activity involving a stretch-shorten cycle and not maximal isometric activity. Evidence in support of this can be obtained from an investigation that compared the effects of vibration on continuous jumping and a countermovement jump (5). In this investigation, 10 days of vibration training resulted in an improvement in jump height during 5 seconds of continuous jumping in which the subjects were asked to minimize ground contact time compared with a relatively smaller improvement in jump height during one maximal countermovement jump. In this instance, the 5 seconds of continuous jumping involved a short stretch-shorten cycle, which may have been more greatly influenced by the stretch reflex and muscle stiffness. Further evidence in support of a specific postvibratory improvement in explosive activity is obtained from the basic science literature. There is strong evidence that, in the postvibratory period, there is a marked potentiation of the stretch reflex in the human plantar flexor muscles (1).

The interprotocol variation, which includes the vibration loading parameters and the movement that is used to test the effects of vibration training, creates difficulties when deciding on the viability of vibration training. This further highlights the need for more research before vibration training becomes a regular component of any training regime.

FUTURE RESEARCH

Although several pathological conditions are associated with exposure to vibration and that there are adverse effects on workers who are exposed to high levels of occupational vibration, the severity of the symptoms that results is a function of the total exposure to and the intensity of the vibration. While the duration of the exposure to vibration is comparably less during vibration training than in an occupational setting, the risk for injury is still high if vibration training is used inappropriately. It is clear from the occupational research that further investigation should be performed in this area to minimize the risk of serious injury to athletes engaged in vibration training.

Further research should also be undertaken to understand the effects of different vibration protocols on performance. The current scientific investigations on vibration training use a wide range of vibration protocols and loading parameters. Some studies required the subject to perform voluntary movements with extra loads; some required voluntary movements without loads; and in some studies, the subjects stood in a static position on the vibration platform. These performance studies also differed in the frequency and amplitude of the vibration and the length of exposure for the vibration treatment. None of the studies offer a rationale explaining why one protocol is superior to another; yet with all types of training, whether it is strength training or cardiovascular training, it is imperative that the volume, intensity, and duration of exposure be controlled and manipulated, depending on the desired outcome. Based on the fact that the tonic vibration reflex is influenced by several variables, including the level of precontraction in the muscle, the position of the body and the vibration characteristics (i.e., vibration waveform, amplitude, and frequency) it is important that the effects of these variables be further investigated and controlled during performance studies on vibration training.

PRACTICAL APPLICATIONS

Vibration may be a potent stimulus for the neuromuscular system. However, the use of vibration as a training modality to enhance the performance of athletes is still in its early stages of development. It would appear, based on the limited scientific evidence, that vibration training may serve as a tool to develop explosive ability in athletes in both acute and chronic training conditions. The benefits of vibration training must be balanced with the potential physiological hazards associated with exposure to vibration. The following recommendations can be made to coaches and physiologists interested in using vibration training:

1. Carefully consider and review the current scientific evidence evaluating the use of vibration training.
2. Carefully consider the appropriate vibration loading parameters to ensure the safety of the athletes. Consideration should be given to the vibration frequency and amplitude, the duration of exposure, and the activity performed during the exposure to vibration.

REFERENCES

1. ARCANGEL, C.S., R. JOHNSTON, AND B. BISHOP. The achilles tendon reflex and the H-response during and after tendon vibration. *Phys. Ther.* 51:889–902. 1971.
2. BISHOP, B. Vibratory stimulation: Neurophysiology of motor responses evoked by vibratory stimulation. *Phys. Ther.* 54:1273–1282. 1974.
3. BONGIOVANNIA, L.G., AND K.E. HAGBARTH. Tonic vibration reflexes elicited during fatigue from maximal voluntary contractions in man. *J. Physiol.* 423:1–14. 1990.
4. BONGIOVANNIA, L.G., K.E. HAGBARTH, AND L. STJERNBERG. Prolonged muscle vibration reducing motor output in maximal voluntary contractions in man. *J. Physiol.* 423:15–26. 1990.
5. BOSCO, C., M. CARDINALE, AND O. TSARPLEA. The influence of whole-body vibrations on jumping performance. *Biol. Sports* 15: 157–164. 1998.
6. BOSCO, C., M. CARDINALE, AND O. TSARPELA. Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *Eur. J. Appl. Physiol.* 79:306–311. 1999.
7. BOSCO, C., R. COLLI, E. INTROINI, M. CARDINALE, O. TSARPELA, A. MADELLA, J. TIHANYI, AND A. VIRU. Adaptive responses of human skeletal muscle to vibration exposure. *Clinic. Physiol.* 19:183–187. 1999.
8. BOSCO, C., M. IACOVELLI, O. TSARPELA, M. CARDINALE, M. BONIFAZI, J. TIHANYI, M. VIRUS, A. DE LORENZO, AND A. VIRU. Hormonal responses to whole-body vibration in men. *Eur. J. Appl. Physiol.* 81:449–454. 2000.
9. BOXTELL, A.V. Differential effects of low-frequency depression, vibration-induced inhibition, and post-tetanic potentiation of H-reflexes and tendon jerks in the human soleus muscle. *J. Neurophysiol.* 55:551–568. 1986.
10. BURKE, D., K. HAGBART, L. LOFSTEDT, AND G.B. WALLIN. The responses of human muscle spindle endings to vibration of noncontracting muscles. *J. Physiol.* 261:673–693. 1976a.
11. BURKE, D., K. HAGBART, L. LOFSTED, AND G.B. WALLIN. The responses of human muscle spindle endings to vibration during isometric contraction. *J. Physiol.* 261:695–711. 1976b.
12. CAFARELLI, E. Peripheral contributions to the perception of effort. *Med. Sci. Sports Exerc.* 14:382–389. 1982.
13. CAFARELLI, E. Force sensation in fresh and fatigued human skeletal muscle. In: *Exercise Sports Science Review* (vol. 16). K.B. Pandolf, ed. New York: MacMillan Publishing, 1988. pp. 139–168.
14. CLAUS, D., K.R. MILLS, AND N.M.F. MURRAY. The influence of vibration on the excitability of alpha motoneurons. *Electroenceph. Clin. Neurophysiol.* 69:431–436. 1988.
15. CORDO, P., V.S. GURFINKEL, L. BEVAN, AND G.K. KERR. Proprioceptive consequences of tendon vibration during movement. *J. Neurophysiol.* 74:1675–1688. 1995.
16. DE RUITER, C.J., R.M. VAN DER LINDEN, M.J.A. VAN DER ZIJDEN, A.P. HOLLANDER, AND A. DE HAAN. Short-term effects of whole-body vibration on maximal voluntary isometric knee extensor force and rate of force rise. *Eur. J. Appl. Phys.* 88:472–475. 2003
17. DESMEDT, J.E., AND E. GODAUX. Mechanism of the vibration paradox: Excitatory and inhibitory effects of tendon vibration on single soleus muscle motor units in man. *J. Physiol.* 285: 197–207. 1978.
18. FLIEGER, J., T.H. KARACHALIOS, L. KHALDI, P. RAPTOU, AND G. LYRITIS. Mechanical stimulation in the form of vibration prevents postmenopausal bone loss in ovariectomized rats. *Calcif. Tiss. Inter.* 63:510–514. 1998.
19. FRITZ, M. Estimation of spine forces under whole-body vibration by means of a biomechanical model and transfer functions. *Aviat. Space Environ. Med.* 68:512–519. 1997.
20. FRITZ, M. Description of the relation between the forces acting in the lumbar spine and whole-body vibrations by means of transfer functions. *Clinic. Biom.* 15:234–240. 2000.
21. FUTASUKA, M., I. PYYKKO, M. FARKKILA, O. KORHONEN, AND J.P. STARCK. Blood pressure, flow, and peripheral resistance of digital arteries in vibration syndrome. *Brit. J. Indust. Med.* 40: 434–441. 1983.
22. GAUTHIER, G.M., J.P. ROLL, B. MARTIN, AND F. HARLAY. Effects of whole-body vibrations on sensory motor system performance in man. *Aviat. Space Environ. Med.* 52:473–479. 1981.

23. GRIFFIN, M.J. *Handbook of Human Vibration.* London: Academic Press, 1996.
24. HARADA, N., AND M.J. GRIFFIN. Factors influencing vibration sense thresholds used to assess occupational exposures to hand transmitted vibration. *J. Indust. Med.* 48:185–192. 1991.
25. HEINONEN, A., P. KANNUS, H. SIEVANEN, M. PASANEN, P. OJA, AND I. VUORI. Good maintenance of high-impact activity-induced bone gain by voluntary, unsupervised exercises: An 8-month follow-up of a randomized controlled trial. *J. Bone Miner. Res.* 14:125–128. 1999.
26. ISSURIN, V.B., D.G. LIEBERMANN, AND G. TENENBAUM. Effect of vibratory stimulation training on maximal force and flexibility. *J. Sport Sci.* 12:561–566. 1994.
27. ISSURIN, V.B., AND G. TENENBAUM. Acute and residual effects of vibratory stimulation on explosive strength in elite and amateur athletes. *J. Sport Sci.* 17:177–182. 1998.
28. JOHNSTON, R.M., B. BISHOP, AND G.H. COFFEY. Mechanical vibration of skeletal muscles. *Phys. Ther.* 50:499–505. 1970.
29. KITAZAKI, S., AND M.J. GRIFFIN. Resonance behaviour of the seated human body and effects of posture. *J. Biomech.* 31:143–149. 1998.
30. LIEBERMANN, D.G., AND V. ISSURIN. Effort perception during isotonic muscle contractions with superimposed mechanical vibratory stimulation. *J. Hum. Move. Stud.* 32:171–186. 1997.
31. LOEBEL, C.C., AND W.J. KRAEMER. A brief review: Testosterone and resistance exercise in men. *J. Strength Cond. Res.* 12:57–63. 1998.
32. MARTIN, B.J., AND H.S. PARK. Analysis of the tonic vibration reflex: Influence of vibration variables on motor unit synchronization and fatigue. *Eur. J. Appl. Physiol.* 75:504–511. 1997.
33. MARTIN, B.J., J.P. ROLL, AND G.M. GAUTHIER. Spinal reflex alterations as a function of intensity and frequency of vibration applied to the feet of seated subjects. *Aviat. Space Environ. Med.* 55:8–12. 1984.
34. MARTIN, B.J., J.P. ROLL, AND G.M. GAUTHIER. Inhibitory effects of combined agonist and antagonist muscle vibration on H-Reflex in man. *Aviat. Space Environ. Med.* 57:681–687. 1986.
35. MCLAIN, R.F., AND J.N. WEINSTEIN. Effects of whole body vibration on dorsal root ganglion neurons: Changes in neuronal nuclei. *Spine* 19:1455–1461. 1994.
36. MESTER, J., P. SPITZENFEIL, J. SCHWARZER, AND F. SEIFRIZ. Biological reaction to vibration—Implication for sport. *J. Sci. Med. Sport.* 2:211–226. 1999.
37. MIYASHITA, K., S. SHIOMI, N. ITOH, T. KASAMATSU, AND H. IWATA. Epidemiological study of vibration syndrome in response to total hand-tool operating time. *Brit. J. Indust. Med.* 40:92–98. 1983.
38. PARK, H.S., AND B.J. MARTIN. Contribution of the tonic vibration reflex to muscle stress and muscle fatigue. *Scand. J. Work Environ. Health.* 19:35–42. 1993.
39. RIBOT-CISCAR, E., C. ROSSI-DURAND, AND J.P. ROLL. Muscle spindle activity following muscle and tendon vibration in man. *Neurosci. Lett.* 258:147–150. 1998.
40. RITTWEGER, J., G. BELLER, AND D. FELSENBERG. Acute physiological effects of exhaustive whole-body vibration exercise in man. *Clin. Physiol.* 20:134–142. 2000.
41. ROGERS, D.K., A.P. BENDRUPS, AND M.L. MCDONALD. Disturbed proprioception following a period of muscle vibrations in humans. *Neurosci. Lett.* 57:147–152. 1985.
42. ROHMERT, W., H. WOS, S. NORLANDER, AND R. HELBIG. Effects of vibrations on arm and shoulder muscles in three body postures. *Eur. J. Appl. Physiol.* 59:243–248. 1989.
43. SEIDEL, H. Myoelectric reactions to ultra-low frequency and low-frequency whole body vibration. *Eur. J. Appl. Physiol.* 57: 558–562. 1988.
44. SUTER, E., AND W. HERZOG. Extent of muscle inhibition as a function of knee angle. *J. Electromag. Kinesiol.* 7:123–130. 1997.
45. TORVINEN, S., H. SIEVANEN, T.A.H. JARVINEN, M. PASANEN, S. KONTULAINEN, AND P. KANNUS. Effect of 4-min vertical whole body vibration on muscle performance and body balance: A randomized cross-over study. *Int. J. Sports Med.* 23:374–379. 2002
46. WASSERMAN, D.E., V.J. BEHRENS, P.L. PELMEAR, R. ILKA, D.D. REYNOLDS, T.E. DOYLE, S. SAMUELOFF, AND R.J. GOFF. Hand-arm vibration syndrome in a group of U.S. uranium miners exposed to hand-arm vibration. *Appl. Occup. Environ. Hyg.* 6(3):183–187. 1991.

Address correspondence to Matthew J. Jordan, mjordan@ucalgary.ca.