Vibration Exercise: The Potential Benefits

Abstract

The aim of this review was to examine the physiological effects of vibration exercise (VbX), including the cardiovascular indices and to elucidate its potential use for those with compromised health. VbX has long been acknowledged as a potential modality in sport, exercise, and health sectors. Muscle force and power have been shown to increase after VbX for athletes, the aged and those with diseases, where neural factors are thought to be the main contributor. Further, similarities to the tonic vibration reflex have been used to propose that the muscle spindle plays a role in activating the muscle which could benefit those with compromised health. There is strong evidence that acute VbX can enhance upper and lower-body muscle power, and there is some indication that longer-term VbX can augment muscle power of upper and lower body extremities, although this is less convincing. It is not conclusive whether VbX increases force attributes. This has been fraught by the type and parameters used for various muscle contractions, and the different sample populations that have varied in chronological age, experience and training status. VbX provides an insufficient stimulus to enhance cardiovascular indices, where VbX cannot increase heart rate to the same extent as conventional aerobic exercise. But when conventional aerobic exercise is not possible, for example, in aged, cardiovascular compromised persons, VbX could be implemented at an early stage because it could provide a safe induction of a slight elevation of cardiovascular function indices while providing neural and myogenic benefits. In conclusion, VbX is a safe modality to increase physiological responses of reflex and muscle activity, and muscle function, for athletes, the aged and compromised health. However, further research should focus on the optimum dose relationship of frequency, amplitude and duration for the various populations.

Introduction

Vibration exercise (VbX) is currently enjoying popularity as an alternative exercise modality for enhancing muscle activity, force and power [1, 12, 60, 105, 108] while others have found little or no effect [36, 40, 41]. VbX has been suggested as an attractive and efficient complement to traditional forms of exercise for athletes, the aged and health compromised individuals. The muscle performance benefit supposedly occurs via neurogenic potentiation involving spinal reflexes and muscle activation, which is based on the tonic vibration reflex [21, 103]. It has been purported that neural factors are responsible for the increases in muscle function, which are similar to those neural changes seen after several weeks of conventional resistance and power training [13, 14]. Further, it has been purported that VbX augments muscle spindle activity that causes a stretch-reflex response and elicits a rapid but small change in muscle length [21], which is of importance to those with diseased tissue or neurological problems. The change in muscle activity is likely to evoke a small increase in oxygen uptake, which suggests muscle energy turnover exists where VbX may have a beneficial effect for cardiovascular indices, such as blood pressure, blood flow and heart rate. Despite its wide use in sport, exercise and health the physiological responses of VbX remain equivocal because a number of studies have used various protocols, of different methods of application, vibration parameters, training duration and exercises performed with vibration. Some recent VbX reviews have been conducted on
specific population groups such as trained [22,133], and untrained [97] but they have not integrated acute, short- and long-term effects of VbX on reflex muscle activity, cardiovascular responses and muscle function for various populations of healthy, and compromised health. Therefore, the purpose of this review was to critically examine the physiological effects of VbX, namely reflex activity, muscle function, and cardiovascular indices and to elucidate its potential use for those with compromised health where safety aspects and loading parameters of VbX are also discussed.

**Method**

A search was conducted using electronic databases Medline, PubMed, ISI Web of Knowledge and Scopus using key words of vibration and whole-body vibration, in combination with exercise, training, power, force, strength, cardiovascular, blood flow, heart rate, reflex, electromyography, Multiple Sclerosis, stroke, Parkinson’s Disease, postmenopausal and elderly. Articles were checked for relevant content and were included from the following 1. published in English; 2. examined acute (single session), short-term (multiple sessions performed up to 2 months), and long-term (multiple sessions greater than 2 months) effects; 3. Status of participants included healthy, trained, untrained and specific health ailments and Conference abstracts and proceedings were not included.

**Vibration exercise**

**Types of vibration exercise**

VbX has taken on many different forms. Small vibratory units have been placed directly on the muscle or tendon [62,132] and larger custom built units have been constructed for flexibility training [112,113]. Vibrating units have also been attached to resistance training equipment to elicit vibration transmission through the cables of various machines [59]. Currently, there are 2 commercial forms of vibration platforms manufactured for the health and fitness industry. The first type of platform (e.g. Galileo®) has a teeterboard that produces side-alternating vertical sinusoidal vibration (SV) to the body. It rotates around an anteroposterior horizontal axis, so when the feet are further from the axis it results in a larger vibration amplitude (Fig. 1). The side-alternating movement is asynchronous where the unilateral vibration is applied alternately to the left and right foot. The other commercial machines (Power Plate®, Nemes®, Vibra Pro®, Vibrafit®, Fit Vibe®, Pneu-vibe®, Vibrogym®, SoloFlex®, Bodypulse®, Juvent 1000®) produce vertical synchronous vibration (VV) where both legs are vibrated as the platform moves predominately in the vertical direction. This results in simultaneous and symmetrical movement of both sides of the body during the exposure (Fig. 1). Hand-held powered vibrating dumbbells have also been commercially manufactured for exercising the upper-body (Galileo TOP®, Mini-VibraFlex®) where the central handle piece of the dumbbell rotates and produces oscillatory movements to the body of varying frequencies (0–30 Hz).

The debate over which platform is superior is currently equivocal. Research performed by Abercromby et al. [1] reported that the lower limb extensors (vastus lateralis and gastrocnemius) were activated significantly more during SV than VV from an acute exposure; however, the activation of the tibialis anterior was significantly greater during VV than SV. Furthermore, during dynamic (from 10° to 35° of knee flexion, at a tempo of 4s up 4s down) and static squatting (18.5° knee flexion), SV produced a greater activation of the lower limb muscles compared to VV. In a later study, the same authors [2] reported that across different knee angles (5–35°) vibration transmitted to the upper-body and head was 71–189% greater during VV than SV. The authors concluded that during SV the pelvis damps the vibration energy more than the VV. Earlier, Rittweger et al. [104] had proposed a similar hypothesis: in SV the feet are alternated between up and down positions, causing rotation of pelvis and flexion of the spinal column, which decreases the vibration energy.
transmission to the head. However, no kinematic analyses have been performed on SV and VV to validate this claim. It should be noted that in Abercromby et al.’s [1] acute study the dynamic squat was only performed through a limited range of knee flexion (10–35°).

Transmission of vibration exercise

The majority of contemporary vibration machines produce periodic sinusoidal oscillations, where energy is transferred from the vibratory machine to the human body. The vibratory load is dependent on 4 parameters: frequency, amplitude, acceleration, and duration. The number of cycles of oscillation determines the frequency; the amplitude refers to the displacement of the oscillatory motion (Eq. 2); the acceleration (m/s² or g) determines the magnitude; and duration refers to the exposure time. Normally, VbX is administered in the range of 0–45 Hz, amplitude of 0–12 mm (peak-to-peak amplitude) and peak acceleration of 0–18 g.

The motion of vibration training is sinusoidal. The acceleration transmitted to the body is based on the principle of peak acceleration (a) being the product of angular frequency (ω) squared and peak-to-peak amplitude (A), where A is converted from mm to m. (Equation 1)

\[ a_{\text{peak}} = \omega^2 A \quad \text{(m/s}^2\text{)} \quad \text{Eq. 1} \]

\[ \omega = (2 \pi f) \quad \text{(Hz)} \quad \text{Eq. 2} \]

Angular frequency (ω) is the product of 2π and vibration frequency (f) (Eq. 2). Where f is the number of vibratory cycles per unit of time. Therefore, 1/f provides the duration of a single cycle, Hz, which is equivalent to cycle per s. Thus, ω is proportional to f as given by 2πf Hz, which is equivalent to cycle per s. For example, a vibration frequency of 26 Hz and peak-to-peak amplitude of 6 mm would produce a peak acceleration of 160 m/s² (16.3 g). Changes in vibration frequency or amplitude will determine the changes in acceleration transmitted to the body. The greatest acceleration (or gravitational load) is high when both frequency and peak-to-peak amplitude are at their maximum. For example, a vibration frequency of 26 Hz, at a peak-to-peak amplitude of 6 mm, will produce a peak angular acceleration of 160 m/s² or 16.3 g. The vibration frequency and amplitude can be manipulated to determine the desired peak acceleration; however, only a few studies have investigated the dose relationship on neuromuscular and performance aspects. Damping and stiffness adjustments are 2 other factors that need to be considered when vibration is transmitted from the vibratory device to the human body. Wakeling et al. [131] have reported that vibration is likely to be damped by tissues and fluids where the mechanical energy is absorbed by structures, leading to heat generation.

Anecdotal reports claim that standing erect, as opposed to squatting, evokes a stronger transmission of the vibration to the head, and shifting body weight to the forefront of the foot will reduce the vibration transmission. Lafortune et al. [70] confirmed this, reporting that when the knees were extended the vibration frequency above 10 Hz was more effective in transmitting to the hip compared to a frequency of less than 5 Hz. Rubin [109] found that at low vibration frequency the vibration transmission to the hip was dissipated; however, when the frequency was raised to 15–35 Hz, a higher response at the hip was evident. A scientific model [134] has been used to describe the transmission of vibration; however, this model has lacked the inclusion of the 3 lower limb joints (ankle, knee and hip) and the researchers have not considered the effect of the range of joint motion on vibration transmission. Abercromby et al. [1] stated that the damping of mechanical energy by the legs depends not only on the compliance of ankle, knee, and hip joints, but also on the modulation of leg muscle activation. These researchers found that the greatest mechanical impedance (as determined by a decrease in joint compliance and an increase in the absorption of vibration energy) occurred at a knee angle of 10–15°. They also found that acceleration of the head decreased as knee angle increased from 10 to 30°, and was greater in acute VV than SV (f= 30 Hz, A= 4 mm). The authors concluded that squatting at a knee angle of 26–30° dissipated head vibration and that the use of small knee flexion angles during VbX increased the likelihood of negative side effects as the greatest mechanical energy is likely to be transmitted to the upper-body and head and should, therefore, be avoided.

Parameters of vibration exercise

Frequency
Prior to the inception of commercialised VbX, vibration studies focused on high vibration frequency; vibratory units were applied directly to the muscle or tendons of animals or humans for a very short duration. McCloskey et al. [80] applied direct acute vibration of 100–200 Hz to the hindlimb of a cat’s triceps surae muscle, and Bongiovanni and Hagbarth [11] applied 2 min of direct vibration of 150 Hz to human tendon ankle dorsiflexors to stimulate the tonic vibration reflex (TVR). It is not exactly known how the scientific merit of low frequency vibration was validated, but Nazarov and Spivak [86] may have had a part in determining it. They used an arbitrary frequency of 23 Hz because they feared that the vibration would disappear during transmission in the tissue if a higher frequency was selected. Another explanation states that from a natural frequency lower limb muscles respond between a range of 5–65 Hz [87]. There is little scientific documentation on the appropriate vibration frequency (f); however, Bosco et al. [13] exposed handball and waterpolo athletes to 10 days of intermittent vibration (f= 26 Hz, SV, Galileo) and reported an increase in vertical jump height by 12%, but gave no rationale as to why 26 Hz was selected. In a follow-up study, Bosco et al. [14] confirmed their earlier findings that acute vibration performed at 26 Hz on an SV (Galileo) platform had a positive effect on muscular performance by shifting the force-velocity and power-force relationship to the right, enhancing average force, velocity and power in a sample size of

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
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<th>Condition</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Acceleration (m/s^2)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abercromby et al. [1]</td>
<td>randomised cross-over</td>
<td>16H (9♂, 7♀)</td>
<td>W, SV</td>
<td>DS (10–35°)</td>
<td>30</td>
<td>4 p-p</td>
<td>NR</td>
<td>30 s</td>
<td>EMG activity of the leg extensors were significantly greater during SV than VV.</td>
</tr>
<tr>
<td>Abercromby et al. [2]</td>
<td>randomised</td>
<td>16H (9♂, 7♀)</td>
<td>W, SV</td>
<td>SS (18.5°)</td>
<td>30</td>
<td>4 p-p</td>
<td>NR</td>
<td>30 s</td>
<td>During SS EMG activity was greater than or equal to responses during DS.</td>
</tr>
<tr>
<td>Adams et al. [3]</td>
<td>randomised</td>
<td>20UT (11♂, 9♀)</td>
<td>W</td>
<td>SS (2.27 rad)</td>
<td>30, 35, 40, 50</td>
<td>2–4; 4–6</td>
<td>NR</td>
<td>30, 45, 60 s</td>
<td>High frequencies were more effective when combined with high displacements, and low frequencies were more effective in conjunction with low displacements for improving CMJ.</td>
</tr>
<tr>
<td>Bazett-Jones et al. [8]</td>
<td>randomised</td>
<td>44UT (33♂, 11♀)</td>
<td>VV</td>
<td>SS (90°)</td>
<td>0, 30, 35, 40, 2–4; 4–6</td>
<td>9.8 m/s^2, 21.2 m/s^2, 27.5 m/s^2, 47.8 m/s^2, 57.2 m/s^2</td>
<td>9×5 s</td>
<td>No significant differences in CMJ for the different vibration frequencies and amplitudes.</td>
<td></td>
</tr>
<tr>
<td>Bosco et al. [13]</td>
<td>randomised</td>
<td>14RA</td>
<td>SV</td>
<td>standing, SS, lunge</td>
<td>26</td>
<td>10</td>
<td>54 m/s^2</td>
<td>5×90 s (10 days)</td>
<td>VbX increased continuous mean jump height (5s) by 12%.</td>
</tr>
<tr>
<td>Bosco et al. [14]</td>
<td>randomised</td>
<td>6EL♀</td>
<td>SV</td>
<td>SS (100°)</td>
<td>26</td>
<td>10</td>
<td>54 m/s^2</td>
<td>10×60 s</td>
<td>Leg press velocity-force and power-force relationship shifted to the right after VbX.</td>
</tr>
<tr>
<td>Cardinale &amp; Lim [25]</td>
<td>randomised</td>
<td>16EL♀</td>
<td>volleyball</td>
<td>W</td>
<td>SS (100°)</td>
<td>30, 40, 50</td>
<td>10 p-p</td>
<td>NR</td>
<td>4×60 s</td>
</tr>
<tr>
<td>Cardinale et al. [24]</td>
<td>randomised</td>
<td>9RA♂</td>
<td>NR</td>
<td>SS (100°)</td>
<td>30</td>
<td>1.5, 3</td>
<td>26.5 m/s^2, 53 m/s^2</td>
<td>10×60 s</td>
<td>30Hz and amplitudes of 1.5 and 3 mm did not significantly increase serum testosterone and insulin growth factor-1 levels.</td>
</tr>
<tr>
<td>DaSilva et al. [39]</td>
<td>randomised</td>
<td>31♂</td>
<td>W</td>
<td>NR</td>
<td>20, 30, 40</td>
<td>4</td>
<td>NR</td>
<td>6×60 s</td>
<td>30Hz increased CMJ, strength, and power parameters more than 20 &amp; 40Hz.</td>
</tr>
<tr>
<td>Delecluse et al. [42]</td>
<td>randomised</td>
<td>18UT♀</td>
<td>W</td>
<td>SS, lunge</td>
<td>35–40</td>
<td>2.5–5</td>
<td>22.6–50 m/s^2</td>
<td>1–3×2–6×30–60 s (3×/wk 12 wks)</td>
<td>VbX with SS increased EMG rms of the rectus femoris and medial gastrocnemius compared to the placebo condition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19UT♀</td>
<td>placebo</td>
<td>SS, lunge</td>
<td>NR</td>
<td>NR</td>
<td>3.9 m/s^2</td>
<td>1–3×2–6×30–60 s (3×/wk 12 wks)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18UT♀</td>
<td>resistance</td>
<td>cardio + knee &amp; leg extensor strength</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>3×/wk; 12 wks</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>19UT♀</td>
<td>control</td>
<td>no training</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>3×/wk; 12 wks</td>
<td></td>
</tr>
<tr>
<td>Di Giminian et al. [44]</td>
<td>randomised</td>
<td>RA 9(4♂, 5♀)</td>
<td>W – individualised</td>
<td>SS (90°)</td>
<td>20–50</td>
<td>2</td>
<td>1.1–53.6 m/s^2</td>
<td>10×1 min (3×/wk 8 wks)</td>
<td>Individualised vibration frequency increased vertical jump performance (11%) compared to fixed vibration frequency (3%) and control (2%).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10(5♂, 5♀)</td>
<td>W – fixed</td>
<td>SS (90°)</td>
<td>30</td>
<td>2</td>
<td>1.1–53.6 m/s^2</td>
<td>10×1 min (3×/wk 8 wks)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11(5♂, 6♀)</td>
<td>control</td>
<td>SS (90°)</td>
<td>0</td>
<td>0</td>
<td>NA</td>
<td>10×1 min (3×/wk 8 wks)</td>
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</table>
6 elite volleyball players. Akin to their previous study, no rationale was given for the selection of the vibration frequency. It took Cardinale and Lim [25] to provide some insight on the optimal vibration frequency. Using electromyography (EMG) to validate the vibration frequency, these authors found that the EMG response of the vastus lateralis, as analysed by the root mean square (rms) was significantly higher in acute 30Hz compared to 40 and 50Hz when standing in a half squat position (knee angle 100°) on a VV (Nemes) platform for 60s (Table 1). Delecluse et al. [43] also reported that standing in a static half squat position on a vibrating platform (f = 35Hz, Amplitude (A) = 5mm, acceleration (a) = 3.9g) increased EMG_{rms} of the rectus femoris and medial gastrocnemius muscles compared to the placebo condition (a = 0.4g) after 12 weeks of VbX. However, both Delecluse et al.'s [43] and Cardinale and Lim's [25] studies were conducted on a VV platform, with no comparison being made to a SV machine.

Recently, a number of studies (Table 1) have examined whether a dose relationship exists between different vibration frequencies and muscular performance, where the majority have used vertical jump (VJ) height as the performance measure. Da Silva et al. [39] found that an acute intermittent vibration protocol performed at a frequency of 30Hz (A = 4mm) increased VJ height and leg power compared to 20Hz and 40Hz. However, this study lacked a control condition; the body posture during vibration was not described; and no measures of EMG were collected. Likewise, Bazett-Jones et al. [8] reported a significant increase of 9% and 8.3% in VJ height in young untrained women when acutely exposed to 40 Hz and 50 Hz compared to the control condition, but there was no increase in VJ height for the untrained men. However, the small sample size (n = 11) of the women compared to the men (n = 33) may have incurred a type I error, and the vibration exposure time of 45s may have been insufficient to elicit the required neuromuscular responses for the males.

VbX is like any other form of training – every individual will have a response to an optimal intensity, and/or training load. In physical conditioning, most fitness programmes consider individual responses, and are tailored to suit the individual; however, in VbX there has been a tendency for one vibration frequency to be used by all. Until recently, this was the status quo; however, Di Giminiani et al. [44] observed that after 8 weeks (3x/week) of training with the vibration frequency individualised by determining the EMG_{rms} activity of the vastus lateralis performed in a half squat position, the mean power of squat jump and jump height from a continuous rebound jumping test increased 11% and 18% respectively in comparison to the fixed (30Hz), or no vibration groups. These results clearly indicate that vibration frequency should be individualised to fully maximise the benefits of vibration training. Just as other fitness and resistance programmes are individualised for the client, vibration training should follow suit. However, it is unknown if EMG_{rms} is the most appropriate measure to individualise each person’s optimal vibration frequency. It may not be practical, as EMG equipment is often expensive, and may not be affordable or readily available in practical settings, such as clinics and gyms. It also requires a certain level of expertise. Further, it should be noted that in Di Giminiani et al.’s [44] study only one site (vastus lateralis) was used to record EMG activity. Other muscles, such as the triceps surae and hamstring group, need to be analysed before a conclusion can be reached that the use of one particular muscle will provide the optimum vibration frequency.

### Table 1

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Condition</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Acceleration (mm/s²)</th>
<th>Duration</th>
<th>Results</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lythgoe et al. [76]</td>
<td>randomised</td>
<td>9 H♂</td>
<td>SS (90°)</td>
<td>VV</td>
<td>5, 10, 15, 20</td>
<td>low (1.2)</td>
<td>24.5 – 75.5 mm²</td>
<td>10s</td>
<td>Amplitude increased with higher vibration frequencies.</td>
<td></td>
</tr>
<tr>
<td>Pelet et al. [44]</td>
<td>VV</td>
<td>9 H♂</td>
<td>SS (150°)</td>
<td>SV</td>
<td>5 – 40</td>
<td>high (2.2)</td>
<td>11.6 – 37.2 mm²</td>
<td>4 min</td>
<td>VR increased linearly from 18 to 34 Hz.</td>
<td></td>
</tr>
<tr>
<td>Rittweger et al. [102]</td>
<td>randomised</td>
<td>8 RA♂</td>
<td>SS (170°)</td>
<td>SV</td>
<td>26</td>
<td>2.5 – 7.5</td>
<td>13.8 – 32.2 mm²</td>
<td>4 min</td>
<td>VR increased linearly with greater amplitudes.</td>
<td></td>
</tr>
<tr>
<td>UT – Untrained; EL – Elite; H – Healthy; RA – Recreationally active; SV – Side alternating vibration; VV – Vertical vibration; DS – Dynamic squat; SS – Static squat; p-p – peak-to-peak</td>
<td></td>
<td></td>
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</table>

Amplitude
Amplitude is defined as the maximum displacement of a vibration point from a mean position, compared to peak-to-peak amplitude \( A \), which is referred to as the height from the lowest to highest vibration wave \( \bullet \) Fig. 2. For SV, the amplitude is dependent on where the feet are placed on the platform. When the feet are close to the middle of the platform it equates to a small peak amplitude \( (\sim 3 \text{ mm}) \). A wide stance equates to a greater amplitude \( (\sim 12 \text{ mm}) \) \( \bullet \) Fig. 3. This differs to VV, where foot placement is independent of amplitude and has a pre-setting of 0–2 mm or 4–6 mm. Using an acute intermittent vibration protocol Cardinale et al. [24] found no differences in insulin growth factor 1 \( (\text{IGF-1}) \) and testosterone levels when participants were exposed to high amplitude \( (A=3 \text{ mm}) \), low amplitude \( (A=1.5 \text{ mm}) \) and zero amplitude \( (A=0 \text{ mm}) \) at a fixed vibration frequency \( (f=30 \text{ Hz}) \). The authors failed to document the type of vibration platform; therefore, if a VV was used the selection of a small amplitude may not have elicited the required response. Using a SV (Galileo) platform where participants stood in an upright stance \( (10^\circ \text{ knee flexion}) \) at a fixed frequency of 26Hz, Rittweger et al. [102] reported that acute VbX increased the oxygen cost increased in all 3 amplitudes \( (2.5, 5, 7.5 \text{ mm}) \) compared to baseline levels, with the highest amplitude \( (7.5 \text{ mm}) \) having the greatest oxygen cost \( (7.3 \text{ ml/kg/min compared to resting 3.6 \text{ ml/kg/min}}) \). For muscular power, Adams et al. [3] showed that acute high vibration frequency \( (50 \text{ Hz, VV, [Power Plate]}) \) with high amplitude \( (4–6 \text{ mm}) \), and low frequency \( (30 \text{ Hz}) \) with low amplitude \( (2–4 \text{ mm}) \) were effective for increasing VI power. Moreover, Lythgoe et al. [76] observed that low vibration amplitude ranging from 2.5 mm to 4.5 mm (SV) was able to elicit an increase in mean blood cell velocity by 27%, when acute vibration frequency was progressively increased from 5 to 30 Hz.

To date, no study has directly compared the different amplitudes between the VV and SV platforms. As discussed earlier, the placement of the feet determines the amplitude in SV, which may affect the transmission of vibration to the various regions of the body. There has been some speculation that different body masses may alter the amplitude of vibration platforms; a heavier mass may decrease the amplitude of the platform. This presumption has been challenged based on recent evidence from Pel et al. [91] who reported no change in amplitude when SV (Galileo) and VV (Power Plate) platforms were loaded with 2 different body masses. The authors observed that the acceleration \( (g) \) from acute vibration in the vertical direction of the SV platform was reduced when vibration frequency was increased from 30 to 40Hz. However, only 2 different body masses \( (62 \text{ kg and } 81 \text{ kg}) \) were used in this study and the authors did not consider that many athletes and overweight individuals that use VbX would be outside this body mass range. Consequently, the range is insufficient to critically discuss the effect of body mass on the frequency of VbX. Additionally, the interaction of body mass and stance \( (\text{knee angle}) \) on amplitude requires further investigation.

A current criticism of the literature is that most studies do not provide such details on how amplitude is calculated to whether it is measured by an accelerometer or computed by a mathematical equation. Much confusion surrounds the terms amplitude, peak-to-peak amplitude, and displacement because they are used interchangeably and standardisation of terminology is required. It is advised that a consensus be established in an attempt to gain consistency between research protocols. Lorenzen et al. [73] recommended that the term ‘peak-to-peak amplitude’ be used, and for vibrating platforms an anatomical landmark, such as the middle toe of the foot, be used to standardise the amplitude measurement, which needs be measured and reported.

Acceleration
VbX generates mechanical vibration resulting in acceleration, which is the product of angular velocity \( (2 \pi f) \) and amplitude \( (A) \), where it has also been coined magnitude and the unit is either expressed as \( \text{m/s}^2 \) or as multiples of terrestrial gravitation in \( g \) \( (\text{where } 1 \text{g}=9.81 \text{ m/s}^2) \). Acceleration is proportional to the force applied. Therefore, increasing acceleration relies on changing the frequency and amplitude to increase acceleration of vibration being transmitted to the body [26], which is similar to adding extra load in conventional resistance training \( (F=ma) \). VbX relies on increasing acceleration to increase force, where the force is likely to be the primary stimulus to promote changes within the body. However, as the vibrations travel through the body the effect of the force is likely to be damped by muscles, tissues and fluids [131]. A high level of acceleration can be potentially harmful but with careful measurement the optimal training stimulus can be monitored, which is important for making comparisons with other studies.
A large number of acute, short- and long-term VbX studies have reported acceleration but have not documented how they measured or calculated it [14,15,23,24,48,59,67,101,110,123,124]. A few studies that have directly measured the acceleration source by securing accelerometers to vibration platforms [8,42,44,76,91,105], and have reported mean accelerations of 2.2 g \( (f=30\text{Hz}, A=2\text{–}4\text{mm, MV}) \), 5.8 g \( (f=50\text{Hz}, A=2\text{–}4\text{mm, MV}) \) [8] 2.5 g to 7.7 g \( (f=25\text{–}50\text{Hz}, A=\text{high},\text{MV}) \), 0.3 g to 14.7 g \( (f=5\text{–}40\text{Hz}, A=\text{high},\text{SV}) \) [91], and 0.1 g to 5.5 g \( (f=20\text{–}55\text{Hz}, A=2\text{–}2\text{mm, MV}) \) [44]. Additionally, some researchers have placed accelerometers on body landmarks to determine the acceleration transmission of the vibration that passes through the various joints [2,37] and found that greater accelerations were observed proximal to the vibration platform compared to distal locations. According to Lorenzen et al. [73] all studies should document maximum acceleration \( (\text{m}/\text{s}^2\text{ or g}) \) and provide an explanation of how peak or mean acceleration was determined.

Duration

Duration refers to the exposure time to vibration. Most VbX studies have either been performed acutely for single or multiple sessions, either intermittently (30 – 60 s exposure) or continuously (3 – 5 min) [13,14]. It appears that Bosco’s [120] acute intermittent protocol of 10 repeated exposures of 1 min interspersed with 1 min rest has been a common duration used in subsequent vibration studies, but with little justification. Currently, there is little scientific evidence on what the optimal duration is for intermittent and continuous sessions. Nevertheless, Adams et al. [3] found no significant differences in vertical jump peak power when untrained participants were exposed to acute vibration durations of 30 s, 45 s, or 60 s \( (f=30\text{–}50\text{Hz} A=2\text{–}4,\text{–}4\text{–}6\text{mm}) \). Moreover Stewart et al. [120] reported that standing \( (5^\circ\text{ knee flexion}) \) on a SV, isometric peak torque increased by 3.8% after 2 min of continuous vibration, compared to decrements in peak torque at 4 and 6 min \( (f=26\text{Hz}, A=4\text{mm}) \). In long-term vibration training studies, various exposure times have been reported for studies conducted over 6 – 12 weeks and 3 – 8 months [1,2,14,15,18,24,25,40,45,48,57]. There seems to be a knowledge deficit regarding the ability of continuous VbX to potentiate performance measures. As with resistance training, there may be a point of diminishing returns with respect to the duration of VbX. Durations of greater than 1 min are likely to either involve lower levels of acceleration (and potential for adaptations in strength and power) or greater injury risk if high duration and accelerations are combined. Therefore, intermittent protocols may be preferred to continuous exposure because it stimulates muscle while limiting fatigue. However, more work is required to determine whether there is an optimal duration exposure time for VbX in acute and long-term studies.

Exercises and posture

Static and dynamic squats are common exercises performed on vibration platforms [13,32,77,123]; however, a combination of lower and upper-body exercises have also been performed on various vibrating platforms [1]. The knee joint angle is a critical factor when performing a static or dynamic squat on a vibrating platform. Abercromby et al. [1] reported that a static squat at 18.5° provided greater muscle activation compared to dynamic squatting (10 – 35° knee angle). Additionally, these authors observed that during dynamic squatting, \( \text{EMG}_{\text{VMO}} \) of vastus lateralis, gastrocnemius, and tibialis anterior activity were higher in smaller \( (10\text{–}15^\circ) \) compared to larger flexion angles \( (31\text{–}35^\circ) \) for acute exposures on both SV and VV platforms. Caution should be given to Abercromby et al.’s [1] findings, as a narrow range of knee angle \( (10\text{–}35^\circ) \) was tested during the dynamic squat and only one fixed angle was assessed for the isometric squat position \( (18.5^\circ) \). Further, it is unknown whether greater knee angles would continue to decrease muscle activity in dynamic squatting, and it is unknown what effect EMG activity has on high \( (120^\circ) \) or low \( (90^\circ) \) isometric squats. It remains equivocal whether a greater knee angle elicits a decrement in EMG activity for dynamic and static squatting, and if amplitude or frequency provides the greatest stimulus for muscle activity change and where the exposure duration influences this as well. Roelants et al. [107] reported that during VV \( (f=35\text{Hz}, A=2.5\text{mm}) \) EMG was significantly higher in single leg squat \( (\text{knee angle }125^\circ) \) compared to bilateral squat at \( 90^\circ \) and \( 125^\circ \) knee angle. Using 2 knee flexion angles of \( 10^\circ \) and \( 70^\circ \) \( (f=20\text{Hz}, A=5\text{–}9\text{mm, SV}) \), Savelberg et al. [114] reported that after 4 weeks \( (3\text{x/week}) \) of VbX the 10° knee angle shifted to a more extended knee joint angle. In contrast, the larger knee angle \( (70^\circ) \) shifted to a more flexed knee joint position, and the authors concluded that vibration caused a change in muscle length which shifted the knee angle. However, to confirm this finding a control condition should have been included. Therefore, future research needs to focus on different isometric knee angles in response to larger knee angles in dynamic squatting and its application to muscle performance.

Safety of vibration exercise

Occupational vibration can be detrimental to one’s health, especially for workers who are constantly and continually exposed to vibrations from different types of machinery [82]. However, most exercise vibration studies are conducted acutely and intermittently with no incidences of ill-effects having being reported. Conversely, Crawther et al. [37] observed that untrained participants exposed to acute vibration frequencies \( (10, 20, 30\text{Hz}) \), amplitudes \( (1.25, 3, 5.25\text{mm}) \) and postures (standing, squat) suffered from side-effects, such as hot feet, itching of the lower limbs, vertigo and severe hip discomfort. Likewise, Cronin et al. [38] reported that untrained participants suffered from vibration pain of jaw, neck and lower limbs from an acute intermittent VbX protocol \( (f=26\text{Hz}, A=6\text{mm}) \), which subsided after 7 – 10 days of physiotherapy treatment. However, Crawther et al. [37] and Cronin et al. [38] did not fully disclose how the participants were familiarised on the vibration platform, or whether they screened the participants for vibration side-effects. Both studies required the participants to slightly flex their knees; this small knee angle may have increased the vibration transmission to areas such as the head or hip. Recent research has concluded that the smaller the knee angle, the greater the vibration transmission to the head [1,91]. The findings of Crawther et al. [37] and Cronin et al. [38] are very uncommon, but highlight the need for researchers and exercise specialists to be fully trained on the use of vibration technology before participants take part in vibration led exercise, research and rehabilitation programmes. Additionally, it has been reported by Rittweger et al. [101], Kerschan-Schandl et al. [67], Russo et al. [110], Roelants et al. [106], Hazell et al. [54], and Broadbent et al. [16] that acute VbX can elicit erythema of the lower limbs, with anecdotal reports from participants suggesting that VbX causes a hot sensation of the legs and acute itchiness, which normally subsides within minutes of VbX and has no deleterious effect on the body.
However, it is unknown what causes the itchiness; one proposal suggests that the increase in blood flow is the main contributor, while another thought is that vibration induces skin shear forces which promotes vasodilatation and is mediated by release of histamine [100]. Broadbent et al. [16] has postulated that acute VbX may cause an excitatory response on mast cells to produce histamine, which causes vasodilatation and promotes erythema itchiness. Results from their study, however, indicate that histamine levels were lower in the leg receiving vibration (f = 40 Hz, A = 5 mm, VV) after muscle damage was elicited from downhill running, compared to those with muscle damage who received no vibration. Further, they speculate that the increase in blood flow from the vibration could have increased the clearance rate of histamine. Therefore, the mechanism causing erythema remains unidentified, and warrants further investigation.

The effects of vibration exercise on reflex activity and Jendrassik manoeuvre

Tendon reflex (stretch reflex)

Rittweger et al. [103] reported an enhancement of the patellar tendon stretch reflex following acute VbX (f = 26 Hz, A = 6 mm, SV, [Galileo]) with dynamic squatting to exhaustion, and suggested that α-motoneurons were augmented by the vibration, which recruited high-threshold units and muscle fibres. However, no effect on patellar tendon reflex has been reported after acute intermittent (f = 26 Hz, A = 4 mm, SV, [Galileo]) or continuous (f = 26 Hz, A = 6 mm, SV, [Galileo]) vibration exposure. Recently Melnyk et al. [81] elicited the stretch reflex in the hamstrings by inducing an anterior Tibial translation during standing, and compared the reflex response between a control and acute intermittent vibration group (f = 30 Hz, A = 4 mm, VV, [Power Plate]). The researchers found post-vibration, anterior tibial translation displacement decreased with a corresponding increase in EMG of the hamstring short latency response. The authors concluded that the effect of increased knee stability was caused by reflex excitability. However, from this study it is not conclusive whether the stretch reflex was potentiated from acute VbX and it remains speculative whether spinal reflexes are the main mechanism.

Hoffmann reflex (H-reflex)

The Hoffmann reflex (H-reflex) is a measure of assessing monosynaptic activity of the spinal cord [93]. The H-reflex differs to the tendon reflex because it is activated by electrical rather than mechanical stimulation, which bypasses the muscle spindle by acting directly on the afferent fibre. The electrical stimulus causes a corresponding H-reflex, which is the result of increased excitability of the α afferent and α-motoneurons. As the strength of the electrical stimulus increases, the efferent fibres become excited and induce a direct muscle contraction, known as the M-response. Further increase in the stimulus strength results in suppression of the H-reflex but M-response becomes augmented.

Thompson and Belanger [121] reported that self-paced inline skating for 35 min elicited a mean vibration frequency of 141 Hz from the skate chassis and 34 Hz from the middle portion of the tibia, which resulted in the H-reflex being suppressed by 35% compared to resting conditions. The authors concluded that pre-synaptic inhibition was the main factor for suppressing the reflex response. Similarly, Armstrong et al. [5] found the H-reflex was suppressed in the first minute post-vibration after a single minute bout of VV (f = 40 Hz, A = 2–4 mm). But earlier work from Nishihiro and associates [88] found that post-vibration the H-reflex and H max/M max ratio was enhanced, suggesting that motoneuron excitability was heightened. The dissonance between Nishihiro and associates [88] and Armstrong et al.’s [5] findings is probably due to the different protocols. Nishihiro et al. [88] used a 3 min exposure performed on SV platform (f = 25 Hz) where the H-reflex was elicited from a seated position, which differs to Armstrong et al.’s [5] 1 min duration performed on VV (f = 40 Hz) with the H-reflex elicited from a supine position.

Jendrassik manoeuvre

The Jendrassik manoeuvre involves contracting remote muscles, normally of the upper-body (particularly the forearm and jaw muscles) to induce a reflex response. A common method for eliciting a reflex is to grasp the hands and pull them apart – this potentiates the stretch reflex and H-reflex. In the clinical setting, the Jendrassik manoeuvre has been used to induce a full-sized reflex in neurologically impaired patients. In young (25 yrs) and older (75 yrs) healthy people directly applied vibration to the quadriceps (f = 100 Hz, A = 2 mm) produced a post-vibration decrease in patella tendon reflex force, but the younger group showed a greater reflex inhibition [50]. Moreover, the effect of the Jendrassik manoeuvre facilitated the patella tendon reflex more in young people than in the older group (97% vs. 64%). The authors concluded that the age-related changes were due to changes in pre-synaptic inhibition pathways and motoneuron input resistance, confirming that the integrity of the spinal interneuronal pathways deteriorate with ageing [19]. The reduction in muscle vibration inhibitory effect of older adults suggests that the pre-synaptic inhibition of Ia afferents may deteriorate with an increase in age, or the aged muscle spindle may reduce the number of Ia afferents activated by the vibratory stimulus. Recently, Cochrane et al. [31] reported that superimposing the Jendrassik manoeuvre upon acute VbX enhanced metabolic rate in old and young people but there were no significant differences in the elevated metabolic rate between the groups.

To date, there is a lack of research on how VbX may influence spinal reflexes but there remains a positive belief that spinal reflexes are responsible for VbX potentiating effects. However, in light of recent research it remains equivocal whether the spinal reflexes are the major contributor because blood flow, muscle temperature, and other neural aspects increase as a result of VbX. Additionally, it has been difficult to ascertain if spinal reflexes are potentiated from VbX due to different vibration methods, parameters (amplitude, exposure duration, rest interval), prescription (number of repetitions, sets, exercises) and participant characteristics (body/muscle mass, training status, age, gender). In the future, this needs to be standardised to determine if VbX influences spinal reflexes.

The effects of vibration exercise on muscle activity

Lower body

It is possible to measure electromyography (EMG) activity without any artefacts in response to vibrating muscle. Seroussi et al. [118] evoked acute vertical sinusoidal vibrations (f = 3–10 Hz; A = 0.4–13 mm) from a servohydraulic shaker, and were successful in removing motion artefacts by passing the raw EMG through a phaseless digital 6 pole Butterworth high pass filter with a cut-off frequency of 30 Hz. They found that when EMG of the erector spinae was adjusted for torque, a significant increase (19%) in mean torque was observed. Likewise, Bongiovanni and Hagbarth
reported that tibialis anterior EMG activity and single motor unit discharge were augmented from a pneumatic vibratory unit ($f=150\text{Hz}, A=1.5\text{mm}$).

Using a small actuator ($f=50\text{Hz}, A=5\text{mm}$) applied acutely to the quadriceps, Warman et al. [132] reported an increase in EMG$_{rms}$ of the rectus femoris during isometric (30%), isokinetic (43%), and concentric (107%) contractions. In a subsequent study, Humphries et al. [58] used the same vibrating actuator and reported no significant differences in peak normalised EMG$_{rms}$ between acute vibration and resting conditions. Additionally, there were no corresponding changes in the rate of force development or peak force. However, the vibration exposure duration was not documented, therefore it may have been too short or too long to elicit the desired responses. Similarly, Torvinen, et al. [126] found no significant changes in soleus mean power frequency and EMG$_{rms}$ from 4 min of VbX ($f=25–40\text{Hz}, A=2\text{mm}, \text{VV}$) (Table 2), but reported a decrease in mean power frequency and EMG$_{rms}$ for the vastus lateralis and glutaeus medius muscles, which was accompanied by no changes in muscle function.

In a subsequent study, Torvinen, et al. [123] used the same exercise routine and time constructs as the previous study, but in the latter study the participants performed the exercise routine on a SV platform and the vibration frequency was incrementally increased from 15–30Hz ($A=10\text{mm}$). During VbX EMG$_{rms}$ was significantly augmented in the soleus and gastrocnemius but there was no change in vastus lateralis EMG$_{rms}$, However, an increase in isometric leg force and Vj height was reported. The authors provided no discussion on the dissonance between the 2 studies, consequently the reader can only surmise, that either the type of vibration platform (VV vs. SV) or vibration parameters ($f=15–30\text{vs. 25–45Hz}, A=2\text{mm vs. 10}\text{mm}$) may explain the variation in results. However, it is feasible that the action of the side alternating platform with a larger amplitude may have contributed to the increase in muscle performance. Recent evidence has reported that using a fixed frequency (30Hz) and amplitude (4mm), a SV platform generates greater muscle activation of lower limb muscles compared to a VV platform [1].

Upper body

The effect of acute upper-body VbX on EMG activity has produced similar results to that of acute lower-body vibration. Using a vibrating dumbbell, Bosco et al. [12] observed that during acute intermittent vibration ($f=30\text{Hz}$) biceps brachii EMG$_{rms}$ increased 2-fold compared to baseline measurements, and during post-vibration bicep power was augmented but no corresponding increase in EMG activity was found. Further evidence of increased EMG$_{rms}$ has been observed from vibrating isometric elbow pull and push actions, with increases in co-contraction at loads of 20% and 40% of maximum force [84]. The authors speculate that the mechanism for increased EMG$_{rms}$ cannot be entirely accounted for by spinal reflexes but by increased motor unit synchronisation and firing frequency. Although Mischi and Cardinale's [84] study provides some new insights to the response of superimposing acute vibration on agonist, antagonist and co-contraction of muscles, caution is required because only one vibration frequency (28Hz) was tested with brief exposures of vibration and the recorded absence of amplitude restricts the findings of the study. Conversely, Moran et al. [85] reported that when a custom built vibrating unit was directly placed on the bicep brachii tendon ($f=65\text{Hz}, A=1.2\text{mm}$) it did not elicit an increase in EMG$_{rms}$ during the lifting phase of bicep curls at 70% 1RM. Similarly, post-vibration showed no enhancement in EMG$_{mep}$ (mean power frequency) and peak force or power.

Finally, a novel study was conducted to investigate acute muscle activity on a VV platform on both the lower (vastus lateralis, and biceps femoris) and upper limb muscles (biceps brachii and triceps brachii) [54]. The investigators used a range of frequencies ($f=25, 30, 35, 40, 45\text{Hz}$), amplitudes ($A=2$ and $4\text{mm}$), and body positions of static squat, dynamic squat, static bicep curl and dynamic bicep curl. They reported that a static squat EMG$_{rms}$ of vastus lateralis and biceps femoris was augmented when vibration frequency and amplitude were increased, but no increase in muscle activity was evident in static and dynamic bicep curls, probably because the transmission of vibration was damped by the lower extremity. It is important to note that the raw EMG signal was passed through a sixth order Butterworth filter between 100Hz and 450Hz, which may have removed important muscle activity signals.

Posture

Roelants et al. [107] has recently determined whether posture affects muscle activation by investigating 3 different isometric squat positions of a two-leg, high squat (knee angle 125°, hip angle 140°); two-leg, low squat (knee and hip angle 90°); and one-leg, high squat (knee angle 125°, hip angle 140°). The investigators reported that acute VbX increased EMG$_{rms}$ activity more in a one-leg high squat, compared to two-leg high and low squats. However, further testing is required to determine if any EMG differences exist in squatting positions that occur between 90° and 125° knee flexion.

Abercromby et al. [1] acutely investigated muscle activity of different lower limb postures of static squat (18.5°) and dynamic squat (eccentric and concentric 10–35° knee angle) performed on both SV and VV platforms ($f=30\text{Hz}, A=4\text{mm}$). For isometric, eccentric and concentric muscle action, EMG$_{rms}$ increased significantly in all 4 lower limb muscles for both SV and VV. In support of this, Delecleeuse et al. [43] reported that standing in a static half-squat position on a VV platform ($f=35\text{Hz}, A=5\text{mm}, a=3.9\text{g}$) increased gastrocnemius and rectus femoris EMG$_{rms}$ activity, compared to placebo ($a=0.4\text{g}$) control (no vibration); however, the sampling period was only conducted over 20s. Conversely, Cormie et al. [36] observed that in a half-squat position (knee angle 100°) there were no changes in average iEMG (integrated) activity of the vastus lateralis, vastus medialis, biceps femoris during acute vibration treatment ($f=30\text{Hz}, A=2.5\text{mm}, \text{VV}$ [Power Plate]).

The effects of vibration exercise on cardiovascular indices

Blood flow

Hand-held tools are normally operated at high vibration (80–100Hz), which has been shown to decrease blood flow to the digits of the hand, resulting in ‘white finger vibration’ [20]. However, Kerschan-Schindl et al. [67] were first to report that acute VbX ($f=26\text{Hz}, A=3\text{mm}, \text{SV [Galileo]}$) increased blood flow of the popliteal artery (100%) and caused erythema in the foot and calf. Furthermore, Lythgo et al. [76] found that when an acute intermittent vibration protocol was performed ($f=10\text{Hz–30Hz}, \text{SV [Galileo]}$), an increase in mean blood cell velocity of the femoral artery was evident, with 30Hz providing the greatest increase in blood flow compared to resting levels. In contrast, Hazell et al. [55] found that an acute intermittent vibration
protocol ($f = 45\text{ Hz}, A = 2\text{ mm}, \text{VV}[\text{Wave}])$ reported no increases in femoral artery blood flow after 3 min. Likewise, Button et al. [20] reported no significant differences in leg blood flow of a vibrating cushion ($f = 60\text{ Hz}, A = \text{not given}, \text{VV}[\text{ATL}])$ placed under the gluteal muscles, and a hand unit placed under the right foot while in the seated position. In this particular study, no rationale was given for using a hand-held device applied to the foot, or why the vibrating cushions were acutely applied to the gluteals rather than directly to the legs. Additionally, the participants were seated with knees and ankles at $90\degree$, which suggests that vibration transmission may have been damped, attenuating blood flow.

Vibration massage has also been shown to increase skin blood flow. 3 min of acute continuous vibration ($f = 30\text{ Hz}, A = 5–6\text{ mm}, \text{VV}[\text{Power Plate}])$ increased gastromenius skin blood flow by $250\%$ compared to baseline, but there were no treatment differences between with and without vibration [72]. Moreover, Maloney-Hinds et al. [78] found that when the forearm was passively vibrated on a VV platform [Power Plate] at $30 \& 50\text{ Hz}$ ($A = 5–6\text{ mm}$) for $10\text{ min}$ it significantly increased skin blood flow within $5\text{ min}$ and remained elevated for $9\text{ min}$ post-vibration.

Heart rate, blood pressure and arterial stiffness

Acute VbX has been reported to have little effect on heart rate (HR) and blood pressure [20, 55, 90]. Kerschan-Schindl et al. [67] observed no change in HR, systolic and diastolic blood pressure values after acute VbX ($f = 26\text{ Hz}, A = 3\text{ mm}, \text{SV}[\text{Galileo}])$. However, exhaustive VbX did increase HR and systolic pressures by $30\%$ and $15\%$ [101]. To date, only one study has investigated the effects of vibration on arterial stiffness by measuring brachial-ankle pulse velocity [90]. Following acute intermittent vibration ($f = 26\text{ Hz}, A = 2–4\text{ mm}, \text{VV}[\text{Power Plate}])$ arterial stiffness was significantly reduced ($3\%$) at $20\text{ and }40\text{ min}$ post-vibration compared to the same time series of no vibration.

The effects of vibration exercise on muscle function

Power

Acute vibration – lower body power

A summary of the studies that examined the acute effects of VbX on lower and upper body power can be found in $\textbf{Table 2, 3}$. Vertical countermovement jump (CMJ) has been used by many investigators to assess muscle power and its acute effects on VbX. The enhancement in VJ height has varied across the different research protocols. For instance, using a SV (Galileo) platform, Cochrane and Stannard [32] reported an $8.2\%$ increase in CMJ height from $5\text{ minutes}$ of continuous vibration ($f = 26\text{ Hz}, A = 6\text{ mm}$) ($\textbf{Table 2}$), and Torvinen et al. [123] observed a $2.5\%$ enhancement following $4\text{ minutes}$ of vibration ($f = 15–30\text{ Hz}, A = 10\text{ mm}$). Likewise, $5\text{ min}$ of continuous VbX has been shown to raise muscle temperature by $1.5\text{ °C}$, which significantly increased CMJ height ($9.3\%$) and power ($4.4\%$) but when the muscle temperature was elevated by the same amount in stationary cycling and hot water bath the increases in CMJ were similar between the $3\text{ conditions}$ [34].

Studies that have used VV platforms (Power Plate, Nemes) have shown similar findings. Bosco et al. [15] has reported an increase in VJ height of $4\%$ from $10\text{ minutes}$ of intermittent vibration ($f = 26\text{ Hz}, A = 4\text{ mm}, \text{VV}[\text{Nemes}])$. Brief, single vibration ($f = 30 \& 40\text{ Hz}, A = 2–4\text{ mm}$) exposures of $30\text{ s}$ and $45\text{ s}$ performed on a VV platform have respectively recorded a $0.6\%$ and $9\%$ improvement in VJ height [8, 36]. Conversely, Torvinen et al. [126] found no significant increases in VJ height when dynamic exercise was combined with $4\text{ min}$ of VbX ($f = 25–40\text{ Hz}, A = 2\text{ mm}, \text{VV}[\text{Kuntat-ory}])$. It is difficult to explain why Torvinen et al.'s [123] earlier study reported a $4.4\%$ increase, as both studies used similar protocols and participants. However, a VV platform was used in the latter study where the amplitude was smaller ($2\text{ mm}$) than the previous study ($10\text{ mm}$), which could have negated the desired responses. The use of VbX to cause acute changes in power would appear similar to using contrast-complex training, a modality also believed to utilise the theory of post-activation potentiation (PAP), which is referred to as an increase in muscle performance preceded by a muscle contractile activity [111] that involves myogenic and neurogenic factors [56]. To date, it is equivocal whether acute VbX causes PAP by enhancing muscle twitch and reflex properties [33, 35, 40, 64, 79, 92].

Measuring muscle power has not only been confined to vertical jump. Leg press, weighted squats, and knee extension have also been used to assess muscle power from an acute bout of VbX. Bosco et al. [14] found a $6–8\%$ increase in single leg press power across loads of $70, 90, 100, 139$kg in elite volleyball players ($n = 6$) from intermittent VbX ($f = 26\text{ Hz}, A = 10\text{ mm}, \text{SV}[\text{Galileo 2000}]$). Similarly, Rhea and Kenn [98] observed a $5.2\%$ increase in squat power ($3\text{ reps, }75\%\text{ 1RM}$) of male college athletes that received vibration ($f = 35\text{ Hz}, A = 4\text{ mm}, \text{VV}$) while dynamic squatting their body weight. However, when ballistic knee extensions were performed with direct vibration ($f = 65\text{ Hz}, A = 1.2\text{ mm}$) that was applied to distal tendon of quadriceps no significant changes in power variables were found [75].

Acute vibration – Upper body power

The effects of acute vibration on upper-body power have been explored less so, and with varying results. Bosco et al. [12] found a post-vibration $8\%$ increase in average power of bicep brachii from $12\text{ international boxes}$ that isometrically gripped a handheld vibrating device ($f = 30\text{ Hz}, A = 6\text{ mm}$). In a similar study, Issurin and Tenenbaum [60] used an isotonic vibrating cable ($f = 44\text{ Hz}, A = 3\text{ mm}$) where non-elite and elite athlete performed $3\text{ sets}$ of $3\text{ reps} (65–70\%\text{ 1RM})$ at a tempo of $2\text{ s}$ per rep. They reported that both non-elite and elite athlete groups produced a $10.2\%$ and $10.7\%$ increase in mean power and $10.4\%$ and $7.9\%$ in peak power during vibration compared to no vibration.

Further support of vibration enhancing upper-body power has been reported by Poston et al. [94], where an Olympic barbell was fitted with a vibrating electric motor and experienced weight lifters performed an isometric vibration bench press hold ($f = 30\text{ Hz}, A = 1.1\text{ mm}$) for $30\text{ s}$ between the second and third sets of bench pressing ($3\text{ reps, }70\%\text{ 1RM}$). Although, the average power of the bench press was higher with vibration than without, there were discrepancies in baseline power outputs, suggesting that either the athletes should have been blinded before receiving vibration or a greater familiarisation period with the vibration apparatus should have been included.

Some researchers have shown little or no effect of vibration on upper-body power. Moran et al. [85] observed no significant pre-post changes in power, moment, and angular velocity when a custom built vibratory unit ($f = 65\text{ Hz}, A = 1.2\text{ mm}$) was directly applied to the tendon of bicep brachii while resistance trained males performed $3\text{ sets}$ x $5\text{ reps}$ of bicep curls ($70\%\text{ 1RM}$). The same group of researchers [74] repeated a similar experiment and used the same vibratory unit ($f = 65\text{ Hz}, A = 1.2\text{ mm}$), and participants but with the addition of $40\%$ and $70\%\text{ 1RM}$ loading with vibration did not produce any significant changes in power.

Review

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<th>Author</th>
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<td>0.30, 0.35, 40</td>
<td>2–4; 4–6</td>
<td>9 × 5s</td>
<td>BW</td>
<td>In women, VbX significantly increased CMJ height (9%) at 40Hz, 2–4 mm and 8.3% at 50Hz 4–6 mm. In men, VbX had no effect on CMJ height.</td>
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<tr>
<td>Bosco et al. [14]</td>
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<td>10 × 60s</td>
<td>BW</td>
<td>Single leg press at 70, 90, 110, 130 kg significantly increased average force, velocity, and power increased (~6%) from VbX.</td>
</tr>
<tr>
<td>Bosco et al. [15]</td>
<td>controlled</td>
<td>14 RA♂</td>
<td>VV</td>
<td>SS (100°)</td>
<td>26</td>
<td>4</td>
<td>10 × 60s</td>
<td>BW</td>
<td>VbX increased leg press power (160% of body mass) by 7% and enhanced CMJ height by 4%.</td>
</tr>
<tr>
<td>Cochrane et al. [34]</td>
<td>cross-over</td>
<td>8 RA (6♂, 2♀)</td>
<td>SV</td>
<td>DS</td>
<td>26</td>
<td>6 p-p</td>
<td>1 × 5min</td>
<td>BW</td>
<td>CMJ height increased significantly (VbX 9.3%; cycle 7.5%; hot bath 7.1%) as did CMJ power (VbX 4.4%; cycle 4.4%; hot bath 6.5%) but no significant differences existed between the conditions</td>
</tr>
<tr>
<td>Cochr &amp; Stannard [32]</td>
<td>randomised</td>
<td>16 EL♀</td>
<td>SV</td>
<td>DS, SS, lunge</td>
<td>26</td>
<td>6</td>
<td>5 × 1min</td>
<td>BW</td>
<td>VbX significantly increased CMJ height (8.1%) compared to no change in cycle and no VbX.</td>
</tr>
<tr>
<td>Lairi et al. [36]</td>
<td>randomised</td>
<td>9 PA♂</td>
<td>VV</td>
<td>SS (100°)</td>
<td>30</td>
<td>2.5</td>
<td>30s</td>
<td>BW</td>
<td>VbX significantly increased height during the CMJ immediately following VbX compared to control. No significant differences were observed in CMJ peak power and peak force during isometric squat (100°).</td>
</tr>
<tr>
<td>Luo et al. [75]</td>
<td>randomised</td>
<td>14 H♀</td>
<td>DV</td>
<td>knee extension</td>
<td>65</td>
<td>1.2</td>
<td>time taken to do reps and sets</td>
<td>During and after VbX no changes in peak angular velocity, time to peak angular velocity, peak moment, time to peak moment, peak power, time to peak power, of the rectus femoris and vastus lateralis were detected.</td>
<td></td>
</tr>
<tr>
<td>Rhea &amp; Kenn [98]</td>
<td>randomised</td>
<td>8 RA♂</td>
<td>VV</td>
<td>DS</td>
<td>35</td>
<td>4</td>
<td>30s</td>
<td>3 sets 5 reps 60–70% 1 RM</td>
<td>VbX significantly increased squat power (5.2%)</td>
</tr>
<tr>
<td>Torvinen et al. [123]</td>
<td>randomised</td>
<td>16 H (8♂, 8♀)</td>
<td>SV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>15–30</td>
<td>10</td>
<td>4 min</td>
<td>BW</td>
<td>VbX significantly increased CMJ (2.5%) compared to control.</td>
</tr>
<tr>
<td>Torvinen et al. [126]</td>
<td>randomised</td>
<td>16 H (8♂, 8♀)</td>
<td>VV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>25–40</td>
<td>2</td>
<td>4 min</td>
<td>BW</td>
<td>There was no significant changes in CMJ.</td>
</tr>
</tbody>
</table>

UT = Untrained; EL = Elite; RA = Recreationally active; BW = body weight; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat; CMJ = Countermovement jump; H = Healthy; DV = Direct vibration

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### Table 3  Acute Effects of VbX on Upper Body Power.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Condition/Group</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Load</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bosco et al. [12]</td>
<td>randomised</td>
<td>12 ♂ national boxers</td>
<td>DB</td>
<td>elbow flexion (2.5 rad)</td>
<td>26</td>
<td>6</td>
<td>5×60s</td>
<td>2.8 kg</td>
<td>VbX increased elbow flexion average power (14%).</td>
</tr>
<tr>
<td>Cochrane &amp; Hawke [29]</td>
<td>randomised</td>
<td>12 climbers</td>
<td>DB</td>
<td>unilateral upper body exercises</td>
<td>26</td>
<td>3</td>
<td>5×60s</td>
<td>3 kg</td>
<td>VbX produced no significant changes in medicine ball throw.</td>
</tr>
<tr>
<td></td>
<td>cross-over</td>
<td>(5♀, 7 ♂)</td>
<td>arm crank</td>
<td>arm crank</td>
<td>NA</td>
<td>NA</td>
<td>5mins</td>
<td>25W</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>unilateral upper body exercises</td>
<td>0</td>
<td>0</td>
<td>5×60s</td>
<td>3 kg</td>
<td></td>
</tr>
<tr>
<td>Issurin &amp; Tenenbaum [60]</td>
<td>randomised</td>
<td>14 EL ♂</td>
<td>DB</td>
<td>unilateral upper body exercises</td>
<td>26</td>
<td>3</td>
<td>5×60s</td>
<td>2.8 kg</td>
<td>VbX increased elbow flexion average power (14%).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>arm crank</td>
<td>arm crank</td>
<td>NA</td>
<td>NA</td>
<td>5mins</td>
<td>25W</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>unilateral upper body exercises</td>
<td>0</td>
<td>0</td>
<td>5×60s</td>
<td>3 kg</td>
<td></td>
</tr>
<tr>
<td>Luo et al. [74]</td>
<td>randomised</td>
<td>11 RT ♂</td>
<td>DV + BC (40%) sham + BC (40%)</td>
<td>dynamic elbow flexion</td>
<td>65</td>
<td>1.2</td>
<td>3 sets 5 reps</td>
<td>40% 1RM</td>
<td>VbX did not increase mean and peak angular velocities, moment and power, time to peak power, and initial power at 100 milliseconds for either resistance loads.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>control</td>
<td>0</td>
<td>0</td>
<td>30s</td>
<td>60 kg</td>
<td>VbX increased average bench press power (5.2 %).</td>
</tr>
<tr>
<td>Moran et al. [85]</td>
<td>randomised</td>
<td>14 RT ♂</td>
<td>DV + BC sham + BC</td>
<td>dynamic elbow flexion</td>
<td>65</td>
<td>1.2</td>
<td>3 sets 5 reps</td>
<td>70% 1RM</td>
<td>VbX did not enhance mean power peak power.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>control</td>
<td>0</td>
<td>0</td>
<td>30s</td>
<td>60 kg</td>
<td>VbX increased average bench press power (5.2 %).</td>
</tr>
<tr>
<td>Poston et al. [94]</td>
<td>randomised</td>
<td>10 RT ♂</td>
<td>vibration</td>
<td>isometric bench press</td>
<td>30</td>
<td>1.1</td>
<td>30s</td>
<td>60 kg</td>
<td>VbX increased average bench press power (5.2 %).</td>
</tr>
</tbody>
</table>

EL = Elite; RA = Recreationally active; RT = Resistance trained; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat; DB = Dumbbell; DV = Direct vibration; +BC = with bicep curls; −BC = without bicep curls; RM = repetition maximum
measures. From these results the researchers proposed that
when performing dynamic exercise, such as bicep curls, it relies
on the stretch-shortening cycle where smaller vibration ampli-
tude may be required to activate and optimise muscle spindle
sensitivity. However, Bosco et al.’s [12] findings contradict this
because they reported an 8% increase in bicep brachii peak
power from 5 min of intermittent dumbbell vibration (f=30Hz,
A=6mm). Therefore, the direct application of the vibratory unit
and its frequency (65 Hz) may have caused the insignificant find-
ings from Moran et al. [85] and Luo et al. [74]. Moreover,
Crone and Hawke [29] have also reported no significant
increases in upper-body power of climbers that were exposed to
an electric powered vibrating dumbbell (3 kg) (f=26Hz, A=3 mm,
[TOP Galileo]). At present the research has focussed on short-
and long-term lower body power but there is lack of conclusive
research on longer exposures of VbX on upper body power.

Short-term vibration (≤2 months) – Lower body power
Repeated single bouts of vibration performed over days or weeks
have been investigated and the findings of the short-term VbX
on lower body and upper body power can be found in ○ Table 4, 5.
Bosco et al. [13] reported a 11.9% increase in VJ height (5 s con-
tinuous jumping protocol) in handball and waterpolo players
after receiving 10 days of intermittent VbX (f=26Hz, A=10 mm,
SV, [Galileo]). Further support for short-term vibration potenti-
ing CMJ has been reported by Fagnani et al. [49] where com-
petitive female athletes increased their CMJ by 8.7% from 8
weeks of vibration training (f=35 Hz, A=4 mm, VJ [Nemes]).
Well-trained strength males (21 – 40 yrs) that underwent 5 weeks
(3x/week) of vibration (f=40Hz, A=not given, VJ [Nemes]) com-
binated with 6RM squats reported an increase in VJ by 8.8% [108].
Annino et al. [4] observed an increase in VJ height (6.3%) in well-
trained ballerinas after performing 2 months (3x/week) of VbX
(f=30Hz, A=5 mm, VJ [Nemes]) additionally, the average power,
force and velocity of leg press increased significantly at loads of
50, 70, and 100kg. In a recent study [44] where vibration fre-
cency was set individually for each participant, the authors
reported that after 8 weeks (3x/week) of vibration training, squat
jump height increased by 11%, continuous rebound jump height
was enhanced by 22% and mean power significantly increased by
18% respectively compared to a fixed (30Hz), or no vibration . But
no significant increases in CMJ height were found after 8 weeks
in all 3 groups. Likewise, other vibration training protocols conducted
over different time periods such as, 9 days [30], and 5 weeks,
(3x/week) [42] have reported no significant increases in VJ.

Long-term vibration (>2 months) – Lower body power
Several studies have investigated the long-term effects of vibra-
tion on muscle power using VJ performance. The majority of
these studies have found increases in VJ jump performance. Delecluse et al. [43] randomised 67 untrained females (21 yrs)
into VbX (f=35–40Hz, A=2.5–5 mm, VJ [Power Plate]), resist-
ance training (8–20RM of knee extension and leg press), placebo
and control groups and found that after 12 weeks (3x/week)
of training, VJ height increased by 7.6% from VbX. Likewise, healthy non-anthletic males and females increased VJ height by 9.0% and
7.7% following 4 and 8 months of VbX (f=25–40Hz, A=2 mm, VJ
[Kuntotary]) [124–125]. In addition, post-menopausal women
have shown increases in VJ height of 19.4% and 4.7% from 24
weeks (3x/week) [106] and 6 months (2x/week) of VbX training
[110]. However, no significant improvements in VJ height have
been reported from 11 weeks (3x/week) [41] of VbX.

In summary, there is strong evidence that acute VbX can enhance
upper and lower-body muscle power, and there is some indica-
tion that VbX can enhance lower and upper-body muscle power
over a longer-term, although this is less convincing. Future stud-
ies need to be conducted to determine the optimal duration of the
rest between repetitions, the optimal frequency and duration
necessary to maximise power in both short and long term studies.

Force

Acute vibration – Upper body force. There are many methods of
applying vibration to the upper-body; some researchers have
used custom-built vibratory units applied directly to the muscle
or attached to resistant training cables, while in recent times
commercially manufactured vibrating dumbbells have also
become available. A summary of the studies that investigated the
acute effects of vibration on upper and lower body force can be
found in ○ Table 6, 7. In a study conducted by Kin-Isler and
colleagues [68], an electromotor was used to transmit vibrations
through a cable attached to a leather belt that was placed over
the belly of the biceps brachii. Using a range of vibration fre-
cuencies (f=6, 12, 24Hz, A=4 mm) and joint angles (90°, 120°,
150°) the researchers reported that during a 10s vibration
exposure, a 6.4% increase in MVC elbow flexors was observed.
However, the length of muscle (conducted at various angles) did
not affect isometric MVC. Finally, vibration has no effect on grip
force when using an electric powered vibrating dumbbell [29] or
when arms are exposed less proportionally to the legs on a
vibrating platform [32, 123, 126].

Acute vibration – Lower body force
There is little consensus on whether acute vibration increases
lower-body force of isometric, isokinetic and isoinertial muscle
deposition. De Ruiter et al. [58] reported that when the knee exten-
sors were electrically stimulated, the maximum force-generat-
ing capacity and isometric contraction significantly declined
after an intermittent acute bout of vibration (f=30Hz, A=8 mm,
SV, [Galileo 2000]). However, no changes in maximal isometric
leg extensor strength were found following 4 min of vibration
(f=25–40Hz, A=2 mm, VJ [Kuntotary]); [126]. Conversely, in a
follow-up experiment using the same design and experimental
protocol, the researchers [123] reported an increase of 3.2% in
leg extensor strength. The use of different vibration machines
and protocols could explain the discrepancy in results. It is pos-
sible that the SV elicited a greater response in leg extensor
strength compared to the VV machine; this has recently been
confirmed by Abercromby et al. [2]. However, other studies from
Humphries et al. [58], Kemertzis et al. [66], and Erskine et al.
[48] have indicated that acute vibration does not enhance iso-
metric or isokinetic force and claim that inhibition rather than
facilitation occurs. On the contrary, there have been reports that
vibration does increase force attributes with Warman et al. [132]
reporting that direct vibration increased isometric knee extensor
force, but no changes were seen in isometric or isokinetic force
(○ Table 7). However, using a vibration platform of 2 and 6 min
exposure (f=26Hz), Stewart et al. [120], and Jacobs and Burns
[63] have reported increases in knee isokinetic peak torque of
3.8% and 7.7% respectively and Mileva et al. [83] reported an
increase in isoinertial peak torque by 25% and 12% using loads
of 30% and 70% 1RM knee extension with a vibrating system
(f=10Hz, A=not given).
<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Group</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annino et al. [4]</td>
<td>randomised controlled</td>
<td>22 ♀ ballerinas</td>
<td>VV + ballet practice</td>
<td>SS (100°)</td>
<td>30</td>
<td>5</td>
<td>5x 40s, 3/wk, 8 wks</td>
<td>VbX increased CMJ height (6.3%), also enhanced leg-press power (8–18%), and velocity (8–26%) at loads of 50, 70, 100 kg.</td>
</tr>
<tr>
<td>Bosco et al. [13]</td>
<td>randomised</td>
<td>14 RA</td>
<td>SV standing, SS, lunge</td>
<td>26</td>
<td>10</td>
<td>5x90s, 10 days</td>
<td>VbX increased continuous (5s) mean jump height by 12%.</td>
<td></td>
</tr>
<tr>
<td>Cochrane et al. [30]</td>
<td>randomised controlled</td>
<td>12 RA (8♂, 4 ♀)</td>
<td>SV standing, SS, DS</td>
<td>26</td>
<td>11 p-p</td>
<td>5x2min, 9 days</td>
<td>No significant differences were noted in CMJ performance following VbX.</td>
<td></td>
</tr>
<tr>
<td>Delecluse et al. [42]</td>
<td>randomised controlled</td>
<td>13 ST (9♂, 4 ♀)</td>
<td>VV sprint training + VbX (DS, SS, lunge)</td>
<td>35–40</td>
<td>1.7–2.5</td>
<td>6x30–60s, 3/wk 5 wks</td>
<td>No significant changes in vertical jump height between VbX and control groups.</td>
<td></td>
</tr>
<tr>
<td>Di Giminian et al. [44]</td>
<td>randomised</td>
<td>9 (4♂, 5 ♀)</td>
<td>VV individualised SS (90°)</td>
<td>30</td>
<td>2</td>
<td>10x1min, 3x/wk, 8 wks</td>
<td>Individualised vibration frequency increased vertical jump height (11%), rebound jump height (22%) and mean power (18%) compared to fixed vibration frequency and control.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 (5♂, 5 ♀)</td>
<td>VV fixed SS (90°)</td>
<td>20–50</td>
<td>2</td>
<td>10x1min, 3x/wk, 8 wks</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 (5♂, 6 ♀)</td>
<td>VV control SS (90°)</td>
<td>0</td>
<td>0</td>
<td>10x1min, 3x/wk, 8 wks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fagnani et al. [49]</td>
<td>randomised controlled</td>
<td>13 Ath ♄ lunge (90°)</td>
<td>VV</td>
<td>35</td>
<td>4</td>
<td>3–4x20–60s 3–4x15–25s 3/wk, 8 wks</td>
<td>VbX significantly increased CMJ height (8.7%) compared to control.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 Ath ♄ control</td>
<td>sports activity</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ronnestad [108]</td>
<td>randomised controlled</td>
<td>7♂RT VV DS</td>
<td>40</td>
<td>NR</td>
<td>3x10RM 4x8RM 4x6RM</td>
<td>Squatting with and without VbX increased 1RM strength (32.4% vs. 24%) and CMJ height (8.8% vs. 4%) but no significant differences were evident between groups.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7♂RT control</td>
<td>DS</td>
<td>0</td>
<td>NR</td>
<td>2–3 x/wk, 5 wks</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**
- **Ath** = Athlete; **RT** = Resisted trained; **ST** = Sprint trained; **RA** = Recreationally active; **SV** = Side alternating vibration; **VV** = Vertical vibration; **DS** = Dynamic squat; **SS** = Static squat; **NR** = Not reported; **NA** = Not applicable; **CMJ** = Countermovement jump
**Table 5** Long-Term Effects (> 2 months) of VbX on Lower Body Power.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Exercise Type</th>
<th>Frequency (Hz) or Load</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Ruiter et al. [41]</td>
<td>randomised controlled</td>
<td>10 RA (6♂, 4♀)</td>
<td>SV</td>
<td>SS (110°)</td>
<td>30</td>
<td>8</td>
<td>3/wk, 11 wks</td>
<td>VbX failed to significantly increase vertical jump height.</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Delecluse et al. [43]</td>
<td>randomised controlled</td>
<td>18 UT ♂ 19 UT ♂ 18 UT ♀</td>
<td>VV placebo resistance</td>
<td>DS, SS, lunge DS, SS, lunge cardio + knee &amp; leg extensor strength</td>
<td>35–40 low cardio (20mins), 20RM (2wks), 15RM (3wks), 12RM (3wks), 10RM (4wks)</td>
<td>2.5–5 low</td>
<td>1–3 × 2–6 × 30–60 s (3/x/wk, 12 wks)</td>
<td>VbX significantly increased vertical jump height (7.6%) but no other changes were seen in the other conditions.</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Roelants et al. [106]</td>
<td>randomised controlled</td>
<td>24 PM ♂</td>
<td>VV</td>
<td>SS, lunge</td>
<td>35–40</td>
<td>2.5–5</td>
<td>1–3 (series) × 2–9 (type) × 30–60 s (3/x/wk, 24 wks)</td>
<td>There was no difference in the increase in isometric and dynamic knee extensor strength between VbX (15.0% and 16.1%) and resistance (18.4% and 13.9%) respectively.</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Russo et al. [110]</td>
<td>randomised controlled</td>
<td>14 PM ♂</td>
<td>SV</td>
<td>SS</td>
<td>12–28 (1 mth) 28 (5 mths) + vitamin D &amp; CaC0 supplements 3 mths prior to study</td>
<td>NR</td>
<td>3 × 1 min (1 mth) 3 × 2 min (5 mths) (2/x/wk, 6 mths, ave number of sessions attended = 34)</td>
<td>VbX significantly increased vertical jump velocity and power (5%) compared to control group.</td>
</tr>
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</tr>
<tr>
<td>Torvinen et al. [124]</td>
<td>randomised controlled</td>
<td>26 H (9♂, 17 ♀)</td>
<td>VV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>1st 2 wks = 25–30 (2 min) 1.5 mths = 25–35 (3 min) 2 mths = 25–35 (4 min)</td>
<td>2</td>
<td>3–5 × /wk, 4 mth</td>
<td>At 2 and 4 months VbX significantly increased CMJ height (10.2%, 8.5%) compared to control.</td>
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<tr>
<td>Torvinen et al. [125]</td>
<td>randomised controlled</td>
<td>27 H (9♂, 18 ♀)</td>
<td>VV</td>
<td>DS, jumping, standing on heels, standing erect current physical activity</td>
<td>1st 2 wks = 25–30 (2 min) 1.5 mths = 25–35 (3 min) 2 mths = 25–40 (4 min) 4 mths = 30–45 (4 min)</td>
<td>2</td>
<td>3–5 × /wk, 8 mth</td>
<td>VbX increased CMJ height (7.8%) compared to control.</td>
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</tr>
</tbody>
</table>

H = Healthy; UT = Untrained; RA = Recreationally active; PM = Postmenopausal; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat; CMJ = Countermovement jump

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### Table 6: Acute Effects of VbX on Upper Body Force.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cochrane &amp; Hawke [29]</td>
<td>randomised cross-over</td>
<td>12 Climbers</td>
<td>DB</td>
<td>unilateral upper body exercises</td>
<td>26</td>
<td>3</td>
<td>5 × 60s</td>
<td>VbX produced no significant changes in hand grip strength, and specific climbing strength.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5♀, 7♂)</td>
<td>arm crank</td>
<td>unilateral upper body exercises</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>arm crank</td>
<td>arm crank</td>
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</tr>
<tr>
<td>Cochrane &amp; Stannard [32]</td>
<td>randomised cross-over</td>
<td>16 EL (♀)</td>
<td>SV</td>
<td>DS, SS, lunge, press up</td>
<td>26</td>
<td>6</td>
<td>5 × 1 min</td>
<td>VbX showed no significant increased in grip strength.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>DS, SS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kin Isler et al. [68]</td>
<td>randomised</td>
<td>10 RA (♀)</td>
<td>DV -6 Hz</td>
<td>90, 120, 150° elbow flexion</td>
<td>6</td>
<td>4</td>
<td>5 × 60s</td>
<td>VbX at 6, 12 and 24Hz of vibration resulted in increased isometric MVC. 48Hz VbX resulted in decreased isometric MVC. In addition, the length of the contracting muscle did not affect the vibration load that was applied with different frequencies.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>DS, jumping, standing on heels, standing erect</td>
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</tr>
<tr>
<td>Torvinen et al. [123]</td>
<td>randomised cross-over</td>
<td>16H (♀)</td>
<td>SV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>15–30</td>
<td>10</td>
<td>4 min</td>
<td>There was no significant changes in grip strength.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>DS, jumping, standing on heels, standing erect</td>
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</tr>
<tr>
<td>Torvinen et al. [126]</td>
<td>randomised cross-over</td>
<td>16H (♀)</td>
<td>VV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>25–40</td>
<td>2</td>
<td>4 min</td>
<td>There was no significant changes in grip strength.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>control</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

H = Healthy; EL = Elite; RA = Recreationally active; DV = Direct vibration; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat.
### Table 7  Acute Effects of Lower Body Force.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Conditions</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Ruiter et al. [40]</td>
<td>randomised controlled</td>
<td>10 RA (6♂, 4♀)</td>
<td>SV SS (110°)</td>
<td>30</td>
<td>8</td>
<td>5 × 60s</td>
<td>Maximum force-generating capacity and isometric contraction significantly declined after VbX.</td>
<td></td>
</tr>
<tr>
<td>Erakine et al. [48]</td>
<td>randomised cross-over</td>
<td>7 H♂</td>
<td>VV SS (half-squat)</td>
<td>30</td>
<td>4</td>
<td>10 × 60s</td>
<td>VbX significantly reduced maximal isometric knee extensor force immediately (9.2%), 1h (8.3%), 2h (7.7%) post VbX. No change in rate of torque development.</td>
<td></td>
</tr>
<tr>
<td>Humphries et al. [58]</td>
<td>controlled</td>
<td>16 H (19♂, 9♀)</td>
<td>DV isometric (120°)</td>
<td>50</td>
<td>5</td>
<td>30s</td>
<td>Isometric force, peak rate of force development, rate of force development of peak force were not significantly different.</td>
<td></td>
</tr>
<tr>
<td>Jacobs &amp; Burns [63]</td>
<td>randomised cross-over</td>
<td>20 UT (10♂, 10♀)</td>
<td>SV SS</td>
<td>26</td>
<td>NR</td>
<td>6 mins</td>
<td>VbX significantly increased peak (7.7%) and average (9.6%), isokinetic torque of knee extension compared to cycling.</td>
<td></td>
</tr>
<tr>
<td>Kemertzis et al. [66]</td>
<td>randomised cross-over</td>
<td>12 H♂</td>
<td>SV static ankle plantar-flexion</td>
<td>26</td>
<td>4–4.5</td>
<td>5 × 1 min</td>
<td>A significant (41%) decrease in the angle of peak plantar-flexor torque occurred after VbX compared to no VbX. No significant changes in plantarflexor ROM or peak torque were found after VbX.</td>
<td></td>
</tr>
<tr>
<td>Mileva et al. [83]</td>
<td>randomised</td>
<td>12 H♂</td>
<td>35% 1RM + VbX knee extension</td>
<td>10</td>
<td>NR</td>
<td>4 sets × 8 reps</td>
<td>During 1RM tests, muscle dynamic strength was significantly higher during VbX than nonvibrated trials, and strength was significantly higher post- than pre-exercise except during 35% 1RM-VbX.</td>
<td></td>
</tr>
<tr>
<td>Torvinen et al. [123]</td>
<td>randomised cross-over</td>
<td>16 H (8♂, 8♀)</td>
<td>SV DS, jumping, calf raise, standing</td>
<td>15–30</td>
<td>10</td>
<td>4 min</td>
<td>VbX significantly increased isometric leg extension force (3.2%) compared to control.</td>
<td></td>
</tr>
<tr>
<td>Torvinen et al. [126]</td>
<td>randomised cross-over</td>
<td>16 H (8♂, 8♀)</td>
<td>VV DS, jumping, calf raise, standing</td>
<td>25–40</td>
<td>2</td>
<td>4 min</td>
<td>There was no significant changes in isometric leg extension force following VbX.</td>
<td></td>
</tr>
<tr>
<td>Warman et al. [132]</td>
<td>controlled</td>
<td>28 H (19♂, 9♀)</td>
<td>DV knee isometric (120°)</td>
<td>50</td>
<td>5</td>
<td>30s</td>
<td>No significant improvements in isometric and isokinetic force were evident.</td>
<td></td>
</tr>
</tbody>
</table>

H = Healthy; UT = Untrained; RA = Recreationally active; DV = Direct vibration; NA = Not applicable; NR = Not reported; DS = Dynamic squat; SS = Static squat; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat

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The discrepancy of the above findings could be due to the various protocols used for testing vibration. These include different methods of vibration, types and parameters of muscle contraction, and duration and frequency of vibration, as well as the muscle contraction velocities and variables.

**Short-term vibration (<2 months) – Upper body force**

A summary of the studies that examined the short- and long-term effects of vibration on upper and lower body force can be found in Table 8, 9. Using an electric motor to transmit eccentric oscillations (f=44Hz, A=3mm) to a cable system a series of seated bench-pull repetitions were performed by male physical education students at 80–100% 1RM for 3 weeks (3x/week) while control groups performed the same resistance routine without vibration or performed calisthenics [59]. The researchers found that by combining vibration with force the 1RM bench-pull significantly increased by 50% compared to a 16% improvement by the conventional resistance group, with no change being reported in the calisthenics group.

In a recent upper-body study by Silva et al. [119], untrained participants (24yrs) were either assigned to isometric bicep training (12 MVCs, 6s in duration) without or with vibration (f=8Hz, A=6mm). The participants were seated with elbow flexed at 90°, and vibrations were produced by an amplifier connected to a steel cable with a hand grip that was applied in the opposite direction of muscle shortening. After 4 weeks of training (3 days/week) there was a significant increase of 26% bicep MVC from the group that received isometric and vibration compared to isometric alone (10% increase bicep MVC).

**Short-term vibration (<2 months) – Lower body force**

Short-term vibration on lower-body force has produced mixed results with de Ruiter et al. [40, 41] and Delecluse et al. [42] reporting no increase in muscle force from short-term vibration training. De Ruiter et al. [40] reported that MVC and maximal force-generating capacity with and without muscle stimulation of knee extensors were not enhanced after 11 weeks (3x/week) of intermittent vibration (f=30Hz, A=8mm, SV [Galileo]). Delecluse et al. [42] found that 5 weeks of vibration (f=35–40Hz, A=1.7–2.5mm, VV [Power Plate]) failed to potentiate isometric and dynamic knee extensor and flexor strength in well-trained sprinters.

Increases in force from VbX have been reported from Mahieu et al. [77] and Fagnani et al. [49]; both studies observed an increase in torque post-vibration. Mahieu et al. [77] noted an increase in isokinetic torque of ankle plantar flexors of young skiers after 6 weeks (3x/week) of vibration training (f=24–28Hz, A=2–4mm, VV [FitVibe]). Fagnani et al. [49] reported a 12.2% in isokinetic knee extensor in trained female athletes after 8 weeks (3x/week) intermittent vibration protocol (f=35Hz, A=4mm, VV [Nemes]). Both studies failed to compare vibration with the appropriate controls of performing the same activity with and without vibration. However, Ronnestad et al. [108] compared 5 weeks (2–3x/week) of weighted squats (6–10RM) with vibration (f=40Hz, A=not given) and without vibration. They reported a 32% increase in 1RM squat from vibration, but it was not significantly different from the 24% increase in 1RM squat without vibration. The differences in vibration duration, amplitude, frequency, muscle groups, and vibration machines used in the aforementioned studies, may account for the discrepancy in results.

**Long-term vibration (>2 months) – Lower body force**

Torvinen et al. [124,125] conducted 2 separate studies on the long-term effects of vibration (f=25–35Hz, A=2mm, VV [Kontorary]) performed over 4 and 8 months in healthy young participants (19–38yrs). In the 4 month study [124] the authors found that isometric knee extensor strength improved by 3.7%, at 2 months compared to the control condition, but no further improvements were evident at 4 months. Likewise, after 8 months [125] vibration had produced no significant differences in isometric knee extensor strength. Therefore, the vibration stimulus of frequency, amplitude, and duration may have not been effective in eliciting the desired neuromuscular responses.

Ideally, the additional load should have been included in the latter stages of an 8 months’ programme, which could have been achieved by progressively increasing body mass with external loads of a weighted vest or belt. Additionally, all of Torvenien’s studies [123–126] have included an exercise routine of light squatting, light jumping and standing performed in addition to the vibration stimulus; however, this routine has never been quantified in terms of load or cadence. Similarly, the dynamic nature of the protocol could have inhibited the vibratory stimulus to realise its full potential.

To overcome the shortcomings of Torvenien’s studies [123–126] Delecluse et al. [43] devised a 12 week (3x/week) periodised training plan, where vibration frequency, amplitude, exercise duration, load, sets and reps were progressively and systemically overloaded. 74 untrained females were randomly allocated to: 1) vibration (f=35–40Hz, A=2.5–5mm, a=2.3–5.1g VV [Power Plate]); 2) cardio-resistance training; 3) placebo (very small amount of vibration a=0.4g VV, [Power Plate]); and 4) control. A 16% and 9% increase of isometric and dynamic knee force were observed in the vibration group, which was similar to the resistance training group (14% and 7% respectively), but significantly different to placebo and control groups.

Roelants et al. [106] reported similar findings, that in older post-menopausal women (64yrs) isometric knee extensor strength increased by 15% and isokinetic strength by 16% from 24 weeks of vibration training (f=35–40Hz, A=2.5–5mm, VV [Power Plate]), however there was no significant difference in the respective increase found in the resistance training group. In a follow-up study using untrained females, this research group [69] confirmed their earlier findings of isometric and isokinetic knee extensor force, but they also noted that the increases were not significantly different from those who did a combined cardio and leg-strength programme.

The same research group [9] conducted a year-long study on older men (67yrs) and repeated the same protocol, and observed that vibration increased muscle mass and isometric force but it was not significantly different from performing a combined cardio, strength, balance, and flexibility programme. Finally, Kvorring et al. [69] reported that after 9 weeks (2–3x/week) of weighted squats with vibration (f=20–25Hz, A=4mm, SV [Galileo 2000]) isometric leg press strength produced an increase of 9.3% which was comparable to the 12% increase in leg strength from weighted squats without vibration. Therefore, combining vibration with squats was no more beneficial than weighted squatting alone.

In summary, it is not conclusive whether acute vibration increases force attributes. This has been fraught by the type and parameters used for various muscle contractions, and the different sample populations that have varied in chronological age, experience and training status. Furthermore, the debate sur-
# Table 8  
Short-Term (≤ 2months) Effects of VbX on Upper & Lower Body Force.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Exercise Type</th>
<th>Frequency (Hz)</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Issurin et al. [59]</td>
<td>randomised controlled</td>
<td>10 RA ♂</td>
<td>conventional strength +</td>
<td>bench pull</td>
<td>NA</td>
<td>NA</td>
<td>bench: 6 × 80–100 % 1RM</td>
<td>VbX significantly increased bench pull force (50%) compared to conventional training (16%) and control (no change).</td>
</tr>
<tr>
<td>8 RA ♂</td>
<td>VbX (cable) flexibility</td>
<td>leg ring flexibility</td>
<td>44</td>
<td>3</td>
<td>flex: 6 × 40–90 s (3wks; 3/wk)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VbX (cable) strength +</td>
<td>bench pull</td>
<td>44</td>
<td>3</td>
<td>bench: 6 × 80–100 % 1RM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 RA ♂</td>
<td>control</td>
<td>calisthenics, jogging and/or &amp; basketball</td>
<td>NA</td>
<td>NA</td>
<td>55 min (3wks; 3/wk)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silva et al. [119]</td>
<td>randomised controlled</td>
<td>9 UT ♂</td>
<td>VbX (cable)</td>
<td>elbow isometric MVC (45°)</td>
<td>8</td>
<td>6</td>
<td>12 MVC, 6s 3/wk, 4 wks VbX + elbow isometric increased MVC force significantly (26%) compared to conventional isometric elbow training (10%).</td>
<td></td>
</tr>
<tr>
<td>10 UT ♂</td>
<td>control</td>
<td>elbow isometric MVC (45°)</td>
<td>0</td>
<td>0</td>
<td>12 MVC, 6s 3/wk, 4 wks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delecluse et al. [42]</td>
<td>randomised controlled</td>
<td>13 ST (9♂, 4♀)</td>
<td>VV</td>
<td>ST + VX (DS, SS, lunge)</td>
<td>35–40</td>
<td>1.7–2.5</td>
<td>6 × 30–60 s; 5 wks (3/wk) VbX did not significantly increase isometric or dynamic knee extensor and flexor force.</td>
<td></td>
</tr>
<tr>
<td>12 ST (9♂, 3♀)</td>
<td>control</td>
<td>ST</td>
<td>NA</td>
<td>NA</td>
<td>5 wks (3/wk)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fagnani et al. [49]</td>
<td>randomised controlled</td>
<td>13 RA ♀</td>
<td>VV</td>
<td>lunge (90°)</td>
<td>35</td>
<td>4</td>
<td>3–4 × 20–60 s 3–4 × 15–25 s 3/wk, 8 wks VbX significantly increased isokinetic leg press peak force (9.3%) and total work (11.2%) compared to control.</td>
<td></td>
</tr>
<tr>
<td>11 RA ♀</td>
<td>control</td>
<td>sports activity</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mahieu et al. [77]</td>
<td>randomised controlled</td>
<td>17 skiers</td>
<td>VV</td>
<td>DS, calf raises, jumping, ski movements</td>
<td>24–28</td>
<td>4–6</td>
<td>3/wk, 6 wks Both VbX and resistance increased isokinetic concentric knee flexor &amp; extensor (60°/s, 180°/s), and concentric ankle plantar- &amp; dorsiflexion (30°/s, 120°/s). However, only ankle plantar-flexion (30°/s) was significantly higher in VbX compared to resistance.</td>
<td></td>
</tr>
<tr>
<td>16 skiers</td>
<td>resistance</td>
<td>DS</td>
<td>calf raises, jumping, ski movements</td>
<td>0</td>
<td>0</td>
<td>3/wk, 6 wks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ronnestad [108]</td>
<td>randomised controlled</td>
<td>7 ♂RT</td>
<td>VV</td>
<td>DS</td>
<td>40</td>
<td>NR</td>
<td>3 × 10RM 4 × 8RM 4 × 6RM Squatting with and without VbX increased 1RM squat strength.</td>
<td></td>
</tr>
<tr>
<td>7 ♀RT</td>
<td>control</td>
<td>DS</td>
<td>0</td>
<td>NR</td>
<td>2–3 × /wk, 5 wks</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ST = Sprint trained; UT = Untrained; RA = Recreationally active; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat; MVC = Maximal voluntary contraction; RT = Resisted trained; NR = Not reported; NA = Not applicable
### Table 9: Long-Term (≥2 months) Effects of VbX on Lower Body Force.

<table>
<thead>
<tr>
<th>Author</th>
<th>Type of Study</th>
<th>Participants</th>
<th>Groups</th>
<th>Exercise Type</th>
<th>Frequency (Hz) or Load</th>
<th>Amplitude (mm)</th>
<th>Duration</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogaerts et al. [10]</td>
<td>randomised controlled</td>
<td>31 O ♂</td>
<td>VV</td>
<td>DS, lunge, calf raise</td>
<td>35–40</td>
<td>2.5–5</td>
<td>4–15 exercises</td>
<td>3 ×/wk 12 mths</td>
</tr>
<tr>
<td>Delecouse et al. [43]</td>
<td>randomised controlled</td>
<td>18 UT ♂</td>
<td>VV</td>
<td>DS, S5, lunge</td>
<td>35–40</td>
<td>2.5–5</td>
<td>1–3 × 2–6 × 30–60 s (3 ×/wk, 12 wks)</td>
<td>VbX significantly increased.</td>
</tr>
<tr>
<td>Kvoring et al. [69]</td>
<td>randomised controlled</td>
<td>9 RA ♂</td>
<td>SS, lunge</td>
<td>SS, lunge</td>
<td>35–40</td>
<td>2.5–5</td>
<td>1–3 (series) × 2–9 (type) × 30–60 s (3 ×/wk, 24 wks)</td>
<td>There was no difference in the increase in isometric knee extensor force between VbX (15.0%) and resistance (18.4%) group.</td>
</tr>
<tr>
<td>Roelants et al. [106]</td>
<td>randomised controlled</td>
<td>24 PM ♂</td>
<td>VV</td>
<td>SS, lunge</td>
<td>35–40</td>
<td>2.5–5</td>
<td>1–3 ×/wk, 9 wk</td>
<td>Squat and VbX + squat increased isometric leg press force 12.1% &amp; 9.3% respectively but no differences were evident between control groups.</td>
</tr>
<tr>
<td>Torvinen et al. [124]</td>
<td>randomised controlled</td>
<td>26H (9♂, 17 ♀)</td>
<td>VV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>1st 2 wks = 25–30 (2 min)</td>
<td>2</td>
<td>3–5 ×/wk, 4 mths</td>
<td>At 2 months VbX significantly increased isometric leg extensor force (3.7%) compared to control, but no differences were seen at 4 mths.</td>
</tr>
<tr>
<td>Torvinen et al. [125]</td>
<td>randomised controlled</td>
<td>27H (9♂, 18 ♀)</td>
<td>VV</td>
<td>DS, jumping, standing on heels, standing erect</td>
<td>1st 2 wks = 25–30 (2 min)</td>
<td>2</td>
<td>3–5 ×/wk, 8 mths</td>
<td>VbX increased evident in isometric leg extensor force but it was no different to the control.</td>
</tr>
</tbody>
</table>

O = Older; PM = Postmenopausal; UT = Untrained; A = Recreationally Active; SV = Side alternating vibration; VV = Vertical vibration; DS = Dynamic squat; SS = Static squat; H = Healthy
rounding the length-tension proposal that muscle must be lengthened in order to benefit from vibration has caused confusion. However, recent evidence suggests that when vibration was applied at 120° knee flexion, which maximises the limb’s greatest mechanical advantage, no increases in force were evident. Moreover, vibration applied to concentrically active muscle has shown to improve muscle force, which cannot explain the length-tension relationship. There may also be an optimal contraction velocity where vibration is most effective, and testing the effect of vibration on self-selected isokinetic contraction velocities warrants further investigation. Overall, acute Vbx has a greater beneficial effect on power and force than short- and long-term studies, this could be due to the lack of knowledge surrounding the optimal method of periodising, loading, and progressing Vbx variables in way that will sufficiently stimulate the musculoskeletal system. Currently there is a lack of scientific-based, short- and long-term Vbx-training programmes. Secondly the acute exposure of Vbx may provide a myogenic and neurogenic potentiation that reaches a threshold, which diminishes rapidly over an extended period of time, suggesting that Vbx acts similar to a warm-up effect that may be promoted by post-activation potentiation.

The effects of vibration exercise on compromised health

Multiple Sclerosis
Multiple Sclerosis (MS) is a demyelinating disease of the central nervous system where decreases in power and strength can impair functional performance along with sensory losses, and visual disturbances. Shuhfried et al. [115] reported that MS patients undertaking acute intermittent Vbx (f=2–4.4 Hz, A=3 mm, [Zep- tor-Med]) improved timed get up and go test compared to the placebo group that performed transcutaneous electrical nerve stimulation of the forearm, however no improvement in functional reach test was found. In a randomised cross over study where MS patients received 30 s of low frequency (f=2Hz, A=6 mm) and high frequency (f=26, A=6 mm, SV [FitVib]) there was a trend for higher torque in the quadriceps and hamstrings that Vbx may provide a myogenic and neurogenic potentiation that reaches a threshold, which diminishes rapidly over an extended period of time, suggesting that Vbx acts similar to a warm-up effect that may be promoted by post-activation potentiation.

Stroke
Stroke can impact on motor function and impair balance, gait and reduce voluntary strength [122]. To date, 2 studies have reported favourable findings of using Vbx for stroke patients. Using a force platform to measure the centre of pressure, postural control, Stroke patients improved their function from an intermittent exposure (4x45 s) of Vbx (f=30Hz, A=3 mm, SSV [Galileo 900]) [129], Tihanyi et al. [122] found that an intermittent exposure (6x60 s) of Vbx (f=20Hz, A=5 mm, VV [Nemes]) improved isometric and eccentric knee extension torque, along with corresponding increase in EMG amplitude of the vastus lateralis compared to a control (no vibration). Conversely, a 6 week vibration study performed 5x/week of 4x45 s (f=30Hz, A=3 mm, SSV [Galileo 900]) reported no significant differences in balance and functional activities between vibration group and those who performed exercise therapy to music [129].

Parkinson’s Disease
Favourable results have been reported from patients suffering from Parkinson’s disease (PD). Turbanski et al. [128] found that intermittent vibration (5x60 s) exercise (f=6Hz, A=3 mm, [Zep- tor-Med]) improved postural stability of tandem standing as measured by Coorden platform system compared to control. Haas et al. [53], reported that PD patients exposed to intermittent (5x60 s) Vbx (f=6Hz, A=1 mm, Zepotor-Med system) significantly improved their motor score by 17% from a rating scale (Unified Parkinson’s Disease Rating Scale). However, the same investigator [52] found no improvement in proprioception from intermittent Vbx (f=6Hz, A=not given, SRT-medical system) compared to control. Conversely, Ebersbach et al. [47] reported a significant improvement in balance score (Tinetti Balance) from PD patients performing Vbx (f=not given, irregular low frequency administered A=not given, SV [Galileo 2000]) 2x/week for 3 weeks, however conventional balance training improved by the same margin.

Age-related aspects of the elderly
There have been positive effects of using Vbx to improve balance in older people [7,10,28,130]. Recently Rees et al. [96] have reported benefits for older people (73 yrs) completing 2 months (3x/week) of Vbx (f=26Hz, A=5–8 mm, SSV [Galileo]) with improvements in chair-rising time, timed-up-and-go test and faster walking speed, but, these increases were comparable to the exercise group that performed the same exercises without vibration. However, Vbx did significantly increase ankle plantar flexion compared to the conventional exercise group but this did not correspond to enhanced physical performance. Kawanabe et al. [65] found that continuous (4 min) Vbx (f=12–20Hz, A=not given, SV [Galileo]) performed 1x/week for 2 months significantly improved 10 m walk time, step length and the maximum standing time on one leg (right and left) in older participants (72 yrs) compared to an exercise routine performed without vibration. However, this experiment was not a randomised controlled study as the choice to have Vbx was determined by the participants. Moreover the study lacked documentation on how the vibration frequency was progressed and the number of reps and sets that were performed by the participants. Bogaerts et al. [9] reported that in older males (60–80 yrs) isometric knee extensor strength, Vj height and muscle mass increased significantly by 9.8%, 10.9%, and 3.4% after 12 months (3x/week) of Vbx (f=35–40Hz, A=2.5–5 mm, VV, [Power Plate]). However, these increases were not significantly different from performing a combined cardiovascular, strength, balance, and flexibility programme conducted over the same duration.

Postmenopausal women
Long-term Vbx studies (≥6 months) have shown that balance, postural sway and muscle power is significantly enhanced in postmenopausal women [51,110,130]. Additionally, isometric (knee joint=130°), isokinetic strength (100°/s) and Vj height have been reported to increase after 6 months of Vbx

(f=35–40 Hz, VV, [Power Plate]), in postmenopausal women [106,130]. Raimundo et al. [95] conducted an 8 month study where 27 postmenopausal women (66 yrs) were randomly assigned to VbX (f = 12.6 Hz, A = 6 mm, Galileo [SV]) or a walk programme (60 min, 70–75% MHR) performed 3x/week. The researchers reported that the walk programme significantly improved 4 m walk time, and chair rise test more than VbX, however VbX had a significant effect of increasing VJ, but neither intervention improved knee isokinetic strength. This finding is not surprising given that only a low frequency dose was used during the 8 months and the vibration frequency was not progressively increased over the course of the study.

Other VbX (f=20–25 Hz, A = 3 mm, SSV [Galileo 2000]) performed 5x/week for 3 months has been shown to improve muscular performance in Cystic Fibrosis (CF) of chair rising time, peak jump force and velocity, but no changes were found in forced expiratory volume and forced vital capacity [99]. In women with Fibromyalgia a significant improvement in pain and fatigue was recorded from receiving intermittent VbX (f=30Hz, A = 2 mm, VV [Power Plate]) 2x/week for 6 weeks compared to exercise (salsa dancing, stretching and relaxation techniques) and control groups.

In a recent study conducted by Lauper et al. [71] they investigated pelvic floor stimulation using 2 different types of vibration platforms, SV (Galileo 900) and stochastic resonance vibration (SRV) (Zeptor-Med) which has 2 separate footplates which vibrate vertically and independently. Using an intravaginal surface EMG electrode the researchers reported that the SRV (f=2, 4, 6, 8, 10, 12 Hz, A = 3 mm) activated the pelvic floor muscles significantly more than SV (f=5,15,25 Hz, A = 2 & 4 mm) and initiated a higher pelvic floor activation than maximum contraction alone in post-partum compared to healthy controls. However, it is unknown whether this increase in muscle activation can lead to an increase in functional performance and whether symptoms of poor pelvic floor activation can be alleviated.

It is unclear if VbX is beneficial for those with osteoarthritis as there has been limited research conducted in this area. Trans et al. [127] randomly allocated patients suffering from knee osteoarthritis to VbX, conventional balance and control groups. The results showed a non-significant (p = 0.051) improvement in proprioception from intermittent (6–9 x 30–70 s) VbX (f=25–30Hz, A = not given, [VibM]) with an increase in knee extensor strength. But those performing balance board with an implanted vibratory device showed a significant increase in proprioception, with no knee strength increases.

There is some evidence to suggest that cardiovascular or aerobic exercise may be able to enhance glycemic control in type II diabetics [89,117], and that resistance training may be a possible treatment to fight metabolic diseases [17,27,46]. Di Loreto et al. [45] found that intermittent VbX (f=30Hz, A = ±4 mm, VV, [Nemes]) decreased plasma glucose levels which may indicate that glucose is transported into the muscle by VbX, which may be of benefit to diabetics. In a study that randomised type 2 diabetics into resistance, vibration, and flexibility groups, the researchers reported that intermittent VbX (f=30–35Hz, A = 2 mm, VV [VibroGym]) performed 3x/week for 12 weeks had no effect on isometric knee extension, while fasting glucose levels, plasma glucose concentration from an oral ingestion of 75g of glucose drink and haemoglobin showed reductions but were not significant from baseline measures [6].

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