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Whole-Body Vibration Approaches in Neurological Disorders

Mario Bernardo-Filho, Danúbia da Cunha de Sá-Caputo, Adérito Seixas and Redha Taiar

Abstract

Bipedalism in humans is associated with an upright spine, however, this condition is not found in other animals with that skill. This may have favored the ability to harness the influence of the gravitational forces on the body. Furthermore, it is suggested that human feet have evolved to facilitate bipedal locomotion, losing an opposable digit that grasped branches in favor of a longitudinal arch that stiffens the foot and aids bipedal gait. Gait is a repetition of sequences of body segments to move the body forward while maintaining balance. The bipedal gait favors the contact of the feet of the individual with the floor. As a result, the mechanical vibration (MV) generated during walking, running or other activity with the feet are, normally, added to the body. In these various situations, the forces would induce the production of MV with consequent transmission to the whole body of the individual and there is the generation of whole-body vibration (WBV) exercise naturally. However, when a person has a disability, this normal addition of the MV to body does not occur. This also happens with the sedentary or bedridden individual due to illness. In this case, there are the MV yielded in vibrating platforms. The exposure of the individual to the WBV leads to physiological responses at musculoskeletal, neurological, endocrinological, and vascular levels. Considering the state of the art of this theme and the previously cited scientific information, it is plausible to assume that WBV could be a useful tool to be used on the management of individuals with neurological conditions, such as in Parkinson's disease, stroke, cerebral palsy, multiple sclerosis, spinal cord injuries, spinocerebellar ataxia and Duchenne muscular dystrophy, and neuropathy (diabetes- and chemotherapy-related), among others. Indeed, improvements due to the WBV have been described regarding motor, and other impairments, in patients with neurological conditions, and these approaches will be presented in this chapter.

Keywords: neurological diseases, whole-body vibration, clinical intervention, bipedalism, gait

1. Introduction

Bipedalism in humans is associated with an upright spine, however, this condition is not found in other animals with that skill. This may have favored the ability to harness the influence of the gravitational forces on the body [1].

Moreover, Bernardo-Filho et al. [2] have suggested that the increase of the load transmitted to the body due to the bipedal movement could be associated with the evolution of human beings on our planet. Furthermore, it is suggested that human feet have evolved to facilitate bipedal locomotion, losing an opposable digit that grasped branches in favor of a longitudinal arch that stiffens the foot and aids bipedal gait [3].

The Biomechanical bipedal gait involves several steps, as it is shown in **Figures 1** and 2. Gait action can be defined as a displacement consisting on the translation of the whole body, following rotational movements. Gait is a repetition of sequences of body segments to move the body forward while maintaining balance. Walking is a complex locomotor task that depends on the satisfactory functioning of the locomotor system at all levels. It also depends on other factors such as age, size, morphology, speed. Gait is a cyclic motor activity that alternates a supporting phase (foot in contact with the ground) and an oscillating phase (no foot contact with the ground). The locomotor cycle (stride) represents all the articular and muscular events that occur between two successive strides on the ground [4].

Biomechanically, this cycle can be divided in two phases, the support or stance phase (the limb is in contact with the ground) and the transfer phase (swing phase) called oscillation or rocking phase (the limb moves above the ground). The support phase represents 60% of the gait cycle and the swing phase 40% of the gait cycle. Whether it is for the support phase or the swing phase, several sub-phases can be described [5].

The loading phase (0 to 10% of the running cycle). This phase begins with the initial contact of the foot with the ground (0 to 2%) and is determined by the lifting of the opposite foot (first bipodal support). The role is to transfer weight to the leg during the support phase, absorb shocks and maintain walking speed while maintaining balance. The middle support phase (10 to 30% of the gait cycle). This is the first half of the unipodal support. It allows the body to move forward over the supported foot and ends when the body's center of gravity is aligned with the fore-foot. The end phase (30 to 50% of the gait cycle) is the second half of the unipodal support. This phase allows the body to move forward until the opposite foot touches the ground. The pre-oscillating phase (50 to 60% of the gait cycle). This phase corresponds to the second bipodal support. The role is to propel the body forward with the transfer of weight to the leg during the support phase. The oscillation start phase (60 to 73% of the gait cycle). It corresponds to the first third of the oscillation phase and ends when the foot passes by the contralateral foot. The role of this phase and the two following phases is to allow the oscillating limb to advance without contact with the ground. The middle phase of oscillation (73 to 86% of the gait cycle) and corresponds to the second third of the oscillating phase. It ends when the tibialis is vertical. Follow, the oscillation end phase (86 to 100% of the walking cycle). This phase corresponds to the third of the oscillating phase. According to

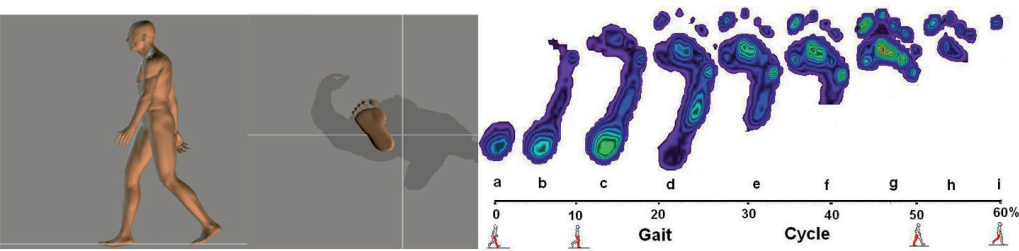


Figure 1. Musculoskeletal complex system represented by the association of segmental movement and the complicated contact with the ground during the gait cycle. The pressure zones indicate the solicited zones during gait.

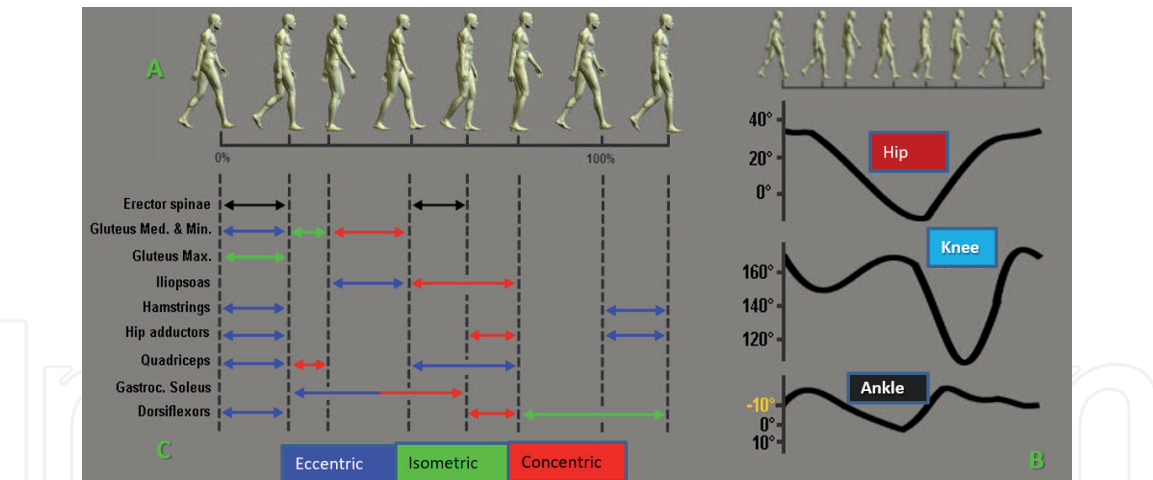


Figure 2.
Kinematics and kinetics of the normal gait.

the above description, gait movement, must have integrated and complex actions of the neuro-musculoskeletal system, and when there are dysfunctions or disabilities related to this system, the gait movement is impaired [6].

The bipedal gait favors the contact of the feet of the individual with the floor [7]. As a result, the mechanical vibration (MV) generated during walking, running or other activity with the feet are, normally, added to the body. Cardinale and Wakeling [8], have pointed out that in the sporting activities the body interact with the external environmental and experience the action of external forces. In these various situations, the forces would induce the production of MV with consequent transmission to the whole body of the individual and there is the generation of whole-body vibration (WBV) exercise naturally. In consequence, as it would be expected, this addition of mechanical vibration has been important to the life and desirable physiological responses occur. However, when a person has a disability, this normal addition of the MV to body does not occur. This also happens with the sedentary or bedridden individual due to illness. In this case, there are the MV yielded in vibrating platforms, which types can be side alternating or vertical [9–15].

MV is a physical agent and, as a vibratory stimulus, has oscillatory and sinusoidal displacement in relation to an equilibrium position. Furthermore, the MV produced in the vibrating platform has also deterministic displacement. In consequence, it is possible to establish the biomechanical parameters, such as frequency, peak-to-peak displacement and peak acceleration to define personalized and controlled protocols that will be used in WBV exercise interventions, as it pointed out in **Table 1** [16, 17]. In a MV, the displacement between two successive points is named the cycle, without a dimension. The number of the cycles in a considered

Biomechanical	Temporal
Frequency	Work time
Peak-to-peak displacement	Rest time
Peak acceleration	Number of sessions and time of each session
	Number of bouts in a session and the time of each bout
	Total time of the intervention
	Week periodicity

Table 1.
Biomechanical and temporal parameters to be considered in the protocols of whole-body vibration exercises.

time is the frequency, that might express in cycle per second (s^{-1}), that is the Hertz (Hz). The displacement of the mechanical vibration has two peaks, a higher and a lower, and the vertical distance between these peaks is the peak-to-peak displacement, measured, for example, in mm. In the highest peak, it is found the maximal rate of change in velocity during a cycle, the highest acceleration, that can be used to characterize the intensity of the exposition, that is the magnitude effect. As an acceleration, it is measured directly in m/s^2 , or in number of times of the Earth acceleration ($\times g$).

In the protocols involving WBV exercises, temporal parameters would be also considered, as it is also indicated in **Table 1**.

The exposure of the individual to the whole-body vibration leads to physiological responses at musculoskeletal, neurological, endocrinological, and vascular levels, as is shown in **Figure 3**.

The comprehension of these responses is important to clarify about the relevance of the whole-body vibration also to the management of individuals with several clinical conditions, such as, chronic obstructive pulmonary disease and pelvic floor, metabolic (metabolic syndrome, obesity, diabetes) and musculoskeletal disorders [2, 15, 18]. Furthermore, the individuals with neurological commitments have been also treated with interventions with whole-body vibration [11, 15, 19].

In general, related to the musculoskeletal level, whole-body vibration increases the muscle strength and the bone mineral density, endurance, and power; improves the balance and decreases the risk of falls and fractures. Furthermore, whole-body vibration also improves functionality, with an increase of the range of motion of the joints, flexibility, and improvement in gait parameters, such as gait speed [13, 15, 20–22].

Whole-body vibration induced through mechanical stimulus also induces endocrinological responses, increasing the concentration of various plasma biomarkers [23]. Furthermore, the improvement of the peripheral circulation with increase of the blood cells velocity [24–26] and peripheral microcirculation [27, 28] is relevant to facilitate the recovery of undesirable conditions related to the vascular system.

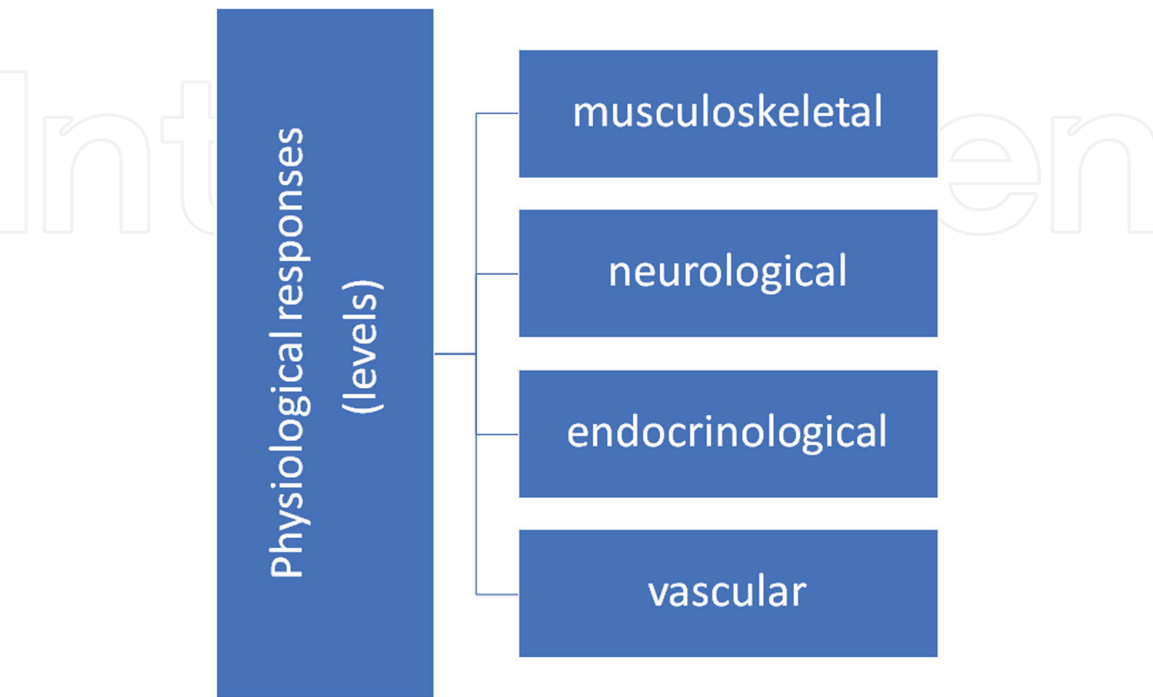


Figure 3.
Possible physiological responses to the exposure to whole-body vibration.

The purpose of this chapter was to show, considering the state of art of the theme and the scientific information, it is plausible to assume that whole-body vibration could be a useful tool to be used on the management of individuals with neurological conditions, such as in Parkinson's disease, stroke, cerebral palsy, multiple sclerosis, spinal cord injuries, spinocerebellar ataxia and Duchenne muscular dystrophy, and neuropathy (diabetes- and chemotherapy-related), among others. Indeed, improvements due to the whole-body vibration have been described regarding motor, and other impairments, in patients with neurological conditions [11, 29].

Considering the scientific information, accessed in relevant databases (PubMed, EMBASE, and SCOPUS), about the use of whole-body vibration on the management of individuals with neurological diseases, some publications were selected and used in this chapter.

2. Whole-body vibration exercise in stroke individuals

Stroke is defined as an event that blood supply to part of your brain is reduced or interrupted, leading to brain tissue from getting oxygen and nutrients. In this situation the brain cells can die in minutes. This condition needs an early action to reduce brain damage and other complications [30].

There are three types of strokes: i) ischemic stroke, referring to a block of blood flow through the artery to the brain, such as blood clots; ii) hemorrhagic stroke, characterizing a damage of the artery in the brain and pressure on brain cells, favoring the intracerebral hemorrhage or the subarachnoid hemorrhage; and iii) transient ischemic attack, that occurs when blood flow to the brain is blocked for only a short time (usually no more than 5 minutes) [31].

The ischemic stroke corresponds to 87% of strokes. More than 795,000 individuals in the United States have a stroke, annually. The general symptoms related to stroke are: sudden numbness or weakness in the face, arm, or leg, especially on one side of the body; sudden confusion, trouble speaking, or difficulty understanding speech; sudden trouble seeing in one or both eyes; sudden trouble walking, dizziness, loss of balance, or lack of coordination, and sudden severe headache with no known cause [32].

The WBV has been used in the management of stroke individuals and studies have reported improvement in functional mobility, muscle strength, spasticity. The vibration type used was vertical and side-alternating, the vibration amplitude from 1 to 4 mm, the mechanical vibration frequency from 5 to 40 Hz, the duration of each bout from 30 seconds to 2.5 minutes, and the duration of WBV protocol from 4 to 12 weeks [33–36].

3. Whole-body vibration exercise in cerebral palsy individuals

Cerebral palsy is a motor disorder at the level of the central nervous system caused by irreversible brain lesions that occur before, during or shortly after birth. Cerebral palsy has a prevalence of 1 in 700 live births, affecting about 18 million people worldwide [37]. The individuals can present compromising of body movement, muscle control, muscle coordination, muscle tone, reflex, posture, balance, cognitive impairment, or seizures. Some symptoms of cerebral palsy are permanent life-long, but some of them can improve or worsen over time. It is common the presence of reduction in the motor repertoire of gestures and a loss in the quality of movement with reduction of normal motor patterns, alterations in posture and in stability. More alterations promote greater disability. Motor

effects of cerebral palsy varied by the individual and can be pyramidal/spastic or extrapyramidal/non-spastic [38–40].

These children present difficulty to achieve and maintain an upright position in a severe cerebral palsy. As the dynamic weight bearing is unavailable, there are a predisposition of them to reduce bone mineral density and development of osteoporosis. In consequence, they can present more prone to muscle weakness, which contributes to pain, deformity and functional loss [41, 42].

Studies have reported that whole body vibration can improve spasticity, muscle strength and coordination in cerebral palsy individuals. Considering the biomechanical parameters, the WBV exercise was performed using a side-alternating or vertical platform, frequency from 5 to 35 Hz, working time from 45 seconds to 3 minutes, from 8 weeks to 6 months [19, 43–45].

4. Whole-body vibration exercise in spinal cord injury individuals

Spinal cord injury can be present because of an unpredictable accident or violent event and it is estimated that 327 million people are affected with this condition annually [46, 47]. Frequently is related to clinical-neurological deficits leading to persisting physical and psychological sequela. Spinal cord injury can be present due: i) a violent attack, as a stabbing or a gunshot; ii) diving into water that is too shallow and hitting the bottom; iii) trauma during a car accident, as a trauma to the face, head, and neck region, back, or chest area; iv) falling from a significant height, head or spinal injuries, as during sporting events; and v) electrical accidents [46, 47].

The symptoms can be i) difficult to walking; ii) loss of control of the bladder or bowels; iii) inability to move the arms or legs; iv) feelings of spreading numbness or tingling in the extremities; v) headache; vi) pain, pressure, and stiffness in the back or neck area; vii) signs of shock; and viii) unnatural positioning of the head [46, 47].

WBV have been used to improve spasticity, balance and walking ability in individuals [48], peripheral arterial properties [49] and walking function [50]. The protocol used in these studies involved a side-alternating platform, working time from 30 seconds to 1 minute, frequency from 8 Hz to 50 Hz, amplitude from 2 to 5 mm. The postures varied from squat position to seated in a chair with foot on the base of the platform.

5. Whole-body vibration exercise in patients with diabetic neuropathy

Nearly 15–20 million people in the United States have some type of neuropathy [51], a nerve injury affecting mostly the nerves that innervate the body extremities, in a “glove and stocking” distribution.

Hyperglycaemia, or raised blood sugar, in uncontrolled diabetes leads to serious damage to multiple body's systems over time, especially the nerves and blood vessels. Therefore, neuropathy is a common complication of diabetes, affecting up to 50% of patients with type 1 and type 2 diabetes [52, 53]. In many cases, the involvement is especially in small nerve fibers of the lower and upper limbs, with symptoms such as numbness, tingling, burning, and pain occurring first, but medium and large nerve fibers may also be affected. As disease progresses, motor symptoms such as muscle weakness in distal and then in more proximal areas, and autonomic symptoms, later on the disease course, appear (e.g. dry eyes, dry mouth, orthostatic dizziness, constipation, bladder incontinence, sexual dysfunction) [54, 55].

Study	WBV type	WBV frequency and peak-to-peak displacement, or magnitude	Other aspects
Lee et al. [56]	Side alternating	15–30 Hz, 1–3 mm	3×3-min bouts, 3 times/week for 6 weeks
Yoosefinejad et al. [57]	Vertical	30 Hz, 2 mm	30s-1 min bouts, twice/week for 6 weeks
Jamal et al. [58]	Unknown	12 Hz, 5 mm	4×3 min bouts, 3 times/week for 6 weeks
Kessler et al. [59]	Unknown	25 Hz, 0.5–1.0 g	4×3 min bouts, 3 times/week for 6 weeks

Table 2.
WBV intervention characteristics of the studies including people with diabetic neuropathy.

Results from high level of evidence primary studies position WBV as an effective intervention for people with diabetic neuropathy. Studies have reported positive effects of WBV on balance and postural control [56–58], pain [58, 59], other neuropathy signs and symptoms [58] and quality of life [58]. The characteristics of the WBV interventions are summarized in **Table 2**.

6. Whole-body vibration exercise in patients with chemotherapy-induced neuropathy

Cancer represents one of the main causes of morbidity and mortality worldwide [60]. Hopefully, the number of cancer survivors is increasing progressively due to the increasing ability to early detect and treat the conditions.

Chemotherapy-induced neuropathy (CIN) is a common side effect of cancer treatment with chemotherapy, with 68.1% of patients suffering from CIN in the first month after chemotherapy [61], 60% after 3 months and 30% after 6 months. The condition may express as sensoric and/or motor, and sometimes also autonomic dysfunction, leading to important limitations in activities of daily life [62, 63]. As other types of neuropathy CIN heavily impairs physical fitness due to the severe consequences of loss of peripheral somatosensory information on balance and locomotion [64, 65].

The relevance of WBV exercise in the management of cancer therapy-related morbidities has been addressed before [66], specifically its implications for cancer survivors suffering from CIN [67]. Evidence from high level of evidence primary studies suggest WBV to be a potentially effective intervention for cancer survivors with CIN. However, only two high level of evidence primary studies have analyzed

Study	WBV type	WBV frequency and peak-to-peak displacement, or magnitude	Other aspects
Schönsteiner et al. [62]	Side alternating	9–23 Hz, peak-to-peak displacement or magnitude not reported	18 minutes/session, 15 training sessions within 15 weeks
Streckmann et al. [68]	Side alternating	18–35 Hz, 2–4 mm	4×30s-1 min bouts, twice/week for 6 weeks

Table 3.
WBV intervention characteristics of the studies including people with CIN.

the effectiveness of WBV in this population, suggesting that WBV could prove useful to reduce pain [68], sensory ability and strength and function [62]. These information are pointed out in **Table 3**.

Although evidence of the relevance of WBV in people with neuropathy (diabetes- and chemotherapy-related) arises from high level of evidence studies, evidence from high methodological quality studies is on demand, considering some methodological issues in the studies. Therefore, high quality studies are needed to strengthen the existing body of knowledge regarding the effectiveness of WBV in people with neuropathy.

7. Whole-body vibration exercise in patients with Parkinson's disease

Neurodegenerative disorders have an high impact for both individuals and society [69] and Parkinson's disease (PD) is among this type of conditions.

PD is a slowly progressive neurodegenerative disorder, which affects nearly 1 million north Americans [70, 71]. Apart from the classic motor symptoms, such as rigidity, bradykinesia, resting tremor and postural instability, usually associated with nigrostriatal system degeneration, other non-motor symptoms, with more complex etiology, including neuroendocrine and metabolic disturbances are present [72, 73].

The burden of PD to society, payers, patients, and health professionals is high and interventions to reduce PD incidence, delay disease progression, and alleviate the disease impact, may reduce the burden of the condition [71].

The benefits of WBV in this population has proven conflicting, with studies reporting greater effects in the WBV group and studies reporting a lack of real benefit when comparing with control groups.

Two studies [74, 75] compared the acute effects of a 1-session WBV program at different vibration frequencies on balance, gait or flexibility parameters in patients with PD. One of the studies [75] suggested that higher frequencies seem to produce more effective results but only reported significant effects in flexibility after a WBV session, when compared with the control group, and the other [74] showed that none of the vibration frequencies had better results than the placebo group.

Other studies have compared the benefits of a WBV program, over several weeks, with placebo [76, 77], with an aerobic exercise program [78], conventional balance training [79] and conventional therapy and combined (conventional + WBV) therapy [80]. When compared to placebo, one study [76] reported no advantage of WBV but the other study [77] reported significantly better results in the WBV group regarding balance and gait parameters. When compared to an aerobic exercise program, the oxygen consumption during exercise was similar and the WBV group did not required a long time of recovery and led to less feeling of fatigue. When compared to conventional balance training the results were positive in both groups, however, posturography parameters only improved in the WBV group. Similarly, when compared to conventional therapy, both groups evidenced an improvement in balance. The combined therapy group (conventional + WBV) achieved significantly better results than the conventional therapy group, but not the WBV group, suggesting that WBV could be a useful co-adjuvant intervention to increase balance in PD patients. These information are indicated in **Table 4**.

WBV seems to be a promising intervention in PD, as an independent or co-adjuvant modality, but the existing result heterogeneity does not allow a confident recommendation. More good quality, placebo controlled, studies are needed to establish the clinical effectiveness of WBV in improving functional parameters in people with PD.

Study	WBV type	WBV frequency and peak-to-peak displacement, or magnitude	Other aspects
Chouza et al. [74]	Side alternating	3, 6 or 9 Hz, 13 mm	5× 1 min bouts, 1 session
Dincher et al. [75]	Side alternating	6, 12 or 18 Hz, 4 mm	5× 1 min bouts, 1 session
Arias et al. [76]	Side alternating	6 Hz, 13 mm	5× 1 min bouts, 12 sessions/5 weeks
Gaßner et al. [77]	Unknown	6 Hz, 3 mm	5× 1 min bouts, 12 sessions/5 weeks
Corbianco et al. [78]	Side alternating	26 Hz, 4 mm	20× 1 min bouts, 4 sessions/weeks for 4 weeks
Ebersbach et al. [79]	Side alternating	25 Hz, peak-to-peak displacement or magnitude not reported	15 min/session, 2 sessions/day, 5 days/week for 3 weeks
Guadarrama-Molina et al. [80]	Vertical	20 Hz, 2 mm	8× 20 sec bouts, 20 sessions, 3 sessions/week

Table 4.
WBV intervention characteristics of the studies including people with PD.

8. Summary

Whole-body vibration exercise is an exercise modality that induces musculo-skeletal, endocrinological, vascular and neurologic responses, which are relevant in the context of neurological conditions. This intervention proved to be promising for people with multiple neurological conditions and its results have been discussed for people with stroke, cerebral palsy, spinal cord injury, neuropathy (diabetes- and chemotherapy-related) and Parkinson’s disease.

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