Effect of whole-body vibration training on bone mineral density in older adults: A systematic review and meta-analysis (#105141)

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Effect of whole-body vibration training on bone mineral density in older adults: A systematic review and meta-analysis

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Background: Whole-Body Vibration (WBV) aims to improve bone mineralization using vertical mechanical accelerations from the plantar surface of the feet through the muscles and bones. A vibration platform is used for this purpose. This systematic review (PROSPERO – CRD 42023395390) analysed the effects of WBV training on bone mineral density (BMD) at anatomical sites most affected by osteoporotic fractures in older adults. **Methodology:** Systematic searches were conducted in the databases. Studies quantifying BMD using the dual-energy X-ray absorptiometry method before and after WBV training in adults aged 55 and older were included. Independent reviewers performed methodological quality analysis (TESTEX) and assessed the risk of bias. BMD values from anatomical sites in the femur, spine, and total hip from WBV training protocols were included in the meta-analysis. The forest plot was generated using the random-effects model, and the effect size was measured by Hedges' *g*. **Results:** Eight studies involving 301 participants were included, with TESTEX=12.5 (excellent quality) and risk of bias (50% low, 37.5% moderate, and 12.5% serious risk), demonstrating with low heterogeneity, a significant effect of WBV training on femur BMD (g = 0.20 [small], $p < 0.05$). However, in the absence of heterogeneity, the spine (g = 0.08 [trivial], p = 0.41) and total hip (g = -0.07 [trivial], p = 0.58) regions did not show a significant effect with WBV training. **Conclusions:** The results

showed that WBV training had a statistically significant effect on femur BMD but not on spine and hip regions.

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ABSTRACT

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Conclusions: The results showed that WBV training had a statistically significant effect on femur BMD but not on spine and hip regions.

Keywords: aging; bone mineral density; vibration stimuli; training plans

INTRODUCTION

The aging process involves morphological and functional declines related to both biological, such as neuromuscular activation and muscle mass reduction (*Fischer et al., 2019*; *Choe, Jeong & Kim, 2020*), and lifestyle factors stemming from sedentary behavior and poor dietary habits (*Tieland Trouwborst & Clark, 2018*; *Massini et al., 2022*). Consequently, these factors also affect the skeletal system, as evidenced by reductions in bone mineral density (BMD) (*Gomez-Cabello et al., 2012*; *Abazović, Paušić & Kovačević*, *2015*; *Mohammad Rahimi et al., 2020*; *Massini et al., 2022*). This bone reduction is more pronounced in women, with an annual decrease of around 5% in the first years after menopause, followed by a yearly loss of 2 to 3%, and in men with reductions of 1 to 2% in old age (Gomez-*Cabello et al., 2012*). BMD reflects the bone tissue remodeling capacity (*Gomez-Cabello et al., 2012*; *Abazović, Paušić & Kovačević*, *2015*; *Mohammad Rahimi et al., 2020*; *Massini et al., 2022*), serving as an index for the risk of developing pathologies and injuries such as osteopenia and osteoporosis (*Abazović, Paušić & Kovačević*, *2015*; *Zha et al., 2012; Mohammad Rahimi et al., 2020; Zamoscinska, Faber & Busch, 2020*). Clinically, osteoporosis is a silent disease characterized by increased bone resorption and an inadequate compensatory balance in forming new bone tissue (*Gomez-Cabello et al., 2012*; *Abazović, Paušić & Kovačević*, *2015*; *Massini et al., 2022*). Fractures are more frequently observed in the femur, spine, and hip regions, with a global annual rate of 1000 fractures per hour (*Camacho-Cardenosa et al., 2019*).

Physical training has been considered a non-pharmacological alternative for preventing and treating osteopenia and osteoporosis (*Liu, Brummel-Smith & Ilich, 2011; Abazović, Paušić & Kovačević*, *2015*; *Marín-Cascales et al., 2018*; *Fernandez et al., 2022*; *Hejazi, Askari & Hofmeister, 2022*). Thus, various exercise modalities, such as aerobic (*Liu, Brummel-Smith & Ilich, 2011; Beavers et al., 2017; Mohammad Rahimi et al., 2020*) and resistance training (*Bemben et al., 2010; Massini et al., 2022*), either planned alone or combined, have been investigated and the effect on BMD maintenance or enhancement being evidenced (*Villareal et al., 2017; Mohammad Rahimi et al., 2020; Massini et al., 2022*). Aside from the benefits of physical training, whole-body vibration (WBV) training has also emerged as an alternative for improving bone mineralization (*Verschueren et al., 2004; Beck & Norling, 2010; Slatkovska et al., 2010; Santin-Medeiros et al., 2015; Marín-Cascales et al., 2018; Camacho-Cardenosa et al., 2019; Mohammad Rahimi et al., 2020*; *Fernandez et al., 2022*). The WBV training involves placing an individual in a standing or squatting position on a vibrating platform (*Slatkovska et al., 2010*; *Harijanto et al.,* *2022*), where vertical accelerations in relation to the ground, starting from the plantar surface of the feet, transmit mechanical vibration through the muscles and bones supporting the body mass (*Slatkovska et al., 2010; Abazović, Paušić & Kovačević, 2015)*. The intensity of WBV is defined by its frequency (hertz, Hz), magnitude expressed as vertical acceleration (g; 1g = 9.8 m/s^2 acceleration due to gravity), oscillations (1–10 mm), and planes (sagittal, frontal, and transversal) (*Slatkovska et al., 2010; Fernandez et al., 2022; Harijanto et al., 2022*). Training recommendations suggest using frequencies between 20 and 40 Hz and amplitudes between 2.0 and 5.0 mm, with daily sessions lasting up to 30 minutes, conducted 3 times a week (*Abazović, Paušić & Kovačević, 2015; Harijanto et al., 2022*).

The hypothetical mechanism underpinning the WBV training effect is the osteogenic stimuli through muscle activation (i.e., tensional stimuli) (*Marín-Cascales et al., 2018*), resulting in the mechanotransduction of vibration-induced stresses within the bone (piezoelectric effect) (*Slatkovska et al., 2010; Moreira-Marconi et al., 2016; Bemben et al., 2018; Mohammad Rahimi et al., 2020; Cheng et al., 2021*). Another hypothesis is that mechanical forces applied to the bone tissue induce interstitial fluid movement along the canaliculi and lacunae of osteocytes, causing cellular-level shear stress and deformations of the osteocyte plasma membrane (*Slatkovska et al., 2010; Dionello et al., 2016; Mohammad Rahimi et al., 2020*). These changes induce bone to enhance the mineral remodeling process, stimulating bone formation (*Liu, Brummel-Smith & Ilich, 2011; Abazović, Paušić & Kovačević, 2015; Dionello et al., 2016; Mohammad Rahimi et al., 2020*). However, there is still no consensus on the effect of WBV training on BMD in different body regions (*Abazović, Paušić & Kovačević, 2015; Zha et al., 2012; Marín-Cascales et al., 2018; Fernandez et al., 2022*), which might be accounted to the different variables (i.e., frequency, intensity, amplitude) of training planned to the protocols available in the literature (*Abazović, Paušić & Kovačević, 2015; Zha et al., 2012; Camacho-Cardenosa et al., 2019; Fernandez et al., 2022; Harijanto et al., 2022*) and participant characteristics (i.e., age, sex, training status) (*Slatkovska et al., 2010*).

In light of these miscellaneous protocols of WBV and their effects on BMD, some systematic reviews and meta-analyses aimed to discern the effect of WBV training on whole-body and regional BMD (*Bemben et al., 2018; Cheng et al., 2021*). However, these investigations have methodological limitations related to confounding factors in their results (*Santin-Medeiros et al., 2015*; *Harijanto et al., 2022*), as they include studies with the combination of (i) WBV with other types of training (resistance or aerobic) (*Dionello et al., 2016*); (ii) treatments with dietary supplements (e.g., vitamins and minerals) (*Slatkovska et al., 2010; Dionello et al., 2016; Marín-Cascales et al., 2018*) and/or osteogenic drugs (e.g., medications and hormones) (*Harijanto et al., 2022*); and (iii) quantification of BMD using different methods (e.g., dual-energy X-ray absorptiometry (DXA) and computed tomography) (*Dionello et al., 2016*). Clearly, this is a limitation to the observation that WBV training affects bone tissue (*Slatkovska et al., 2010; Moreira-Marconi et al., 2016; Harijanto et al., 2022*), justifying the need for further studies to eliminate these biases from the results (*Harijanto et al., 2022; Massini et al., 2022*). Therefore, the current systematic review and meta-analysis aimed to discern the effect of WBV training (per se) on anatomical sites, constraining the evidence to the most vulnerable sites to osteoporotic fractures in older adults. Therefore, this study will contribute to providing enough evidence on the practice of WBV as a non-pharmacological rehabilitation method that is safe and cost-effective, like has been speculated by previous studies (*Slatkovska et al., 2010; Fischer et al., 2019*).

SURVEY METHODOLOGY

This systematic review and meta-analysis followed the recommendations outlined in the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0), and its writing adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist *(Page et al., 2021)* (see Supplementary File). The study was registered in the International Prospective Register of Systematic Reviews (PROSPERO – CRD 42023395390) in February 2023.

High-sensitivity searches, which means not constrain the search to a given period of time and nor to a given language of publication, were conducted in the Embase, ESPORTDiscuss, LILACS, PEDro, PubMed, and SciELO electronic databases (see Supplementary File), covering studies published until January 30, 2023. The search used the Population, Intervention, Comparator, and Outcome (PICO) descriptors, as follows. Population: "*older adults*" OR "e*lderly*" OR "*aging*"; Intervention: "*whole body vibration*" OR "*vibration platform*" OR "*vibratory exercise*"; Comparator: pre- vs. post-training difference in BMD as a result of a WBV training program (comparison with a control group was not performed due to studies using different types of exercises, e.g., impact, resistance, or aerobic exercise, or not engaging in exercise, generating a confounding bias in effect size estimation) (*Fischer et al., 2019; Dolan et al., 2020; Massini et al., 2022*); Outcome: "*bone mineral density*" OR "*bone mineral content*" OR "*bone metabolism*" OR "*bone mass*" with filters: "*full text*", "*humans*", "*middle age + age: 45 + years*". The search strategy underwent peer review by an information scientist using the Peer Review of Electronic Search Strategies (PRESS) form (*McGowan et al., 2016*). The reliability of the search strategy was confirmed by referencing the study by Bemben et al. (*Bemben et al., 2010*).

Manual searches were conducted in the references of eligible articles and their citations in the PubMed, Scopus, and Google Scholar databases to add other relevant titles. Additionally, attempts were made to email the authors of selected articles to request any missing relevant information. Two authors (DAM and ABP) conducted the searches to avoid any selection bias. After completing the searches, the authors compared the lists of included and excluded studies using the Rayyan online tool (*Ouzzani et al., 2016*). Any discrepancies observed were analysed through discussion and agreement with a third author (DMPF).

Article Selection Criteria

Studies that provided quantification of BMD were included. The inclusion criteria were as follows: (i) complete studies conducted in humans aged 55 years and older; (ii) studies that quantified the BMD of anatomical sites or body regions (e.g., femur, spine and total hip) that present a high incidence of osteoporotic fractures using only DXA to consider that the measurements be a standard reference for the population, and therefore comparable (*Massini et al., 2022*), and not adding confounding factors with other methods (*Santin-Medeiros et al., 2015; Harijanto et al., 2022*); and (iii) peer-reviewed studies. The exclusion criteria were as follows: (i) studies conducted in clinical populations that limit training protocols (cardiovascular and orthopedic diseases) or interfere with bone metabolism (e.g., diabetes, obesity) (*Massini et al., 2022*); (ii) studies that combined WBV with other training protocols (resistance, aerobic, and impact exercises); (iii) studies administering dietary supplements or osteogenic drugs; (iv) case studies, literature reviews (systematic review and meta-analysis); and (v) studies with low methodological quality.

Data Extraction

Two authors (DAM and AGM) extracted data using a pre-pilot spreadsheet which was independently verified by a third author (TAFA) from the review team. When data were presented only in graphs, WebPlotDigitizer software (Version 4.6, WebPlotDigitizer, Pacifica, California, USA) was used to extract the data (*Drevon, Fursa & Malcolm, 2017*). The following data were extracted: (i) authors' names; (ii) year of publication; (iii) characteristics of the population (sample size, sex, age, height, and body mass); (iv) WBV training protocol; and (v) pre- and post-training BMD.

Methodological Quality Assessment and Risk of Bias

Two independent authors (DAM and TAFA) conducted the assessment, and discrepancies were analysed by a third author (AGM) using the "Tool for the Assessment of Study Quality and Reporting in Exercise" (TESTEX) checklist (*Smart et al., 2015*). The checklist assigns one point if the criterion is met and zero otherwise. It comprises 2 sections related to quality (items 1–5) and study reporting (items 6–12), with criteria 6 and 8 designed by 3 and 2 sub-criteria each one (respectively), amounting 15 points at all (see detailed information in table 1). Based on summarized scores, studies were classified as "excellent quality" (12–15 points), "good quality" (9–11 points), "fair quality" (6–8 points), or "poor quality" (< 6 points) (*Nunes et al., 2020*) (Table 1).

* Please insert Table 1 around here*

Additionally, two authors (DAM and AGM) assessed the risk of bias using the second version of the Cochrane risk-of-bias tool for non-randomized studies (ROBINS-I) (*Sterne et al., 2016*) in the following domains: (i) risk of bias due to confounding factors; (ii) risk of bias in the selection of participants for the study; (iii) risk of bias in the classification of interventions; (iv) risk of bias due to deviations from intended interventions; (v) risk of bias due to missing data; (vi) risk of bias in the measurement of outcomes; and (vii) risk of bias in the selection of the reported result. Studies were categorized as having a low risk of bias if they received a "low risk" rating across all domains. Studies were considered to have a moderate risk of bias if at least 1 domain received a "moderate risk" rating, a serious risk of bias if at least 1 domain was rated as "serious risk," or if there were multiple domains rated as "moderate risk" that may affect the validity of the results. Studies were classified as having a critical risk of bias if at least 1 domain received a "critical risk" rating or if there were multiple domains rated as "serious risk" that could affect the validity of the results. Weighted summary and traffic light risk-of-bias plots for non-randomized included studies were produced using the Risk-of-bias visualization (robvis) online tool (https://mcguinlu.shinyapps.io/robvis/) (*McGuinness & Higgins, 2021*). Discrepancies were resolved through discussion with another author (DMPF).

Statistical Analysis

The statistical analysis was performed by an author (DAM) and reviewed by a second one (ABP). The magnitude of the study results was determined by Hedges' g and a 95% confidence interval ($CI_{95\%}$). For these estimates, the sample size, mean values, and standard deviation of BMD pre- and post-training for each anatomical site in the femur, spine, and hip in each condition (applied WBV training protocols) of each study included in the meta-analysis were used. The relative effects of training (Δ%) were calculated in percentages according to Equation 1 (*Massini et al., 2022*).

$$\Delta\% = \left[\frac{(\bar{x}_{post} - \bar{x}_{pre})}{\bar{x}_{pre}}\right] \cdot 100 \qquad [1]$$

Where "Δ%" is the training effect in percentage, "$\bar{x}_{pre}$" is the mean BMD before training, and "$\bar{x}_{post}$" is the mean BMD after training. The study estimates were combined in the meta-analysis using a random-effects model and presented as forest plots. Inconsistency was checked using the results of the meta-analysis, based on visual inspection of Hedges' g estimates with overlapping or non-overlapping $CI_{95\%}$, as well as statistical tests for heterogeneity (I^2) determined by combining the Cochran Q test ($\alpha < 0.10$) with the Higgins test (*Higgins & Thompson, 2002*). Heterogeneity (I^2) was categorized as follows: $0 < I^2 \leq 25$ % [no heterogeneity], $25\ \% < I^2 \leq 50$ % [low heterogeneity], $50\ \% < I^2 \leq 75$ % [moderate heterogeneity], and > 75 % [high heterogeneity] among studies (*Massini et al., 2022*). Sensitivity analysis to identify potentially influential or outlier WBV training protocols was performed using the amplitude defined as 1.5 times the interquartile range (IQR = Q3 - Q1) for Hedges' *g* and the Cook's distance with studentized residuals for moderators: age and week (*Viechtbauer & Cheung, 2010*). If one or more studies were identified as leverage points or outliers, the overall analysis was performed after removing the study(ies). Publication bias analyses were not assessed due to the inclusion of fewer than 10 studies (*Higgins, Thomas & Chandler, 2023*). Finally, meta-regression analyses were conducted to investigate the relationship between the mean age (years) and duration (weeks) with effect size (Hedges' *g*) for each anatomical region with a minimum of twenty WBV protocols. These moderators were selected to verify the effect of WBV training on BMD according to the aging process, as well as whether time undergone training intervention enhances the effect. The effect size for Hedges' *g* was categorized as ≤ 0.19 [trivial], 0.20 – 0.59 [small], 0.60 – 1.19 [moderate], and ≥ 1.20 [large] (*Hopkins et al., 2009*). A significance level of $\alpha = 0.05$ was adopted for all statistical procedures.

RESULTS

Figure 1 presents the flowchart for all stages of the systematic review and meta-analysis, and Table 2 outlines the key characteristics of the 8 included studies; 4 were conducted in Europe (*Verschueren et al., 2004; Santin-Medeiros et al., 2015; Camacho-Cardenosa et al., 2019; Fernandez et al., 2022*), 3 in Asia (*Zha et al., 2012; Cheng et al., 2021; Song & Yang, 2021*), and 1 in Oceania (*Beck & Norling, 2010*). These studies included 301 participants (~96% women and ~4% men) aged from 55 to 93. Regarding the fourteen included training protocols, 5 different vibration platforms were observed. Training protocol variables included daily sessions lasting between 6 and 30 minutes, frequencies ranging from 12.5 to 55 Hz, intensity (acceleration) between 0.30 and 5.09 g, and amplitude between 0 and 14 mm. Weekly frequencies ranged from 2 to 3 times, and the protocols had durations between 18 and 52 weeks. Finally, a relative BMD variation was observed for anatomical sites of the femur ($\Delta\% = 2.8 \pm 5.3$, $CI_{95\%} = 0.7 – 4.9\%$), spine ($\Delta\% = 1.2 \pm 2.5$, $CI_{95\%} = -0.7 – 3.2\%$), and total hip ($\Delta\% = -1.3 \pm 1.4$, $CI_{95\%} = -4.9 – 2.3\%$).

* Please insert Figure 1 around here*

* Please insert Table 2 around here*

Meta-analysis

Figure 2 presents the WBV training protocols for the body regions included in the meta-analysis. The studies that analyse the femur region (Panel A) combined with the random-effects model showed a significant effect of WBV protocols ($g = 0.20$, $CI_{95\%} = 0.04 – 0.37$, $p < 0.05$, [small]). Inconsistency analysis through visual inspection of the overlap of $CI_{95\%}$ combined with statistical tests showed low heterogeneity ($I^2 = 27.7$ %; $Q_{[26]} = 35.95$, $p = 0.09$). For the spine region (Panel B), using the random-effect model with no heterogeneity ($I^2 = 0$ %; $Q_{[8]} = 4.29$, $p = 0.83$), there was no significant effect of the WBV protocols on BMD ($g = 0.08$, $CI_{95\%} = -0.12 – 0.29$, p = 0.41, [trivial]). Similarly, in the total hip region (Panel C), according to the random-effect model with no heterogeneity ($I^2 = 0$ %; $Q_{[2]} = 0.27$, $p = 0.87$), there was also no significant effect of WBV protocols on BMD ($g = -0.07$, $CI_{95\%} = -0.33 – 0.18$, $p = 0.58$, [trivial]).

* Please insert Figure 2 here*

Methodological Quality and Risk of Bias

Table 1 presents the results of each TESTEX methodological quality scale criterion for all included studies. Four studies showed excellent methodological quality (*Verschueren et al., 2004; Beck & Norling, 2010; Zha et al., 2012; Camacho-Cardenosaet al., 2019*) and 4 were rated as good (*Santin-Medeiros et al., 2015; Cheng et al., 2021; Song & Yang, 2021; Fernandez et al., 2022*). Therefore, the mean methodological quality value presented by the TESTEX checklist was 12.5 points (excellent quality), ranging between 10 and 15 points.

Regarding the risk of bias presented in the upper panel (Traffic light plot) of Figure 3, moderate risks were observed in 1 study (*Cheng et al., 2021*) related to bias due to confounding factors, 1 study (*Santin-Medeiros et al., 2015*) related to bias due to missing data, and another study (*Camacho-Cardenosa et al., 2019*) related to bias in the selection of the reported result. Only 1 study (*Fernandez et al., 2022*) showed a serious risk related to bias in the intervention classification. The overall risk of bias presented in the lower panel (Weighted bar plot) of Figure 3 showed 50% low risk, 37.5% moderate risk, and 12.5% serious risk.

* Please insert Figure 3 around here*

Sensitivity Analysis

The examination of outliers (1.5·IQR) of Hedges' *g* revealed 1 WBV protocol for the femur region *Cheng et al.* (*2021*) (HFr) W and 1 for the spine region *Song and Yang* (*2021*) (HA) L2-4). However, the study by Cheng et al. (*2021*) showed a moderate bias due to confounding factors, and the study by *Song and Yang* (*2021*) did not exhibit any bias considered moderate. After removing the protocol from Cheng et al. (*2021*) (HFr) W, no heterogeneity was observed (I^2 = 7.1%; $Q_{[25]}$ = 26.91, p = 0.36), resulting in a reduction in the overall analysis for the femur region (g = 0.16, $CI_{95\%}$ = 0.01 – 0.32, $p < 0.05$, [trivial]), and Δ% = 2.2 ± 4.6 ($CI_{95\%}$ = 0.4 – 4.1%). For the spine region, after removing the protocol from *Song and Yang* (*2021*) (HA) L2-4), there was no change in heterogeneity (I^2 = 0%; $Q_{[7]}$ = 0.97, p = 0.99), although the overall analysis reduced (g = 0.03, $CI_{95\%}$ = -0.16 – 0.22, p = 0.74, [trivial]), and Δ% also decreased to 0.5 ± 1.2 ($CI_{95\%}$ = -0.5 – 1.5%). Cook's distance and studentized residuals analyses did not identify leverage points or outliers for the remaining protocols regarding moderators (age and week) on Hedges' *g*.

Meta-regression

Meta-regression analyses revealed a significant inverse effect of the average age of participants on the effect size ($F_{[1,24]}$ = 7.954, $p < 0.01$, r^2 = 0.249). The estimated Hedges' *g* was: -0.025 x Age + 1.90 ($CI_{95\%}$: -0.043 – -0.007) with an explanatory power of only 25% for the age increase on the effect size reduction. Similarly, the duration in weeks of WBV training protocols also showed a significant inverse effect on the effect size ($F_{[1,24]}$ = 6.419, $p < 0.05$, r^2 = 0.211). The estimated Hedges' *g* was: -0.017 x Week + 0.678 ($CI_{95\%}$: -0.032 – -0.003) with an explanatory variance of only 21% for the increase in the duration of WBV training on the reduction of the effect size. This effect may have been influenced by studies with longer durations conducted in populations with higher average ages. Notably, these analyses together indicate that the maintenance of WBV training cannot reverse the age-related loss of BMD.

DISCUSSION

The primary objective of this systematic review was to investigate the effect of WBV training per se on BMD in older adults. The current meta-analysis evidenced a significant effect of WBV training on anatomical sites in the femur region throughout 18 to 52 weeks. However, this effect showed no statistical significance for the spine and total hip regions, indicating that WBV training had specific effects on different body regions. Meta-regression analyses demonstrated significant effects inversely related to increasing age and training duration, indicating that the maintenance of WBV training is not sufficient to reverse the bone loss process associated with aging. This effect is evident in the study by *Fernández et al.* (*2022*) for the femur and total hip regions.

Only 2 studies included in this systematic review included male participants (*Zha et al., 2012; Camacho-Cardenosaet al., 2019*). The low percentage of male participants and the lack of separate analyses by sexes do not allow applying the results to men or comparing them with women (*Massini et al., 2022*). The anthropometric characteristics (height and body mass) were similar among the included studies, although age showed a wide range (approximately 40 years). The limited number of studies included prevented an assessment of whether the effect of manipulating the variables in the WBV training is altered with age during subgroup analyses (*Abazović, Paušić & Kovačević*, *2015*).

The variables of WBV training are not yet fully defined (*Slatkovska et al., 2010; Santin-Medeiros et al., 2015*), and the way that previous studies followed planning the variables in WBV training is partially aligned with each other, therefore making it difficult to observe a standardized recommendation in the literature (*Abazović, Paušić & Kovačević*, *2015; Marín-Cascales et al., 2018*). Regarding the recommendation for the variable frequency, only the study by *Zha et al.* (*2012*) used a frequency of 55 Hz. However, frequencies above ~50 Hz are not recommended due to the possibility of adverse events such as intense muscle pain and even hematoma in untrained individuals (*Abazović, Paušić & Kovačević*, *2015; Marín-Cascales et al., 2018*). As for the variable amplitudes, investigations used both lower (*Beck & Norling, 2010; Fernandez et al., 2022*), and higher oscillations (*Beck & Norling, 2010; Zha et al., 2012; Camacho-Cardenosa et al., 2019*). The difference in the effect (Δ%) can be explained by the combination with the rate of sessions per week, where studies with lower oscillations and 2 weekly sessions (*Beck & Norling, 2010; Santin-Medeiros et al., 2015*) had a smaller Δ% compared to the study with 3 weekly sessions (*Fernandez et al., 2022*). Therefore, it is recommended to carry out training based on people's capabilities.

On the other hand, when the rate of sessions per week was kept unchanged the increasing in amplitude have been enhanced the effect (in Δ%) more pronounced in the protocol with higher amplitude per session (*Song & Yang, 2021*). Therefore, the most significant effects were reported to protocols with frequencies between 40 and 45 Hz, amplitudes between 3.0 and 4.0 mm, and 3 sessions per week, as seen in the studies by *Cheng et al.* (*2021*) and *Song and Yang* (*2021*). Regarding the duration of the studies, this did not limit the presented results because bone formation and stabilization occur between 3–4 and 6–8 months, respectively (*Kohrt et al., 2004; Massini et al., 2022*). Only the study of *Camacho-Cardenosa et al.* (*2019*) had a duration of 4.2 months, although the reports for improvements in BMD were aligned with other studies (*Arce-Esquivel & Ballard, 2015; Massini et al., 2022*) regardless of the applied training modality.

The main constraint in conducting meta-analyses and establishing robust evidence on the effects of WBV training on BMD is the heterogeneity present in the methodologies of the studies (*Fischer* *et al., 2019*). In this regard, considering only the intragroup effect (pre- vs. post-training) is a strategy to eliminate the confounding bias related to the different control models in the included studies (*Dolan et al., 2020; Massini et al., 2022*). However, the low heterogeneity absence in this meta-analysis is due to the differences in WBV training protocols (e.g., intervention duration, frequency and volume of sessions, type, and amplitude of vibrations and exercises performed on the platform) (*Fischer et al., 2019*). Therefore, using a random-effects model during the meta-analysis is an attempt to weigh the studies relatively more equitably than fixed effects (*Higgins, Thomas & Chandler, 2023*).

Therefore, the small effect size for the femur region and the trivial effects for the spine and total hip regions (*Hopkins et al., 2009*), with their respective relative gains (Δ%), demonstrate that bone mineralization response to WBV training is like resistance training (*Arce-Esquivel & Ballard, 2015; Fischer et al., 2019; Massini et al., 2022*). This indicates that bone tissue does not exhibit much plasticity compared to other body tissues (e.g., muscle) (*Massini et al., 2022*). Thus, the differences in results between the femur region and the spine and total hip could be explained by: (i) the mechanotransduction varying in different body regions due to the nonlinear musculoskeletal system and different body positions influencing the amount of stimuli each region receives during WBV training (*Abazović, Paušić & Kovačević, 2015; Marín-Cascales et al., 2018*); and (ii) the difference in the number of WBV training protocols (large variance and small sample size) included compared to the femur region, reducing the statistical power to observe the effect (*Slatkovska et al., 2010; Marín-Cascales et al., 2018; Santo André et al., 2023*). In addition, aging might reduce the effect of WBV training on bone mineralization, since the mechanical stimulation from vibration cannot be effective in activating muscles adequately in older individuals, therefore also reducing the stimuli of muscles on bone mineral metabolism (*Cheng et al., 2021; Song & Yang, 2021*) although no information is available about how different bone sites adjust mineral mass and density to WBV training in older adults.

Regarding the methodological quality (TESTEX = 12.5) of this systematic review (*Smart et al., 2015*), its results were based on studies with good methodological quality (*Nunes et al., 2020*). However, in some cases, the TESTEX score revealed limitations in reporting the exercise protocol with adequate details. Nevertheless, this is essential for interpreting the results of the studies selected after the search screening (*Fischer et al., 2023*). Thus, the TESTEX results were compared with the risk of bias (*Sterne et al., 2016*), and from the risk of bias analysis was observed that the study by *Cheng et al.* (*2021*) did not report the process of group formation, which information might have influenced the results when missed, as suggested to *Sterne et al.* (*2016*). The study by *Santin-Medeiros et al. (2015)* did not show all data from the sample, although it provided inclusion and exclusion criteria for participants, reducing bias in including participants with health (or pathological) conditions able to influence bone metabolism (*Massini et al., 2022*). However, the study by *Fernandez et al.* (*2022*) allowed participants to choose which of the studied groups they would be part of. Although this is a great strategy for adherence, its weakness is that sedentary individuals tend to choose the control group, and those who enjoy physical exercise tend to choose the intervention groups. Indeed, this can introduce bias in the outcome because adaptations from previous training may influence the result of the current intervention (e.g., muscle memory theory) (*Sharples & Turner, 2023*) due to mechanical stimuli being applied to the muscle-bone axis (*Ireland, Rittweger & Degens, 2014; Harijanto et al., 2022*).

The sensitivity analysis (*Viechtbauer & Cheung, 2010*) identified only the WBV_{HFr} training from the study by *Cheng et al.* (*2021*) as an outlier, although the other protocol from this same study (WBV_{MFr}), as well as two other WBV protocols from the study by *Song and Yang* (*2021*) (WBV_{MA} and WBV_{HA}), showed much higher effects (>10%) compared either to WBV_{HFr} training of *Cheng et al.* (*2021*) or other studies, regardless of the exercise planned for the training protocol (i.e., aerobic, resistance, impact) (*Liu, Brummel-Smith & Ilich, 2011; Arce-Esquivel & Ballard , 2015; Beavers et al., 2017;Mohammad Rahimi et al., 2020; Massini et al., 2022*). One possible explanation for the protocols of these studies showing higher effects (*Cheng et al., 2021; Song & Yang, 2021*) is that they combined frequencies (40 and 45 Hz) with amplitudes (3.0 and 4.0 mm), while other studies prioritized only frequency (*Verschueren et al., 2004; Fernandez et al., 2022*). The study of *Zha et al.* (*2012*), using higher frequencies and amplitudes (45 to 55 Hz and 8.0 mm), had good results (FN = 3.2% and LS = 2.5%), although less pronounced, which may have occurred due to excessive stimulation (i.e., the negative influence of the high overload) (*Abazović, Paušić & Kovačević, 2015; Marín-Cascales et al., 2018*). However, this is an observation from the analysis of the previous studies (*Marín-Cascales et al., 2018; Harijanto et al., 2022*), and therefore this is a supposition that should be still verified by new clinical studies.

Regarding the meta-regression analysis, the results showed that the older the participants, the smaller the trends to be the effects of WBV training on BMD. This can be explained by the fact that mechanosensitivity and the osteogenic response of bone cells to the mechanical and metabolic stress of physical exercise decrease with age (*Kohrt et al., 2004; Ireland, Rittweger & Degens, 2014*; *Abazović, Paušić & Kovačević, 2015*). This mechanism may also explain the negative effect of the duration of WBV training on BMD, as longer protocols were investigated in populations with higher average age (*Ireland, Rittweger & Degens, 2014; Abazović, Paušić & Kovačević, 2015*). However, another possible explication is that bone formation, resorption, and mineralization occur between 12 and 16 weeks, followed by stabilization (steady state) of bone mass characterized between 24 and 32 weeks. Thus, increasing the duration of WBV training will only trend to maintain BMD, which trend has been also observed with other sport or physical activity interventions (*Kohrt et al., 2004; Massini et al., 2022*).

LIMITATION

A limitation of this systematic review is the small number of included studies, which hinders statistical tests' power to detect smaller effects (in regions of the spine and total hip). It also limits subgroup analyses and explores the potential moderators in meta-regression (*Abazović, Paušić & Kovačević, 2015; Mohammad Rahimi et al., 2020; Massini et al., 2022; Santo André et al., 2023*). Additionally, the small number of male participants prevents the application of these results to this population, even though men can also develop osteopenia and osteoporosis due to factors such as physical inactivity and being bedridden for prolonged periods (*Slatkovska et al., 2010; Ireland,* *Rittweger & Degens, 2014; Abazović, Paušić & Kovačević, 2015*). Generalizing the results should be seen with caution due to potential limitations in the heterogeneity of WBV planning (*Slatkovska et al., 2010; Moreira-Marconi et al., 2016*). Therefore, future studies should consider the inclusion of men, as well as a comparison between sexes, in order to avoid sex as a confounding factor (*Massini et al., 2022*). Regarding the differences between WBV training, it is also suggested to analyse in future studies the combination of frequencies between 40 and 45 Hz, in amplitudes between 3.0 and 4.0 mm, and with at least 3 training sessions per week, as recommended by *Cheng et al.* (*2021*) and *Song and Yang* (*2021*). Such future studies must also attempt to plan protocols with intervention for a minimum period of 6 months to be aligned with the response time of bone remodelling (*Kohr*t *et al., 2004; Massini et al., 2022*). Additionally, some studies recommend monitoring the occurrence of adverse events, such as muscle pain (*Abazović, Paušić & Kovačević, 2015; Marín-Cascales et al., 2018*).

CONCLUSIONS

The reviewed studies indicated that WBV training had a statistically significant but clinically small effect only on the femur region, with no significant effects observed in the spine and total hip regions, demonstrating different effects on each body region (mainly for women). Meta-regression analyses for the femur region evidenced that WBV training, regardless of its duration, cannot reverse bone loss due to aging in a population mostly made up of women, which in turn highlights the need for further studies involving older men. However, the current analysis of the literature reinforces that WBV training is a safe and effective non-pharmacological intervention for improving bone mass and density, particularly in the femur region. Nevertheless, a detailed analysis of the effects of WBV training on BMD still requires appropriate and controlled variables of training to ensure ecological validity, and application as an effective clinical practice in improving bone health. Therefore, WBV is gaining popularity as a treatment tool to improve musculoskeletal disorders and improve health-related quality of life.

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Danilo A. Massini conceived and designed the experiments, performed the experiments, prepared figures and/or tables, and approved the final draft.
- Tiago A. F. Almeida performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Anderson G. Macedo performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- André B. Peres performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Víctor Hernández-Beltrán analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- José M. Gamonales analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Mário C. Espada analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Cassiano M. Neiva performed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Dalton M. Pessôa Filho conceived and designed the experiments, performed the experiments, prepared figures and/or tables, and approved the final draft.

Data Availability

The following information was supplied regarding data availability:

This study is a systematic review and meta-analysis, using data obtained from the included studies rather than raw data. Studies included in this analysis are available in Table 2.

Supplemental Information

Supplemental information for this article can be found online.

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Table 1(on next page)

Methodological quality assessment using the TESTEX checklist.

Table 1. Methodological Quality Assessment Using the TESTEX Checklist.

Study	Criterion: Study quality					Criterion: Study reporting										Total	
	Eligibility criteria	Randomization specified	Allocation concealment	Similar groups at baseline	Blinding of assessor	Study reporting: Participants adherence > 85 %	Study reporting: Adverse events	Study reporting: Exercise adherence	Intention-to-treat analysis	Between-group statistical comparisons reported: primary outcome	Between-group statistical comparisons reported: secondary outcome	Point and variability measures	Activity monitoring in control groups	Relative exercise intensity remained constant	Exercise volume and energy expenditure	Scores	Rating quality
	1	**2**	**3**	**4**	**5**	**6a**	**6b**	**6c**	**7**	**8a**	**8b**	**9**	**10**	**11**	**12**		
Verschueren et al. (2004)	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	13	Excellent
Beck & Norling (2010)	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	13	Excellent
Zha et al. (2012)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	Excellent
Santin-Medeiros et al. (2015)	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	12	Good
Camacho-Cardenosa et al. (2019)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	14	Excellent
Cheng et al. (2021)	1	0	1	1	1	0	0	0	1	1	0	1	1	1	1	10	Good
Song & Yang (2021)	1	1	0	1	1	1	0	0	1	1	0	1	1	1	1	11	Good
Fernandez et al. (2022)	1	0	1	1	1	0	0	1	1	1	1	1	1	1	1	12	Good

Table 2 (on next page)

Main characteristics of the selected studies regarding population features, WBV protocol, and effects on BMD

Fe: femoral; FN: femoral neck; Fp: proximal femur; InTr: Intertrochanter; L: lumbar vertebrae; LS: lumbar spine; n: number of participants; TH: total hip; Tr: trochanter; W: Ward's triangle; WBV: whole-body vibration..

Table 2. Main characteristics of the selected studies regarding population features, WBV protocol, and effects on BMD. 1

Study	Participants			Whole-Body Vibration Protocol							Bone Mineral Density			
	Groups	**n Sex**	**Age Height Weight (years) (cm) (kg)**	**Instrument**	**Session (Duration)**	**Frequency (Hz)**	**Intensity (accelerations) (g)**	**Amplitudes (mm)**	**Frequency (times week)**	**Study duration (weeks)**	**Bone sites**	**Pre-training (g/cm^2)**	**Post-training (g/cm^2)**	**Δ%**
Zha et al. (2012)	WBV	21 Women 6 Men	77.7 ± 7.8 154.0 ± 8.0 54.4 ± 11.5	MYF Testing Equipment, Guangzhou, China.	1 X 10 min 1 min rest. 1 X 5 min 1 min rest. 1 X 5 min 1 min rest. (Total 6 min)	Vertical vibration changed cyclically between 45 and 55 Hz, at 1 Hz per second.	0.3 0.5 0.8	8	3	24	FN LS	0.589 ± 0.121 0.751 ± 0.146	0.608 ± 0.121 0.770 ± 0.146	3.22 2.52
Camacho Cardenosa et al. (2019)	WBV	21 Women 6 Men	69.0 – –	Galileo 2000, Germany	4 X 0.5 min, 1 min rest.	2.6	2.55	14	2	18	Fe Tr InTr	0.889 ± 0.306 0.697 ± 0.303 1.048 ± 0.351	0.903 ± 0.297 0.704 ± 0.297 1.074 ± 0.347	1.57 1.00 2.48
Fernandez et al. (2022)	WBV$\leq_{64y}$	48 Women	60.0 ± 2.9 158.9 ± 4.8 62.8 ± 10.7	PowerPlate Pro5 airdaptive system (Performance, Health Systems, LLC, NorthBrook, IL, United States)	20 min	30 – 50	The chosen vibration amplitudes and frequencies were applicable to obtain an acceleration close to 0.75–7.04 g	0.2 – 0.4 0.6 – 0.8	3	52	FN L_{1-4} TH	0.820 ± 0.090 1.290 ± 0.110 0.850 ± 0.110	0.820 ± 0.090 1.280 ± 0.100 0.850 ± 0.110	0.00 -0.78 0.00
	WBV$>_{64y}$	51 Women	68.3 ± 2.8 156.9 ± 6.1 64.7 ± 10.7								FN L_{1-4} TH	0.860 ± 0.100 1.250 ± 0.100 0.890 ± 0.100	0.840 ± 0.090 1.260 ± 0.100 0.880 ± 0.100	-2.33 0.80 -1.12
Verschue-ren et al. (2004)	WBV	15 Women	64.6 ± 3.3 159.0 ± 5.0	PowerPlate, Amsterdam. The	30 min	35 – 40	2.28 – 5.09	1.7 – 2.5	3	24	Fp L_{1-4}	0.878 ± 0.136 0.904 ± 0.143	0.886 ± 0.134 0.901 ± 0.145	0.91 -0.33

65.5 ± 8.9	Netherlands

(*continued*) 2

Table 2. (continued).

Study	Participants			Whole-Body Vibration Protocol							Bone Mineral Density			
	Groups	**n Sex**	**Age Height Weight**	**Instrument**	**Session**	**Frequency**	**Intensity (accelerations)**	**Amplitudes**	**Frequency**	**Study duration**	**Bone sites**	**Pre-training**	**Post-training**	**Δ%**
			(years) (cm) (kg)		**(Duration)**	**(Hz)**	**(g)**	**(mm)**	**(times week)**	**(weeks)**		**(g/cm²)**	**(g/cm²)**	
Beck &	WBV_{HI}	15	68.9 ± 7.0	Galileo 2000,	2 X 3 min,	30	1.0	0 – 14	2	32	FN	0.750 ± 0.112	0.741 ± 0.114	-1.20
Norling		Women	157.1 ± 6.0	Germany	1 min rest						Tr	0.591 ± 0.120	0.605 ± 0.112	2.37
(2010)			61.4 ± 8.9		(Total 6 min)						LS	0.876 ± 0.122	0.872 ± 0.120	-0.46
	WBV_{HI}	13	68.5 ± 8.6		15 min	30	0.3	–			FN	0.749 ± 0.156	0.739 ± 0.156	-1.34
		Women	160.2 ± 7.0								Tr	0.591 ± 0.127	0.577 ± 0.137	-2.37
			68.4 ± 10.3								LS	0.941 ± 0.200	0.941 ± 0.206	0.00
Santin-	WBV	19	82.3 ± 5.1	Fitvibe Excel	20 min	20	–	2.0	2	32	FN	0.620 ± 0.090	0.610 ± 0.080	-1.75
Medeiros		Women	–	Pro, Bilzen,							Tr	0.570 ± 0.090	0.560 ± 0.090	-2.88
et al.			–	Belgium)							InTr	0.910 ± 0.140	0.880 ± 0.130	-2.94
(2015)														
											W	0.410 ± 0.110	0.400 ± 0.090	-2.04
											TH	0.760 ± 0.110	0.740 ± 0.100	-2.88
Cheng et	WBV_{MFr}	19	64.8 ± 3.8	American-made	20 min	20	–	3.0	3	24	FN	0.790 ± 0.080	0.810 ± 0.090	2.53
al. (2021)		Women	158.2 ± 7.5	powerplate							Tr	0.660 ± 0.110	0.710 ± 0.080	7.58
			59.3 ± 7.2	vibrometers							W	0.600 ± 0.100	0.680 ± 0.060	13.3
	WBV_{HFr}	18	65.1 ± 3.2		20 min	40	–	3.0	3	24	FN	0.790 ± 0.100	0.820 ± 0.070	3.80
		Women	157.7 ± 6.0								Tr	0.660 ± 0.060	0.730 ± 0.100	10.6
			58.5 ± 7.3								W	0.590 ± 0.040	0.690 ± 0.100	16.9
Song &	WBV_{LA}	19	63.9 ± 2.1	Power Plate	20 min	45	–	2.0	3	24	FN	0.800 ± 0.070	0.800 ± 0.050	0.00
Yang		Women	158.8 ± 4.6	vibrator							Tr	0.660 ± 0.030	0.660 ± 0.050	0.00
(2021)				system										
			57.3 ± 3.3	(Performance							L_{2-4}	0.970 ± 0.080	0.990 ± 0.110	2.06
	WBV_{MA}	18	64.1 ± 1.7	Health Systems,	20 min	45	–	3.0	3	24	FN	0.790 ± 0.040	0.800 ± 0.030	1.27
		Women	158.5 ± 5.2	Northbrook, IL, USA)							Tr	0.670 ± 0.110	0.740 ± 0.060	10.4
			57.2 ± 4.6								L_{2-4}	0.960 ± 0.090	0.960 ± 0.100	0.00
	WBV_{HA}	19	64.2 ± 1.8		20 min	45	–	4.0	3	24	FN	0.790 ± 0.030	0.820 ± 0.060	3.80

Women	159.1 ± 6.6	Tr	0.660 ± 0.090	0.730 ± 0.110	10.6
	56.9 ± 4.1	L_{2-4}	0.970 ± 0.120	1.040 ± 0.080	7.21

Fe: femoral; FN: femoral neck; Fp: proximal femur; InTr: Intertrochanter; L: lumbar vertebrae; LS: lumbar spine; n: number of participants; TH: total hip; Tr: trochanter; W: Ward's triangle; WBV: whole-body vibration.

6

Figure 1

Whole-body vibration PRISMA flow diagram.

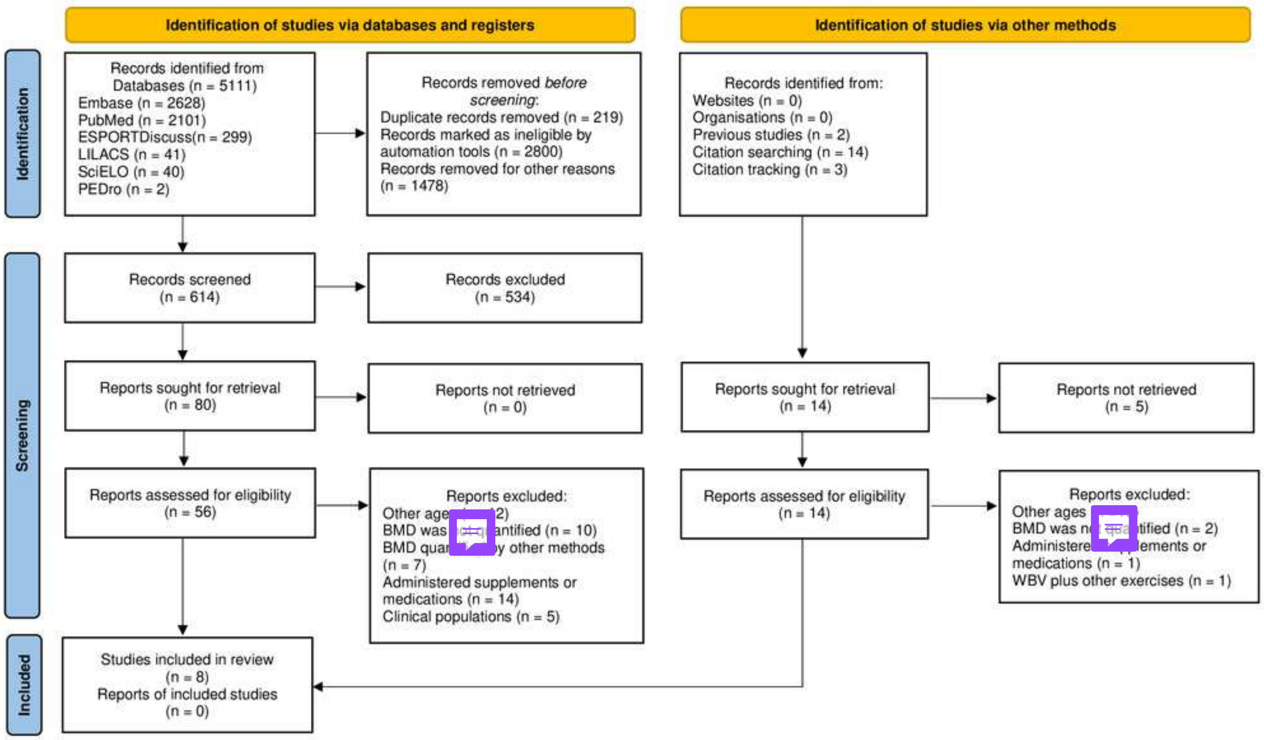

Figure 2

Whole-body vibration meta-analysis.

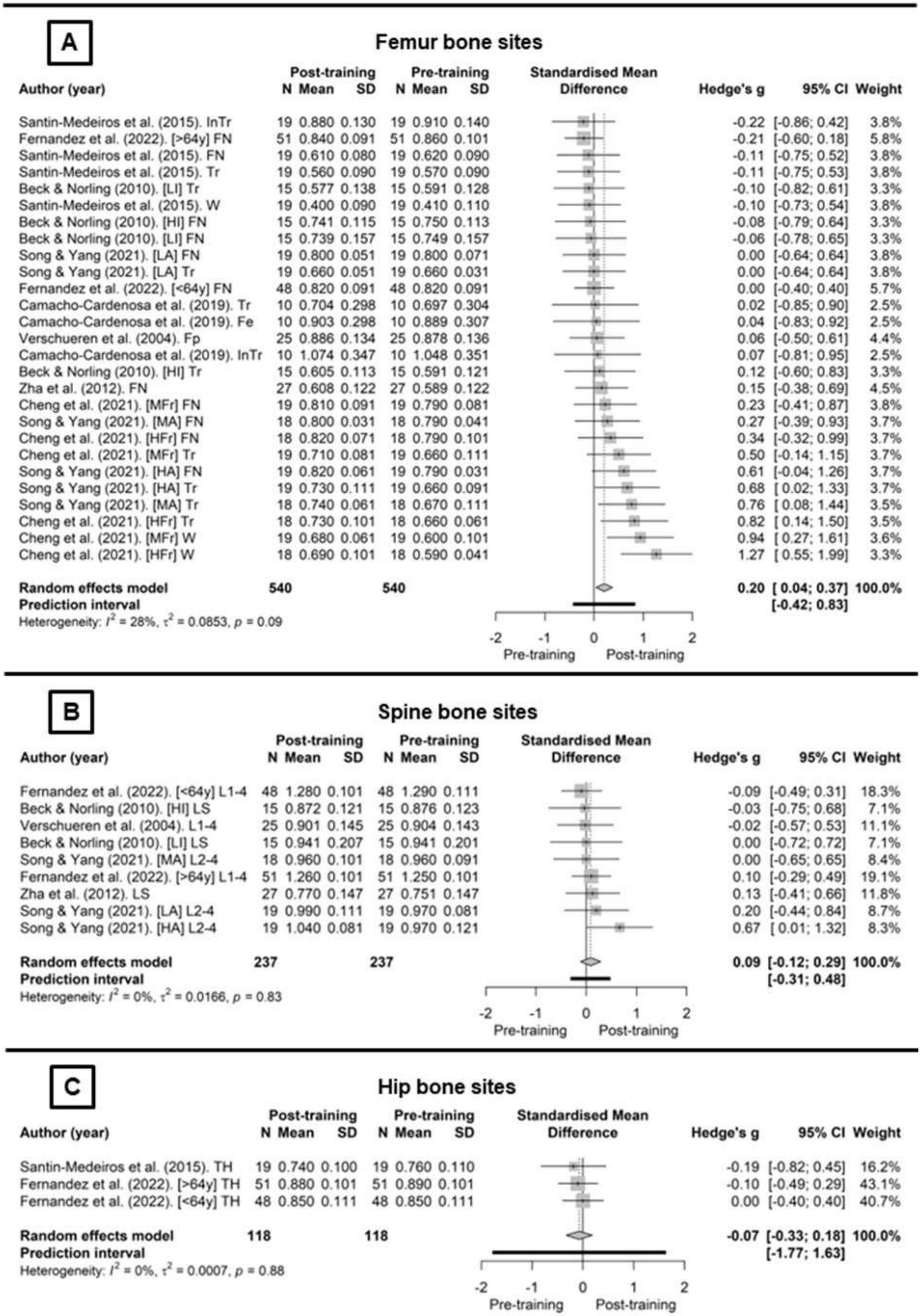
A
Femur bone sites
Post-training
Pre-training
Standardised Mean Difference
Author (year) N Mean SD N Mean SD Hedge's g 95% CI Weight
Santin-Medeiros et al. (2015). InTr 19 0.880 0.130 19 0.910 0.140 -0.22 [-0.86; 0.42] 3.8%
Fernandez et al. (2022). [>64y] FN 51 0.840 0.091 51 0.860 0.101 -0.21 [-0.60; 0.18] 5.8%
Santin-Medeiros et al. (2015). FN 19 0.610 0.080 19 0.620 0.090 -0.11 [-0.75; 0.52] 3.8%
Santin-Medeiros et al. (2015). Tr 19 0.560 0.090 19 0.570 0.090 -0.11 [-0.75; 0.53] 3.8%
Beck & Norling (2010). [LI] Tr 15 0.577 0.138 15 0.591 0.128 -0.10 [-0.82; 0.61] 3.3%
Santin-Medeiros et al. (2015). W 19 0.400 0.090 19 0.410 0.110 -0.10 [-0.73; 0.54] 3.8%
Beck & Norling (2010). [HI] FN 15 0.741 0.115 15 0.750 0.113 -0.08 [-0.79; 0.64] 3.3%
Beck & Norling (2010). [LI] FN 15 0.739 0.157 15 0.749 0.157 -0.06 [-0.78; 0.65] 3.3%
Song & Yang (2021). [LA] FN 19 0.800 0.051 19 0.800 0.071 0.00 [-0.64; 0.64] 3.8%
Song & Yang (2021). [LA] Tr 19 0.660 0.051 19 0.660 0.031 0.00 [-0.64; 0.64] 3.8%
Fernandez et al. (2022). [<64y] FN 48 0.820 0.091 48 0.820 0.091 0.00 [-0.40; 0.40] 5.7%
Camacho-Cardenosa et al. (2019). Tr 10 0.704 0.298 10 0.697 0.304 0.02 [-0.85; 0.90] 2.5%
Camacho-Cardenosa et al. (2019). Fe 10 0.903 0.298 10 0.889 0.307 0.04 [-0.83; 0.92] 2.5%
Verschueren et al. (2004). Fp 25 0.886 0.134 25 0.878 0.136 0.06 [-0.50; 0.61] 4.4%
Camacho-Cardenosa et al. (2019). InTr 10 1.074 0.347 10 1.048 0.351 0.07 [-0.81; 0.95] 2.5%
Beck & Norling (2010). [HI] Tr 15 0.605 0.113 15 0.591 0.121 0.12 [-0.60; 0.83] 3.3%
Zha et al. (2012). FN 27 0.608 0.122 27 0.589 0.122 0.15 [-0.38; 0.69] 4.5%
Cheng et al. (2021). [MFr] FN 19 0.810 0.091 19 0.790 0.081 0.23 [-0.41; 0.87] 3.8%
Song & Yang (2021). [MA] FN 18 0.800 0.031 18 0.790 0.041 0.27 [-0.39; 0.93] 3.7%
Cheng et al. (2021). [HFr] FN 18 0.820 0.071 18 0.790 0.101 0.34 [-0.32; 0.99] 3.7%
Cheng et al. (2021). [MFr] Tr 19 0.710 0.081 19 0.660 0.111 0.50 [-0.14; 1.15] 3.7%
Song & Yang (2021). [HA] FN 19 0.820 0.061 19 0.790 0.031 0.61 [-0.04; 1.26] 3.7%
Song & Yang (2021). [HA] Tr 19 0.730 0.111 19 0.660 0.091 0.68 [0.02; 1.33] 3.7%
Song & Yang (2021). [MA] Tr 18 0.740 0.061 18 0.670 0.111 0.76 [0.08; 1.44] 3.5%
Cheng et al. (2021). [HFr] Tr 18 0.730 0.101 18 0.660 0.061 0.82 [0.14; 1.50] 3.5%
Cheng et al. (2021). [MFr] W 19 0.680 0.061 19 0.600 0.101 0.94 [0.27; 1.61] 3.6%
Cheng et al. (2021). [HFr] W 18 0.690 0.101 18 0.590 0.041 1.27 [0.55; 1.99] 3.3%
Random effects model 540 540 0.20 [0.04; 0.37] 100.0%
Prediction interval [-0.42; 0.83]
Heterogeneity: I^2 = 28%, τ^2 = 0.0853, p = 0.09
-2 -1 0 1 2
Pre-training Post-training
B
Spine bone sites
Post-training
Pre-training
Standardised Mean Difference
Author (year) N Mean SD N Mean SD Hedge's g 95% CI Weight
Fernandez et al. (2022). [<64y] L1-4 48 1.280 0.101 48 1.290 0.111 -0.09 [-0.49; 0.31] 18.3%
Beck & Norling (2010). [HI] LS 15 0.872 0.121 15 0.876 0.123 -0.03 [-0.75; 0.68] 7.1%
Verschueren et al. (2004). L1-4 25 0.901 0.145 25 0.904 0.143 -0.02 [-0.57; 0.53] 11.1%
Beck & Norling (2010). [LI] LS 15 0.941 0.207 15 0.941 0.201 0.00 [-0.72; 0.72] 7.1%
Song & Yang (2021). [MA] L2-4 18 0.960 0.101 18 0.960 0.091 0.00 [-0.65; 0.65] 8.4%
Fernandez et al. (2022). [>64y] L1-4 51 1.260 0.101 51 1.250 0.101 0.10 [-0.29; 0.49] 19.1%
Zha et al. (2012). LS 27 0.770 0.147 27 0.751 0.147 0.13 [-0.41; 0.66] 11.8%
Song & Yang (2021). [LA] L2-4 19 0.990 0.111 19 0.970 0.081 0.20 [-0.44; 0.84] 8.7%
Song & Yang (2021). [HA] L2-4 19 1.040 0.081 19 0.970 0.121 0.67 [0.01; 1.32] 8.3%
Random effects model 237 237 0.09 [-0.12; 0.29] 100.0%
Prediction interval [-0.31; 0.48]
Heterogeneity: I^2 = 0%, τ^2 = 0.0166, p = 0.83
-2 -1 0 1 2
Pre-training Post-training
C
Hip bone sites
Post-training
Pre-training
Standardised Mean Difference
Author (year) N Mean SD N Mean SD Hedge's g 95% CI Weight
Santin-Medeiros et al. (2015). TH 19 0.740 0.100 19 0.760 0.110 -0.19 [-0.82; 0.45] 16.2%
Fernandez et al. (2022). [>64y] TH 51 0.880 0.101 51 0.890 0.101 -0.10 [-0.49; 0.29] 43.1%
Fernandez et al. (2022). [<64y] TH 48 0.850 0.111 48 0.850 0.111 0.00 [-0.40; 0.40] 40.7%
Random effects model 118 118 -0.07 [-0.33; 0.18] 100.0%
Prediction interval [-1.77; 1.63]
Heterogeneity: I^2 = 0%, τ^2 = 0.0007, p = 0.88
-2 -1 0 1 2
Pre-training Post-training

Figure 3

Whole-body vibration publications bias.