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REVIEW

Effects of whole-body vibration on muscle strength, bone mineral content and density, and balance and body composition of children and adolescents with Down syndrome: a systematic review

M. B. Saquetto [1,2] · F. F. Pereira [2] · R. S. Queiroz [2,3] · C. M. da Silva [1,2] · C. S. Conceição [1,2] · M. Gomes Neto [1,2,4]

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Abstract
The aim of this study is to verify the effects of whole-body vibration (WBV) training on the muscle strength of children and adolescents with Down syndrome. We searched MEDLINE, Cochrane, SciELO, Lilacs and PUBMED databases and included manual searches to identify randomised controlled trials to investigate the effects of WBV on the structure and body function of children and adolescents with Down syndrome. Two reviewers independently selected the studies and performed statistical analysis. In total, five studies with 171 patients that compared WBV with exercise and/or control were included. Two studies demonstrated a significant difference between the muscle strength of children and adolescents with Down syndrome who received WBV training and that of those who did not receive the intervention. The studies included in this systematic review showed that WBV training has positive effects on bone mineral density (BMD), body composition and balance. Results of this study showed that WBV training improves muscle strength, BMD, body composition and balance of children and adolescents with Down syndrome, and a more in-depth analysis of its effects on other variables in this population is required, as well as of parameters to be used.

Keywords Adolescents · Children · Down syndrome · Rehabilitation · Whole-body vibration

Introduction

For years, children afflicted with the genetic abnormality known as Down syndrome (DS) have had a relatively short life. Life expectancy for individuals with DS has increased in recent years, shifting from 30 years in the 1980s [1] to over 60 years in this decade [2] with the emergence of novel therapeutic modalities [3].

Characterised by ligament laxity, muscular hypotonia and low bone mineral density (BMD), individuals with DS also present with mental retardation and delayed perception of response. These characteristics hinder postural control, resulting in delayed development and motor acquisition [4–6].

The low BMD observed in this population can also be influenced by factors such as body mass index, family history, endocrine abnormalities and vitamin intake. In addition, deficits in muscle strength and torque can reduce BMD. These associated factors can negatively influence balance and gait, thereby leading to a great risk of fractures in this population [4,7].

The study of Wu [8] aimed to assess bone mineral content (BMC) and BMD in pre-adolescent boys with and without DS at 7–10 years of age. Their results supported that the pelvis may be the first site to show the detrimental effect of DS in BMC and BMD.

The relationship between body composition and bone metabolism has been the subject of intensive research, and the

✉ M. B. Saquetto
msaquetto@ufba.br

1 Departamento de Fisioterapia, Instituto de Ciências da Saúde, Curso de Fisioterapia da Universidade Federal da Bahia – UFBA, Av. Reitor Miguel Calmon s/n - Vale do Canela, Salvador, BA 40110-100, Brazil

2 Grupo de Pesquisa em Fisioterapia – UFBA, Salvador, BA, Brazil

3 Departamento de Saúde I, Curso de Fisioterapia da Universidade Estadual do Sudoeste da Bahia – UESB, Jequié, BA, Brazil

4 Programa de Pós Graduação em Medicina e Saúde – UFBA, Salvador, BA, Brazil

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complex links among bones, adipose tissues and the muscular system have been explored. Body mass and composition may influence mechanical forces exerted on bones, and the frequency of forces is defined by an individual's physical activity. Both the static load generated by adipose tissues and the dynamic load generated by muscle tissues create tensions in the bone and benefit bone formation [9,10].

Considering these alterations, some techniques have been studied and applied in this population to investigate their potential in reducing the risks to and vulnerability of the health of these individuals, thereby improving their quality of life and increasing their life expectancy. Whole-body vibration (WBV) is one such intervention that aims to improve BMD, and it has positive effects on the musculoskeletal, cardiorespiratory and neuromuscular systems. Increased calcium deposition, muscle strength, respiratory capacity and quality of life have already been reported by other studies that have examined the effects of WBV [11,12].

Regarding to the physical principles of WBV, vibration is used as an oscillatory motion on a point of equilibrium. In general, the WBV platform used in studies is in a side-alternating or vertical synchronous mode, usually with the user standing on the equipment. In addition, a new model (i.e., dual mode) induces vibrations in all three planes. The acceleration load imposed on the neuromuscular system during WBV exercises is characterised by the interaction between the vibration frequency and the amplitude of platform displacement [13].

Lienhard et al. [14] evaluated the influence of different magnitudes and directions of vibration platform acceleration on surface electromyography (sEMG) during WBV exercises, and they suggested that vibrations mainly in the vertical direction should be recommended. Moreover, lower body sEMG activity can be increased by increasing the vertical acceleration load.

The effects of WBV training on children and adolescents with DS have not been demonstrated in previous reviews. Thus, this study aimed to verify the effects of WBV training on the muscle strength, BMC and BMD and balance and body composition of children and adolescents with DS.

Methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [15].

Eligibility criteria

All controlled trials that studied the effects of WBV in children and adolescents with DS were included. To be eligible, the trial should have randomised children and/or adolescents to at least one intervention group, and their control group should comprise children and adolescents with DS.

Search methods for identification of relevant studies

We searched the MEDLINE, LILACS, SciELO, Physiotherapy Evidence Database (PEDro) and Cochrane Library databases until May 2017 without language restrictions. A standard protocol for this search was developed and where possible, a controlled vocabulary was used. Keywords and their synonyms were used to sensitise the search.

For the identification of controlled trials in the PubMed/MEDLINE database, an optimally sensitive strategy developed for the Cochrane Collaboration was used [16]. In this search strategy, the keywords used were categorised into the following three groups: study design, participants and interventions. In the search strategy, there were the following keywords: whole-body vibration, vibration intervention, Down syndrome, children and adolescents, and vibration platform, and the following combinations were made: Down syndrome and whole-body vibration, vibration intervention and Down syndrome, vibration and Down syndrome children, whole-body vibration and adolescents with Down syndrome and vibration plate and Down syndrome.

The reference lists of all the articles eligible for inclusion in this systematic review were analysed to detect other potentially eligible studies. For ongoing studies or when the confirmation of any data or additional information was required, the authors were contacted by e-mail.

Data collection and analysis

A search strategy was used to obtain the titles and abstracts of studies that could be relevant for this review. Two authors independently evaluated each abstract identified in the search. If at least one of the authors considered a reference to be eligible, the full text was obtained for complete analysis. Two authors independently evaluated full-text articles for eligibility according to the inclusion and exclusion criteria. A standardised data extraction form was used for the inclusion and exclusion criteria.

Two authors independently extracted data from the published reports using the standard data extraction forms adapted from the Cochrane Collaboration [15] model, considering the following: (1) aspects of the study population such as the average age and sex; (2) aspects of the intervention performed (sample size, type of exercise performed, presence of supervision, frequency and duration of each session); (3) follow-up; (4) loss to follow-up; (5) outcome measures; and (6) presented results.

Disagreements were resolved by one of the authors. Any further information required from the original author was requested by e-mail.

Quality assessment of studies included in the meta-analysis

The quality of each study identified in this systematic review was classified using the PEDro scale. This is a useful tool for assessing the quality of physical therapy and rehabilitation trials [17] based on a Delphi list [16] that consists of 11 items. However, item 1 is not used to calculate the PEDro score. Two researchers independently scored the studies using a 0–10 scale [17].

Results

Description of selected studies

We identified six abstracts in our initial search. Among these papers, two studies used the same population, intervention and control but presented results with different outcomes. Five studies [18,19,20,21,22] were considered potentially relevant and selected for detailed analysis. Figure 1 shows the PRISMA flow diagram of the studies included in the review. The five articles were fully analysed and approved by both reviewers. Data from each controlled trial were then extracted. Both reviewers scored each article using the PEDro scale. The results of their assessments are presented in Table 1.

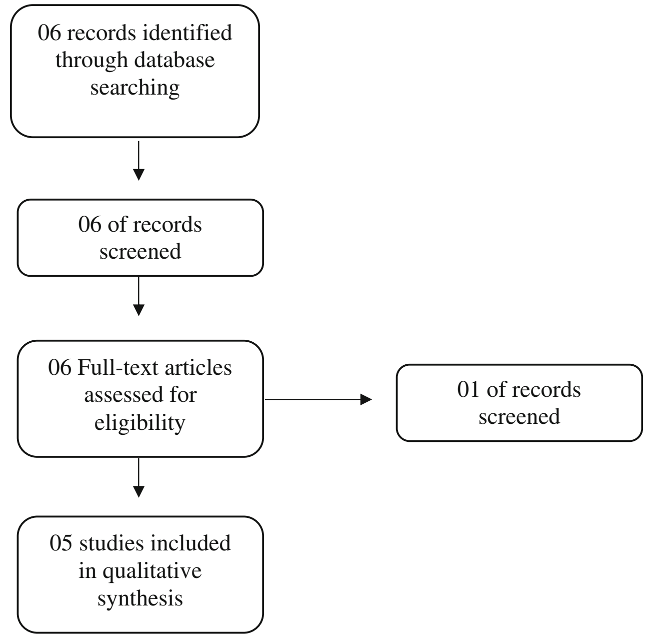

Fig. 1 PRISMA flow diagram of the studies included in the review

Characteristics of included trials

The five trials included in the review were randomised controlled trials (RCTs) [18,19,20,21,22]. The final study sample included 25 [23]–30 [18,19,20,22] children, totalling 145 participants. All studies analysed in this review included children and adolescents with DS, whose ages ranged from 8 [18] to 20 [22] years. Studies included participants of both sexes. The sample sizes, outcomes and results of the studies are summarised in Table 2.

The intervention performed was WBV training with a frequency of 25–30 Hz [18,19,20,21,22] and a vibration time of 5–10 [18,19,21,22] and 10–15 min [22]. Most of the study interventions lasted 20 weeks [20,21,22], but two studies used interventions of 12 [19] and 24 [18] weeks, with a frequency of three times a week. Two studies used side-alternating vibration, in which patients were in a standing position and physiotherapists blocked the child's knees [18,19]. Three studies used synchronous vibration, in which patients were in a squatting position and physiotherapists only supervised the activities [20,21,22] (Table 3).

With regard to the control groups, the participants' routines in three studies [20,21,22] were unchanged, whereas the other two studies [18,19] included a physiotherapy programme. The physiotherapy programmes added by Eid [18] and Emara [21] included lower limb stretching, muscle strength training, postural control and balance exercises. This programme is described in detail in Table 3.

Risk of bias and assessment of quality

The clinical trials analysed were found to be of moderate methodological quality. The methodological quality assessment made using the PEDro scale (a score out of 10) showed a mean score of 5 (4–8), and 60% of studies had a score that indicated low methodological quality (Table 1). The RCTs presented low quality of evidence because of design limitations, such as concealed allocation, blinded participants, blinded therapists and intention-to-treat analysis. The risk associated with selective reporting was unclear, and none of the studies blinded the therapists or participants.

Outcomes of included studies

Muscle strength

Two studies investigated the effects of WBV [19,20] on muscle strength. Eid [18] measured the muscle strength of the knee flexors, and extensors of the dominant side were measured in pounds using a handheld dynamometer. No significant difference was found in the pre-treatment mean values of the knee flexors ($p = 0.76$); the pre-test mean (standard deviation—SD) was 13.92 (1.72) and 13.71 (2.06) for the control and study groups, respectively. Similarly, the pre-test mean (SD) of the knee extensors was 13.94 (0.83) and 14.04 (1.31) for the control and study groups, respectively ($p = 0.80$).

Table 1 Study quality on the PEDro scale

	Study	1*	2	3	4	5	6	7	8	9	10	11	Total
1	Eid 2015 [18]	✓	✓	✓	✓			✓	✓	✓	✓	✓	8
2	Emara 2016 [19]	✓	✓	✓	✓						✓	✓	5
3	González-Agüero et al. 2013 [20]		✓		✓						✓	✓	4
4	Matute-Llorente et al. 2015 [21]	✓	✓		✓						✓	✓	4
5	Villarroya et al. 2013 [22]	✓	✓		✓						✓	✓	4

1, eligibility criteria and source of participants; *2*, random allocation; *3*, concealed allocation; *4*, baseline comparability; *5*, blinded participants; *6*, blinded therapists; *7*, blinded assessors; *8*, adequate follow-up; *9*, intention-to-treat analysis; *10*, between-group comparisons; *11*, point estimates and variability

*Item 1 does not contribute to the total score

Table 2 Characteristics of the included studies

	Study	Patients (diagnosis, *N*, age, gender)	Intervention groups		Outcome measures	Results
			Treatment	Control		
1	Eid 2015 [18]	DS, 30, 8–10 years, 76.5%, female	Physiotherapy programme + WBVT	Physiotherapy programme	BMI, IQ level, FM of flexors and knee extensors and balance	Each group demonstrated significant improvements in stability indices and muscle strength after treatment, with significantly greater improvements seen in the study group when compared with the control group.
2	Emara 2016 [19]	DS, 30, 10–12 years, 43.3%, female	Physiotherapy programme + WBVT	Physiotherapy programme	BMI, FM of flexors, abductors and extensors of hip, flexors of knee and flexors and extensors of ankle	There were no significant changes in body weight, BMI, waist circumference, and percentage of body fat in both groups. Fat-free mass increased significantly in the WBV group only. There was significant increase in lower limb strength in both groups when compared with their pre- and post-treatment results. Comparison of post-treatment results revealed more increase in lower limb strength in the WBV group.
3	González-Agüero et al. 2013 [20]	DS, 30, 12–18 years, 36.7%, female	WBVT	Routine daily activities	BMI, dual-energy X-ray absorptiometry, pubertal stage and lean and fat mass	No group by time interactions were found for any variable, but the WBV group showed a higher reduction in body fat in the upper limbs and a tendency toward higher percent increase in lean body mass.
4	Matute-Llorente et al. 2015 [21]	DS, 25, 12–18 years, 32%, female	WBVT	Routine daily activities	BMI, pubertal stage, and BMC and BMD	WBV group improved whole-body BMC and BMD, showing group by time interactions in BMC and BMD. Lumbar spine BMC and BMD also increased in the WBV group. Regarding bone structure, WBV group showed improvements in tibial BMC, volumetric BMD (vBMD), cortical vBMD and cortical thickness of the radius.
5	Villarroya et al. 2013 [22]	DS, 30, 11–20 years, 36.7%, female	WBVT	Routine daily activities	Anterior, posterior, medial and lateral oscillation of COP, and COP oscillation speed	After WBV training, no significant differences were found in any parameter in the VCG and nVCG and neither in the nVDSG, but there was a decrease of mean values in the analysed PPs under C4, with significant differences in medial/lateral COP excursion and COP mean velocity and a significant decrease in the C4/C1 ratio of the mean velocity in VDSG.

WBVT, whole-body vibration training; *DS*, Down syndrome; *BMI*, body mass index; *BMD*, bone mineral density; *BMC*, bone mineral content; *COP*, centre of oscillation of pressure; *FM*, muscle strength; *VCG*, speed of the control group; *VDSG*, Down syndrome group speed; *PPs*, postural patterns

Table 3 Characteristics of the experimental intervention in the trials included in the review

	Study	Duration	Volume	Frequency	Vibration system	Posture	Time (min)	Length (week)	Therapist's assistance
1	Eid 2015 [18]	3×/week	10 repetitions	25–30 Hz	Side-alternating	Standing	5–10	24	Blocking the child knees
2	Emara 2016 [19]	3×/week	5 repetitions	25–30 Hz	Side-alternating	Standing	9	12	Blocking the child knees
3	González-Agüero et al. 2013 [20]	3×/week	10 repetitions	25–30 Hz	Synchronous	Squatting	10–15	20	Supervision
4	Matute-Llorente et al. 2015 [21]	3×/week	10 repetitions	25–30 Hz	Synchronous	Squatting	5–10	20	Supervision
5	Villarroya et al. 2013 [22]	3×/week	10 repetitions	25–30 Hz	Synchronous	Squatting	5–10	20	Supervision

After the intervention, comparing the post-treatment mean values of the two groups revealed a statistically significant improvement in favour of the study group in terms of strength of the following muscle groups: knee flexors ($p = 0.04$; effect size of 0.81) and knee extensors ($p = 0.01$; effect size of 0.8). Thus, a large difference between the improvements in muscle strength was noted in both groups.

Emara et al. [19] used a handheld dynamometer to evaluate muscle strength. The difference between the values of pre- and post-treatment mean in the WBV and control groups was 5.27 and 2.5 for hip flexors, 5.36 and 3.33 for hip extensors, 3.09 and 2.04 for hip abductors, 6.01 and 2.14 for knee extensors, 4.73 and 1.75 for knee flexors and 2.14 and 1.06 for ankle plantar flexors, respectively.

Analysis of both groups revealed a significant increase in muscle strength in all the groups following the intervention. Analysis between the groups revealed more improvement in favour of the WBV group at $p = 0.001$ for hip flexors, $p < 0.001$ for hip extensors, $p = 0.028$ for hip abductors, $p = 0.001$ for knee extensors, $p = 0.005$ for knee flexors and $p = 0.003$ for ankle plantar flexors.

BMC and BMD

One study [21] evaluated total and lumbar region BMC and BMD. Both the intervention and control groups showed statistical increases in total BMC of 2.8 and 1.9% (95% CI, 3.5–2.1 and 2.9–0.9), respectively, and in lumbar BMC of 6.6 and 4.0% (95% CI, 8.6–4.7 and 6.1–1.9), respectively, with no statistically significant differences between the groups ($p > 0.05$).

BMD significantly improved by 3.3% (95% CI, 4.9–1.7) in the WBV group and 2.2% (95% CI, 3.4–1.0) in the control group in the lumbar spine region ($p < 0.05$). In the proximal region of the tibia, volumetric BMD (vBMD) also showed a significant improvement of 7% (95% CI, 7.4–6.7) among participants who received the WBV training intervention. Significant statistical increases were observed in the tibial cortical vBMD and cortical thickness at 66% of the radius of 2.4 and 10.9% (95% CI, 2.6–2.3 and 12.4–9.3), respectively (all, $p < 0.05$). No difference was found between the groups. vBMD was measured with peripheral quantitative computed tomography.

Balance

The Eid [18] study evaluated balance using the Biodex Stability System (BSS; Biodex, Inc., Shirley, NY, USA). BSS measured the degree of tilting for each axis during dynamic conditions. The calculated medial–lateral stability index, anterior–posterior stability index and overall stability index observed post-intervention were 1.24 and 1.09, 1.05 and 0.92 and 1.37 and 1.19 for the control and intervention groups, respectively, with statistical significance in the intervention groups ($p < 0.05$).

Villarroya et al. [22] also reported that WBV training exerts significant effects on the stability of children and adolescents with DS, and they observed a reduction in the mean velocity of oscillations and level of lateromedial inclination ($p < 0.05$). These measures were considered from the analysis of the postural patterns through the pressure oscillation centre.

Body composition

Emara et al. [19] and González-Aguero et al. [20] evaluated the body composition of individuals and found a significant improvement in fat-free mass of 0.8% ($p = 0.018$) and a reduction in fat in the upper limbs ($p < 0.05$), with a tendency to increase lean body mass ($p = 0.08$).

Discussion

In this systematic review, two studies demonstrated a significant difference between muscle strength in children and adolescents with DS who received WBV training and muscle strength of those who did not receive the intervention. The individual studies included in this systematic review showed that WBV training had positive effects on BMD, body composition and balance.

WBV is a potential tool in the rehabilitation of paediatric patients [23]. However, no systematic review of the effects of WBV in children with DS has been performed. This systematic review is important, because it analyses WBV as a potential co-adjuvant modality in rehabilitation.

Considering the clinical characteristics of individuals with DS, interventions aimed at increasing muscle strength, BMD and BMC, and balance and body composition are fundamental in improving the functionality of these individuals in childhood and adolescence, with consequent repercussions in adulthood. The improvement in function includes minimised vulnerability to fractures, dislocations and complications resulting from hypermobility and motor acquisitions in an adequate time.

This review demonstrated significant improvements in the muscle strength indices of participants who received WBV in the studies by Eid [18] and Emara [19], as well as in BMD of participants who received WBV in the study by Matute-Llorente et al. [23] Other research with different paediatric populations that used WBV training as an intervention, in association with or without exercise training, similarly showed significant improvements in body composition, BMD and muscle strength [23–28].

Semler et al. [27] also investigated muscle strength and showed improvements in this factor in children with imperfect osteogenesis. WBV has the capacity of osteogenesis, allowing an increase in bone deposition and reducing resorption [8,24]. However, despite Högler et al. [28] suggesting that rotational WBV therapy is not a practical, effective and safe treatment tool to increase bone formation and strength in osteogenesis imperfecta (OI), Hoyer-Kuhn et al. [29] commented that their design provides insufficient power to conclude that WBV in OI is not effective and safe.

Improvements in BMD reduce a person's risk of fractures, to which children and adolescents with DS are prone. Given their low BMD, both men and women with DS are more predisposed to osteopenia than those without DS [7]. Thus, this lack of bone mass increases the risk of osteoporosis and leaves individuals with DS vulnerable to fractures, especially with advancing age [30].

A high fracture rate in individuals with DS might also be due to high fall tendencies. They observed that improvements in balance among individuals with DS can protect them from future fracture. Improvements in balance of patients with DS who underwent WBV training [20,24] suggest great body stability, such as that observed in the reduction in trunk oscillation in children with cerebral palsy [31].

WBV training has emerged as a novel intervention strategy for individuals with DS, and it has the potential to improve the functional capacity and quality of life of these individuals. However, only few studies in the literature examined the use of WBV training with this specific population. In addition, the studies included in this review evaluated only the structure and function of the body; they did not analyse the impact of WBV training on the activity and participation of children and adolescents with DS.

The results of this study should be interpreted with caution. Although the five studies were analysed and a consensus was reached regarding the application of the WBV method, the control groups performed different activities among themselves. Therefore, without uniformity of the evaluated outcomes, including only two studies that evaluated muscle strength and for only one joint, the effects of WBV on other muscular regions cannot be confirmed.

The data of this systematic review were obtained from studies that added WBV training to a conventional physiotherapy programme, which does not allow for a comparison of only the two techniques alone. This scenario does not invalidate the improvements in the variables identified by this study but limits the ability of the study to affirm the greater effects of one technique over the other. However, as a treatment adjunct to conventional physiotherapy, the acquired benefits of WBV training are significant.

Considering the limitations of this study and comparing its findings with those of the studies in the literature, WBV training is clearly capable of producing positive effects on the structure and body function of children and adolescents with DS, without any known adverse effects.

However, the protocols differ in terms of the type of vibration (standing or squatting) and the type of interference of the physiotherapist (supervision or blocking the child knees); therefore, the results must be interpreted with caution. The findings demonstrate that WBV training is effective in supporting conventional physiotherapy for improving the functionality of individuals affected by DS.

Compliance with ethical standards

Conflicts of interest None.

References

1. Baird PA, Sadovnick AD (1987 Jun) Life expectancy in Down syndrome. J Pediatr 110(6):849–854. https://doi.org/10.1016/S0022-3476(87)80395-5
2. Malt EA[1], Dahl RC, Haugsand TM, Ulvestad IH, Emilsen NM, Hansen B, Cardenas YE, Skøld RO, Thorsen AT, Davidsen EM.

Health and disease in adults with Down syndrome. Tidsskr Nor Laegeforen 2013 Feb 5;133(3):290–294. doi: https://doi.org/10.4045/tidsskr.12.0390.
3. Carfi A, Antocicco M, Brandi V, Cipriani C, Fiore F, Mascia D, Settanni S, Vetrano DL, Bernabei R, Onder G (2014) Characteristics of adults with Down syndrome: prevalence of age-related conditions. Froint Med 1(51):1–5
4. Wang HY, Long IM, Liu MF (2012) Relationships between task-oriented postural control and motor ability in children and adolescents with Down syndrome. Res Dev Disabil 33(6):1792–1798. https://doi.org/10.1016/j.ridd.2012.05.002
5. Pachajoa H, Riascos AJ, Castro D, Isaza C, Quintero JC (2014) Down syndrome passed from mother to child. Biomedica 34(3): 326–329. https://doi.org/10.1590/S0120-41572014000300002
6. Ulrich DA, Lloyd MC, Tiernan CW, Looper JE, Angulo-Barroso RM (2008) Effects of intensity of treadmill training on developmental outcomes and stepping in infants with Down syndrome: a randomized trial. Phys Ther 88(1):114–122. https://doi.org/10.2522/ptj.20070139
7. Mckelvey KD, Fowler TW, Akel NS, Kelsay JA, Gaddy D, Wenger GR, Suva J (2013) Low bone turnover and low bone density in a cohort of adults with Down syndrome. Osteoporos Int 24(4):1333–1338. https://doi.org/10.1007/s00198-012-2109-4
8. Wu J (2013 Nov) Bone mass and density in preadolescent boys with and without Down syndrome. Osteoporos Int 24(11):2847–2854. https://doi.org/10.1007/s00198-013-2393-7
9. Faje A, Klibanski A (2012 Sep) Body composition and skeletal health: too heavy? Too thin? Curr Osteoporos Rep 10(3):208–216. https://doi.org/10.1007/s11914-012-0106-3
10. Srikanth R, Cassidy G, Joiner C, Teeluckdharry S (2011 Jan) Osteoporosis in people with intellectual disabilities: a review and a brief study of risk factors for osteoporosis in a community sample of people with intellectual disabilities. J Intellect Disabil Res 55(1): 53–62. https://doi.org/10.1111/j.1365-2788.2010.01346.x
11. Matute-Llorente A, González-Agüero A, Gómez-Cabello A, Vicente-Rodríguez G, Casajús Mallén JA (2014 Apr) Effect of whole-body vibration therapy on health-related physical fitness in children and adolescents with disabilities: a systematic review. J Adolesc Health 54(4):385–396. https://doi.org/10.1016/j.jadohealth.2013.11.001
12. Park SY, Son WM, Kwon OS (2015) Effects of whole body vibration training on body composition, skeletal muscle strength, and cardiovascular health. J Exerc Rehabil 11(6):289–295. https://doi.org/10.12965/jer.150254
13. Rauch F, Sievanen H, Boonen S, Cardinale M, Degens H, Felsenberg D, Roth J, Schoenau E, Verschueren S, Rittweger J (2010) Reporting whole-body vibration intervention studies: recommendations of the International Society of Musculoskeletal and Neuronal Interactions. J Musculoskelet Neuronal Interact 10(3): 193–198
14. Lienhard K, Vienneau J, Nigg S, Meste O, Colson SS, Nigg BM (2015) Relationship between lower limb muscle activity and platform acceleration during whole-body vibration exercise. J Strength Cond Res 29(10):2844–2853. https://doi.org/10.1519/JSC.0000000000000927
15. Moher D, Liberati A, Tetzlaff J, Altman DG, Prisma G (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 339:2535
16. Higgins JP, Green S. The Cochrane Library. Issue 4. Chichester: John Wiley & Sons; Cochrane handbook for Systematic Reviews of Interventions 4.2.6. 2006.
17. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M (2003) Reliability of the PEDro scale for rating of quality randomized controlled trials. Phys Ther 83(8):713–721
18. Eid MA (2015) Effect of whole-body vibration training on standing balance and muscle strength in children with Down syndrome. Am J Phys Med Rehabil 94(8):633–643. https://doi.org/10.1097/PHM.0000000000000224
19. Emara HA (2016) Effects of whole body vibration on body composition and muscle strength of children with Down syndrome. Intern J Ther Rehabil Res 5(4):1–8
20. González-Aguero A, Matute-Llorente A, Gómez-Cabello A, Casajús JA, Vicente-Rodríguez G (2013) Effects of whole body vibration training on body composition in adolescents with Down syndrome. Res Dev Disabil 34(5):1426–1433. https://doi.org/10.1016/j.ridd.2013.01.023
21. Matute-Llorente A, González-Aguero A, Gómez-Cabello A, Olmedillas H, Vicente-Rodríguez G, Casajús JA (2015) Effect of whole body vibration training on bone mineral density and bone quality in adolescents with Down syndrome: a randomized controlled trial. Osteoporos Int 26(10):2449–2459. https://doi.org/10.1007/s00198-015-3159-1
22. Villarroya MA, González-Aguero A, Moros T, Gómez-Trullén E, Casajús JA (2013) Effects of whole body vibration training on balance in adolescents with and without Down syndrome. Res Dev Disabil 34(10):3057–3065. https://doi.org/10.1016/j.ridd.2013.06.015
23. El-Shamy SM (2014 Feb) Effect of whole-body vibration on muscle strength and balance in diplegic cerebral palsy: a randomized controlled trial. Am J Phys Med Rehabil 93(2):114–121. https://doi.org/10.1097/PHM.0b013e3182a541a4
24. Humphries B, Fenning A, Dugan E, Guinane J, Macrae K (Dec 2009) Whole-body vibration effects on bone mineral density in women with or without resistance training. Aviat Space Environ Med 80(12):1025–1031. https://doi.org/10.3357/ASEM.2573.2009
25. Kilebrant S, Braathen G, Emilsson R, Glansén U, Söderpalm A, Zetterlund B, Westerberg B, Magnusson P, Swolin-Eide D (2015 Mar) Whole-body vibration therapy in children with severe motor disabilities. J Rehabil Med 47(3):223–228. https://doi.org/10.2340/16501977-1921
26. Matute-llorente A, González-aguero A, Gómez-cabello A, Tous-fajardo J, Vivente-Rodríguez G, Casajús JA (2016) Effect of whole-body vibration training on bone mass in adolescents with and without Down syndrome: a randomized controlled trial. Osteoporos Int 27(1):181–191. https://doi.org/10.1007/s00198-015-3232-9
27. Semler O, Fricke O, Vezyroglou K, Estrela C, Stabrey A, Schoenau E (2008) Results of a prospective pilot trial on mobility after whole body vibration in children and adolescents with osteogenesis imperfecta. Clin Rehabil 22(5):387–394. https://doi.org/10.1177/0269215507080763
28. Högler W, Scott J, Bishop N, Arundel P, Nightingale P, Mughal MZ, Padidela R, Shaw N, Crabtree N (2017 Aug 1) The effect of whole body vibration training on bone and muscle function in children with osteogenesis imperfecta. J Clin Endocrinol Metab 102(8): 2734–2743. https://doi.org/10.1210/jc.2017-00275
29. Hoyer-Kuhn H, Schoenau E, Semler O (2017 Aug 30) Comment on “The effect of whole body vibration training on bone and muscle function in children with osteogenesis imperfecta”. J Clin Endocrinol Metab 102(11):4260–4261. https://doi.org/10.1210/jc.2017-01514
30. Villani ER, Onder G, Carfì A, Di Segni C, Raimondo S, Silvestrini A, Meucci E, Mancini A (2016) Thyroid function and its implications in oxidative stress influencing the pathogenesis of osteoporosis in adults with Down syndrome: a cohort study. Horm Metab Res 48(9):565–570. https://doi.org/10.1055/s-0042-112127
31. Unger M, Jelsma J, Stark C (2013) Effect of a trunk-targeted intervention using vibration on posture and gait in children with spastic type cerebral palsy: a randomized control trial. Dev Neurorehabil 16(2):79–88. https://doi.org/10.3109/17518423.2012.715313