Systematic Review and Meta-Analysis

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Effectiveness of whole-body vibration in patients with cerebral palsy

A systematic review and meta-analysis

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Abstract

Background: This study examined the effects of systemic vibration exercises on cerebral palsy patients.

Methods: Literature published in Cumulated Index to Nursing and Allied Health Literature (CINAHL), Cochrane library, Embase, Physiotherapy Evidence Database (PEDro), and PubMed was reviewed. A total of 2978 studies were initially retrieved. After further reading of the full texts 17 articles were finally included. A quality assessment of the included studies was conducted using the risk of bias (RoB) 2.0, and the Funnel plot and the Egger test were conducted to confirm the publication bias. Subgroup analysis was carried out according to the dependent variables, the international classification of functioning, disability, and health (ICF), frequency, treatment period and age.

Results: The overall effect size of homogeneity was 0.474 (CI = 0.148–0.801). The analysis of the dependent variables showed the following order of the effect size: balance, muscle strength, spasticity, bone density, range of motion of the joint, gait function, and motor function. In the ICF classification, the effect size was observed to follow the order of body structure and function, activity, and participation. The effect size in the intervention according to the treatment period showed the following order: 7 to 12 weeks, 1 to 6 weeks, and 14 to 24 weeks. The age-dependent classification showed the following order in the effect size: school age, adolescent and adult, and infant and school age.

Conclusions: Systemic vibration is the most effective intervention to improve the balance and gait in patients with cerebral palsy and improve the body structure and function according to the ICF.

Abbreviations: CINAHL = Cumulated Index to Nursing and Allied Health Literature, CP = cerebral palsy, CPT = conventional physical therapy, EPT = exercise therapy program, GMFCS = gross motor function classification system, ICF = International Classification of Functioning, Disability, and Health, PEDro = Physiotherapy Evidence Database, PMS = passive muscle stretching, PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analysis, PT = physical therapy, RoB = risk of bias, RT = residence training, WBV = whole-body vibration.

Keywords: cerebral palsy, meta-analysis, systematic review, whole-body vibration

1. Introduction

Whole-body vibration (WBV) activates muscles in the entire body through vibration stimulation of the footplate.[1] which promotes brain plasticity because it stimulates somatosensory sensations in the sole.[2] As the use of WBV in medical institutions has increased, research to improve physical disabilities experienced by patients with nervous system damage is being conducted.[3,4] Cerebral palsy (CP) is neurodevelopmental condition resulting from brain injury that occurs before cerebral development is complete.[3] WBV has been effective in patients with cerebral palsy, as documented over the past 20 years.[5–21]

However, the outcomes are inconsistent and tend to depend on the experience and judgment of the subject using interventional devices in clinical practice.[4] because different application intensities were used in individual studies conducted on cerebral palsy patients. Therefore, it is necessary to determine the best application method through quantification. When applying interventions for motor functions, patients with cerebral palsy are more vulnerable to muscle fatigue than normal children and

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The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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adolescents of the same age. Moreover, interventions of excessive intensity have a detrimental effect on the bodies of cerebral palsy patients.[22–24] The settings are critical. Establishing the best-practice guidelines for patients with cerebral palsy requires improvement in the quality of WBV treatment by integrating protocols from existing studies. Recently, studies using the international classification of functioning, disability, and health (ICF) model and systematic reviews and meta-analyses are increasing.

In addition to a previous meta-analysis by Yang et al,[25] Park et al[26] examined the effects of WBV on stroke patients and performed detailed subgroup analyses, such as the intensity and duration of intervention and the number of interventions per week. Thus, Park et al's study is comparable to previous ones and is considered to be more suitable for generalization. On the other hand, systematic reviews and meta-analyses conducted on cerebral palsy patients are lacking. A previous meta-analysis by Saquetto et al[27] included few studies but did not consider the results of interventions in the 3 aspects of the ICF model. In addition, it is difficult to generalize the results because subgroup analysis was not performed according to the intensity of each intervention, frequency per week, duration, and degree of disability. In addition, only children of a specific age were included.

Therefore, the purpose of this review was to set goals by assessing patients with cerebral palsy on (1) body structure and function, (2) activity, and (3) participation according to the ICF model; the aim was to confirm the specific effect sizes through subgroup analysis.

2. Methods

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[28] Two physical therapists with Master and doctoral degrees in physical therapy conducted the study together. Two authors independently (YG Han, MK Kim) reviewed the titles and abstracts. After exclusion of duplicates, 1 author (YG Han) performed a full text review, and the final list of studies was discussed among the writing group (YG Han and MK Kim). Unresolved discrepancies were resolved by discussion with a third reviewer.

2.1. Search strategy

This study was designed according to participants, intervention, comparison, and outcome chart. The subjects were those diagnosed with cerebral palsy. The intervention was WBV training, which was compared with patients receiving traditional physical therapy, those receiving no intervention, and those receiving other interventions. The interventions were assessed based on their effects on the patient: body structure and function, daily life (activity), and participation.[29]

The data search was conducted from January 2023 to February 2023. Literature written in English and published in Cumulated Index to Nursing and Allied Health Literature (CINAHL), the Cochrane Central Register of Controlled Trials, Physiotherapy Evidence Database (PEDro), PubMed, and the Web of Science were selected. "Vibration" and "cerebral palsy" were used as keywords to minimize the number of articles that would be missed by searching with only 1 keyword. This systematic review was conducted following the registration on the prospective register of systematic reviews (PROSPERO, CRD42023417638). Since this was a meta-analysis of published articles, it was exempt from institutional review board (IRB) review.

2.2. Eligibility criteria

The following selection criteria were used: patients diagnosed with cerebral palsy; studies that compared WBV with other therapy types or nonintervention groups; studies related to the body structure, function, activity, and participation in measurable results; studies published in English; and randomized controlled trials (RCT) or randomized cross-over design studies. The exclusion criteria for this study were as follows: studies that had used a single experimental design without a control group; non-experimental studies, such as research studies, case studies, qualitative studies, animal experiments, and duplicate publications reporting the same results; non-peer-reviewed gray literature (also abstract or poster); studies with insufficient data for effect size analysis; and studies with errors in the results presented in tables or figures.

2.3. Data extraction

With the agreement of all members of the research team, the author names, published year, publication type, study participants, assessment tools, program type, program effectiveness, and outcomes were recorded for data coding.

2.4. Quality assessment

This study was assessed using the Cochrane risk of bias 2.0 (RoB 2.0) tool for randomized trials.[30] Following the Cochrane Handbook systematic reviews of interventions criteria, 2 researchers independently performed the quality assessment, discussed it, and reached a consensus. The domains of RoB 2.0 were as follows: process of randomization (domain 1), deviation from intended interventions (domain 2), data of missing outcome (domain 3), estimation of outcomes (domain 4), selection of reported results (domain 5) and overall bias.

2.5. Data analysis

This review analyzed the data collected using R Studio version 4.2.1. For effect-size analysis, the number of subjects belonging to the experimental and control groups, the average, and the standard deviation were extracted from each study. If a study reported results as the interquartile range or the minimal–maximal range, including the median, the result value was converted into the mean and standard deviation. Ruck et al[7] who reported results as a change, calculated the effect size using the change and standard deviation, and Wan et al[31] collected data based on the median, which complemented the methods of Hozo et al[32] and Bland et al,[33] who used calculation methods.

Based on the standardized mean difference (SMD) of Cohen d and Hedge g, the corrected effect size of the SMD was calculated.[34] Since Cohen d value is sensitive to the sample size and tends to overestimate the effect size with a small sample size, it is necessary to correct this.[35] Therefore, in this study, Hedge g value was calculated to obtain the summary value of the effect size.

The Z value was obtained to confirm the overall effect size, and the significance level was set to $P < .05$. Hedge g value was used, and effect sizes of ≤ 0.3, ~ 0.5, ≥ 0.8, and ≥ 1.3 were set as small, moderate, large, and very large effect sizes, respectively.[36] When an effect size of ≥ 0.5 was observed in various fields, including health and medical care, it was judged as clinically meaningful,[37,38] and the effect size of each study was analyzed based on the 95% confidence intervals.[39,40] And, because the distribution effect sizes in visual observation was inconsistent and the methodological characteristics of the included studies were different, a random effects model was used.

The publication bias in this meta-analysis was determined by making a subjective visual judgment and evaluating the funnel plot.[41] This evaluation was confirmed using Egger regression test.[42] In Egger regression test, the closer the intercept of the regression line was to 0, the smaller the publication bias. First, Egger regression test was conducted after the visual judgment of the funnel diagram. Sutton et al[43] did not recommend the funnel

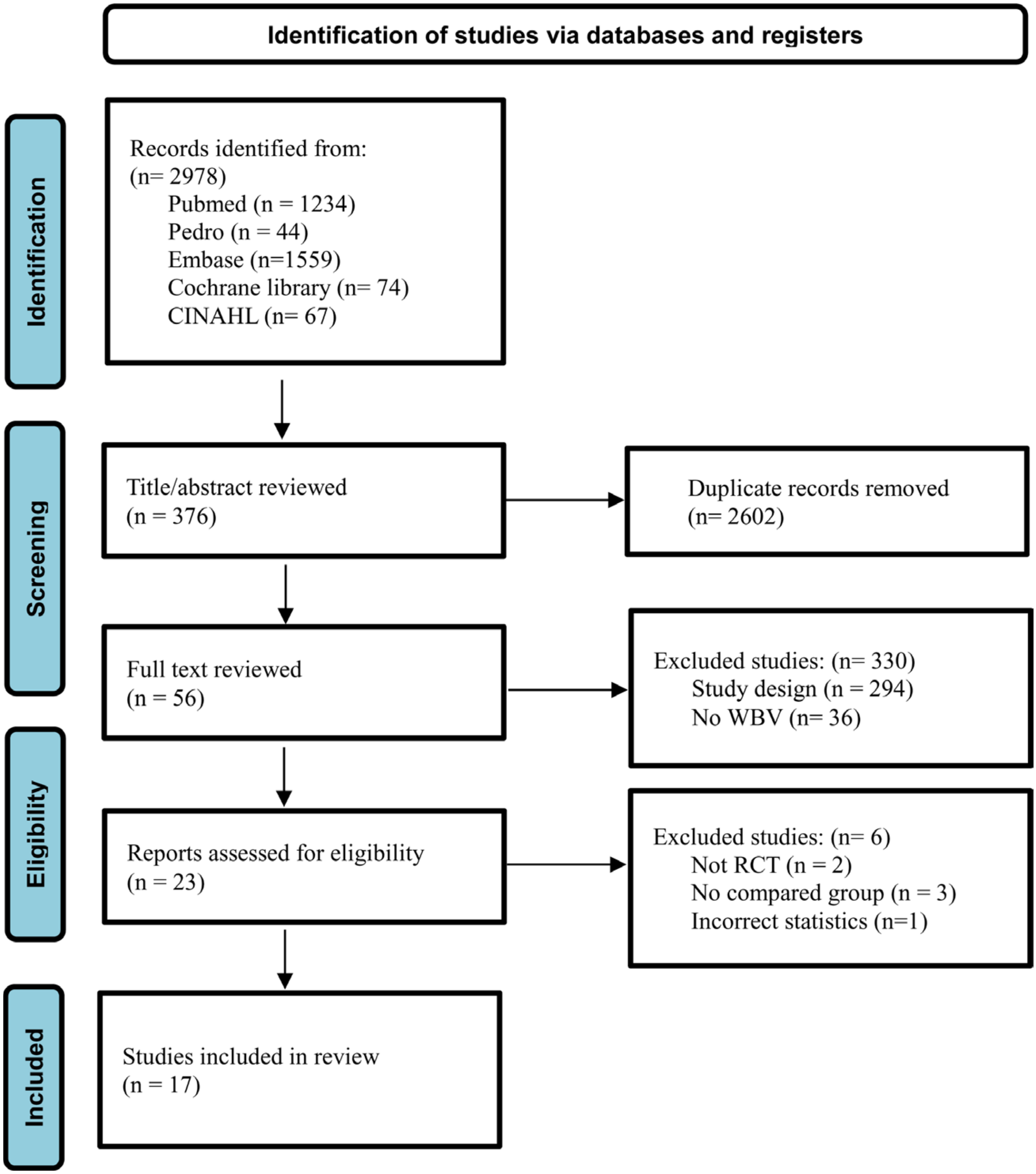

Figure 1. Search and selection process flowchart. The above PRISMA flowchart outlines the study search strategy for both the systematic review and meta-analysis. PRISMA = Preferred Reporting Items for Systematic Reviews and Meta-Analysis.

plot and Egger regression test for meta-analyses including fewer than 10 studies because the study power is low when the number of studies was small. Therefore, when the number of studies was small in this meta-analysis, statistical tests and an examination of funnel plots were not performed to evaluate publication bias.

3. Results

3.1. Search results

A total of 2978 studies were initially retrieved. After 2602 duplicate articles were excluded, the title abstracts were read to exclude irrelevant literature. After further reading of the full texts 336 articles excluded and 17 articles were finally included. The RISMA flow diagram of the study selection process is shown in Figure 1.

3.2. General characteristics of included studies

Table 1 lists the general characteristics of the subjects included in this study. Seventeen studies were finally included,[5–21] and coding was completed in the order of the group, number of subjects, gender, age, the gross motor function classification system (GMFCS) stage, and CP type.

Table 1

General characteristics of included studies.

No	Study	Group	Number of participants	Sex (M/F)	Age	GMFCS	CP type
1	Ahlborg et al[5]	Exp	7	4/3	32.14 ± 6.52	1 (1), 2 (4), 3 (2)	Spastic diplegia (7)
		Con	7	4/3	30.29 ± 5.88	1 (1), 2 (2), 3 (4)	Spastic diplegia (7)
2	Wren et al[6]	Exp	31	18/13	9.4 ± 1.4	1 (10), 2 (4), 3 (15), 4 (2)	Diplegia (18) Hemiplegia (4) Triplegia (2) Quadriplegia (7)
		Con	31	18/13	9.4 ± 1.4	1 (10), 2 (4), 3 (15), 4 (2)	Diplegia (18) Hemiplegia (4) Triplegia (2) Quadriplegia (7)
3	Ruck et al[7]	Exp	10	8/2	8.17 ± 2.58	2 (1), 3 (5), 4 (4)	NR
		Con	10	6/4	8.67 ± 2.84	2 (1), 3 (4), 4 (5)	NR
4	El-Shamy & Mohamed[8]	Exp	15	9/6	11.73 ± 0.79	1 or 2 (NR)	Diplegia (15)
		Con	15	8/7	11.6 ± 1.12	1 or 2 (NR)	Diplegia (15)
5	Ugger et al[9]	Exp	27	17/10	12.63 ± 0.83	1 (13), 2 (8), 3 (6)	Diplegia (15) Rt Hemiplegia (9) Lt Hemiplegia (3)
		Con	27	17/10	12.63 ± 0.83	1 (13), 2 (8), 3 (6)	Diplegia (15) Rt Hemiplegia (9) Lt Hemiplegia (3)
6	Lee and Chon[10]	Exp	15	6/9	10 ± 2.26	1 or 2 (NR)	Diplegia (NR) Quadriplegia (NR)
		Con	15	9/6	9.66 ± 2.58	1 or 2 (NR)	Diplegia (NR) Quadriplegia (NR)
7	Katusic et al[11]	Exp	45	32/13	4.7 ± 1.07	2 (4), 3 (5), 4 (3), 5 (33)	Diplegia (NR) Himiplegia (NR)
		Con	44	20/24	4.97 ± 1	2 (4), 3 (6), 4 (4), 5 (30)	Diplegia (NR) Himiplegia (NR)
8	Ibrahim et al[12]	Exp	15	NR	9.63 ± 1.41	1 or 2 or 3 (NR)	Diplegia 15
		Con	15	NR	9.63 ± 1.41	1 or 2 or 3 (NR)	Diplegia 15
9	El-Shamy[13]	Exp	15	12/3	9.66 ± 1.2	1 (7), 2 (8)	Diplegia 15
		Con	15	11/4	9.93 ± 1.1	1 (6), 2 (9)	Diplegia 15
10	Ko et al[14]	Exp	12	5/7	9.37 ± 2.69	1 (5), 2 (2), 3 (5)	Diplegia 8 Rt Hemiplegia 2 Lt Hemiplegia 2
		Con	12	5/7	9.52 ± 2.16	1 (8), 2 (4)	Diplegia 6 Rt Hemiplegia 3 Lt Hemiplegia 3
11	Cheng et al[15]	Exp	16	9/7	9.8 ± 2.3	1 or 2, 3 (4)	Diplegia 11 Quadriplegia 5
		Con	16	9/7	9.8 ± 2.3	1 or 2, 3 (4)	Diplegia 11 Quadriplegia 5
12	Tupimai et al[16]	Exp	12	NR	10.58 ± 2.35	1 (2), 2 (2), 3 (8)	Spastic Type 12
		Con	12	NR	10.58 ± 2.35	1 (2), 2 (2), 3 (8)	Spastic Type 12
13	Ko et al[17]	Exp	12	5/7	9.37 ± 2.69	1 (5), 2 (2), 3 (5)	Diplegia 8 Rt Hemiplegia 2 Lt Hemiplegia 2
		Con	12	5/7	9.52 ± 2.16	1 (8), 2 (4)	Diplegia 6 Rt Hemiplegia 3 Lt Hemiplegia 3
14	Stark et al[18]	Exp	24	13/11	1.58 ± 0.26	2 (11), 3 (4), 4 (9)	NR
		Con	24	13/11	1.58 ± 0.26	2 (11), 3 (4), 4 (9)	NR
15	Dudoniene et al[19]	Exp	10	6/4	8.56 ± 1.07	NR	Diplegia 10
		Con	10	5/5	8.7 ± 0.9	NR	Diplegia 10
16	Ali et al[20]	Exp	30	NR	5–8	NR	Diplegia (NR) Himiplegia (NR)
		Con	30	NR	5–8	NR	Diplegia (NR) Himiplegia (NR)
17	Mohamed et al[21]	Exp	15	NR	7.11 ± 0.56	2 (15)	Diplegia 15
		Con	15	NR	7.52 ± 0.63	2 (15)	Diplegia 15

Con = control group, CP = cerebral palsy, Exp = experimental group, GMFCS = gross motor function classification scale, M/F = male/female, NR = not reported.

3.3. Type of intervention, frequency, amplitude, dosage and outcome of included study

The subjects of all studies included were assigned randomly to the experimental and control groups. Table 2 lists the type of design of included study. The experimental group included cerebral palsy patients who received WBV, and the control group included patients who received other interventions or none. Fourteen studies were RCT in the review. On the other

Table 2

Type of intervention, frequency, amplitude, dosage and outcome of included studies.

No	Study	Group	Type of Intervention	WBV Freqency	WBV Amplitude	Dosage	Outcome
1	Ahlborg et al[5]	Exp Con	WBV RT	25–40 Hz 6 min	NR	3 times per week × 8	1. Spasticity 2. Isokinetic muscle strength 3. 6MWT 4. TUG 5. GMFM.
2	Wren et al[6]	Exp Con	WBV ST without WBV	30 Hz 10 min	NR	7 times per week × 24	1. L3 vertebral body 2. Tibia metaphysis 3. Tibia midshaft 4. Calf muscle strength
3	Ruck et al[7]	Exp Con	WBV + PT PT	12–18 Hz 9 min	2–4 mm	5 times per week × 24	1. Lumbar spine areal BMD 2. Femur region areal BMD 3. 10MWT 4. GMFM
4	El-Shamy & Mohamed[8]	Exp Con	WBV + PT PT	25 Hz 10 min	1.7 mm	5 times per week × 24	1. BMD ① Femur ② Lumbar spine ③ Total body
5	Ugger et al[9]	Exp Con	STTEP No intervention	35–40 Hz 3–4 min	NR No intervention	2, 3, 4 times per week × 4	1. 1-min walking test 2. 2-D postural analysis 3. US imaging 4. Sit-ups in 1 min
6	Lee & Chon[10]	Exp Con	WBV + CPT CPT	5–25 Hz 18 min	2–6 mm	3 times per week × 8	1. Muscle Thickness ① Tibialis anterior ② Gastrocnemius ③ Soleus 2. 3-D gait analysis ① Hip angle ② Knee angle ③ Ankle angle ④ Gait speed ⑤ Stride length ⑥ Cycle time
7	Katusic et al[11]	Exp Con	WBV + PT PT	40 Hz 20 min	NR	2 times per week × 12	1. GMFM 88 2. MMAS
8	Ibrahim et al[12]	Exp	WBV + PT	12–18 Hz 9 min	4–6 mm	3 times per week × 12	3. Knee extensor strength 4. Spasticity (S/W leg) ① Knee extensor ② Hip adductors ④ Ankle plantar flexors 5. 6MWT 6. TUG
11	Cheng et al[15]	Exp Con	WBV ST without WBV	20 Hz 10 min	2 mm	Immediate effect	1. ROM ① KAROM ② AAROM ③ KPROM ④ APROM 2. Spasticity ① RI ② MAS 3. TUG 4. 6MWT
12	Tupimai et al[16]	Exp Con	WBV + PMS PMS	20 Hz 10 min	Shoulder-width apart	5 times per week × 6	1. MAS (S/W score) ① Hip adductor ② Quadriceps ③ Hamstring 2. FTSST 3. PBS
13	Ko et al[17]	Exp	WBV + CPT	20–24 Hz 9 min	1–2 mm	2 times per week × 3	1. Joint-position sense ① Knee ② Ankle 2. Postural balance test 3. OptoGait system ① Gait speed ② Step length ③ Step width

(*Continued*)

Table 2

(*Continued*)

No	Study	Group	Type of Intervention	WBV Freqency	WBV Amplitude	Dosage	Outcome
14	Stark et al[18]	Exp Con	WBV No intervention	12–24 Hz 9 min	2.5 mm	10 times per week × 14	1. GMFM 66 2. PEDI ① Mobility ② Self-care
15	Dudoniene et al[19]	Exp Con	VT + CPT CPT	15 Hz 5–10 min	2–6 mm	5 times per week × 3	1. ROM (R/L) ① Hip flexion ② Hip extension ③ Foot dorsiflexion ④ Foot plantar flexion 2. Spasticity (R/L) ① Knee extensors 3. GMFM D, E
16	Ali et al[20]	Exp Con	WBV + RPT Core stability + RPT	30 Hz 10 min	2 mm	3 times per week × 12	1. Biodex stability ① Over all SI ② A-P SI ③ M-L SI
17	Mohamed et al[21]	Exp Con	WBV + ETP SPT + ETP	12–18 Hz 9 min	2–4 mm	days per week × 24	1. Biodex stability ① Over all SI ② A-P SI ③ M-L SI 2. 6MWT

6MWT = 6 minute walking test, 10MWT = 10 meter walking test, A-P = Anterior-posterior, AAROM = Ankle active range of motion, APROM = Ankle passive range of motion, BMD = Bone mineral density, Con = Control group, Exp = Experimental group, EPT = exercise therapy program, CPT = conventional physical therapy, FTSST = Five times sit-to-stand test, GMFM = Gross motor function measure, KAROM = Knee active range of motion, KPROM = Knee passive range of motion, M-L = Medial-lateral, MAS = Modified ashworth scale, MMAS = Modified Modified ashworth scale, NR = Not reported, PBS = Pediatric balance scale, PEDI = Pediatric evaluation of disability inventory, PMS = passive muscle stretching, PT = Physical therapy, RI = Relaxation index, R/L = Right/left, ROM = Range of motion, RT = Residence training, SI = stability index, SPT = Suspension therapy, ST = Standing therapy, STTEP = Selective trunk-targeted exercise programme using WBV, S/W = Strong/weak, TUG = Timed up and go test, US = Ultrasound, VT = Vibration therapy, WBV = Whole body vibration therapy, WeeFIM = functional independent measure for children.

hand, the studies by Wren et al,[6] Ugger et al,[9] and Tupimai et al,[16] were controlled, randomized cross-over trials. The experimental and control groups were assigned alternately, so the results were derived by dividing the study into 2 separate ones, as done in other meta-analyses. In addition to the dependent variable and ICF classification criteria, additional subgroup analysis was performed as a moderator variable because the frequencies, treatment periods, and ages showed a wide range.

Ages were classified into 7 stages according to the criteria presented by the American Academy of Pediatrics: pre-term, newborn, infant, toddler, preschool child, school-aged child, and adolescent. Motor growth did not change significantly in the adolescents according to the GMFCS stage, so the analysis was performed by integrating them into the adult group.

3.4. Assessment of quality

The RoB 2.0 results are shown in Figure 2. There were 7 papers with low risk, 4 with some concern, and 6 with high risk.

3.5. Homogeneity test of overall effect size

The overall effect size of homogeneity test was 0.474 (CI = 0.148~0.801, I^2 = 76%, τ^2 = 0.389), which was moderate, as shown in Figure 3.

3.6. Effect size according to dependent variables

An analysis of the dependent variables indicated the following order of effect sizes: balance (g = 0.791, CI = −0.075~1.658), muscle power (g = 0.565, CI = −0.349~1.480), spasticity (g = 0.363, CI = 0.079~0.646), bone density (g = 0.348, CI = −0.327~1.023), range of motion of joints (g = 0.296, CI = −0.343~0.935), gait function (g = 0.291, CI = −0.319~0.901), and motor function (g = 0.249, CI = 0.002~0.496), as listed in Table 3.

3.7. Effect size according to ICF

Body structure and function includes balance (b235), joint mobility (b710), strength (b730), muscle tone (b735), structure of body (s760), gait pattern (b770), bone density and muscle thickness (s770), proprioceptive sense (b260) is included. Activity included motor function (d410-d449), walking (d450). Participation included activities of daily living and domain of participation (d230-d710). The ICF classification indicated the following order of effect sizes: body structure and function (g = 0.515, CI = 0.096~0.935), activity (g = 0.291, CI = −0.152~0.734), and participation (g = 0.244, CI = −0.205~0.692) (Fig. 4).

3.8. Effect size according to frequencies

In terms of frequency, the effect size of high frequency (g = 0.564, CI = 0.134~0. 993) was larger than that of high frequency (g = 0.479, CI = −0.084~1.042) (Fig. 5).

3.9. Effect size according to treatment period

The effect sizes of the intervention according to the treatment periods showed the following order: 7 to 12 weeks (g = 1.965, CI = −0.460~4.390), 1–six weeks (g = 0.406, CI = 0.103~0.710), and 14 to 24 weeks (g = 0.101, CI = −0.487~0.689) (Fig. 6).

3.10. Effect size according to age

The age-dependent classification indicated the following order of effect sizes: school-aged children (g = 0.594, CI = 0.065~1.123), adolescents and adults (g = 0.556, CI = 0.080~1.031), and infant and school-aged (g = 0.166, CI = −0.163~0.495) (Fig. 7).

3.11. Publication bias

No publication bias was found in the overall effect sizes using Egger test (P = .161). but a low level of asymmetry was found in the funnel plots (Fig. 8).

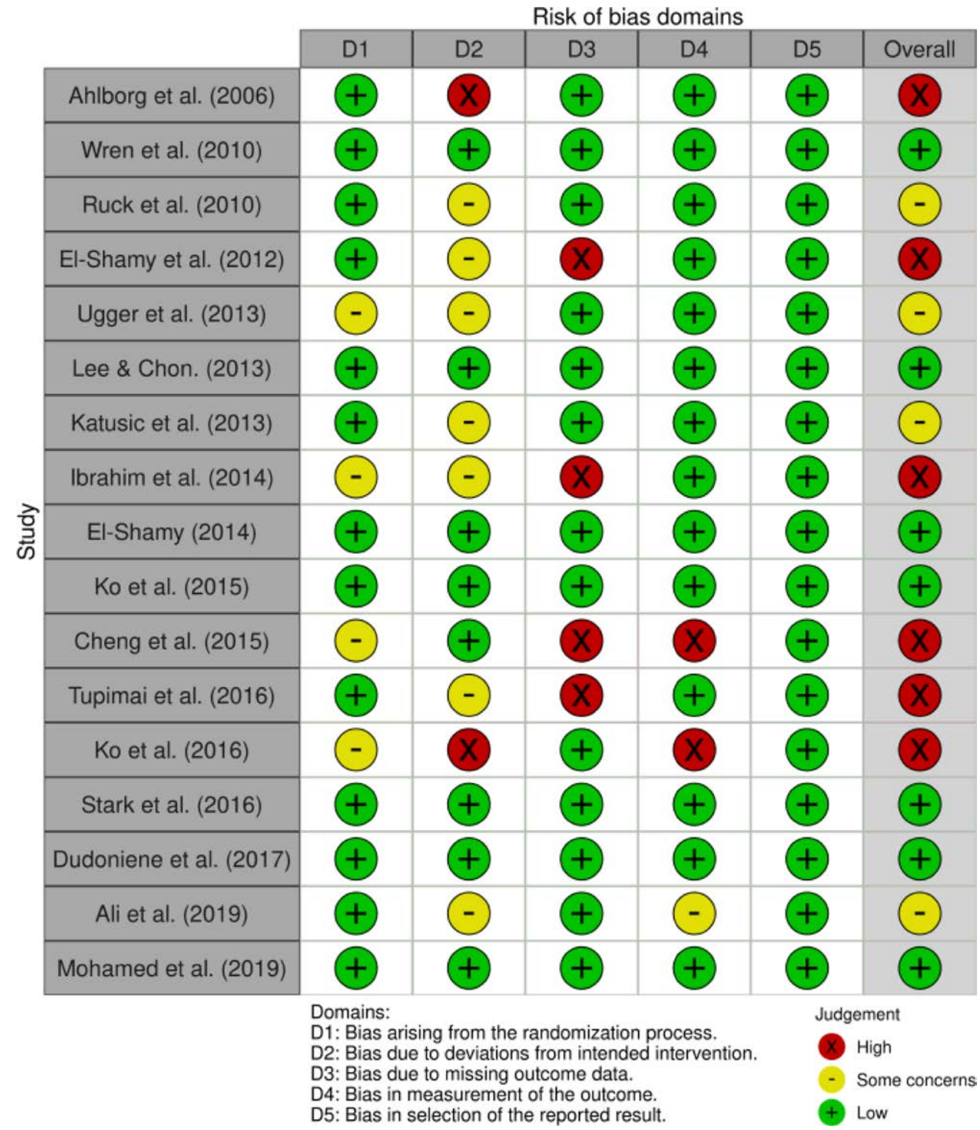

Figure 2. Results of RoB 2.0. The above figure outlined the risk of bias results for all studies included within this paper.

4. Discussion

This review was conducted to determine whether whole-body vibration differs from control groups when used alone or in combination with other interventions. Other interventions included PT, CPT, RT, EPT and PMS. The results suggest that WBV is a sufficiently effective intervention for cerebral palsy patients ($g = 0.474$). No publication bias was found in the overall effect sizes using Egger test ($P = .161$), but a low level of asymmetry was found in the funnel plots. Although this shift maintained the effect size at a medium level, high heterogeneity was observed in the homogeneity tests conducted for each included study. Therefore, subgroup analyses were performed to identify the causes of heterogeneity, and detailed analyses were conducted.

First, in the analyses of the effect sizes by each dependent variable, clinically meaningful results were obtained for balance and muscle strength ($g = 0.791$ and $g = 0.565$, respectively). On the other hand, small effect sizes were observed for the other variables. The results suggest that WBV exercises were relatively more effective for balance and muscle strength than the other goals in cerebral palsy patients. The reason for this result is that in the case of muscle strength, the WBV stimulates the somatosensory system of the soles of the feet to induce the spinal cord reflex of the subject.[44] The tonic stretch reflex that occurs helps activate the muscles in the entire body.[45] Therefore, as reported in individual intervention studies, clinically meaningful results were observed in the muscle strength item of this study.

In addition, it is vital to maintain the position of the head in space for posture control,[46] and vibration stimulation through WBV is transmitted from the soles of the feet to the head through the pelvis and shoulders.[47,48] In a subject undergoing WBV, the equilibrium organs are activated in response to the continuous shaking of the head and trunk, and the subject is required to maintain the position of the head and trunk on the platform while resisting the disturbance caused by the vibrations.[43,47,49] Therefore, WBV exercises provide suitable conditions for improving the subject balance, which showed a high effect size in this study.

Nevertheless, relatively small effect sizes close to 0.3 were observed for the other dependent variables, and no significant results were found except for spasticity and motor function. This result contrasts with Park et al[26] who conducted a meta-analysis of stroke patients. The highest effect size was found for stiffness and bone density ($g = 1.24$ and $g = 0.99$, respectively), and small effect sizes were found for balance and muscle strength ($g = 0.28$ and $g = 0.16$, respectively).[26]

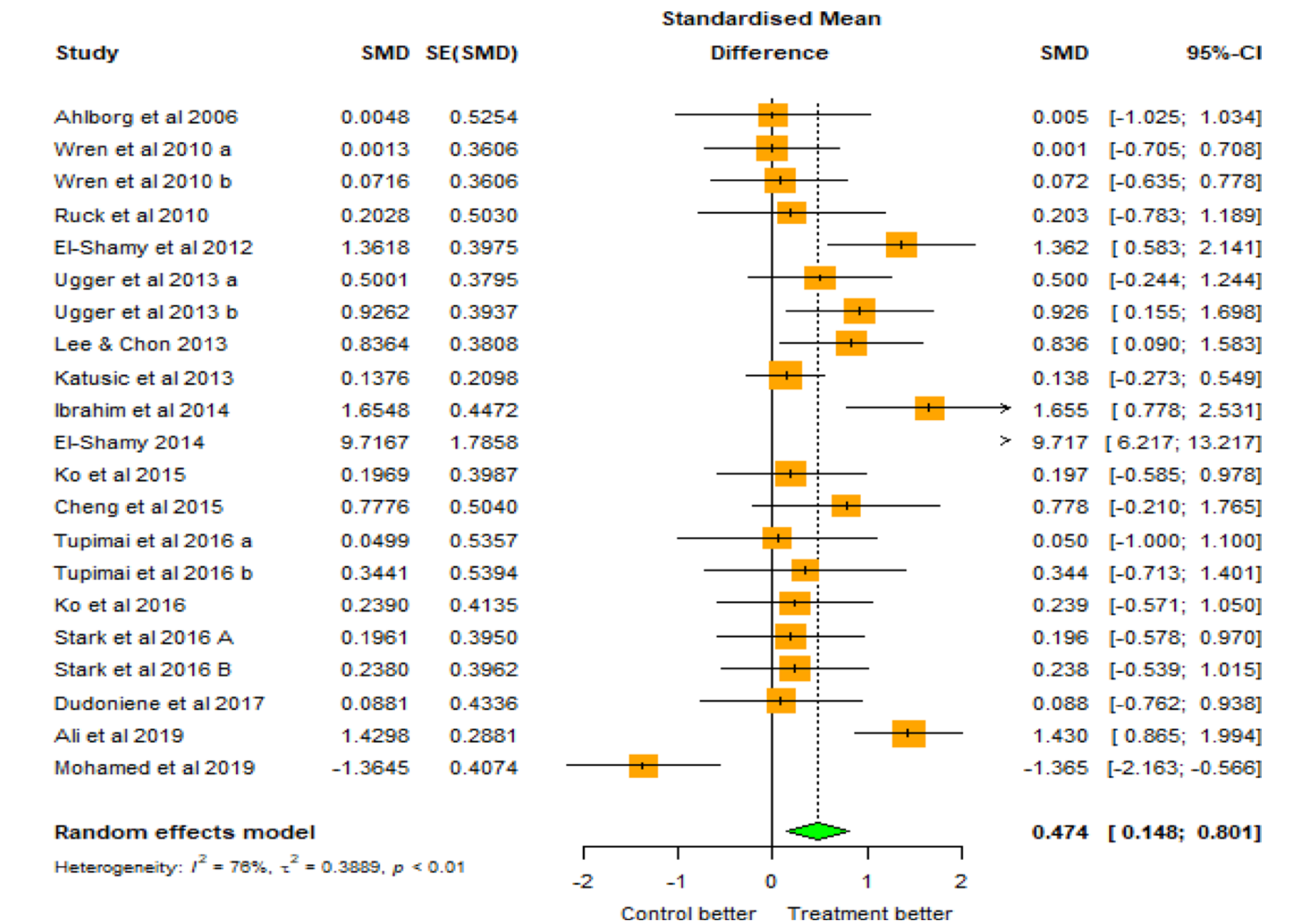

Figure 3. Overall effect size. The forest plot shows the first author, effect size, heterogeneity and geographic location for the included studies. Measure of all outcomes with confidence internal of results have also been displayed. SMD = standard mean difference, 95% CI = 95% confidence interval.

Table 3

Effect size according to treatment effectiveness.

Group	Number of studies	Point estimate	Standard error	95% CI
Range of motion	2	0.296	0.326	−0.343 to 0.935
Muscle power	6	0.565	0.177	−0.349 to 1.480
Spasticity	7	0.363	0.145	0.079–0.646
Bone density	4	0.348	0.344	−0.327 to 1.023
Balance	10	0.791	0.442	−0.075 to 1.658
Motor function	9	0.249	0.126	0.002–0.496
Gait function	10	0.291	0.311	−0.319 to 0.901

The reason the present results differ from previous studies is because of pathological differences between patients with cerebral palsy and stroke. Patients with cerebral palsy accumulate damage before their brains mature, and spasticity worsens over time.[50] The subjects included in this study are also characterized by earlier brain damage compared with those of Park et al[26] In particular, in patients with cerebral palsy, bone often grows faster than muscle, contractures progress gradually,[51] and it becomes difficult to recover the joint contractures and torsion after a certain age.[22] Therefore, in this study, the positive effect of WBV exercise on spasticity in cerebral palsy patients was reduced somewhat.

Although mechanical stimulation through weight-bearing is necessary for the normal development of bones, this development is delayed in patients with cerebral palsy. The time when weight is first supported is delayed. Abnormal bone growth causes bone and joint damage, and structural transformations occur.[22,52,53] WBV exercise was judged to be insufficient to significantly alter the density and stiffness of the bones of patients with cerebral palsy because it is difficult to recover deformed bone and muscle structure by non-surgical interventions alone.[50]

On the other hand, WBV is a safe intervention for cerebral palsy patients,[7] and despite the relatively small effect size overall, moderate effect sizes were observed for stiffness and bone density. Thus, it cannot be concluded that WBV has no positive effect. Therefore, this intervention method could be sufficiently effective in a clinic if a method to combine WBV with other interventions, or a way of using it more efficiently, can be found through follow-up research.

The results of this meta-analysis indicate that clinically significant values were found for body structure and function ($g = 0.515$). Nevertheless, small effect sizes were found ($g = 0.291$ and $g = 0.244$, respectively) in the activity and participation items, and there was no significant difference. Therefore, the results of this meta-analysis suggest that WBV is the most effective intervention method to improve the body structure and function of cerebral palsy patients in the ICF classification.

Most of the subjects included in this study were school-aged children, and activities in which children can participate on their own are needed to increase ICF activities and participation, including activities of daily living at home and school and within the community both inside and outside the treatment room.[54] On the other hand, WBV exercises are performed in

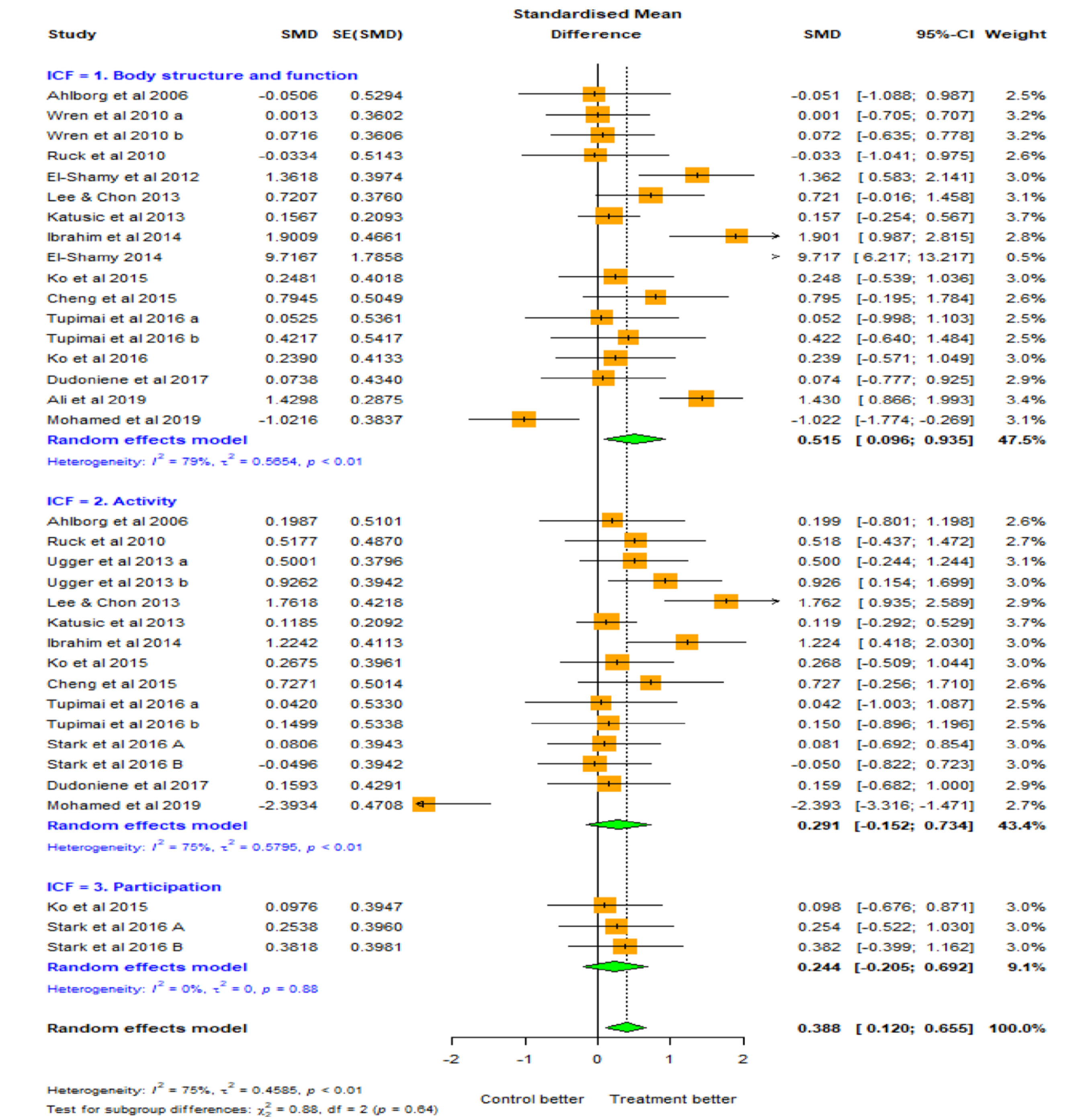

Figure 4. Forest plot according to ICF. The forest plot shows the first author, effect size, heterogeneity and geographic location for the included studies according to ICF. Measure of all outcomes with confidence internal and weighting of results have also been displayed. SMD = standard mean difference, 95% CI = 95% confidence interval.

a specific room with a power outlet because it uses mechanical equipment.[55] It was thought this was insufficient to improve the subject daily life and social participation greatly. However, positive results were shown in the low range for activity and participation because promoting structural changes in the body, such as strength training and balance training, helps improve activity and participation.[10,56] Therefore, WBV could help improve all 3 elements of ICF in cerebral palsy patients if combined with other interventions focused on daily life and participation.

Classification according to frequency was conducted by dividing it into high and low frequencies, and a relatively high effect size was found for high frequency (g = 0.564). Nevertheless, because a medium effect size of 0.479 was found, even at low frequency, WBV may be sufficiently effective when used in clinical practice. Indeed, the higher the frequency, the stronger and higher the EMG response that activates the subject muscles.[44] The intensity setting is very important for rehabilitating cerebral palsy patients, and stimulation above a threshold is required to induce physical changes.[40,57] In previous studies, the minimum frequency that triggered the strengthening of the subject muscles using WBV was 10. The greater the frequency and amplitude, the

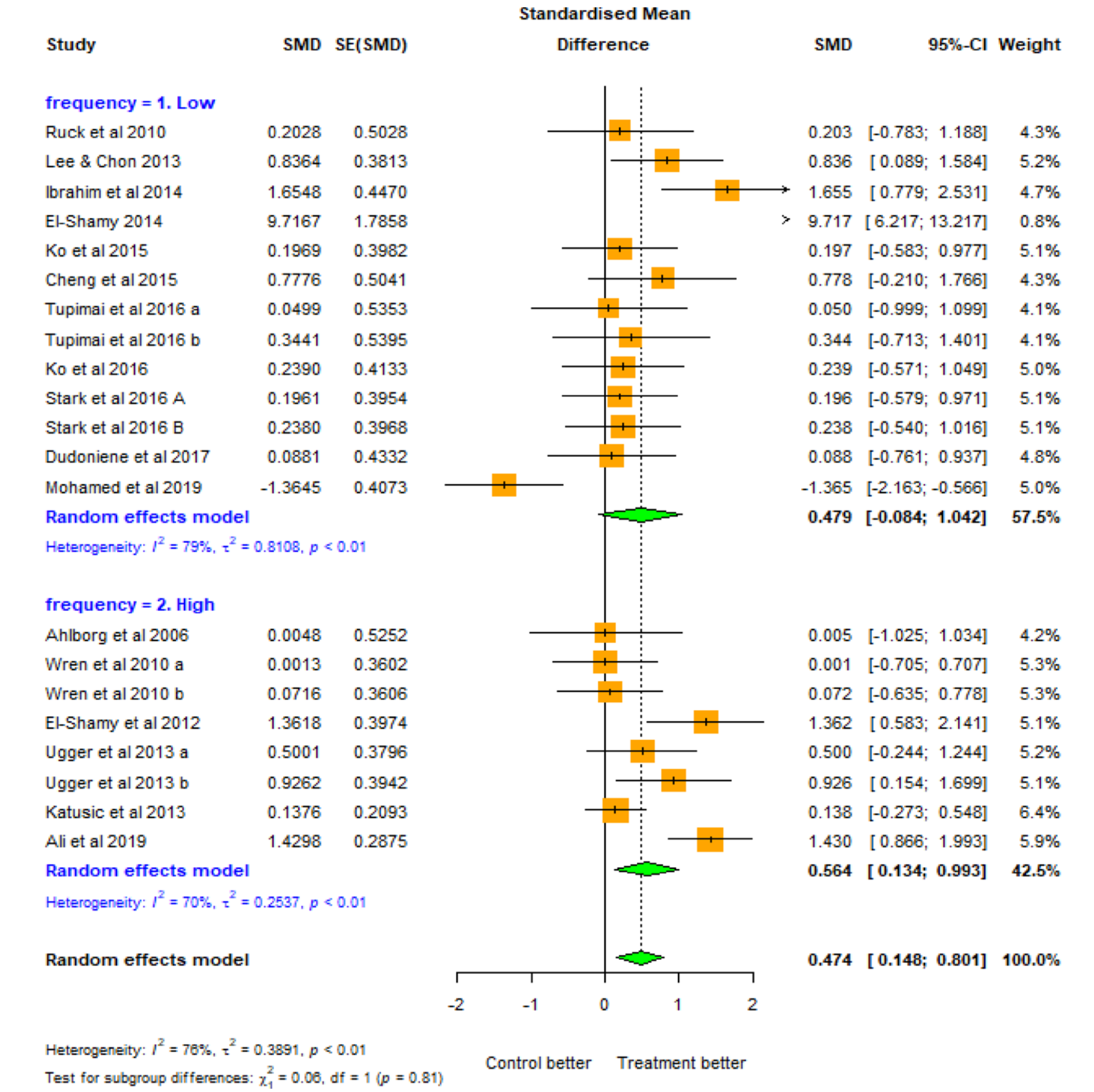

Figure 5. Forest plot according to frequencies. The forest plot shows the first author, effect size, heterogeneity and geographic location for the included studies according to frequencies. Measure of all outcomes with confidence internal and weighting of results have also been displayed. SMD = standard mean difference, 95% CI = 95% confidence interval.

stronger the force transmitted to the subject musculoskeletal system.[44] Therefore, a large effect size was observed in the high-frequency group, in which higher-intensity training was applied.

Confounding results were observed for interventions based on treatment duration. We hypothesized that extended treatment periods would result in larger effect sizes. On the other hand, non-linear results were observed in the present meta-analysis. An effect size of 0.406 was observed for treatment durations of 1–six weeks, and a very large effect size of 1.965 was observed for 7 to 12 weeks, but a small effect size of 0.101 was observed for 14 to 24 weeks of intervention. Therefore, the relationship between the treatment period and effect size was close to the curve, and the effect of the WBV intervention duration increased until a point, after which the effect decreased rapidly. In previous studies, when WBV has been applied for an extended period, the effect on the body is reduced due to adaptation to the frequency and amplitude,[58] and long-term stimulation of muscle spindles increases muscle fatigue and negatively affects the body.[55,59] In Park et al's[26] meta-analysis conducted on stroke patients, the effect size decreased as the treatment period increased. Similar trends were observed in this meta-analysis conducted on cerebral palsy patients.

In the classification by age, a small effect size was observed for infants and pre-schoolers and was not statistically significant (g = 0.166). On the other hand, a clinically significant

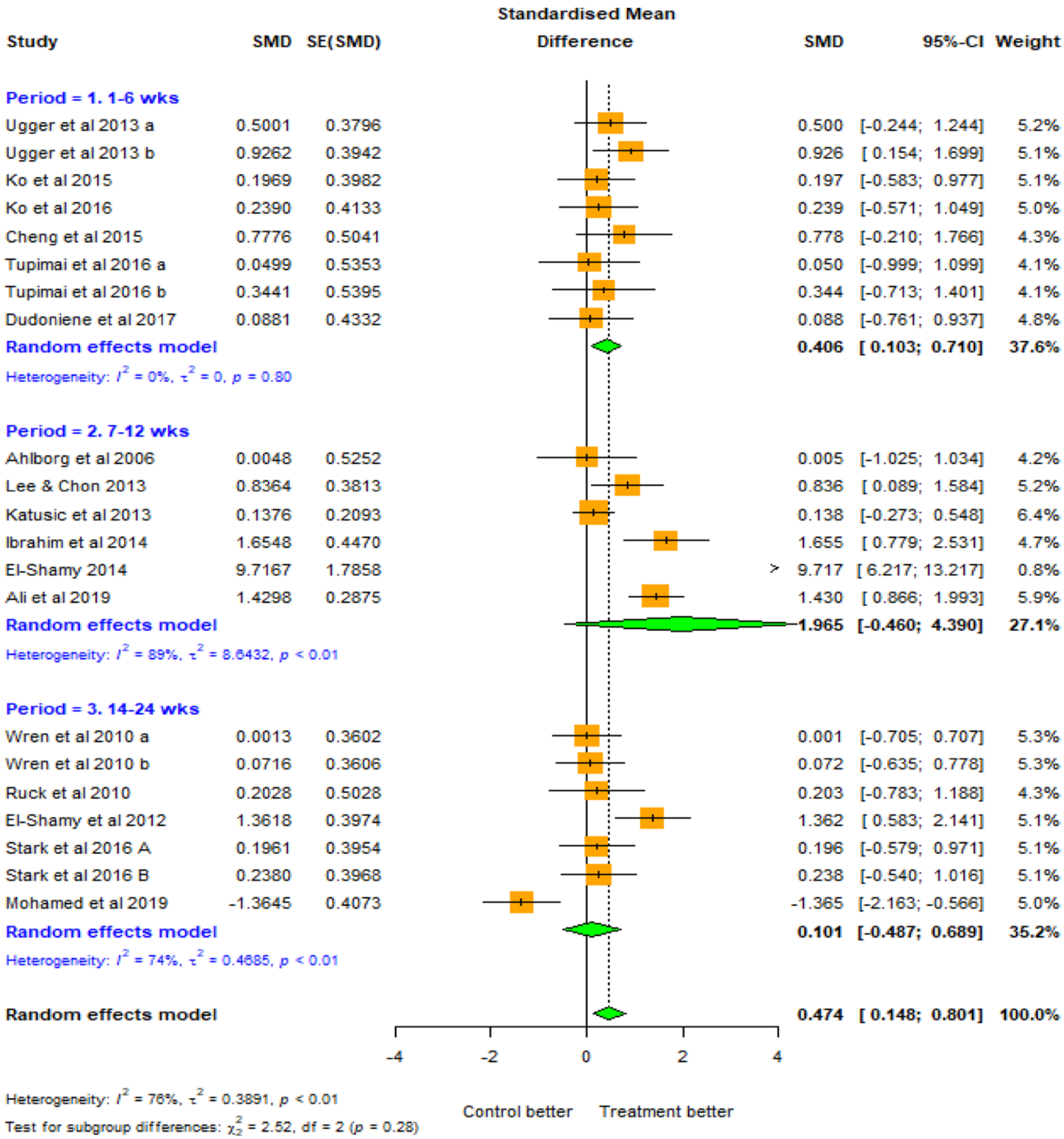

Figure 6. Forest plot according to treatment period. The forest plot shows the first author, effect size, heterogeneity and geographic location for the included studies according to treatment period. Measure of all outcomes with confidence internal and weighting of results have also been displayed. SMD = standard mean difference, 95% CI = 95% confidence interval.

effect size was observed for school-aged children, adolescents, and adults ($g = 0.589$ and $g = 0.556$, respectively). Although a large effect size was observed in the school-aged group compared to the adolescent and adult groups, no significant difference was observed. To perform WBV, the subject must maintain a static posture on the platform while the vibration stimulus is provided. In the case of infants and pre-schoolers, however, concentration on specific tasks is low, and the endurance is insufficient to avoid muscle fatigue. For effective rehabilitation,[56,60] the subject willingness to participate is very important.[61] Unlike play-oriented exercise, the WBV exercise provides intervention in a static posture. Therefore, the effect was relatively small for children younger than school-aged children. Accordingly, a study on modified WBV, including elements that could arouse children interest, should be conducted to develop a WBV procedure for infants and pre-schoolers.

A limitation of this study was the difficulty of generalizing the results because not enough studies were included. In addition, among the literature included, some studies were relatively outdated. Therefore, it is necessary to conduct research focusing on the latest research. Moreover, additional analyses of other dependent and moderating variables not included in this study are required because the intervention goals for children and adolescents with cerebral palsy are diverse. Finally, a subgroup analysis was not performed according to the relevant

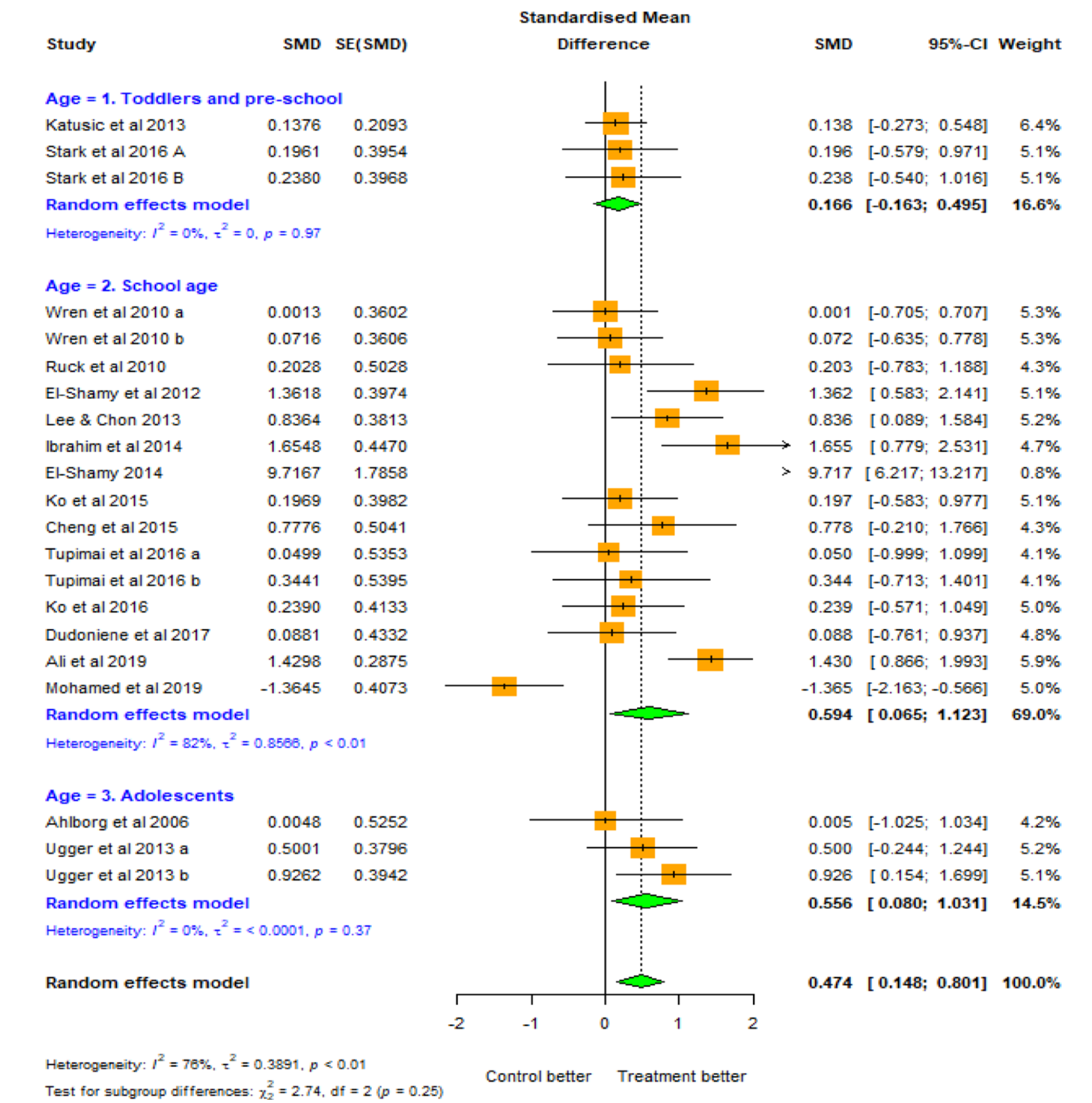

Figure 7. Forest plot according to age. The forest plot shows the first author, effect size, heterogeneity and geographic location for the included studies according to age. Measure of all outcomes with confidence internal and weighting of results have also been displayed. SMD = standard mean difference, 95% CI = 95% confidence interval.

variables because there was a lack of clear reports on the GMFCS stage and this type of cerebral palsy in the literature included in this study. A more detailed study without the shortcomings will help verify the effectiveness of WBV for children with cerebral palsy.

5. Conclusion

This review confirmed the effects of WBV interventions in patients with CP when used alone or in combination with other interventions. We observed no difference in the effect of intervention according to frequency. Additionally, Systemic vibration is the most effective intervention to improve the balance and gait in patients with cerebral palsy and improve the body structure and function according to the ICF. Therefore, this study findings may provide an effective guideline for patients with CP.

Author contributions

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Funding acquisition: Myoung-Kwon Kim.
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Methodology: Myoung-Kwon Kim, Yong-Gu Han.
Project administration: Myoung-Kwon Kim.
Software: Yong-Gu Han.

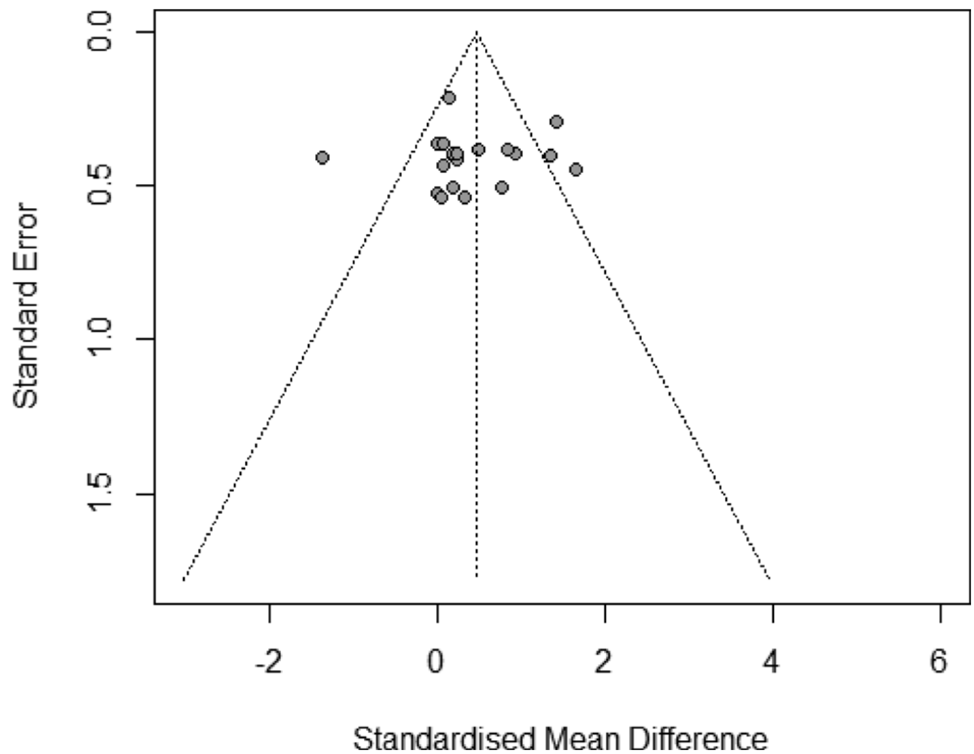

Figure 8. Funnel plot at combined effect. The funnel plot assesses publication bias on the standard mean difference.

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Writing – review & editing: Myoung-Kwon Kim, Yong-Gu Han.

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