Systematic Review/Meta-analysis

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Effects of whole-body vibration on chronic ankle instability: a systematic review

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Background and objective: Chronic ankle instability (CAI) is one of the most common sports injuries, and whole-body vibration (WBV) training has been used lately as a potential rehabilitation modality for these patients. The authors conducted a systematic review and meta-analysis to assess whether WBV training positively affects patients with CAI.

Materials and methods: The authors systematically searched four databases, including MEDLINE (PubMed), Scopus, Web of Science, and Cochrane Central Register of Controlled Trials, for randomized and non-randomized trials evaluating the effects of WBV on individuals with CAI. The authors used Cochrane RoB2 to assess the risk of bias in randomized trials. A meta-analysis was conducted if three or more studies measured the same outcome. Effect estimates were pooled using a random-effects model.

Results: Results were retrieved from seven articles encompassing 288 participants who had CAI. The reach distance of the Star Excursion Balance Test (SEBT) was regarded as the study's main finding. The authors saw a significant training effect on certain planes of motion on dynamic balance. The findings showed that the post-intervention measurements in the WBV group compared to control groups showed improvements in the posterolateral, posteromedial, and medial directions, respectively. There were also promising results on improvements in muscle activity, strength, and proprioception sense measurements with a great diversity in the reported parameters.

Conclusion: The authors observed a significant WBV training effect on dynamic balance over posterolateral, posteromedial, and medial reach distances. These findings suggest future studies on the effects of WBV on muscle activity, strength, and proprioception in addition to dynamic and static balance.

Keywords: ankle injuries, chronic ankle instability, ligament, postural balance, whole-body vibration

Introduction

The lateral ankle sprain is a common sports injury that can lead to chronic ankle instability (CAI), decreased neuromuscular control, and impaired proprioception, significantly impacting individuals' daily activities and sports performance[1–3]. Recurrent episodes of ankle sprains, persistent pain, and feelings of instability characterize CAI[4]. It can be challenging to treat CAI, and traditional rehabilitation methods may not always be effective[5]. Whole-body vibration (WBV) training has been suggested as a potential treatment option for CAI[6].

WBV training comprises a series of exercises performed while standing on a vibration platform that oscillates[7]. The platform produces vibrations that stimulate the muscles and joints, increasing muscle activity, strength, proprioception, and balance[8]. WBV works by stimulating the muscles and joints through the oscillations of the platform, which leads to increased muscle activity and improved proprioception[9,10]. During WBV training, the vibrations cause the muscles to contract and relax more frequently than during traditional exercise, leading to increased muscle activation and strength[11].

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This type of training has been shown to improve balance, strength, and flexibility in various populations, including athletes, older adults, and individuals with neurological conditions[12–17]. Studies have shown that WBV might improve ankle stability, reduce pain, and increase the range of motion in individuals with CAI[18,19]. Additionally, WBV has been shown to improve joint range of motion and flexibility, which can be beneficial for individuals with CAI who may have limited mobility[5,20,21].

There are limited systematic reviews on the beneficial effects of WBV on patients with CAI to summarize the available evidence. Therefore, this study aimed to evaluate the effects of WBV in patients with CAI.

Materials and methods

The findings of the review were reported according to the PRISMA 2020 (Supplemental Digital Content 1, http://links.lww.com/MS9/A313) and AMSTAR (Assessing the methodological quality of systematic reviews) guidelines[22] (Supplemental Digital Content 3, http://links.lww.com/MS9/A315). This systematic review has been registered with PROSPERO under registration ID CRD42022303845.

Eligibility criteria

We utilized PICO framework to define the eligibility criteria. The eligibility criteria for the participants encompassed all skeletally mature patients diagnosed with CAI, irrespective of age, gender, or ethnicity. We included the studies evaluating the effects of any type of WBV on CAI alone or in addition to other treatments. No intervention or interventions other than WBV were considered as the comparator. The selected outcome measures comprised any reported outcome measure evaluated using a validated scale, such as ankle balance, active and passive repositioning, and ankle joint strength. All relevant randomized controlled trials (RCTs) assessing the impact of WBV on CAI or comparing it with other treatments were included without any time or language restrictions. Non-RCTs were excluded except when addressing our study objectives and PICO without significant risk of bias.

Information sources

We systematically searched four databases, including MEDLINE (PubMed), Scopus, Web of Science, and Cochrane Central Register of Controlled Trials, language, or geological confinements on January 2022. Search terms were related to WBV and its effect on CAI. Our detailed search strategy is presented in Appendix 1 (Supplemental Digital Content 2, http://links.lww.com/MS9/A314).

Search strategy

Search terms were related to WBV and its effect on CAI. Our detailed search strategy is presented in Appendix 1 (Supplemental Digital Content 2, http://links.lww.com/MS9/A314).

Selection process

We imported the search results into the Rayyan tool, a web-based application that utilized artificial intelligence technologies to facilitate the screening process[23,24]. Any duplicate entries were identified and manually re-checked before being removed using Rayyan's automated duplication feature, which utilized a similarity threshold of 85%. Two independent reviewers then thoroughly examined the titles and abstracts of the selected studies that met the predefined eligibility criteria. Subsequently, these same reviewers independently assessed the full text of all potentially eligible retrieved records. In cases of disagreement, a third author was consulted. The reasons for excluding certain studies were carefully recorded.

HIGHLIGHTS

- Chronic ankle instability (CAI) is one of the most common sports injuries, for which whole-body vibration (WBV) has been used for rehabilitation.
- This systematic review is the most comprehensive study that evaluated the effects of WBV on CAI.
- We observed a significant WBV training effect on dynamic balance over certain planes of motion.

Data collection process

Two reviewers extracted data from each included publication. We resolved any disagreements regarding data extraction by discussing or consulting a third review author if necessary. The extracted data included publication characteristics (the first author, year of publication), study characteristics (type of intervention and comparator, duration of intervention, functional outcome measures, and main findings), and participants' characteristics [number of cases and controls, Cumberland Ankle Instability Tool (CAIT) of case and control groups, their age, and gender distribution].

Risk of bias assessment

We used Cochrane RoB2 to assess the risk of bias in randomized trials[25]. To assess the risk of bias, two authors independently evaluated all the included studies and recorded supporting data to judge the chance of bias in each domain (low, unclear, or high). They talked about any disagreements and archived final choices. We reported the risk of bias judgments for each domain in each included study in risk of bias summary figures. Judgments for each domain over all included studies were detailed in risk of bias graphs. Risk of bias will be categorized as 'low risk,' 'high risk,' or 'unclear risk,' which is described in the Cochrane Handbook for Systematic Reviews of Interventions[25].

To evaluate publication bias over ponders, a contour-enhanced funnel plot was conducted utilizing Fisher's z-transformed correlation for a visual review of potential publication bias. This plot was planned to have contour lines corresponding to perceived points of reference of statistical centrality (P-value = 0.01, 0.05, and 0.1). A test for funnel plot asymmetry was conducted.

Data synthesis

All studies that met our eligibility criteria and reported our outcome of interest were assessed to qualify for quantitative synthesis. We presented the results of each included study with the 95% confidence interval (CI) for the effect measure, in conjunction with the synthesized effect estimate, in a forest plot. We used mean difference (MD) as our summary measure. The MD was not reported directly in the included studies, so we had to compute the MD for each group using pre-intervention and post-intervention means reported in included studies. We performed a meta-analysis on MD based on the random-effects model.

We conducted random-effects meta-analyses to assess the overall impact of the interventions. The analyses were supplemented with prediction intervals, χ^2 statistics, and I^2 statistics. The χ^2 statistics were interpreted as significant if τ^2 exceeded zero or if the P-value was less than 0.10. The I^2 measure was employed to evaluate the variability across studies and assess the effect of heterogeneity on the meta-analysis. In our interpretation, I^2 values between 0% and 40% were considered insignificant, while values between 30% and 60% were categorized as medium. Substantial heterogeneity was defined by I^2 values between 50% and 90%, while an I^2 value greater than 75% indicated significant heterogeneity.

Results

The literature search acquired 69 studies. After removing duplicates and screening and identifying 45 titles and abstracts, 11 remaining studies were potentially eligible trials. Accordingly, the seven full-text papers describing RCTs were included in the present meta-analysis (Fig. 1).

Study populations

The participant characteristics of the included WBV trials are described in Table 1. The selected studies included 313 patients with CAI who participated either in the WBV training or control groups (Table 1). The sample sizes ranged from 26 to 72; women and men were included, with a mean age of 19–40 years. All of the studies used clinical criteria of CAI to diagnose and used CAIT to describe the level of disability in locomotion.

Intervention characteristics

The WBV training protocols differed in terms of frequency, intensity, and duration and are summarized in Table 1. Treatment sessions were conducted for 6 weeks duration except for one cross-over trial, which investigated the effect of acute exposure to WBV[29]. Only one study used the two-times-a-week protocol; the majority employed three-times-a-week WBV exposure. Additional exercises varied substantially between the selected studies. The most common exercise was a set of four exercises, including one-legged stance, cross-legged sway, runner's pose, catching, and throwing a volleyball against the wall, used in three studies[27,28,31]. Three exercises (double-leg stance, one-legged stance, and tandem stance) and two (single-leg heel raises and single-leg squats), semi-squat, and squat positions were also used in different studies. The training sessions consisted of 3–6 sets of 35–70 s WBV training with from 40 to 120 s rest periods between the WBV bouts. The vibration frequency and amplitude ranged between 5 and 40 Hz and 2 and 6 mm, respectively.

Outcome measures

Eight different outcome measures for the WBV effect were found in the seven studies. These eight main groups of proprioceptive

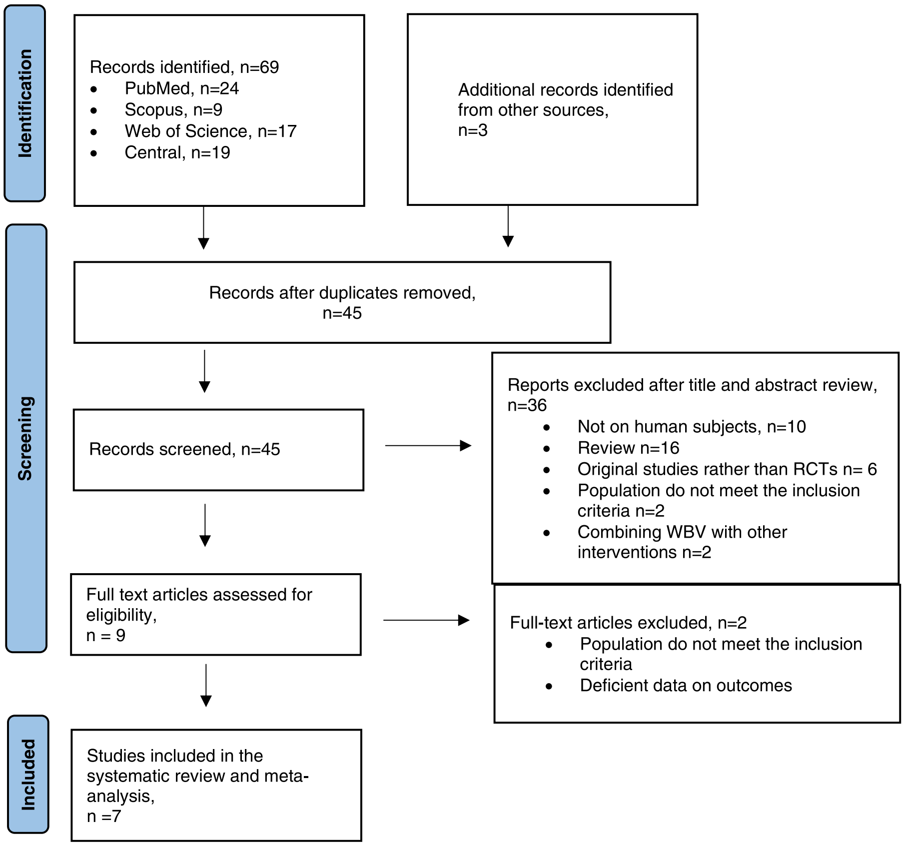


Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram of studies.

Table 1

Characteristics of the included studies

References	Subjects	Duration	Intervention	Functional outcome measure(s)	Main findings		Main findings interpretation
					WBV group	Control group	
Cloak *et al.*,[26]	38 female dancers WBV group: 19 Control group: 19	6 weeks	WBV group: standing on the vibration platform in two postures: single-leg heel raises, single-leg squats (3 × 50–70 s, 10–14 min/day, 2 times/week, 6 weeks, 30–40 Hz) Control group: no intervention	*Balance*: Single-leg balance test center of pressure distribution (COP)	Pre: 1.05 (0.57) Post: 0.33 (0.42)	Pre: 1.01 (0.44) Post: 0.82 (0.46)	Significant difference in COP between the WBVT and control group ($P = 0.04$).
	Male: female WBV group: 0:19 Control group: 0:19			*Muscle activity*: mean power frequency (MPF)	Pre: 6.2 (3.6) Post: 6.6 (3.6)	Pre: 7.1 (3.9) Post: 7.3 (2.3)	No significant difference in MPF between the WBVT and control groups ($P = 0.915$).
	Age WBV group: 19 (0.8) Control group: 19 (1.3)			*Balance*: SEBT reach distance	Anterior Pre: 75.5 (7.1) Post: 80.2 (7.2) Anteromedial Pre: 81 (5.5) Post: 85 (9.2) Medial Pre: 84.8 (8) Post: 92 (12.5) Anterolateral Pre: 68.5 (9.4) Post: 79.4 (8.5)	Anterior Pre: 74.7 (6) Post: 74.9 (6.1) Anteromedial Pre: 79.1 (6) Post: 78.1 (7.7) Medial Pre: 82.4 (6.6) Post: 83.7 (7.8) Anterolateral Pre: 74.4 (15.6) Post: 80.4 (15.7)	Significant difference in anterior ($P = 0.036$), anteromedial ($P = 0.038$), medial($P = 0.047$), and anterolateral ($P = 0.015$) was observed in SEBT reach distances between the WBVT and control groups. No significant difference was observed in posteromedial, posterior, posterolateral, and lateral directions.
	CAIT WBV group: 18.4 (1.3) Control group: 18 (1.5)						
Jeong and Kim,[27]	30 football players WBV group: 15 NMT group: 15	6 weeks	WBV group: standing on the vibration platform doing four exercises including one-legged stance, cross-legged sway, runner's pose, catching and throwing a volleyball against the wall. (5 × 5 min, 60 s rest 30 min/day, 3 times/week, 6 weeks, 5–25 Hz, 3–6 mm) NMT group: agility training, one-leg sideways jumps, vertical jumps, and one-leg figure-eight jumps	*Muscle activity*: EMG maximum voluntary isometric contraction (MVIC)	Tibialis anterior Pre: 23.65 (3.29) Post: 30.15 (5.52) Peroneus longus Pre: 21.31 (5.24) Post: 28.74 (6.13) Gastrocnemius Pre: 18.27 (4.02) Post: 25.55 (4.99)	Tibialis anterior Pre: 24.15 (3.67) Post: 27.74 (5.11) Peroneus longus Pre: 22.15 (4.95) Post: 25.14 (7.81) Gastrocnemius Pre: 17.79 (3.86) Post: 21.23 (6.51)	The muscle activity increase of the Tibialis anterior, Gastrocnemius, and peroneus longus in the WBV group was significantly higher than that of the NMT group ($P < 0.05$).
	Male: Female NA Age WBV group: 19.93(4.29) NMT group: 19.86(3.94)			*Balance*: whole path length (WPL) and surface area (SA) of the center of pressure (COP)	WPL (mm) Pre: 73.54 (8.35) Post: 68.67 (7.47) SA (cm^2) Pre: 27.51 (3.12) Post: 23.23 (2.62)	WPL (mm) Pre: 72.89 (7.95) Post: 70.26 (8.33) SA (cm^2) Pre: 26.98 (2.92) Post: 25.12 (3.64)	A significantly greater effect of WBVE compared to that of NMT on balance ability (WPL and SA values) was observed ($P < 0.05$).
	CAIT WBV group: 19.93(4.29) NMT group: 19.86(3.94)						
Sierra-Guzmán *et al.*,[28]	50 recreational athletes WBV group: 17 N-VIB group: 17 Control group: 17	6 weeks	WBV group: performing four exercises (one-legged stance with eyes shut, cross-legged sway with resistance elastic band, runner's pose with single-leg heel raises, and catching and throwing a volleyball against the wall) while standing on the BOSU balance trainer placed on the vibration platform. N-WBV group:	*Muscle activity*: reaction time (RT) by EMG, and electrical activity determined by the integrated iEMG		Peroneus brevis Pre: 60.99 (9.17) Post: 54.90 (6.99) Peroneus longus Pre: 61.20 (10.72) Post: 55.21 (9.04) Tibialis anterior Pre: 65.31 (11.78) Post: 59.07 (9.99)	There were no significant differences in RT between the groups. However, significant difference in RT was seen in WBV group in pre and post.

	Male: Female WBV group: 12 N-VIB group: 12 Control group: 10 Age WBV group: 22.4 (2.6) N-VIB group: 21.8 (2.1) Control group: 23.6 (3.4) CAIT WBV group: 18.9 (3.2) N-VIB group: 19.9 (4.1) Control group: 19.8 (2.9)		conducting the same exercises on the BOSU balance trainer placed on the floor (3 series, 4 exercises of 45 s, 45 s rest; 3 times/week, 6 weeks, 30–40 Hz, 2–4 mm) Control group: no intervention	*Isokinetic strength test:* Peak torque values			No significant differences were found in any of the isokinetic strength variables.
Adelman *et al.*,[29]	23 patients 1 CAI group: 23 cross-over trials	Single WBV training	WBV group: Performing an isometric squat position (~ 40° knee flexion) on the vibration platform (6 series, 1exercise of 1 min, 2 min rest; single WBV exposure, 30 Hz) Control group: isometric squat position	*Dynamic postural stability:* Time to stabilize (TTS)			WBV did not influence TTS.
	Male: Female 14:12 Age 20 (1 18–30 years CAIT 16.35 (4.82 (5–25)			*Muscle activity:* EMG MVIC			WBV did not influence lower extremity muscle activity.
Chang *et al.*,[30]	63 volleyball and basketball players WBV group:21 non-training group: 21 balance training group: 21		WBV group: performing three exercises (double-leg stance, one-legged stance, and tandem stance) on the vibration platform with eyes closed Balance training: performing three exercises (double-leg stance, one-legged stance, and tandem stance) on the BOSU with eyes closed (4–5 × 45 s, 40 s rest, 3 times/week, 6 weeks, 5 Hz, 3 mm) Non-training group: continuing normal daily activity Balance training group: used a balance ball (BOSU balance trainer)	*Dynamic balance*: SEBT reach distance	*Anteromedial* Pre: 87.01 (15.30) Post: 93.69 (9.58) *Posterolateral* Pre: 68.10 (10.76) Post: 80.14 (12.39) *Lateral* Pre: 64.73 (13.36) Post: 70.33 (13.39)	*Anteromedial* Non-training group Pre: 87.99 (11.85) Post: 80.63 (11.20) Balance training group Pre: 85.18 (6.14) Post: 98.25 (7.07) *Posterolateral* Non-training group Pre: 68.17 (13.02) Post: 69.68 (6.47) Balance training group Pre: 63.37 (13.12) Post: 91.65 (13.01) *Lateral* Non-training group Pre: 67.41 (8.20) Post: 59.69 (3.06) Balance training group Pre: 65.85 (13.26) Post: 85.58 (16.49)	The anteromedial, posterolateral, and lateral directions reach distance in the SEBT were significantly different between 2 groups.
	Male: Female WBV group: 0:21 Non-training group: 0:21			*Joint position sense*	*Active repositioning* 15° of ankle inversion Pre: 7.78 (5.60) Post: 4.67 (2.49) 0° in ankle neutral position Pre: 6.94 (3.83) Post: 4.55 (2.87) 10° of ankle eversion Pre: 7.22 (4.94) Post: 4.35 (2.24)	*Active repositioning* 15° of ankle inversion Pre: 8.33 (1.40) Post: 6.73 (1.66) 0° in ankle neutral position Pre: 9.06 (2.94) Post: 9.25 (1.02) 10° of ankle eversion Pre: 7.00 (4.10) Post: 6.84 (2.92)	Significant decreases for an ankle inversion of 15°, neutral ankle position, and an ankle eversion of 10° ($P < 0.05$) exhibited.

Table 1

(*Continued*)

References	Subjects	Duration	Intervention	Functional outcome measure(s)	Main findings: WBV group	Main findings: Control group	Main findings interpretation
	Age WBV group: 20.31 (1.28) Non-training group: 21.23 (1.47)			*Isokinetic strength test*	*Ankle inversion* 30°/s of concentric Pre: 28.47 (9.79) Post: 32.27 (9.25) 30°/s of eccentric Pre: 30.23 (6.53) Post: 33.15 (9.75)	*Ankle inversion* 30°/s of concentric Pre: 26.89 (11.14) Post: 21.90 (7.35) 30°/s of eccentric Pre: 23.06 (9.06) Post: 23.31 (7.13)	A significant improvement in 30°/s of concentric and eccentric contractions of the ankle invertor was observed in the isokinetic strength test.
	CAIT WBV group: 19.21 (1.89) Non-training group: 19.25 (1.91)						
Sierra-Guzman *et al.*,[31]	50 recreational athletes VIB group: 17 NVIB group: 16 Control group: 17		VIB group: performing four exercises (one-legged stance with eyes shut, cross-legged sway with resistance elastic band, runner's pose with single-leg heel raises and catching and throwing a volleyball against the wall) while standing on the BOSU balance trainer placed on the vibration platform (3 series, 4 exercises of 45 s, 45 s rest; 3 times/week, 6 weeks, 30–40 Hz, 2–4 mm) N-WBV group: conducting the same exercises on the BOSU balance trainer placed on the floor Control group: no intervention	*Ankle balance:* Overall stability index			No significant differences in ankle balance were observed.
	Male: Female VIB group: 11:6 NVIB group: 10:6 Control group: 12:5 Age VIB group: 22.4 (2.6) NVIB group: 21.8 (2.1) Control group: 23.6 (3.4) CAIT 24			*Dynamic balance*: SEBT reach distance			No significant differences among groups and also within groups before or after the training were observed.
Shamseddini *et al.*,[32]	34 individuals WBV group: 12 Control group: 10		WBVS group: semi-squat position on the device with 30° of knee flexion and wear the shoe with an unstable surface WBV (isolated WBV): semi-squat position on the device with 30° of knee flexion (3 × 35–60 s, 45 s rest, 3 times/week, 4 weeks, 30–40 Hz, 3 mm) Control group: no intervention	*Dynamic balance*: SEBT reach distance	*Posteromedial* Pre: 87.14 (13.90) Post: 97.90 (18.21) Anterior Pre: 62.99 (10.02) Post: 73.64 (11.42) Posterolateral Pre: 69.54 (17.23) Post: 86.29 (18.37)	*Posteromedial* Pre: 90.10 (17.53) Post: 96.04 (14.74) Anterior Pre: 60.04 (8.07) Post: 59.82 (5.30) Posterolateral Pre: 73.89 (14.87) Post: 75.81 (20.69)	A significant group-by-time interaction was observed for anterior and posterolateral directions of SEBT. Group-by-time interaction and between-group comparisons were not significant for SEBT posteromedial direction.
	Male: female WBV group: 4:8 Control group: 5:5			*Functional performance*: Hop-test (cm)	Pre: 48.62 (20.40) Post: 53.19 (19.85)	Pre: 53.49 (33.52) Post: 56.98 (33.52)	Significant group-by-time interaction ($P=0.004$) for Hop-test was observed.
	Age WBV group: 35.83 (12.08) Control group: 38.40 (10.49)			*Muscle strength*: Peak torque value (nm/kg)			No significant group-by-time interactions were observed for muscle strength.
	CAIT <24			*Joint position tests*			No significant group-by-time interactions for passive and active joint position sense errors in evaluated angles were observed.

RT, Reaction Time.

tests were: Star Excursion Balance Test (SEBT), Joint Position Sense (JPS), Hop Tests, Biodex Stability System (BSS), and Time to Stabilization (TTS).

Meta-analysis of results of SEBT

Four studies were included for the meta-analyses in which SEBT was used as a balance measurement tool. The effect sizes for these outcomes are summarized in Figure 2. These studies included 136 individuals; 69 underwent experiment and 67 participated in non-vibration or as the control group. The mean overall effect size for post-intervention static balance values was calculated in the posterolateral (MD [95% CI] = 5.87 [0.64, 11.10], $Z = 2.20$, $P = 0.03$), posteromedial (MD [95% CI] = 6.13 [1.02, 11.24], $Z = 2.35$, $P = 0.02$), anteromedial (MD [95% CI] = 4.98 [– 2.66, 12.62], $Z = 1.28$, $P = 0.2$), medial (MD [95% CI] = 3.88 [– 0.31, 8.08], $Z = 1.81$, $P = 0.07$), and anterior (MD [95% CI] = 3.01 [– 0.53, 6.55], $Z = 1.67$, $P = 0.1$) directions. The results present methodological homogeneity verified by $I^2 = 0\%$ in four subgroup analyses. However, middle heterogeneity was found in two subgroup analyses with I^2 equal to 39% in the anterior and 70% in the anteromedial directions.

Figure 3 shows risk of bias in included studies.

Electromyography (EMG) results

Electromyography (EMG) was employed in four investigations to measure the activity and weariness of the peroneus longus (PL), peroneus brevis, gastrocnemius (GCM), and tibialis anterior muscles (TA). The included studies reported five diverse outcomes, including maximal voluntary isometric contractions (MVIC), median power frequency (MPF), reaction time (RT), and electrical activity. Due to the difference between the units used in the measurement of muscle activity, we could not perform the meta-analysis. Results from Jeong *et al.*[27] showed significantly higher muscle activity in TA, GCM, and PL WBV training group than in the control group. By contrast, the single, acute exposure to WBV, which was investigated by Adelman *et al.*[29], does not have a meaningful impact on neuromuscular function. Regarding the MPF, RT, and iEMG results, Cloak *et al.*[26] and Sierra-Guzmán *et al.*[28] observed no significant differences between WBV and the control group. However, within-group analysis in Sierra-Guzmán *et al.*[31] study showed a significant decrease in muscle RT in B, TA, and PL in WBV. The results for EMG are presented in Table 1.

Single-leg balance test results

The center of pressure (COP) area was recorded in two studies. According to results from both studies, a significant balance ability decrease in surface area in COP between the WBV training and control groups ($P < 0.05$) was observed[26,27] (Table 1).

Isokinetic muscle strength test results

These values were recorded by three different studies in different angle velocities[28,30,32]. Thus, we could not perform the meta-analysis. The results of the isokinetic muscle strength test are presented in Table 1.

JPS test

Chang *et al.*[30] showed improvement in active repositioning at certain ankle degrees. In contrast, Shamseddini *et al.*[32] reported no significant improvements in active joint repositioning. However, both studies agree on the lack of improvements in passive repositioning after WBV. Detailed results are presented in Table 1.

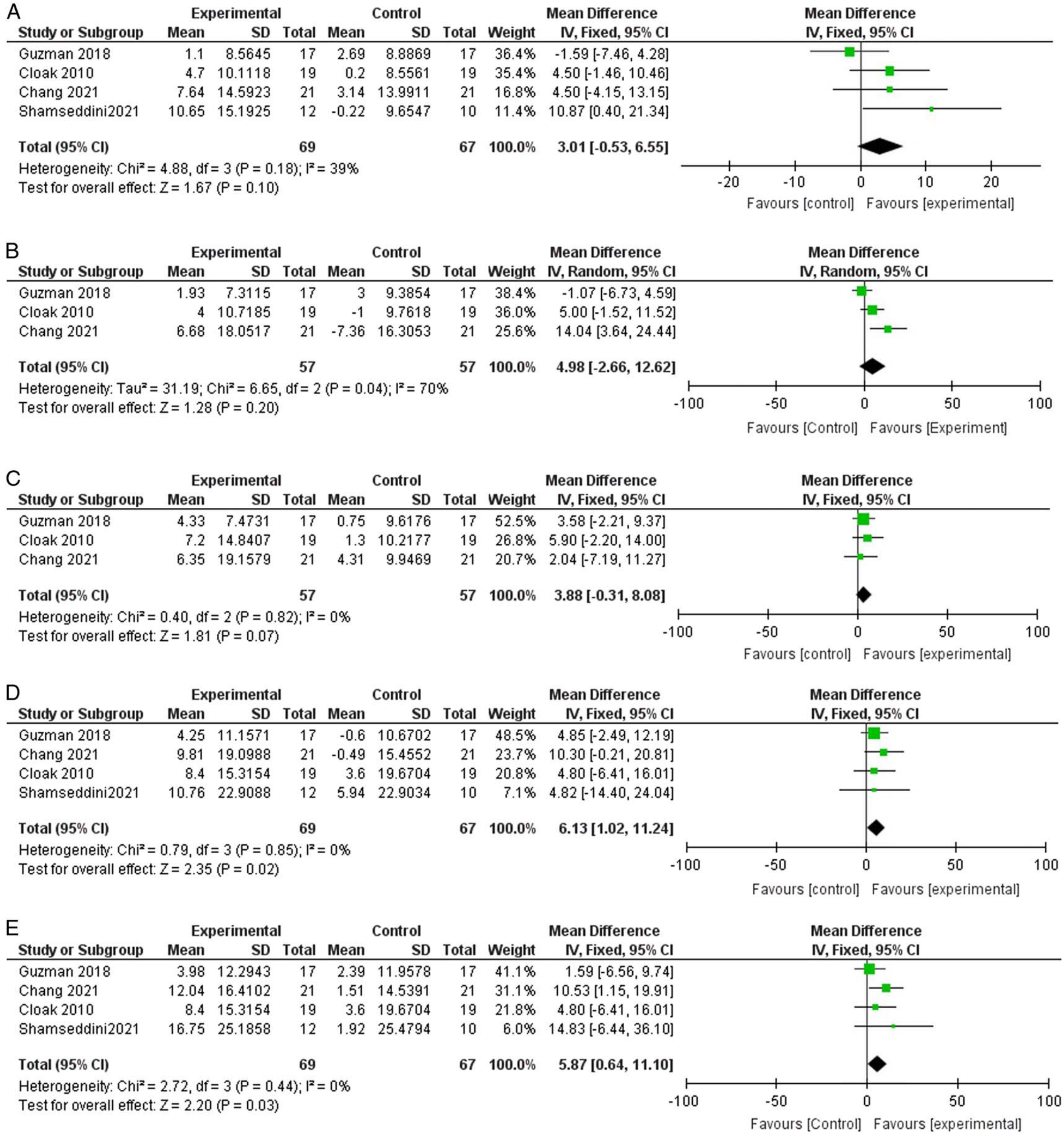
Discussion

In this review, we used a comprehensive search strategy in five databases to retrieve controlled clinical trials investigating the effect of WBV in patients with CAI. We ultimately presented and analyzed the results of seven retrieved articles with 288 participants with CAI systematically to investigate the effect of WBV exposure on static and dynamic balance, muscle strength, muscle activity, and proprioception. The SEBT reach distance was considered the primary outcome in the current study. We observed a significant training effect on dynamic balance over certain planes of motion. The findings showed that the post-intervention measurements in the WBV group compared to control groups revealed improvements in the posterolateral and posteromedial reach distances.

As ankle injuries are more often due to participation in sports and, in addition, women often experience more significant laxity in ligaments than men, it is expected that female athletes are at a greater risk for CAI[33]. Similarly, in our review, women constitute the majority of participants. WBV training has been used in a limited number of researches as a method of CAI rehabilitation; thus, little has been known about the absolute effectiveness of this treatment.

Balance deficit significantly correlates with the risk of recurring sprains[34]; the static and dynamic balance are crucial components of ankle stability. Also, ankle muscle activity and strength play a significant role[35,36]. Mechanical vibration training, including WBV, is thought to be effective for dynamic balance via improvements in neuromuscular activity[37]. Strength, balance, and proprioception are all needed for the multidirectional SEBT. The patient must maintain balance on the afflicted leg while simultaneously reaching as far as they can in order to test dynamic postural control. Using this method, the reach distance in every eight directions will be measured[38]. Based on our meta-analysis, compared with the control group, individuals with CAI experienced enhanced reach distance in specific directions, especially in posterolateral, posteromedial, and medial as the result of WBV training. Besides the improved dynamic balance, the static balance was also assessed, in which the COP area was the commonly recorded parameter[26,27]. Decreased values in the mean radius of the COP suggest increased ankle stability. A significant balance ability decrease in surface area in COP between the WBV training and control groups was observed.

Another critical component of ankle stability is muscle activity. There was a great diversity in the reported muscle activity parameters and EMG measurements between the studies. It is reasonable to assume that improved muscle activity results from improved vibration-responsive muscle sites, such as nerve endings in the muscle spindles and Golgi tendon organs, being activated during WBV training, which accounts for the improved MVIC and improved muscle RT within the



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Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Guzman 2018	1.1	8.5645	17	2.69	8.8869	17	36.4%	-1.59 [-7.46, 4.28]
Cloak 2010	4.7	10.1118	19	0.2	8.5561	19	35.4%	4.50 [-1.46, 10.46]
Chang 2021	7.64	14.5923	21	3.14	13.9911	21	16.8%	4.50 [-4.15, 13.15]
Shamseddini2021	10.65	15.1925	12	-0.22	9.6547	10	11.4%	10.87 [0.40, 21.34]
Total (95% CI)			**69**			**67**	**100.0%**	**3.01 [-0.53, 6.55]**

Heterogeneity: Chi² = 4.88, df = 3 (P = 0.18); I² = 39%
Test for overall effect: Z = 1.67 (P = 0.10)

B

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Guzman 2018	1.93	7.3115	17	3	9.3854	17	38.4%	-1.07 [-6.73, 4.59]
Cloak 2010	4	10.7185	19	-1	9.7618	19	36.0%	5.00 [-1.52, 11.52]
Chang 2021	6.68	18.0517	21	-7.36	16.3053	21	25.6%	14.04 [3.64, 24.44]
Total (95% CI)			**57**			**57**	**100.0%**	**4.98 [-2.66, 12.62]**

Heterogeneity: Tau² = 31.19; Chi² = 6.65, df = 2 (P = 0.04); I² = 70%
Test for overall effect: Z = 1.28 (P = 0.20)

C

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Guzman 2018	4.33	7.4731	17	0.75	9.6176	17	52.5%	3.58 [-2.21, 9.37]
Cloak 2010	7.2	14.8407	19	1.3	10.2177	19	26.8%	5.90 [-2.20, 14.00]
Chang 2021	6.35	19.1579	21	4.31	9.9469	21	20.7%	2.04 [-7.19, 11.27]
Total (95% CI)			**57**			**57**	**100.0%**	**3.88 [-0.31, 8.08]**

Heterogeneity: Chi² = 0.40, df = 2 (P = 0.82); I² = 0%
Test for overall effect: Z = 1.81 (P = 0.07)

D

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Guzman 2018	4.25	11.1571	17	-0.6	10.6702	17	48.5%	4.85 [-2.49, 12.19]
Chang 2021	9.81	19.0988	21	-0.49	15.4552	21	23.7%	10.30 [-0.21, 20.81]
Cloak 2010	8.4	15.3154	19	3.6	19.6704	19	20.8%	4.80 [-6.41, 16.01]
Shamseddini2021	10.76	22.9088	12	5.94	22.9034	10	7.1%	4.82 [-14.40, 24.04]
Total (95% CI)			**69**			**67**	**100.0%**	**6.13 [1.02, 11.24]**

Heterogeneity: Chi² = 0.79, df = 3 (P = 0.85); I² = 0%
Test for overall effect: Z = 2.35 (P = 0.02)

E

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Fixed, 95% CI
Guzman 2018	3.98	12.2943	17	2.39	11.9578	17	41.1%	1.59 [-6.56, 9.74]
Chang 2021	12.04	16.4102	21	1.51	14.5391	21	31.1%	10.53 [1.15, 19.91]
Cloak 2010	8.4	15.3154	19	3.6	19.6704	19	21.8%	4.80 [-6.41, 16.01]
Shamseddini2021	16.75	25.1858	12	1.92	25.4794	10	6.0%	14.83 [-6.44, 36.10]
Total (95% CI)			**69**			**67**	**100.0%**	**5.87 [0.64, 11.10]**

Heterogeneity: Chi² = 2.72, df = 3 (P = 0.44); I² = 0%
Test for overall effect: Z = 2.20 (P = 0.03)

Figure 2. Effects of WBV training on SEBT: (A) anterior, (B) anteromedial, (C) medial, (D) posteromedial, and (E) posterolateral directions.

WBV group. However, results from iEMG muscle make this hypothesis less desirable[39].

Assessing muscle strength is under clinical consideration for patients with CAI. Agonist–antagonist muscle interaction is an essential indicator of ankle stability and also an indicator of the efficacy of rehabilitation training. Some studies have suggested that patients with CAI commonly experience concentric invertor strength deficits and also reduced evertor isokinetic strength in the ankle[37,40]. The dynamometer is used to assess the isokinetic strength of the invertor and evertor muscles of the ankle. Both concentric and eccentric degrees of contractions of the ankle inversion and eversion were calculated as peak torque values. Results for ankle muscle strength were controversial within the included studies; two of them reported no significant changes in concentric–eccentric eversion and inversion peak torque[28,32]. However, Chang *et al.*[30] reported improved concentric–

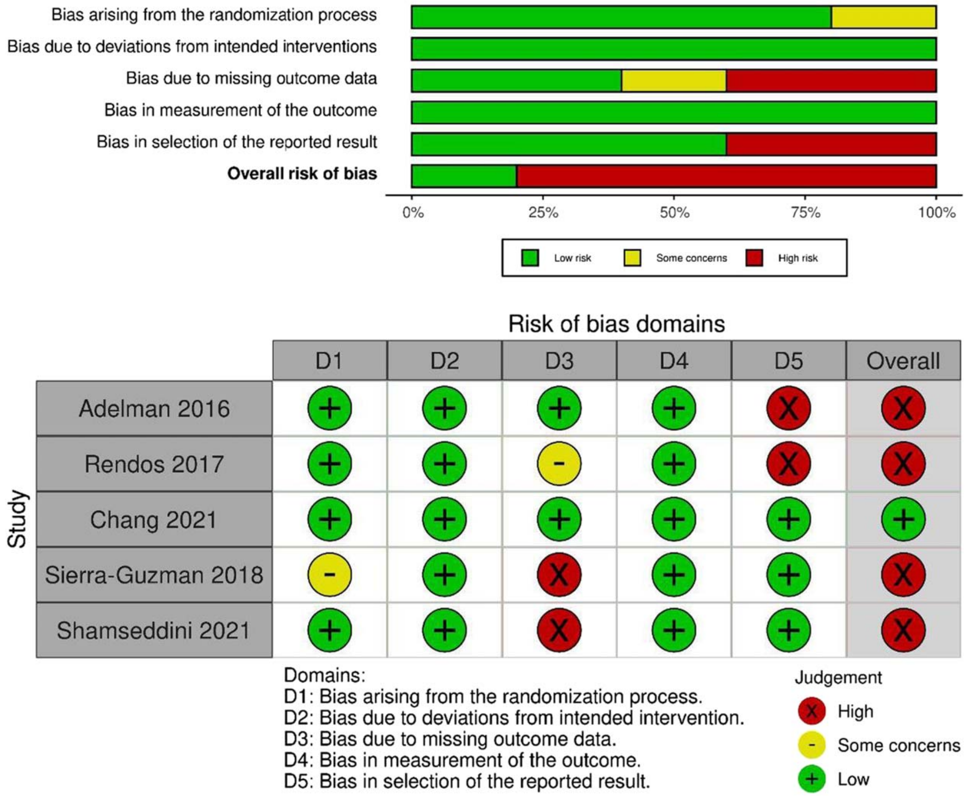

Figure 3. Risk of bias in included studies.

eccentric ankle invertor at a low angular velocity (30°/s) in the WBV group, which may suggest a potential decrease in postural sway in patients with CAI.

Since proprioception is impaired in patients with CAI, the JPS test is used to assess the degree of sensorimotor dysfunction of these patients[41]. Our included studies agree on the lack of improvements in passive repositioning after WBV. However, regarding active repositioning, the results were controversial. As the WBV frequency may be a critical factor in rehabilitation effectiveness, WBV training with different frequencies (5 Hz vs. 30–40 Hz) can explain these opposed observations[42].

This study had several limitations. First, the diversity of the measured outcomes limited us from providing adequate evidence regarding the effectiveness of WBV training. Second, the relationship between training program details and outcomes was not analyzed due to the lack of relevant data. Further research is required to investigate the long-term effect of WBV training and also to determine the optimal characteristics of WBV training, including intensity, frequency, and duration of the training sessions. Additionally, in clinical practice, interventions are commonly applied in combination with each other in order to achieve the maximal therapeutic effect. Thus, an investigation of the combined effect of WBV and other rehabilitation programs on patients with CAI seems to be needed. It is worth mentioning that in this study, we opted to set a significance level of 0.1 for our statistical analysis. This decision was driven by considerations that align with the nature and objectives of our research. Our study may encounter limitations related to sample size. In such cases, traditional significance levels (e.g. 0.05) may lead to underpowered analyses. A *P*-value of 0.1 accommodated these limitations. Second, our research aimed to explore potential relationships and trends rather than confirm well-established hypotheses.

In summary, foot and ankle injuries and pathologies encompass a wide spectrum[43–49], and when considering the positive effects of WBV on dynamic balance in patients with CAI based on our systematic review, it is essential to exercise caution and consider the broader context of rehabilitation, individualized evaluation[50], and the potential risks associated with this modality[51]. Future research should delve deeper into WBV's effectiveness, optimal parameters, and its role as part of a comprehensive CAI treatment plan.

Conclusions

We observed a significant WBV training effect on dynamic balance over posterolateral, posteromedial, and medial reach distances. These findings suggest future studies on the effects of WBV on muscle activity, strength, and proprioception in addition to dynamic and static balance.

Ethical approval

Ethics approval was not required for this systematic review.

Consent

Informed consent was not required for this systematic review.

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Author contribution

A.N.-A.: conceptualized the study; A.H.H. and A.N.-A.: designed and implemented the study; S.E., S.M.H., Z.M.G., and S.P.: analyzed the data; A.N.-A., A.H.H., S.E., S.M.H., Z.M.G., M.S., and S.P.: wrote the initial draft of the manuscript. All authors critically revised the article. All authors read and approved the final version of the manuscript.

Conflicts of interest disclosure

The authors have no conflicts of interest to declare.

Research registration unique identifying number (UIN)

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Guarantor

Bijan Forogh.

Data availability statement

Datasets generated during the current study are available from corresponding author, B.F., upon reasonable request.

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References

[1] Doherty C, Delahunt E, Caulfield B, *et al.* The incidence and prevalence of ankle sprain injury: a systematic review and meta-analysis of prospective epidemiological studies. Sports Med 2014;44:123–40.

[2] Gutierrez GM, Kaminski TW, Douex AT. Neuromuscular control and ankle instability. PM R 2009;1:359–65.

[3] Willems T, Witvrouw E, Verstuyft J, *et al.* Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. J Athl Train 2002;37:487.

[4] Hertel J, Corbett RO. An updated model of chronic ankle instability. J Athl Train 2019;54:572–88.

[5] Denegar CR, Miller SJ III. Can chronic ankle instability be prevented? Rethinking management of lateral ankle sprains. J Athl Train 2002;37:430.

[6] Kim K-M, Needle AR, Kim J-S, *et al.* What interventions can treat arthrogenic muscle inhibition in patients with chronic ankle instability? A systematic review with meta-analysis. Disabil Rehabil 2023;1–16.

[7] Dolny DG, Reyes GFC. Whole-body vibration exercise: training and benefits. Curr Sports Med Rep 2008;7:152–7.

[8] El-Shamy SM. Effect of whole-body vibration on muscle strength and balance in diplegic cerebral palsy: a randomized controlled trial. Am J Phys Med Rehabil 2014;93:114–21.

[9] Schuhfried O, Mittermaier C, Jovanovic T, *et al.* Effects of whole-body vibration in patients with multiple sclerosis: a pilot study. Clin Rehabil 2005;19:834–42.

[10] Hong J, Velez M, Moland A, *et al.* Acute effects of whole-body vibration on shoulder muscular strength and joint position sense. J Hum Kinet 2010;25:17–25.

[11] Kosar AC, Candow DG, Putland JT. Potential beneficial effects of whole-body vibration for muscle recovery after exercise. J Strength Cond Res 2012;26:2907–11.

[12] Kurt C, Pekünlü E. Acute effect of whole-body vibration on isometric strength, squat jump, and flexibility in well-trained combat athletes. Biol Sport 2015;32:115–22.

[13] Cochrane D, Stannard S. Acute whole-body vibration training increases vertical jump and flexibility performance in elite female field hockey players. Br J Sports Med 2005;39:860–5.

[14] Bautmans I, Van Hees E, Lemper J-C, *et al.* The feasibility of whole-body vibration in institutionalised elderly persons and its influence on muscle performance, balance and mobility: a randomised controlled trial [ISRCTN62535013]. BMC Geriatr 2005;5:1–8.

[15] Tseng S-Y, Hsu P-S, Lai C-L, *et al.* Effect of two frequencies of whole-body vibration training on balance and flexibility of the elderly: a randomized controlled trial. Am J Phys Med Rehabil 2016;95:730–7.

[16] Chanou K, Gerodimos V, Karatrantou K, *et al.* Whole-body vibration and rehabilitation of chronic diseases: a review of the literature. J Sports Sci Med 2012;11:187.

[17] Yang F. Application of vibration training in people with common neurological disorders. Manual of Vibration Exercise and Vibration Therapy; 2020. pp. 343–53.

[18] Feland J, Lesley T, Hunter I, *et al.* Whole-body vibration and stretching enhances dorsiflexion range of motion in individuals with chronic ankle instability. Phys Ther Sport 2020;44:1–7.

[19] Shamseddini Sofla F, Hadadi M, Rezaei I, *et al.* The effect of the combination of whole-body vibration and shoe with an unstable surface in chronic ankle instability treatment: a randomized clinical trial. BMC Sports Sci Med Rehabil 2021;13:1–11.

[20] Van Den Tillaar R. Will whole-body vibration training help increase the range of motion of the hamstrings? J Strength Cond Res 2006;20: 192–6.

[21] Hubbard TJ, Hertel J. Mechanical contributions to chronic lateral ankle instability. Sports Med 2006;36:263–77.

[22] Page MJ, McKenzie JE, Bossuyt PM, *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. Int J Surg 2021;88: 105906.

[23] Ouzzani M, Hammady H, Fedorowicz Z, *et al.* Rayyan – a web and mobile app for systematic reviews. Syst Rev 2016;5:1–10.

[24] Valizadeh A, Moassefi M, Nakhostin-Ansari A, *et al.* Abstract screening using the automated tool Rayyan: results of effectiveness in three diagnostic test accuracy systematic reviews. BMC Med Res Methodol 2022; 22:1–15.

[25] Higgins J. Cochrane Handbook for Systematic Reviews of Interventions, Version 5.1. 0 [updated March 2011]. The Cochrane Collaboration; 2011, www cochrane-handbook org

[26] Cloak R, Nevill AM, Clarke F, *et al.* Vibration training improves balance in unstable ankles. Int J Sports Med 2010;31:894–900.

[27] Jeong Y-S, Kim J-H. Effects of whole-body vibration exercise on lower extremity muscle activity and balance ability in football player with chronic ankle instability. J Kor Phys Ther 2017;29:293–8.

[28] Sierra-Guzmán R, Jiménez JF, Ramírez C, *et al.* Effects of synchronous whole-body vibration training on a soft, unstable surface in athletes with chronic ankle instability. Int J Sports Med 2017;38: 447–55.

[29] Adelman D, Pamukoff D, Goto S, *et al.* Acute effects of whole-body vibration on dynamic postural control and muscle activity in individuals with chronic ankle instability. Athl Train Sports Health Care 2016;8: 63–9.

[30] Chang WD, Chen S, Tsou YA. Effects of whole-body vibration and balance training on female athletes with chronic ankle instability. J Clin Med 2021;10:2380.

[31] Sierra-Guzmán R, Jiménez-Diaz F, Ramírez C, *et al.* Whole-body-vibration training and balance in recreational athletes with chronic ankle instability. J Athl Train 2018;53:355–63.

[32] Shamseddini Sofla F, Hadadi M, Rezaei I, *et al.* The effect of the combination of whole-body vibration and shoe with an unstable surface in chronic ankle instability treatment: a randomized clinical trial. BMC Sports Sci Med Rehabil 2021;13:28.

[33] Quatman CE, Ford KR, Myer GD, *et al.* The effects of gender and pubertal status on generalized joint laxity in young athletes. J Sci Med Sport 2008;11:257–63.

[34] Pierobon A, Raguzzi I, Soliño S, *et al.* Minimal detectable change and reliability of the star excursion balance test in patients with lateral ankle sprain. Physiother Res Int 2020;25:e1850.

[35] Terrier R, Rose-Dulcina K, Toschi B, *et al.* Impaired control of weight bearing ankle inversion in subjects with chronic ankle instability. Clin Biomech (Bristol, Avon) 2014;29:439–43.

[36] Van Deun S, Staes FF, Stappaerts KH, *et al.* Relationship of chronic ankle instability to muscle activation patterns during the transition from double-leg to single-leg stance. Am J Sports Med 2007;35:274–81.

[37] Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athl Train 2002;37:364–75.

[38] Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. J Athl Train 2012;47:339–57.

[39] Rittweger J. Vibration as an exercise modality: how it may work, and what its potential might be. Eur J Appl Phys 2010;108:877–904.

[40] Willems T, Witvrouw E, Verstuyft J, *et al.* Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. J Athl Train 2002;37:487–93.

[41] Xue X, Ma T, Li Q, *et al.* Chronic ankle instability is associated with proprioception deficits: a systematic review and meta-analysis. J Sport Health Sci 2021;10:182–91.

[42] Otzel DM, Hass CJ, Wikstrom EA, *et al.* Motoneuron function does not change following whole-body vibration in individuals with chronic ankle instability. J Sport Rehabil 2019;28:614–22.

[43] Hoveidaei AH, Roshanshad A, Vosoughi AR. Clinical and radiological outcomes after arthrodesis of the first metatarsophalangeal joint. Int Orthop 2021;45:711–9.

[44] Vosoughi AR, Medhati P, Hosseini E, *et al.* Clinical outcomes following treatment of deep surgical site infection after fixation of calcaneal fractures: a retrospective case–control study. Foot Ankle Surg 2023;29: 334–40.

[45] Vosoughi AR, Fereidooni R, Shirzadi S, *et al.* Different patterns and characteristics of Talar injuries at two main orthopedic trauma centers in Shiraz, south of Iran. BMC Musculoskelet Disord 2021;22:1–13.

[46] Vosoughi AR, Borazjani R, Ghasemi N, *et al.* Different types and epidemiological patterns of calcaneal fractures based on reviewing CT images of 957 fractures. Foot Ankle Surg 2022;28:88–92.

[47] Vosoughi AR, Heyes G, Molloy AP, *et al.* Management of tibialis anterior tendon rupture: recommendations based on the literature review. Foot Ankle Surg 2020;26:487–93.

[48] Biglari F, Sadighi M, Khabiri SS, *et al.* Epidemiology of traumatic orthopedic injuries: a cross-sectional survey from Northern Tehran, Iran. J Orthop Spine Trauma 2022;8:90–4.

[49] Ebrahimpour A, Chehrassan M, Hoveidaei AH, *et al.* Surgical management of extremity fractures in COVID-19 patients. J Orthop Spine Trauma 2021;7:127–33.

[50] Trajanovic MD, Canciglieri Junior O. Personalized medicine in orthopedic – state of the art. Personalized Orthopedics: Contributions and Applications of Biomedical Engineering; 2022. pp. 3–31.

[51] Cardinale M, Pope MH. The effects of whole-body vibration on humans: dangerous or advantageous? Acta Physiol Hung 2003;90:195–206.