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Effects of external ankle support on balance control outcomes following muscle fatigue in individuals with ankle instability: A systematic review and meta-analysis

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Abstract

Introduction: Lateral Ankle sprain is a common sports injury with a high incidence rate after muscle fatigue. Health specialists are searching for the best conservative approach to reduce the complications of this injury and decrease the incidence rate after fatigue. This systematic review and meta-analysis aimed to assess the effectiveness of external ankle support on balance in patients with ankle instability following muscle fatigue.

Methods: We conducted a systematic search of PubMed, Scopus, and Web of Science up to April 29, 2024, to find articles involving populations with ankle instability, interventions using external ankle support (taping or ankle orthoses), and outcomes related to balance assessed during muscle fatigue. The Risk of Bias 2 tool was used for risk of bias assessment. Data on patients, interventions, fatigue protocols, and outcomes were extracted and analysed. A meta-analysis was performed using Review Manager 5.3 software, calculating standardized mean differences with 95% confidence intervals (CI) for each outcome.

Results: Nine crossover studies involving 230 subjects were included. The narrative synthesis shows that external ankle supports improve the single leg hop test [Mean difference=7.84, P=0.01], center of pressure range and velocity, and ankle inversion. The meta-analysis results indicate that compared to the control group, external ankle supports after muscle fatigue significantly change Y balance clinical test-posterolateral [MD=1.22, 95% CI (0.16, 2.28), p=0.03], Y balance clinical test-posteromedial [Mean difference=2.60, 95% CI (0.42, 4.79), p=0.03], center of pressure time to stabilization-mediolateral [Mean difference=-0.68, 95% CI (-1.29, -0.07), p=0.04], center of pressure time to stabilization-vertical [Mean difference=-0.62, 95% CI (-0.94, -0.30), p=0.01], and vertical ground reaction force [Mean difference=0.58, 95% CI (0.21, 0.96), p=0.02].

Discussion: External ankle supports are an effective conservative intervention for improving specific aspects of balance in patients with ankle instability, particularly following muscle fatigue. Significant improvements were observed in the Y Balance Test, center of pressure measures, vertical ground reaction force, and single leg hop performance. Healthcare professionals are encouraged to incorporate external ankle supports into rehabilitation programs for individuals with ankle instability. These supports can enhance balance, improve functional outcomes, and help mitigate the negative effects of muscle fatigue on postural stability.

Take-home message: External ankle supports are effective in improving balance and functional performance in individuals with ankle instability, particularly after muscle fatigue. Incorporating these supports into rehabilitation programs can enhance postural stability and reduce the risk of recurrent injuries.

Keywords: Ankle sprain; ankle instability; postural control; orthoses; taping

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INTRODUCTION

Ligamentous ankle injuries are common, with approximately 75% of all ankle injuries classified as sprains [1]. Among musculoskeletal injuries related to sport activities, lateral ankle sprain account for one of the highest percentages, particularly in multidirectional sports such as football [2] and basketball [3]. Despite conservative treatment, 20-40% of patients may continue to experience recurrent episodes of ankle instability. These episodes often result in functional disability and impose a significant economic burden on the healthcare system [4]. Ankle instability can manifest in two forms: mechanical, characterized by excessive ankle movement post-injury, and functional, where damaged ligaments fail to adequately control the joint during activities such as running, cutting, or turning [5].

For individuals with ankle instability, the likelihood of injury recurrence is approximately 70% [6]. Recurrent injuries can lead to complications such as ankle arthritis and in some cases, the end of a professional sports career [7]. Complications associated with ankle instability include ligament damage, muscle strength imbalances, delayed muscle reaction times, and proprioception deficits [8, 9]. Athletes with ankle instability demonstrate distinct biomechanical differences compared to healthy athletes [9]. These individuals tend to place more weight on the lateral part of their feet during initial contact [10,11]. They also exhibit a smaller range of motion in the sagittal plane and greater ankle inversion, which increases the likelihood of repeated lateral ankle sprain [11]. Furthermore, athletes with ankle instability often experience increased ground reaction forces, longer center of pressure (COP) durations, and prolonged time to stabilization (TTS), along with a decreased time to peak ground reaction force. Notably, the peak joint reaction force during jump landings in individuals with ankle instability can reach three to six times their body weight [12, 13].

Previous studies have shown that one-third of lateral ankle sprain cases occur during the final stages of sport competitions [14,15]. This finding suggests that lateral ankle sprains are associated with the continuous contraction of lower limb muscles without adequate rest for the athlete [15]. Muscle fatigue, defined as the inability to maintain the required or expected strength, plays a significant role in the occurrence of lateral ankle sprain [16,17]. Fatigue induces various biomechanical changes, such as increased knee internal rotation, peak knee valgus angle, and peak proximal tibial anterior shear force. It also reduces the knee and hip flexion angle during landing [18]. These kinematic changes can adversely affect ankle proprioception, postural control, work rate, and muscular force output [19].

Athletes with ankle instability often benefit from using external ankle supports, which improve proprioception, enhance neuromuscular control, and prevent excessive ankle motion in the frontal and sagittal planes, and reduce vertical ground reaction forces [20-22]. Commonly used external ankle supports include tapes and ankle orthoses [21]. Studies have shown that the use of external ankle supports significantly reduces the recurrence rate of lateral ankle sprains, decreasing it from 1.41 to 0.47 per 1,000 athletes in basketball and from 0.98 to 0.07 per 1000 athletes in volleyball [23].

The combination of ankle instability and athletes' fatigue during sports competition creates a heightened risk of lateral ankle sprains due to their combined negative effects on balance. Therefore, answering the question "Can the use of external ankle supports significantly improve balance control in individuals with ankle instability during fatigue?" is crucial. This systematic review and meta-analysis aimed to synthesize evidence on the effectiveness of external ankle supports in enhancing balance control among individuals with ankle instability under fatigue conditions.

METHODS

PROSPERO registration

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodological review criteria was employed in this systematic review to ensure systematic data gathering and analysis [24]. This study protocol was registered in the PROSPERO database under the registration number: CRD42024555308.

Inclusion and exclusion criteria

The criteria for inclusion were outlined as follows: (1) the study design was a crossover clinical trial, (2) the research sample comprised of individuals diagnosed with ankle instability, encompassing functional, mechanical, and chronic types of ankle instability, (3) the experimental group used ankle orthoses or tape during fatigue, (4) the control group used placebo or no intervention during fatigue, and (5) the outcome indicators were at least one clinical test, spatiotemporal, kinetic, kinematic, and muscle activity variable. Only peer-reviewed studies published in English language and in any part of the world with original data were included in this review. Commentaries, editorials, opinions, reviews, abstract-only studies, non-English language, in-vitro studies were excluded from this review.

Search strategy

Two investigators (H.KH and M.B) conducted a systematic search using PubMed, Scopus, and Web of Science, covering the period from the inception of each database to April 29, 2024. No filters were applied to any of the databases. The principal investigator (M.B) selected the search keywords based on Medical Subject Headings (MeSH) terms and free-text literature. The search query was adapted for each database according to its specific search criteria to ensure access to relevant research (Table 1). Additionally, we reviewed the reference citations in the bibliographies of eligible publications to identify further studies that met the inclusion criteria.

Table 1. The search strategy used in the current review.

Search query	Database	Result
("recurrent ankle sprain*"[All Fields] OR "repetitive ankle sprain*"[All Fields] OR "ankle instability"[All Fields] OR "ankle ligament* injur*"[All Fields] OR "unstable ankle" [All Fields]) AND (fatigue*[All Fields] OR exhaust*[All Fields]) AND (tap* [All Fields] OR orthos*[All Fields] OR brac*[All Fields] OR strap*[All Fields] OR elastic [All Fields] OR kinesio*[All Fields] OR prophylactic*[All Fields] OR "external support"[All Fields]) AND ("postural control"[All Fields] OR "postural stability"[All Fields] OR balance[All Fields] OR equilibrium[All Fields] OR kinematic*[All Fields] OR kinetic*[All Fields] OR "clinical test*"[All Fields] OR performance*[All Fields] OR function*[All Fields] OR "hop test"[All Fields] OR "time to stabilization"[All Fields] OR "center of pressure"[All Fields] OR cop[All Fields] OR "star excursion balance test"[All Fields] OR "run*"[All Fields] OR "change of direction"[All Fields])	PubMed	41
(TS= ("recurrent ankle sprain*") OR TS= ("repetitive ankle sprain*") OR TS= ("ankle instability") OR TS= ("ankle ligament* injur*") OR TS= ("unstable ankle")) AND (TS= (fatigue*) OR TS= (exhaust*)) AND (TS= (tap*) OR TS= (orthos*) OR TS=(brac*) OR TS=(strap*) OR TS=(elastic) OR TS=(kinesio*) OR TS=(prophylactic*) OR TS=("external support")) AND (TS=("postural control") OR TS=("postural stability") OR TS=(balance) OR TS=(equilibrium) OR TS=(kinematic*) OR TS=(kinetic*) OR TS=("clinical test*") OR TS=(performance*) OR TS=(function*) OR TS=("hop test") OR TS=("time to stabilization") OR TS=("center of pressure") OR TS=(cop) OR TS=("star excursion balance test") OR TS=("run*") OR TS=("change of direction"))	Web of Science	34
(ALL ("recurrent ankle sprain*") OR ALL ("repetitive ankle sprain*") OR ALL	Scopus	174

("ankle instability") OR ALL ("ankle ligament* injur*") OR ALL ("unstable ankle")) AND (ALL (fatigue*) OR ALL (exhaust*)) AND (ALL (tap*) OR ALL (orthos*) OR ALL (brac*) OR ALL (strap*) OR ALL (elastic) OR ALL (kinesio*) OR ALL (prophylactic*) OR ALL ("external support")) AND (ALL ("postural control") OR ALL ("postural stability") OR ALL (balance) OR ALL (equilibrium) OR ALL (kinematic*) OR ALL (kinetic*) OR ALL ("clinical test*") OR ALL (performance*) OR ALL (function*) OR ALL ("hop test") OR ALL ("time to stabilization") OR ALL ("center of pressure") OR ALL (cop) OR ALL ("star excursion balance test") OR ALL ("run*") OR ALL ("change of direction"))		

Screening and data extraction

After using Endnote software to remove duplicate articles, two investigators (H.KH and M.B) independently conducted a preliminary screening of the pertinent articles based on the title and abstract. Subsequently, the full text of the remaining articles was reviewed using eligibility criteria by H.KH and M.A. Any disagreement between the investigators was resolved by the principal author (M.B). The extracted data included the name of the first author, year of publication, sample size, demographic characteristics, fatigue protocol, type of intervention, relevant outcomes with their Mean ± SD, and key findings.

Methodological quality assessment

Two investigators (H.KH and M.B) have used the Risk of Bias 2 tool for crossover designs to assess study quality [25]. This instrument does not appraise blind protocols in the case of crossover surveys where subjects are exposed to all conditions and may not be blinded. Five domains were used by the researchers when they assessed included studies, and based on that, an outcome was reached using a three-level risk grading system (low risk, some concerns, and high risk) with respect to bias. The Cohen's kappa was used to assess the inter-rater reliability between the two investigators assessment, and the conflicts were resolved through discussion.

Data synthesis

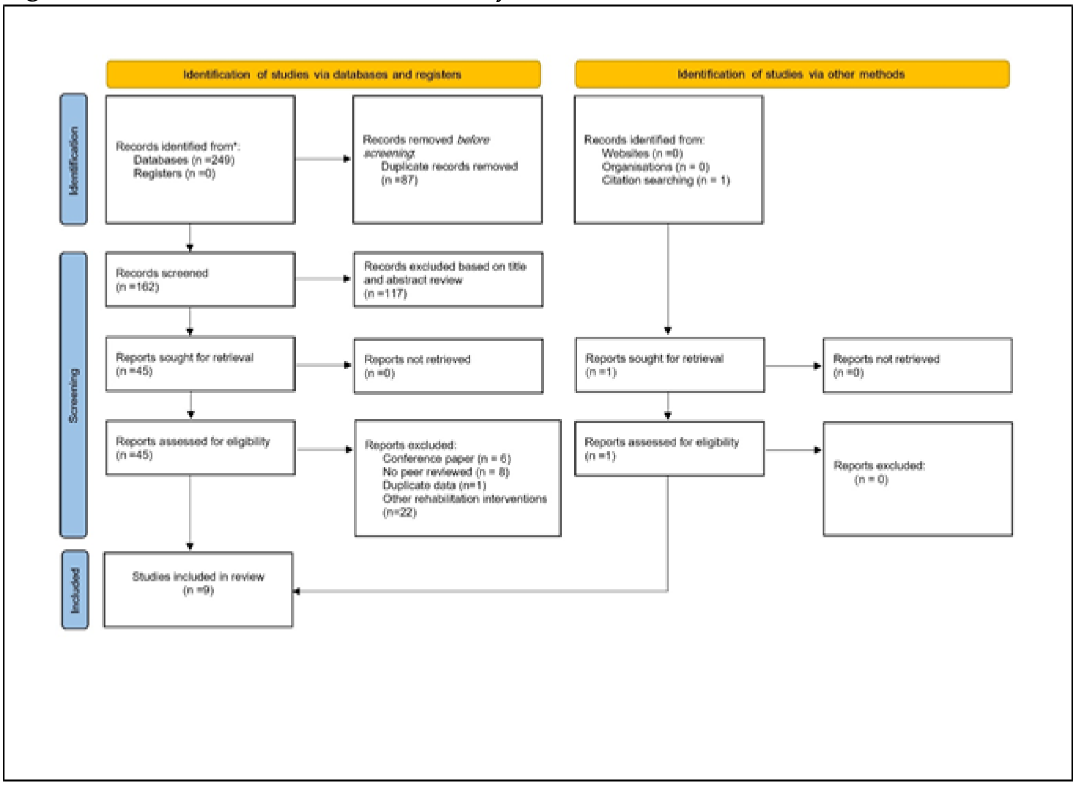
The data on population, intervention, fatigue protocol, and some of the outcomes, which could not be statistically analysed due to dissimilarities in measurement devices, were synthesized narratively. We used statistical analysis to synthesize the rest outcome data, using the Review Manager 5.3 for conducting meta-analysis. Continuous outcomes were represented as standardized mean differences along with a 95% confidence interval (CI). Results were considered homogeneous when $P > 0.05$ and $I^2 < 50\%$. Conversely, outcomes were considered heterogeneous when $P \leq 0.05$ and $I^2 \geq 50\%$. A fixed effects model was applied for homogeneous data while a random effects model was utilized for heterogeneous data. We aimed to assess publication bias using funnel plots and the Egger regression test. Additionally, we performed sensitivity analyses to determine the impact of an individual study on the overall synthesized findings. P-values less than 0.05 suggested statistically significant differences.

RESULTS

Study selection

A total of 249 full-text articles were retrieved from the database searches. After removing duplicates (n=87), 162 reports were screened. During the initial review of titles and abstracts, 117 reports were excluded. As a result, 45 reports were selected for full-text evaluation. Based on the predefined inclusion and exclusion criteria, nine studies were included in this study [26-34]. Some outcomes from five studies were analysed narratively [28, 30-34]. The study selection process is illustrated in Fig. 1, which shows the PRISMA flowchart.

Figure 1. PRISMA 2020 flowchart for study identification.



Risk of bias assessment

Two investigators (H.KH and M.B) independently evaluated the methodology of nine research studies by examining 45 criteria, associating each study with five criteria of Risk of Bias 2 tool. Initially, they achieved consensus on 41 criteria, reflecting an inter-rater agreement rate of 91%. The inter-rater reliability analysis using Cohen's kappa revealed a k-coefficient of 0.88 and a 95% CI ranging from 0.830 to 0.910. Following additional discussions, they reached complete agreement. The results revealed that one study had a high risk of bias [34], three studies had some concerns for bias [26,27,29], and five studies had a low risk of bias [28,30-33]. The domains for each item of the Risk of Bias 2 tool can be found in Figure 2. All studies were found to have a low risk of bias regarding deviations from the intended interventions and missing outcome data. Four studies were flagged for a high risk of bias in the randomization process [26,27,29,34]. Moreover, two studies had uncertainty in the measurement of the outcome [28,34], while three studies had uncertainty in the reported results [26,32,34]. The overall bias weighting is displayed in Figure 3.

Figure 2. Quality assessment result with Risk of Bias 2 tool.

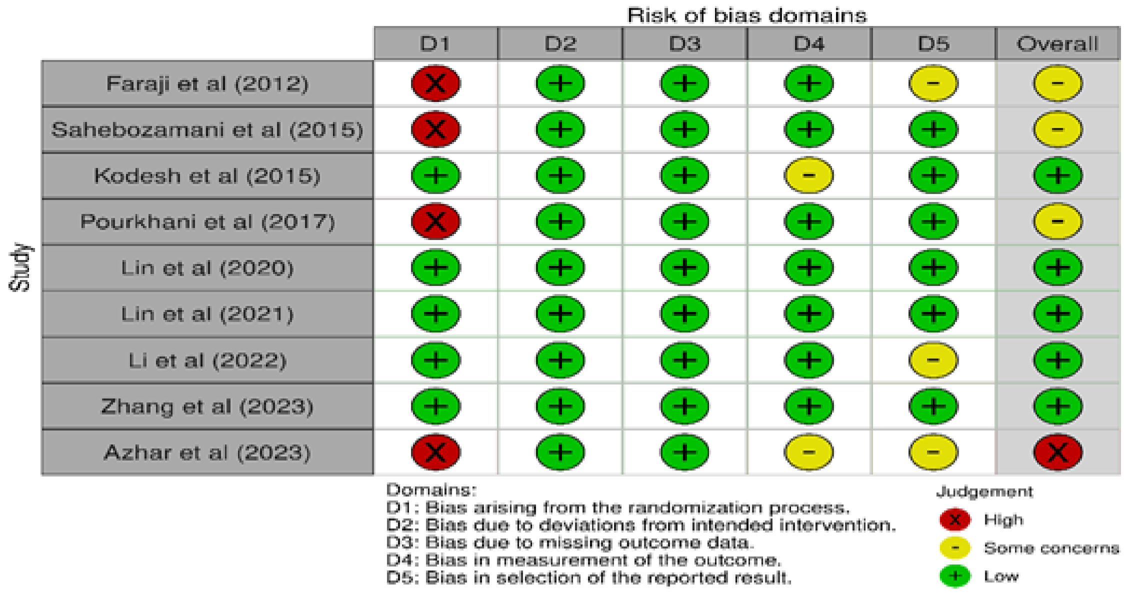
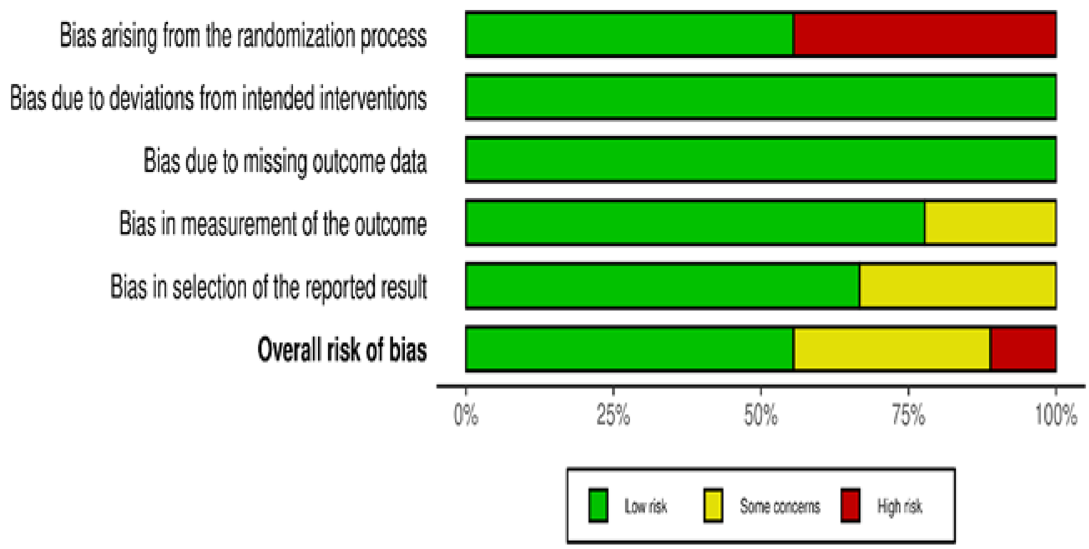


Figure 3. Bias weighting.



Participants demographic characteristics

A total of 230 subjects participated in the included studies. Of these participants, 98 were men, 69 were women, and the participants gender was not reported in two studies [26,34]. The average age ranged from 18 to 24.9 years, with a mean ± SD of 21.3±2.3 years. The weight ranged from 55.71 to 77.7 kg, with a mean ± SD of 65.6 ± 5.4 Kg. The height ranged from 163.8 to 182.53 cm, with a mean ± SD of 173.52 ± 2.8 cm. All nine studies included physically active subjects, with three studies reporting the duration of physical activity (e.g., 3 hrs/week) [27,30,34] and six studies reporting the activity level of the participants (athletes or students) [26,28,29,31-33]. Out of the nine studies, only five provided a description of the selection criteria for participants with ankle instability, as endorsed by the International Ankle Consortium [29-33]. Details of participants' characteristics are shown in Table 1.

External ankle support characteristics

Tape and ankle orthoses were used within each outcome and are presented in Table 1. In the two studies, both tape and ankle orthoses were used [30,31]. In three other studies, only ankle orthoses were used [26,27,33]. The types of ankle orthoses were soft and semirigid. Soft ankle orthoses were either in the form of air cast [27] or made from soft neoprene materials [27,33]. The semirigid type had a stirrup or spring on the medial and lateral side of the ankle to limit inversion/eversion while allowing plantar flexion/dorsiflexion [26, 27, 33]. Tape was the only form of support used in four studies [28,29,32,34]. One study used a nonelastic taping technique in the shape of a figure of eight with two heel locks [34], while another study used a closed basket weave technique with pre-wrap, two proximal/distal anchors, and 3 vertical and horizontal weaving stirrups [29]. Elastic taping was utilized in three studies [28,30- 32], using horizontal I strip, vertical Y strip, and horizontal Y strip around the ankle-foot complex to limit rearfoot inversion and internal rotation. In one study, vertical strips were also applied from the foot over the gastrocnemius, tibialis anterior, and peroneus longus muscles to reduce ankle-joint loading [33]. The type of external ankle supports used in each study can be found in Table 1.

Fatigue protocol

Fatigue protocols in four studies [26,27,29,33] included the modified Southeast Missouri agility (SEMO) drill, stationary lunges, and quick jumps. The SEMO drill involved sprints, backpedaling, and shuffling in a 3.6×5.7 m area. In stationary lunges, participants performed five lunges per leg. Quick jumps were executed adjacent to a wall, comprising 10 swift, two-foot leaps with arms raised overhead, aiming for a target on the wall set at 50% of the previously recorded Vertmax. Other studies focused on rhythmic ankle plantarflexion until 70% of maximum heel height was not achieved [30,31] and used isokinetic machines for eversion/inversion [28] and plantar flexion/dorsiflexion [32]. One study featured a 5-minute Youth Soccer Fatigue Simulation with various soccer actions [34]. The study characteristics are presented in Table 1.

Table 1. Characteristics of the included studies (N=9).

Author (year)	Population	External Ankle Support	Fatigue Protocol	Task Performed	Assessment tool	Outcomes	Findings
Faraji et al (2012) [26]	Total: 35 participants (sex unspecified) Mean age: 18±2 Mean height: 171.7±9.6 Mean weight:62.9±9.7	Soft ankle orthoses Semirigid ankle orthoses	SEMO, stationary lungs, and quick jumps	Single leg stance test	Biodex balance system	Overall postural control index	Considering the positive effect of orthoses on the balance of athletes during fatigue, orthoses can be used to prevent ankle instability.
Sahebozamani et al (2015) [27]	Total: 15 participants. male/female: 7/8 Mean age: 19.46 ± 1.50 Mean height: 182.53 ± 5.28 Mean weight: 67.70 ± 5.91	Soft ankle orthoses Semirigid ankle orthoses	SEMO, stationary lungs, and quick jumps	Single leg stance test	Biodex balance system	Overall postural control index	Both varieties of AO didn't have any effect on dynamic postural control following fatigue
Kodesh et al (2015) [28]	Total: 20 participants male/female: 8/12 Mean age: 24.9± 2.6 Mean height: 170±0.1 Mean weight: 77.7±14.8	Kinesiotape Non elastic tape	Inversion/ eversion exercise on the isokinetic machine	The participants should put their affected leg on the center of "Y" and reach the maximum distance with the unaffected leg	Y balance test vibromyograph	Anterior, posteromedial, and posterolateral reach distances Muscle activity	KT did not yield notable impacts on dynamic postural control after inducing fatigue in ankle muscles in individuals with ankle instability
Pourkhani et al (2017) [29]	Total: 20 participants male/female:0/20 Mean age: 22.02±1.98 Mean height: 163.80±2.74 Mean	Closed basket weave ankle tape Sham tape	SEMO, stationary lungs, and quick jumps	Single leg landing	Force plate	TTS in the mediolateral, and vertical directions	In athletes experiencing ankle instability , post-fatigue taping did not enhance dynamic balance

	weight:58.68±7.10						
Lin et al (2020) [30]	Total: 33 participants male/female:25/8 Mean age: 22.1±2.3 Mean height: 173.6±2.8 Mean weight: 65.4± 1.7	Soft ankle orthoses kinesiotape	Rhythmic ankle plantarflexion	Single leg lateral drop landing	Force plate	Vertical ground reaction force Landing rate Landing time Difference of COP range in mediolateral and anteroposterior directions Difference of COP velocity in mediolateral and anteroposterior directions	AO could impede the capacity to absorb landing impact forces, whereas Kinesiotape could enhance postural stability
Lin et al (2021) [31]	Total: 33 participants male/female:25/8 Mean age: 22.1±2.3 Mean height: 173.6±2.8 Mean weight: 65.4± 1.7	Soft ankle orthoses kinesiotape	Rhythmic ankle plantarflexion	Single leg lateral drop landing	Force plate	Maximal joint angle Range of joint angle The range of the centre of mass	While ankle orthoses can enhance postural control in the frontal plane, it may limit distal joint movement, potentially causing a knee landing posture that increases the risk of secondary knee injuries.
Li et al (2022) [32]	Total: 28 participants male/female: 15/13 Mean age: 21.2±2.0 Mean height: 172.3±8.0 Mean weight: 64.1±10.1	Kinesiotape Sham tape	Maximum voluntary plantarflexion and dorsiflexion was done on a CONTREX isokinetic dynamometer	Maximum voluntary plantarflexion and dorsiflexion Single leg stance The participants should put their affected leg on the center of "Y" and reach the maximum distance with the unaffected leg	Dynamometer Y balance test Force plate	Maximum voluntary Isometric contracture Anterior, posteromedial and posterolateral , reach distance COP mediolateral sway range COP anteroposterior	The impact of KT appears to enhance dynamic postural regulation in people with functional ankle instability following muscle fatigue in the ankle, and this impact is not closely associated with the techniques of taping.

						sway range COP mediolateral velocity range COP anteroposterior velocity range	
Zhang et al (2023) [33]	Total: 18 participants male/female:18/0 Mean age: 19.9±1.6 Mean height: 182.2±6.6 Mean weight:70.8±8.3	Soft ankle orthoses Semirigid ankle orthoses	SEMO, stationary lungs, and quick jumps	Single leg landing	Infrared motion capture system and the force plate	Sagittal and frontal range of motion and angle TTS in the mediolateral, and vertical directions ground reaction force in vertical direction.	The semi-rigid ankle orthoses enhanced dynamic stability in the medial and vertical planes, decreased ankle inversion angle, and lowered vertical ground reaction force following fatigue.
Azhar et al (2023) [34]	Total: 28 participants (sex unspecified) male/female: N/C Mean age: 19.02±1.03 Mean height: 165.43±4.02 Mean weight:55.71±5.6	Rigid tape kinesiotape	Youth soccer fatigue stimulation	The participants should put their affected leg on the center of "Y" and reach the maximum distance with the unaffected leg. They jump far as far possible with the affected leg	Single leg hop test Y balance test	Reach distance of Y balance test and single leg hop test	Tape has a considerable beneficial impact on maintaining ankle instability and lower limb performance in elite youth soccer players with ankle instability.

Note: Abbreviations: N/C: SEMO: southeast Missouri agility drill, COP: center of pressure, TTS: time to stabilization, KT: kinesiotape

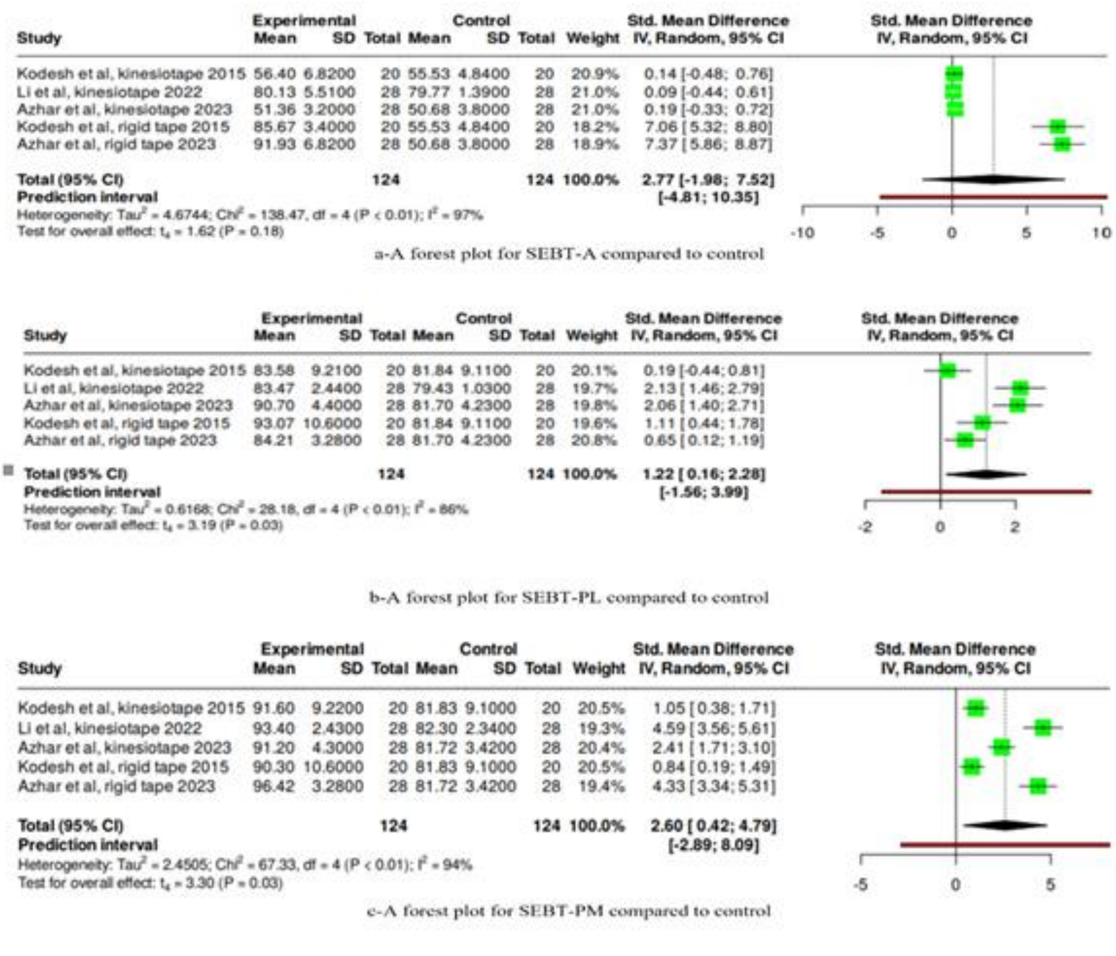
Outcomes

The outcomes of balance control, including those related to clinical tests, COP, ground reaction force, spatiotemporal and kinematics of landing, and muscle activity, were reported in these studies. In the following, we have categorized the outcomes and presented the results.

Clinical tests

Three studies [28,32,34] analyzed the effectiveness of external ankle supports on balance control using the Y balance test, which is a modified version of the Star Excursion Balance Test. In the anterior direction, there was no difference between the group with external ankle supports (124 participants) and the control group (124 participants) (ES: 2.77, CI: 1.98 to 7.52, p > 0.05). The overall effect was not significant and there was variability in results (I2=97%, p<0.01) (Figure 4a). On the other hand, significant differences were observed between the two groups in both the posterolateral (Figure 4b) and posteromedial (Figure 4c) directions (ES: 1.22, CI: 0.16 to 2.28, p < 0.05; and ES: 2.6, CI: 0.42 to 4.79, p < 0.05, respectively). Despite effects in these directions, considerable variability among studies persisted due to heterogeneity rather than random chance (86% and 94% heterogeneity detected). In one study [34], the single leg hop test was used for balance control assessment. The taping group showed a significantly longer reach distance (90.03±6.81 vs 82.19±11.92, p=0.012).

Figure 4. The forest plot for Y balance test compared to control.



COP range and velocity

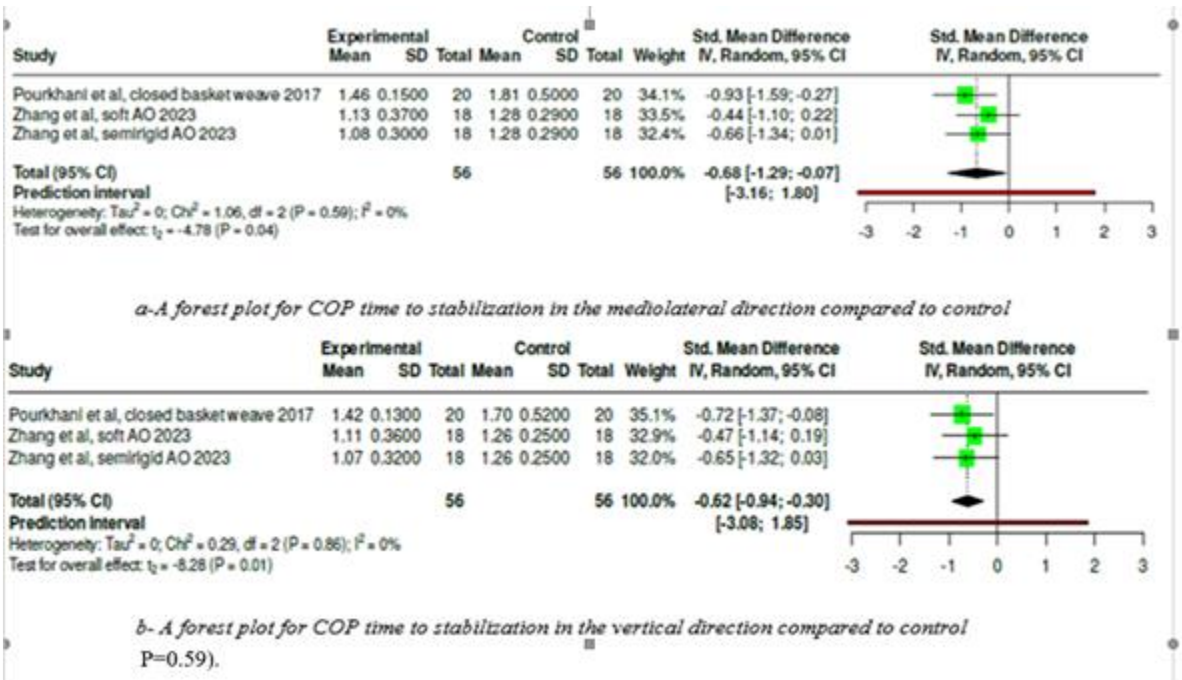
During landing with fatigue, COP range between the ML direction for soft ankle orthoses was 0.77 to -0.15 and for kinesiotape it was -0.62 to 0.43. In the anteroposterior direction, the COP difference range for soft ankle orthoses were 0.57 and for kinesiotape it was -0.28, respectively.

Despite the small differences in these ranges, kinesiotape significantly reduced the COP range in both the mediolateral and anteroposterior directions ($p<0.05$) [30, 31]. Additionally, the COP velocity in the anteroposterior direction was significantly lower for kinesiotape compared to soft ankle orthoses (Mean difference=3.70) and control (Mean difference=0.55) [30]. In static standing after fatigue, kinesiotape significantly decreased ML COP sway range (9.97±9.22 vs 10.17±4.36, $p<0.001$) [32].

COP TTS

For the comparisons of COP TTS in the mediolateral direction, three groups were analyzed (Figure 5a) [29,33], including a total of 56 subjects in the experimental cohort and 56 subjects in the control cohort. We utilized a random effects model with the inverse variance method to calculate the standard mean differences. The results revealed a statistically significant difference between the two cohorts (Standard mean difference: -0.68, 95% CI: -1.29 to -0.07). The overall effect was significant, with a p-value <0.05. Notable variability was not detected (I2:0%, P=0.59), indicating that ES across cohorts were consistent in both magnitude and direction. For the COP TTS in the vertical direction (Figure5b), three groups were analyzed, comprising the same cohorts of 56 subjects each. The standard mean difference analysis yielded a summarized value of -0.62 (95% CI: -0.94 to -0.30), indicating a significant difference between the experimental and control cohorts. Again, the test for overall effect was significant, with a p-value below 0.05. As with the mediolateral direction, no significant heterogeneity was observed, suggesting that the ES across the cohorts were uniform in both size and direction (I2:0%).

Figure 5. The forest plot for COP TTS compared to control.

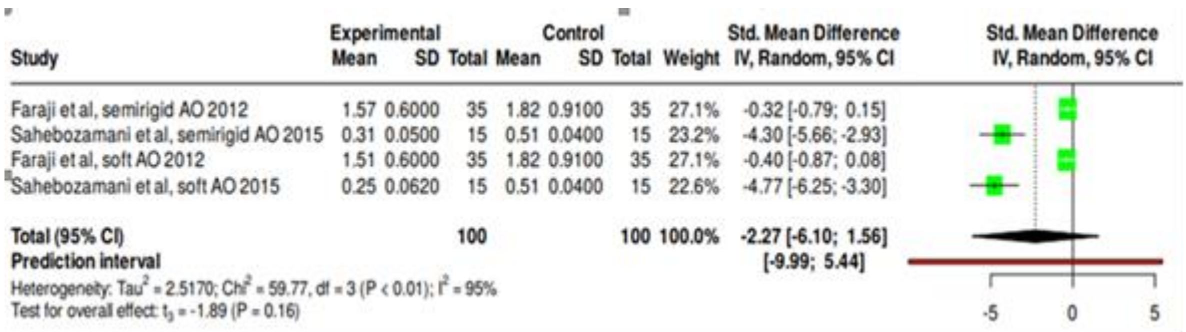


Overall postural control index

A total of 200 subjects (100 in the experimental group and 100 in the control group) were examined for the postural control index total scores with Biodex device [26, 27]. Meta-analysis was performed using the random effects model and Inverse Variance method, and no statistically significant difference between groups was found, with a pooled standard mean difference of -2.27

(95% CI: -6.1 to 1.56). The overall effect is not significant, and there is significant heterogeneity (P < 0.01) observed, indicating that 95% of the variability is not due to chance, but due to heterogeneity, showing that there were mixed findings in both the magnitude and direction of the effect (I2: 95%, p<0.01) (Figure 6).

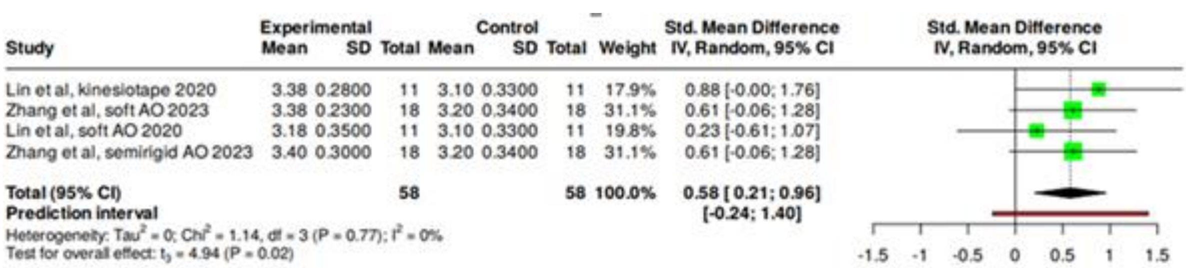
Figure 6. The forest plot for postural control index compared to control.



Vertical ground reaction force

A pooled analysis of 116 subjects [30, 33] (58 in each experimental and control group) was run on vertical ground reaction force, and a statistically significant difference was found between groups in favor of the experimental group (Standard mean difference: 0.58, 95% CI: 0.21-0.96, P=0.02, Figure 7. There was no heterogeneity, indicating that ES were roughly in the same direction and of the same magnitude across studies (I2:0%, P=0.77).

Figure 7. The forest plot for vertical ground reaction force compared to control.



Spatiotemporal landing parameters

Lin et al. [30] found that there were no significant changes in landing rate and landing time during fatigue when using both soft ankle orthoses and kinesiotape. The soft ankle orthoses had a mean difference of 1.88 for landing rate and -8.55 for landing time, while the kinesiotape had a mean difference of 1.21 for landing rate and -4.84 for landing time. However, it is worth noting that the p-value for these results was 0.053, indicating a trend towards significance.

Ankle inversion angle

A significantly lower ankle inversion angle was achieved by the semirigid ankle orthoses after fatigue when compared to the lace-up ankle orthoses (93.9% vs. 51.6%, p=0.026). Also, the semirigid ankle orthoses resulted in a significantly lower peak ankle inversion angle compared to the lace-up ankle orthoses (84.2% vs. 44.8%. p=0.025) [31,33].

Muscle strength and activity

Two studies were conducted to measure muscle strength and activity using dynamometers [32] and vibromyography [28]. The results of these studies indicated that the application of kinesiotape had no impact on the muscle activity of the fibularis longus (frequency range: 0.61-0.17) after fatigue [28]. Furthermore, taping also did not cause any significant difference in maximum voluntary contraction in plantarflexion (83.04±25.56 vs 87.71±26.45) and dorsiflexion (24.86±7.71 vs 25.87±8.21) [32].

Publication bias

A funnel plot is a straightforward scatter plot depicting the ESs of interventions from studies. A minimum of ten studies was necessary to provide evidence for the funnel plot [35]. Due to the limited number of studies included, we were unable to create a funnel plot. Regression analyses conducted on the synthesized outcomes revealed no evidence of bias (all $P > 0.05$).

Sensitivity analysis

We methodically eliminated randomized control trials for each specific outcome to evaluate the impact on the overall results. Our analysis demonstrated that the overall findings stayed consistent, irrespective of the exclusion of any particular randomized control trial.

DISCUSSION

This systematic review and meta-analysis aimed to assess the effectiveness of external ankle supports, including tape and ankle orthoses on different aspects of balance control. The results of this study demonstrate the complexity of these interventions, revealing both significant effects and variations across the studies. While the Y balance test did not show a significant improvement in the anterior direction, notable enhancements were observed in the posterolateral and posteromedial directions when external ankle supports were applied [28,32,34]. External ankle supports significantly reduced the COP range in both mediolateral and anteroposterior directions, indicating their effectiveness in managing sway during landing with fatigue. Moreover, external ankle supports reduced COP velocity in the anteroposterior direction compared to the control group [30-32]. The meta-analysis showed significant reductions in TTS in both mediolateral and vertical directions for the external ankle support group [29,33]. However, there were no statistically significant differences in the overall postural control index measured by the Biodex device [26,27]. The experimental group observed a significant improvement in vertical ground reaction force [30, 33], indicating a positive impact of external ankle supports on force dynamics during landing.

During fatigue with external ankle supports, no significant changes in landing rate and time were observed [30]. Semirigid ankle orthoses resulted in a significantly lower ankle inversion angle compared to lace-up ankle orthoses after fatigue [31,33]. External ankle supports did not have a significant effect on muscle activity of the fibularis longus or maximum voluntary contraction in plantarflexion and dorsiflexion following fatigue [28, 32]. These findings suggest that external ankle supports may enhance balance control in specific movement patterns, but their broad advantages may not apply to all balance assessments.

The impact of ankle instability on the posteromedial direction of the Y balance test appears to be more significant than in other directions [28,32,34]. This meta-analysis aligns with previous data that demonstrates significant changes in reach distances during the Y balance test when using external ankle supports, compared to participants without support [22]. These devices may help compensate for the lack of normal afferent feedback from injured proprioceptors by stimulating sensory receptors in the skin, thus improving afferent input [37]. However, the physiological reasons behind these effects are still unclear.

Research demonstrated impaired postural control in functional ankle instability by measuring a delayed TTS following single-leg jump [38]. It seems that the external ankle supports slightly improves this deficiency of reduced COP TTS in these patients [29,33]. Although the range of COP movement in both mediolateral and anteroposterior directions was reduced, this effect was not observed in the overall postural control index measured by the Biodex device [26,27]. This may be because other aspects of COP parameters are also considered when calculating the index [39].

The movements of the joints, starting from the distal end of the extremities and moving towards the proximal end, play a crucial role in dissipating energy of vertical ground reaction force during a jump landing [9]. The entire lower limb is affected by these movements, and deviations can result from abnormal motion or a loss of muscle function around the ankle that external ankle supports can restrict them [9,10]. During a jump landing task, these forces can reach up to 6.2 times the person's body weight, increasing the likelihood of further injuries in the lower limbs if the force is not properly dissipated [12,13].

The velocity and time of load are related to the shock wave that passes through the body [40, 41] and are believed to be responsible for impact-related injuries. A soft landing allows reducing the potential for protecting structures from the increased forces associated with rapid deceleration [42,43]. Research has shown that, compared with healthy subjects, functional ankle instability patients would use less time in loading of ground reaction force when performing jump landing activities [12,13]. However, the result of this study shows that external ankle supports cannot show any effect on landing time and rate.

Several constraints of this meta-analysis should be considered. Firstly, the number of included randomized control trials is limited, and the sample sizes of the experimental studies are also modest. Furthermore, there was variability in the patients' baseline activity levels and the fatigue protocol. Moreover, different types of external ankle support were used and combined into meta-analyses for all the results. It is possible that certain external ankle supports with higher stiffness (such as semirigid ankle orthoses or nonelastic taping) could have a more effect on ankle biomechanics. As a result, the combined estimates might be influenced by the types of external ankle supports used in each study included in this meta-analysis.

CONCLUSION

Our findings suggest that external ankle supports may effectively improve specific components of balance, such as enhanced postural control in the posterolateral and posteromedial directions of the Y Balance Test. However, their effectiveness may vary depending on the specific balance assessment methods employed. Notably, external ankle supports significantly reduced the center of pressure (COP) range and velocity in both mediolateral and anteroposterior directions during landing under conditions of muscle fatigue. This indicates that these supports can stabilize the ankle joint and enhance balance during dynamic movements. Additionally, external ankle supports positively influenced vertical ground reaction force during landing, suggesting potential improvements in the distribution and absorption of forces, which are critical for safe and efficient movement patterns.

However, no significant improvements were observed in metrics such as landing rate, landing time, or the postural control index as assessed using the Biodex device. These findings highlight that the benefits of external ankle support might not extend uniformly across all aspects of balance and postural control. The heterogeneity among the included studies, including variations in the types of external ankle supports and assessment protocols, underscores the need for standardized guidelines and methodologies in future research. This will help establish a more comprehensive understanding of the mechanisms and effectiveness of external ankle supports.

Healthcare professionals should consider incorporating external ankle supports into rehabilitation programs for individuals with ankle instability, particularly following periods of muscle fatigue. By enhancing postural control and reducing the risk of instability, external ankle supports may play a crucial role in restoring balance and improving functional outcomes in affected individuals.

Finally, our findings, while emphasizing the effectiveness of external ankle supports in enhancing balance following fatigue in individuals with ankle instability, align with a broader perspective on addressing both physical and psychological challenges in rehabilitation. Innovative approaches to mental health and psychosocial well-being [44-47], can complement rehabilitative interventions, improving not only biomechanical conditions but also the emotional and social dimensions of functional recovery.

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