

Article

Kinesiology Taping Added to Whole-Body Vibration-Based Stabilization Training for Chronic Ankle Instability: A Randomized Controlled Trial

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Abstract

Chronic ankle instability (CAI) is associated with impaired neuromuscular control, dynamic balance, and perceived ankle stability. This two-group randomized controlled trial investigated the additional effects of kinesiology taping during whole-body vibration (WBV)-based stabilization training in recreational badminton players with CAI. Forty participants (21 men and 19 women; mean age approximately 24 years) were randomly assigned to a stabilization exercise with taping group (SET; $n = 20$) or a stabilization exercise group (SE; $n = 20$). Both groups performed 30 min of WBV-based stabilization training five times per week for 6 weeks. Training intensity progressed from 35 Hz and 2 mm to 40 Hz and 4 mm with increasing task difficulty. In the SET group, 5 cm Kinesio Tex tape was applied to the affected ankle using a standardized three-strip technique with approximately 30% tension. The primary outcome was the Star Excursion Balance Test (SEBT), while peroneus longus muscle activation and Cumberland Ankle Instability Tool (CAIT) scores were secondary outcomes. Outcomes were analyzed using a 2×2 mixed-design ANOVA, with statistical significance set at $p < 0.05$. Significant group $\times$ time interactions were observed for SEBT scores ($p = 0.018$), peroneus longus muscle activation ($p = 0.022$), and CAIT scores ($p = 0.012$). Mean improvements were greater in the SET group than in the SE group for SEBT scores (11.7 ± 10.2 vs. 4.0 ± 9.5 percentage points), peroneus longus muscle activation (19.9 ± 15.3 vs. $7.9 \pm 16.5\%$ MVIC), and CAIT scores (4.6 ± 3.2 vs. 1.8 ± 3.4 points). These findings suggest that kinesiology taping added to WBV-based stabilization training may provide an additional short-term benefit for dynamic balance, peroneus longus muscle activation, and perceived ankle stability in recreational badminton players with CAI; however, because no sham-taping condition was included, these findings do not establish the independent efficacy of kinesiology taping.



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1. Introduction

Lateral ankle sprains typically occur due to excessive rearfoot supination combined with external rotation of the lower limb [1]. Lateral ankle sprains are among the most common musculoskeletal injuries in athletes [2–4], accounting for a substantial proportion of sports-related injuries [3,4]. The incidence of ankle sprains is particularly high in sports

involving running, jumping, landing, and rapid changes in direction because of the biomechanical demands of these activities [4]. A systematic review involving 201,600 participants reported 32,509 ankle injuries across 70 sports in 38 countries [4]. A systematic review and meta-analysis of prospective epidemiological studies reported a higher incidence of ankle sprains in females than in males (13.6 vs. 6.94 per 1000 exposures), with indoor and court sports showing the highest cumulative incidence rate (7 per 1000 exposures) [5]. For prevention, bracing and neuromuscular training have been supported for reducing recurrent ankle sprains, whereas early mobilization, exercise, manual therapy, and non-steroidal anti-inflammatory drugs have been supported for the management of acute ankle sprains [6]. Badminton is also a physically demanding sport involving repeated jumping, lunging, and sudden changes in direction. According to the 2023 National Sports Participation Survey in Korea, badminton ranked second among sports club activities, following soccer and futsal [7].

Persistent foot impairments and neuromuscular dysfunction following an ankle sprain may contribute to recurrent sprains and functional limitations [8,9]. Appropriate activation of the ankle-stabilizing muscles is essential for protecting the joint from potentially harmful external forces and maintaining dynamic joint stability [9]. The tibialis anterior, peroneus longus, and medial gastrocnemius contribute to ankle stabilization during tasks performed on unstable surfaces [10]. In a prospective study of predominantly recreational basketball players, 73% of players who sustained an ankle injury reported a previous ankle injury, and a history of ankle injury was associated with nearly fivefold higher odds of subsequent ankle injury [11].

Chronic ankle instability (CAI) is characterized by symptoms including pain, swelling, muscle weakness, reduced range of motion, impaired postural control, and recurrent episodes of “giving way” [12]. It is also associated with deficits in sensorimotor function, including balance, strength, joint position sense, and neuromuscular activation [13]. These impairments may restrict participation in sports and daily activities and negatively affect health-related quality of life [14].

In addition to objective sensorimotor impairments, individuals with CAI commonly report persistent perceived ankle instability that may not be fully captured by objective balance or strength measures alone. The Cumberland Ankle Instability Tool (CAIT) is a validated patient-reported outcome measure used to quantify the severity of perceived ankle instability [15]. However, whether the combination of whole-body vibration (WBV) training and kinesiology taping produces concurrent improvements in dynamic balance, peroneus longus muscle activation, and perceived ankle instability remains unclear.

Rehabilitation programs for CAI commonly include balance training, strength training, and neuromuscular exercises, whereas WBV has been investigated as an adjunctive intervention. WBV delivers mechanical oscillations to the body through a vibration platform and may stimulate muscle spindles and other sensory receptors, thereby facilitating neuromuscular activation and reflexive muscle contractions [16,17]. These physiological responses may contribute to improvements in muscle function, joint stability, balance, joint position sense, and dynamic postural control [18,19].

Tan et al. [20] reported that WBV improved sensorimotor outcomes in individuals with CAI. Studies involving athletes with ankle instability have also reported improvements in dynamic balance following rehabilitation programs involving WBV or balance training [21,22]. Moreover, combined WBV and wobble-board training improved balance and ankle stability in athletes with functional ankle instability [23]. Although these findings have been supported by a systematic review, substantial heterogeneity has been identified in vibration frequency, intervention duration, exercise protocols, and outcome measures, indicating the need for further controlled studies using standardized protocols [24]. A

recent systematic review likewise indicated that WBV may improve dynamic balance in individuals with CAI, although the findings varied according to the assessment direction and intervention protocol [25].

Kinesiology taping has been widely investigated in sports and rehabilitation because of its potential effects on muscle activity and muscular performance [26,27]. However, these studies involved different body regions and populations, and their findings cannot be directly generalized to individuals with CAI. A systematic review and meta-analysis of athletes with CAI reported that kinesiology taping may improve certain aspects of ankle function and sports performance, although its effects were not consistent across all outcome measures [28]. Recent evidence also suggests that taping outcomes may depend on the application method. In individuals with CAI, dynamic-balance responses differed according to tape length [29], while taping applied at 35% tension improved proprioceptive sensitivity and functional stability compared with zero-tension taping [30]. Khalili et al. [31] reported that adding kinesiology taping to a 6-week balance-training program resulted in greater improvements in balance, postural stability, and ankle instability severity than balance training alone in female athletes with functional ankle instability. The clinical relevance of changes in these outcomes should also be considered. For the CAIT, a change of at least 3 points has been established as the minimal detectable change and minimal clinically important difference in individuals with CAI [32]. For the complete eight-direction SEBT, an average minimal detectable change of approximately 6.4% has been reported [33].

However, although WBV and kinesiology taping have each demonstrated potential benefits, it remains unclear whether adding kinesiology taping to an active, longer-term WBV-based stabilization program provides additional benefits beyond those achieved with the same WBV-based training alone. Therefore, the purpose of this study was to determine whether adding kinesiology taping to WBV-based stabilization training would produce greater improvements in dynamic balance, peroneus longus muscle activation, and perceived ankle instability than the same WBV-based stabilization training performed without taping in recreational badminton players with CAI. We hypothesized that the SET group would demonstrate greater pre-to-post improvements in SEBT performance, peroneus longus muscle activation, and CAIT scores than the SE group.

2. Materials and Methods

2.1. Participants

This study was a two-group, parallel randomized controlled trial with a 1:1 allocation ratio. This report was prepared in accordance with the CONSORT 2025 reporting guidelines [34], and the completed checklist is provided as Supplementary Table S1. No patients or members of the public were involved in the design, conduct, or reporting of the trial, and no important changes were made to the study protocol after trial commencement. This study recruited 40 recreational badminton players aged 19 years or older who regularly participated in local badminton clubs in Gyeonggi Province, Republic of Korea, and met the eligibility criteria for chronic ankle instability (CAI). Participant recruitment and data collection were conducted from 21 May 2021 to 22 August 2022. Recruitment notices were posted at local badminton clubs in Gyeonggi Province, and club members were informed of the purpose and procedures of the study.

2.1.1. Eligibility Criteria

Individuals who expressed an interest in participating were screened using the Cumberland Ankle Instability Tool (CAIT), a self-reported questionnaire, and a survey of their previous ankle-injury history, in accordance with the CAI selection criteria of the International Ankle Consortium [35]. The inclusion criteria were as follows: (1) a history of at

least one significant ankle sprain, with the initial sprain occurring more than 12 months before enrollment; (2) interruption of physical activity for at least one day because of inflammatory symptoms, such as pain or swelling, following the initial sprain; (3) at least two self-reported episodes of “giving way” within the previous 6 months; and (4) a Cumberland Ankle Instability Tool (CAIT) score of <24 . The exclusion criteria were a history of orthopedic surgery involving either lower extremity, a history of lower-extremity fracture, known contraindications to whole-body vibration, such as kidney stones or acute intervertebral disc herniation, and neurological conditions that could affect balance [35]. Individuals with current ankle swelling at screening or a known allergy or hypersensitivity to kinesiology tape were also excluded. Participants with bilateral CAI were also included. When both ankles met the eligibility criteria, the ankle with the lower CAIT score, indicating greater perceived instability, was designated as the affected side for the intervention and all outcome measurements [36].

2.1.2. Sample Size and Trial Procedures

An a priori sample-size calculation was performed using G*Power version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) for a two-tailed independent-samples t-test. The effect size was derived from the between-group difference in the pre-to-post change in modified Star Excursion Balance Test anterior reach distance reported by Shamseddini Sofla et al. [37]. The expected effect size ($d = 1.14$) was derived from a previous study using an SEBT-based dynamic balance outcome in individuals with ankle instability. Because the previous study used modified SEBT anterior-reach distance and a different intervention comparison, this value was used only as an approximate planning estimate for the present study. With an effect size of $d = 1.14$, an α level of 0.05, a statistical power of 0.90, and an allocation ratio of 1:1, the minimum required sample size was 36 participants, with 18 participants per group. To account for an anticipated attrition rate of approximately 10% during the intervention period, 40 participants were recruited, with 20 allocated to each group. It is acknowledged that this effect size is exceptionally large relative to typical adjunct-intervention effects in sports rehabilitation, and the resulting sample size may not have been sufficient to detect a more modest, clinically realistic between-group difference. The SEBT was designated as the primary outcome, whereas peroneus longus muscle activation and CAIT were considered secondary outcomes. The sample-size calculation was based on an SEBT-derived effect size. Because the source study used modified SEBT anterior-reach distance rather than the eight-direction composite score used in the present study, the effect size was treated as an approximate planning estimate for the primary outcome. This study was approved by the Institutional Review Board of Gachon University (1044396-202104-HR-073-01) on 20 May 2021. The 40 eligible participants were informed of the study purpose, assessment and intervention procedures, protection of personal information, voluntary nature of participation, and their right to withdraw from the study at any time. Written informed consent was obtained from all participants before enrollment. After completion of the baseline assessments, participants were randomly allocated in a 1:1 ratio to the SET or SE group using a computer-generated randomization sequence in IBM SPSS Statistics. Allocation concealment was maintained using opaque, sealed envelopes until group assignment. The randomization sequence was generated and managed by an independent researcher who was not involved in participant recruitment, intervention delivery, or outcome assessment. This researcher was responsible only for assigning participants to the groups and had no further involvement in the study. All outcome assessments were performed by an assessor blinded to group allocation. Participants were instructed not to disclose their group allocation to the assessor. Because the presence of kinesiology tape was apparent, the participants and treating therapists

could not be blinded to group allocation. The trial was retrospectively registered with the Clinical Research Information Service (CRIS) on 16 June 2021 (KCT0006263), after enrollment of the first participant on 21 May 2021. The full trial protocol and statistical analysis plan are not publicly available. Participant flow and study procedures are shown in Figure 1.

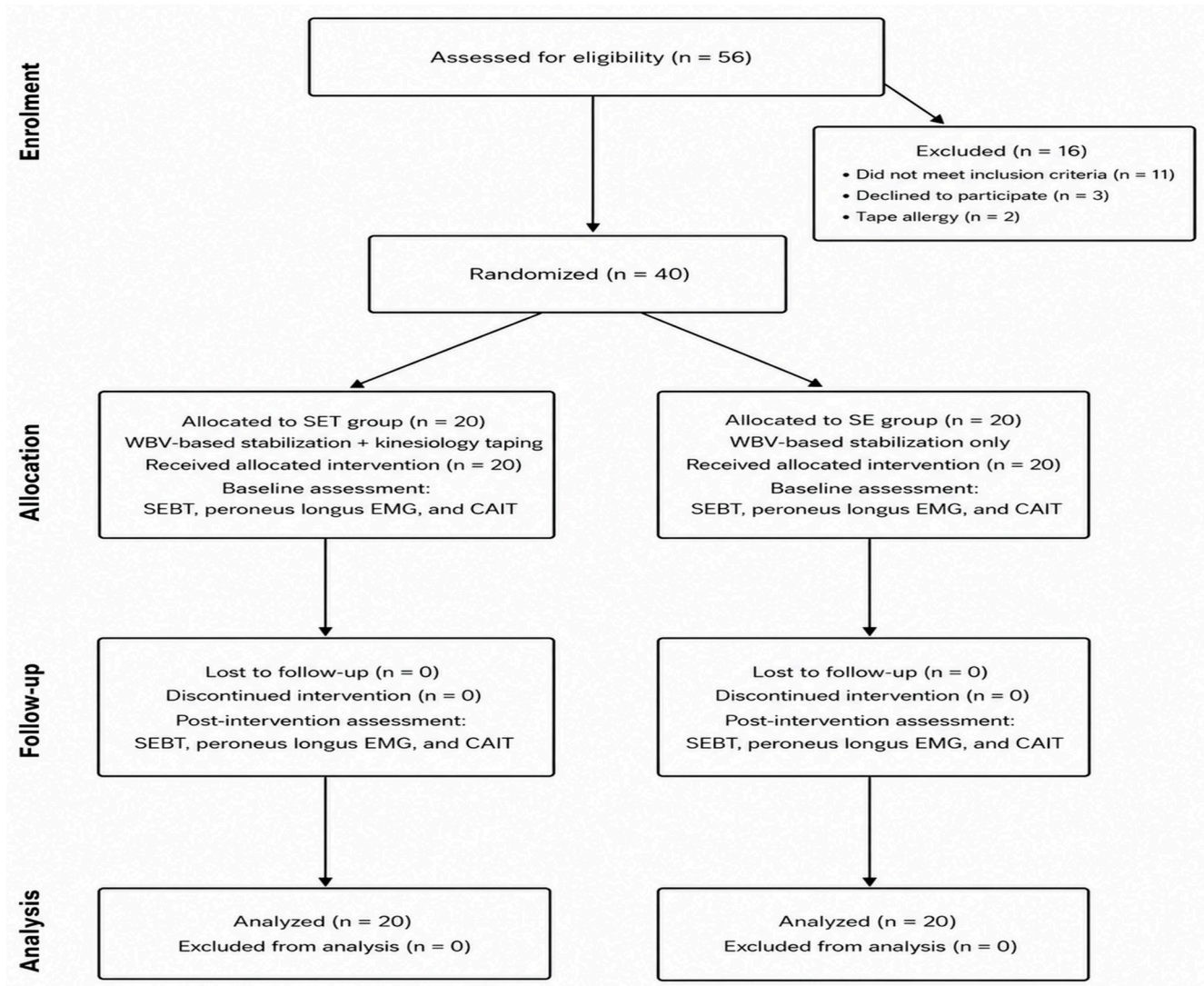


Figure 1. CONSORT 2025 participant flow and study procedures.

2.2. Intervention

The training program consisted of four exercise tasks. Each task was performed for three sets, with 45 s of WBV exercise followed by 45 s of rest per set. A 5 min warm-up and a 5 min cool-down were performed before and after the main exercise program, respectively. Both groups participated in whole-body vibration (WBV)-based stabilization training five times per week for 6 weeks, with each session lasting approximately 30 min. The stabilization exercise with taping group (SET group) received WBV-based stabilization training combined with kinesiology taping, whereas the stabilization exercise group (SE group) performed the same WBV-based stabilization training without taping.

The WBV-based ankle stabilization program was adapted with minor modifications from the intervention protocol described by Sierra-Guzmán et al. [36]. The modifications included progressive increases in task difficulty, restricted visual input, the addition of elastic-band resistance and heel raises, and variations in the direction and speed of the ball-

passing-and-catching task. The main exercise program consisted of four tasks performed on a whole-body vibration platform (TT2590X7, TurboSonic Co., Seoul, Republic of Korea). The first task involved maintaining a single-leg stance on the affected limb. The second task was cross-legged sway, during which the non-weight-bearing limb was moved from side to side while single-leg stance was maintained. The third task involved maintaining a single-leg runner's pose. The fourth task involved repeatedly passing and catching a ball with the therapist while standing with both feet on the vibration platform. A 22 cm-diameter exercise ball (Redondo® Ball, TOGU GmbH, Prien-Bachham, Germany) was used for the ball-passing-and-catching task. During weeks 1–2, participants practiced the four basic tasks with their eyes open while WBV was applied at a frequency of 35 Hz and an amplitude of 2 mm. For the ball task, the therapist stood 1.5 m in front of the participant and delivered the ball slowly in a predictable forward direction, while the participant repeatedly caught and returned the ball. During weeks 3–4, WBV was applied at a frequency of 40 Hz and an amplitude of 4 mm, and task difficulty was progressively increased while the eyes-open condition was maintained. During cross-legged sway, an elastic resistance band was applied to the non-weight-bearing limb to increase the postural-control demands on the stance limb. A yellow band (Thera-Band®, Hygenic Corporation, Akron, OH, USA) was used in week 3, and resistance was progressed to a red band in week 4 when the supervising therapist judged that the participant could perform the task while maintaining adequate postural stability and control; otherwise, the yellow band was maintained. A heel raise was added during the single-leg runner's pose. For the ball task, throwing speed was increased relative to weeks 1–2, and the direction was varied upward, downward, left, and right to reduce predictability, while participants caught and returned each throw. During weeks 5–6, WBV was maintained at 40 Hz and 4 mm. The first three tasks were performed with a light-blocking eye mask to reduce visual input. During cross-legged sway, the elastic-band resistance achieved in week 4 was maintained. For safety, the ball-passing-and-catching task was performed with the eyes open, with the throwing speed maintained at the weeks 3–4 level while the direction was varied unpredictably. Progression of elastic-band resistance and ball-throwing speed was determined by the supervising therapist based on the participant's movement quality and postural stability.

In the SET group, three strips of elastic kinesiology tape were applied to the affected ankle. The tape used was a 5 cm-wide elastic kinesiology tape (Kinesio Tex, Kinesio Holding Corp., Albuquerque, NM, USA). First, an I-strip was applied from the lateral malleolus to the medial malleolus. Second, a long Y-strip was anchored at the lateral aspect of the ankle, with its two tails directed proximally along both sides of the peroneus longus muscle belly. Finally, a short Y-strip was anchored at the posterior aspect of the heel over the Achilles tendon, with its two tails directed toward the medial malleolus and the great toe, respectively, thereby covering the ankle joint [38,39]. Each tape strip was applied with approximately 30% tension over the body of the tape, whereas the anchors at both ends were applied without tension. To standardize the applied tension across participants, the tape length was determined using a modified version of the cutting-length method described by Yin et al. [40]. After the anatomical length of the application area was measured, a tension coefficient of 1.30 and a correction factor of 1.10 for the tape's initial elongation after removal of the backing paper were applied to determine the cutting length. The taping procedures were performed by two physical therapists who met the prespecified eligibility criterion of at least 2 years of clinical experience. Before the study, both therapists were trained in and practiced the standardized application procedure to ensure consistency. The tape was applied at least 20 min before the start of each exercise session to allow the adhesive to stabilize and was removed immediately after the session. A new set of tape strips was applied at each session using the same standardized procedure.

A minimum attendance of 24 of the 30 sessions ($\geq 80\%$) was defined as the adherence criterion. Make-up sessions were provided within the same week when necessary. All randomized participants met this attendance criterion. During the intervention period, participants were instructed not to receive additional ankle rehabilitation, taping, or pharmacological treatment for ankle symptoms. When a participant missed a scheduled session for personal reasons, a make-up session was provided during the same week to maintain the intervention frequency of five sessions per week. At each session, the treating therapists asked participants about adverse events or discomfort and instructed them to report any symptoms. Participants were monitored for skin-related adverse events at the taping site, including itching, erythema, and contact dermatitis, as well as dizziness or acute pain associated with WBV exposure. If an adverse event persisted or the intervention was considered unsafe to continue, the intervention was discontinued immediately. All training sessions were supervised by a physical therapist.

2.3. Outcome Measurements

The primary outcome, dynamic balance, was assessed using the Star Excursion Balance Test (SEBT), which has demonstrated intratester reliability coefficients ranging from 0.78 to 0.96 [40]. The reaching task was performed in eight directions: anterior, antero-medial, medial, posteromedial, posterior, posterolateral, lateral, and anterolateral. Each direction was tested three times, and the mean reach distance was recorded in centimeters. The mean reach distance in each direction was normalized to the length of the affected limb and expressed as a percentage using the following equation: Normalized reach distance (%) = reach distance / limb length $\times$ 100. The mean of the normalized reach distances across the eight directions was used as the overall SEBT score. The test procedure was based on the method described by Hertel et al. [41].

Peroneus longus muscle activation was measured using a surface electromyography system (TeleMyo 2400 G2 Telemetry EMG System, Noraxon USA Inc., Scottsdale, AZ, USA). The signals were sampled at 1000 Hz and band-pass filtered at 15–500 Hz. Before electrode placement, hair was removed from the measurement site, and the skin was cleaned using alcohol pads to reduce skin impedance. The electrodes were placed over the peroneus longus muscle belly on the lateral aspect of the affected lower leg, approximately one-third of the distance distal to the fibular head along the line toward the lateral malleolus. Surface electromyographic signals were processed using MyoResearch XP Master Edition software (version 3.16; Noraxon USA Inc., Scottsdale, AZ, USA), and the signals were full-wave rectified. Because changes in the mechanical demands of a single-leg landing task can alter lower-extremity muscle activation and neuromechanical control, a single-leg drop-landing task was used to assess the neuromuscular response of the peroneus longus during dynamic landing [42].

Participants performed a single-leg drop landing from a 30 cm high box onto the affected limb. Three successful trials were collected at each assessment. Muscle activation was recorded throughout the single-leg drop-landing task. Electromyographic activity was analyzed over a 200 ms interval extending from 100 ms before to 100 ms after initial ground contact [43,44]. The mean RMS amplitude within this interval was calculated and normalized to the maximal voluntary isometric contraction, and the results were expressed as %MVIC. For the peroneus longus MVIC test, participants performed maximal ankle eversion while the examiner applied manual resistance in the direction of inversion. The contraction was maintained for 5 s, and the mean value of the middle 3 s was used for analysis after excluding the first and last seconds [45]. The MVIC test was repeated three times, and the mean of the three trials was used as the reference value for EMG normalization.

Perceived ankle instability was assessed using the CAIT. The CAIT is a 9-item patient-reported questionnaire with a total score ranging from 0 to 30, with lower scores indicating greater ankle instability. Participants completed the CAIT before and after the 6-week intervention, and the total score was used for statistical analysis [13].

2.4. Data Analysis

All statistical analyses were performed using IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA). The normality of the data was assessed using the Shapiro–Wilk test. Baseline categorical variables were compared between groups using the chi-square test, whereas continuous variables were compared using independent-samples t-tests. Changes in Star Excursion Balance Test (SEBT) scores, peroneus longus muscle activation, and Cumberland Ankle Instability Tool (CAIT) scores were analyzed using a 2×2 mixed-design analysis of variance (ANOVA), with group (SET and SE) as the between-subject factor and time (pre- and post-intervention) as the within-subject factor. The intervention effect for each outcome was evaluated based on the group $\times$ time interaction, and partial eta squared (η^2) was calculated as the effect size for the interaction. Between-group differences in mean changes and their corresponding 95% confidence intervals (CIs) were also calculated to estimate the magnitude and precision of the intervention effects. All statistical tests were two-tailed, and the level of statistical significance was set at $p < 0.05$. All 40 randomized participants had complete pre- and post-intervention outcome data and were analyzed according to their originally assigned groups. Therefore, no missing-data imputation was required.

3. Results

3.1. General Characteristics of Participants

Fifty-six individuals were assessed for eligibility, of whom 16 were excluded before randomization: 11 did not meet the eligibility criteria (ankle swelling, $n = 2$; CAIT scores not meeting the eligibility cutoff, $n = 9$), three declined to participate, and two reported an allergy to kinesiology tape. The remaining 40 participants were randomized to the SET ($n = 20$) or SE ($n = 20$) group. All 40 participants completed the 6-week intervention and postintervention assessments, completed all 30 scheduled intervention sessions (100% attendance), and had complete outcome data. Two participants in the SET group experienced transient erythema at the taping site. The erythema resolved promptly after tape removal, and both participants subsequently continued the intervention without discontinuation. No adverse events were reported in the SE group, and no WBV-related dizziness, acute pain, or intervention-related discontinuations occurred in either group. Table 1 presents the baseline characteristics of the participants. Badminton experience was 6.00 ± 3.22 years in the SET group and 6.30 ± 3.31 years in the SE group ($p = 0.773$), while the number of previous ankle injuries was 3.20 ± 1.61 and 2.80 ± 1.58 , respectively ($p = 0.432$). No significant between-group differences were observed in any baseline characteristic.

3.2. Changes in Dynamic Balance

The SEBT score increased from $70.4 \pm 9.5\%$ at baseline to $82.1 \pm 13.0\%$ after the intervention in the SET group and from $72.0 \pm 8.9\%$ to $76.0 \pm 14.9\%$ in the SE group. The mixed-design ANOVA revealed a significant main effect of time [$F(1, 38) = 25.37, p < 0.001$], whereas the main effect of group was not significant [$F(1, 38) = 0.44, p = 0.513$]. A significant group $\times$ time interaction was observed [$F(1, 38) = 6.11, p = 0.018, \eta^2 = 0.139$], indicating a significantly greater change over time in the SET group than in the SE group. The between-group difference in mean change was 7.7 percentage points (95% CI, 1.39–14.01) (Table 2).

Table 1. Demographic and clinical characteristics of the participants ($N = 40$).

Variables	SET Group ($n = 20$)	SE Group ($n = 20$)	p
Sex (Male/Female), n (%)	11 (55.0)/9 (45.0)	10 (50.0)/10 (50.0)	0.752
Age (years)	24.40 ± 2.85	23.53 ± 2.47	0.312
Height (cm)	171.87 ± 5.96	168.53 ± 8.94	0.177
Weight (kg)	68.87 ± 10.58	66.20 ± 13.02	0.482
Badminton experience (years)	6.00 ± 3.22	6.30 ± 3.31	0.773
Number of previous ankle injuries	3.20 ± 1.61	2.80 ± 1.58	0.432

Values are presented as n (%) for categorical variables and mean $\pm$ SD for continuous variables. p -values were calculated using the chi-square test for sex and independent-samples t -tests for continuous variables. SET, stabilization exercise with taping; SE, stabilization exercise.

Table 2. Changes in Dynamic Balance in the Study Participants ($N = 40$).

Variables	Time $F(p)$	Group $F(p)$	Group $\times$ Time $F(p)$	ηp^2
SEBT (%)	25.37 (<0.001)	0.44 (0.513)	6.11 (0.018)	0.139

Values are presented as F statistics with p -values in parentheses. ηp^2 represents partial eta squared for the group $\times$ time interaction. SEBT, Star Excursion Balance Test.

3.3. Changes in Peroneus Longus Muscle Activation

Peroneus longus muscle activation increased from $20.5 \pm 10.4\%$ MVIC at baseline to $40.4 \pm 24.7\%$ MVIC after the intervention in the SET group and from $24.2 \pm 14.4\%$ MVIC to $32.1 \pm 27.6\%$ MVIC in the SE group. The mixed-design ANOVA showed a significant main effect of time [$F(1, 38) = 30.53$, $p < 0.001$], whereas the main effect of group was not significant [$F(1, 38) = 0.15$, $p = 0.703$]. A significant group $\times$ time interaction was observed [$F(1, 38) = 5.70$, $p = 0.022$, $\eta p^2 = 0.131$], indicating that the change over time differed significantly between the groups. The between-group difference in mean change was 12.0% MVIC (95% CI, 1.81–22.19) (Table 3).

Table 3. Changes in Peroneus Longus Muscle Activation in the Study Participants ($N = 40$).

Variables	Time $F(p)$	Group $F(p)$	Group $\times$ Time $F(p)$	ηp^2
Muscle activation (%MVIC)	30.53 (<0.001)	0.15 (0.703)	5.70 (0.022)	0.131

Values are presented as F statistics with p -values in parentheses. ηp^2 represents partial eta squared for the group $\times$ time interaction. MVIC, maximal voluntary isometric contraction.

3.4. Changes in Perceived Ankle Instability

The CAIT score increased from 18.9 ± 4.5 at baseline to 23.5 ± 3.9 after the intervention in the SET group and from 19.9 ± 3.8 to 21.8 ± 5.2 in the SE group. The mixed-design ANOVA showed a significant main effect of time [$F(1, 38) = 37.58$, $p < 0.001$], whereas the main effect of group was not significant [$F(1, 38) = 0.07$, $p = 0.787$]. A significant group $\times$ time interaction was observed [$F(1, 38) = 6.96$, $p = 0.012$, $\eta p^2 = 0.155$], indicating that the change over time differed significantly between the groups. The between-group difference in mean change was 2.8 points (95% CI, 0.69–4.91) (Table 4).

Table 4. Changes in Perceived Ankle Instability in the Study Participants ($N=40$).

Variables	Time $F(p)$	Group $F(p)$	Group $\times$ Time $F(p)$	ηp^2
CAIT (score)	37.58 (<0.001)	0.07 (0.787)	6.96 (0.012)	0.155

Values are presented as F statistics with p -values in parentheses. ηp^2 represents partial eta squared for the group $\times$ time interaction. CAIT, Cumberland Ankle Instability Tool.

4. Discussion

The present study examined the effects of whole-body vibration (WBV)-based stabilization training combined with kinesiology taping on dynamic balance, peroneus longus muscle activation, and perceived ankle instability in recreational badminton players with chronic ankle instability (CAI). The SET group received WBV-based stabilization training combined with kinesiology taping, whereas the SE group received the same training without taping. After the 6-week intervention, the SET group demonstrated significantly greater improvements than the SE group in dynamic balance, peroneus longus muscle activation, and perceived ankle instability. The between-group differences in mean change were 7.7 percentage points (95% CI, 1.39–14.01) for SEBT performance, 12.0% MVIC (95% CI, 1.81–22.19) for peroneus longus muscle activation, and 2.8 points (95% CI, 0.69–4.91) for CAIT scores. Because both groups received the same WBV-based stabilization training, the observed between-group differences indicate an additional effect of the combined taping condition relative to WBV-based training alone. However, because no taping-only or sham-taping group was included, these findings do not establish the independent efficacy of kinesiology taping, and the observed additional effect may also include nonspecific expectation, attention, or contextual effects.

Peroneus longus muscle activation improved to a significantly greater extent in the SET group than in the SE group. Individuals with functional ankle instability have demonstrated reduced peroneus longus activation before initial contact during single-leg drop landing [46] and reduced peroneal electromyographic activity following a sudden inversion perturbation during walking [47]. The reduced peroneal activation observed in these studies may reflect impaired sensorimotor control associated with CAI [48]. WBV produces repeated changes in muscle length, thereby stimulating muscle spindles and facilitating reflexive neuromuscular activation during exercise [17]. Therefore, the increases in peroneus longus muscle activation observed in both groups may be partly attributable to the repeated neuromuscular demands required to maintain postural stability during WBV-based stabilization exercises. A recent systematic review reported that moderate-to-high WBV frequencies may increase lower-extremity muscle activation; however, neuromuscular responses varied according to vibration frequency, amplitude, and body position, and the overall certainty of the evidence was very low [49]. Accordingly, the increase in peroneus longus activation observed in the present study may reflect the combined effects of vibration exposure and progressively challenging stabilization tasks rather than vibration alone. The greater improvement in the SET group may also be related to additional cutaneous afferent input provided by kinesiology taping. Applying controlled tension to the skin may stimulate cutaneous mechanoreceptors, enhance afferent sensory feedback to the central nervous system, and support more precise motor control around the ankle. Chang et al. reported that kinesiology taping applied at 35% tension improved proprioceptive sensitivity, cortical responsiveness, and selected measures of functional stability compared with zero-tension taping in collegiate athletes with CAI [30]. Because approximately 30% tension was applied in the present study, enhanced cutaneous sensory input represents one possible explanation for the greater improvement observed in the SET group; however, this mechanism was not directly assessed. Nevertheless, Chang et al. evaluated immediate responses, whereas the present study did not directly measure proprioception or cortical activity. Therefore, this mechanism was not directly confirmed in the present study.

The SET group demonstrated a significantly greater improvement in dynamic balance than the SE group, as indicated by SEBT performance. WBV-based stabilization training continuously challenges postural control by producing external perturbations that require coordinated activation of the ankle musculature and repeated sensorimotor adjustments. A recent systematic review reported that WBV training may improve dynamic balance in

individuals with CAI, although significant effects were not consistently observed across all SEBT directions or intervention protocols [25]. The present study used the mean normalized reach distance across all eight SEBT directions as an overall measure of multidirectional dynamic balance. Therefore, the extent to which changes in individual reach directions contributed to the overall improvement could not be determined. The greater improvement in the SET group may be related to the additional sensory feedback provided by kinesiology taping during stabilization training. Khalili et al. reported greater improvements in balance and postural stability when kinesiology taping was added to balance exercises in female athletes with functional ankle instability [31]. More recent studies further indicate that the effects of kinesiology taping may depend on the application method. Yu et al. found that dynamic-balance responses in individuals with CAI differed according to tape length [29], whereas Chang et al. showed that functional-stability responses differed between 35% tension and zero-tension taping [30]. These findings suggest that the coverage and tension of the tape may influence the sensory input provided during functional tasks. However, both studies assessed immediate responses, whereas the present study evaluated 6-week changes using the eight-direction SEBT. An additional contributing factor may be the greater increase in peroneus longus activation observed in the SET group. Chia et al. reported that ankle-evertor strength was positively associated with Y-Balance Test composite scores in both individuals with CAI and healthy controls. In individuals with CAI, lower eversion strength and greater passive peroneal muscle stiffness were also associated with increased postural sway [50]. These findings suggest that better peroneal muscle function may support dynamic postural control. However, the present study did not analyze the association between changes in peroneus longus activation and changes in SEBT performance. Consequently, the greater increase in peroneus longus activation cannot be considered a direct cause of the improvement in dynamic balance. The mean improvement in SEBT performance was 11.7 percentage points in the SET group, and the between-group treatment-effect estimate was 7.7 percentage points (95% CI, 1.39–14.01). For clinical context, a systematic review reported an average MDC of approximately 6.4% for the complete eight-direction SEBT [33]. However, this MDC was established for interpreting individual-level change and should therefore be considered a reference for measurement variability rather than a direct threshold for judging the clinical importance of the group-level or between-group effect.

The SET group also demonstrated a significantly greater improvement in CAIT scores than the SE group, indicating a greater reduction in perceived ankle instability. The mean improvement was 4.6 points in the SET group and 1.8 points in the SE group, with a between-group treatment-effect estimate of 2.8 points (95% CI, 0.69–4.91). This finding indicates that objectively measured dynamic balance and self-perceived ankle instability may represent related, although not identical, dimensions of ankle function. The concurrent improvements in SEBT and CAIT scores in the SET group may therefore reflect improvements in both functional postural control and perceived ankle stability. However, because associations among the changes in peroneus longus activation, SEBT performance, and CAIT scores were not examined, it cannot be concluded that improvements in the objective outcomes directly caused the reduction in perceived instability.

From a practical perspective, the present findings suggest that the standardized kinesiology taping procedure used in this study may be considered as an adjunct to a WBV-based stabilization program performed five times per week for 6 weeks in recreational badminton players with CAI. Kinesiology taping is noninvasive, permits relatively unrestricted ankle movement, and can be applied during single-leg stance, balance, jumping, and direction-changing exercises. Nevertheless, the present study evaluated the additional effect of

taping during WBV-based stabilization training rather than the effectiveness of taping as a standalone intervention.

This study has several limitations. First, the relatively small sample consisted only of recreational badminton players, which limits the generalizability of the findings. In addition, sample-size planning was based on a relatively large effect estimate derived from a related but nonidentical SEBT outcome and intervention comparison. A more conservative moderate effect size ($d = 0.50$ – 0.60), which may be more typical for adjunct taping interventions in sports rehabilitation, would have required a substantially larger sample. For example, under a commonly used power of 0.80, approximately 90–128 participants (45–64 per group) would have been required; under the statistical power actually used in this study (0.90), approximately 120–172 participants (60–86 per group) would have been required. Second, the absence of taping-only, sham-taping, and non-WBV control groups prevented the independent and combined effects of taping and WBV from being distinguished. In addition, participants and treating therapists could not be blinded because of the visible taping intervention. This may have introduced performance or expectation bias, particularly for the self-reported CAIT outcome. Third, proprioception, peroneal reaction time, lower-extremity kinematics, and relationships among changes in the outcome measures were not assessed, limiting mechanistic interpretation. Fourth, only the overall SEBT score was analyzed; therefore, direction-specific effects could not be determined. Finally, no follow-up assessment was conducted to evaluate the persistence of the intervention effects. Future studies should incorporate sham-taping or taping-only control conditions, objective measures of proprioception and neuromuscular or biomechanical function, direction-specific balance outcomes, analyses of relationships among changes in the outcome measures, and longer-term follow-up, as well as studies involving participants from other sports and different levels of participation.

5. Conclusions

The present study demonstrated that WBV-based stabilization training combined with kinesiology taping resulted in significantly greater improvements in dynamic balance, peroneus longus muscle activation, and perceived ankle instability than the same training performed without taping in recreational badminton players with CAI. These findings support an additional short-term benefit of the combined intervention under the conditions examined in this study, but they do not establish the independent efficacy of kinesiology taping.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/app16189025/s1>, Table S1: CONSORT 2025 Checklist.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

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