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Cross-Education Balance Effects After Unilateral Rehabilitation in Individuals With Chronic Ankle Instability: A Systematic Review

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Objective: To conduct a systematic review of existing literature on cross-education balance effects after unilateral training in the population with chronic ankle instability (CAI).

Data Sources: PubMed, SPORTDiscus, CINAHL Plus.

Study Selection: To be included in the systematic review, studies were required to have been published in English, included participants with CAI, had participants undergo a unilateral therapeutic exercise for the lower extremity, and measured balance performance of the untrained lower extremity before and after the intervention.

Data Extraction: The certainty of evidence in each included study was assessed via the Downs and Black checklist. A score of 24 to 28 indicated *excellent* or *very low risk of bias;* 19 to 23, *good or low risk of bias;* 14 to 18, *fair* or *moderate risk of bias;* and <14, *poor* or *high risk of bias*. We extracted information from each study regarding design, participant characteristics, inclusion criteria, independent and dependent variables, intervention, and results. Baseline and postintervention balance performance data for participants' untrained limbs were used to calculate the Hedges *g* effect sizes and 95% CIs.

Data Synthesis: Our search returned 6 studies that met the inclusion criteria. The articles' risk of bias ranged from high to low (11–19). In 4 of 5 studies that examined unilateral balance training, the authors reported a cross-education effect. In the lone study that examined resistance training at the ankle joint, a cross-education effect was also present. Several cross-education effects were associated with large effect sizes. This systematic review was limited by a small number of studies that varied in methods and quality.

Conclusions: Our results suggest that unilateral therapeutic exercise can improve balance performance of the untrained limb of individuals with CAI. More work is needed to determine which training protocols are most effective for generating a cross-education effect.

Key Words: balance training, resistance training, postural control

Key Points

- Providing unilateral therapeutic exercise to patients with chronic ankle instability appears to result in improved balance performance of the untrained limb.
- Because various training methods have been used across studies, the protocols that are most effective for cross-education remain unknown.

Acute lateral ankle sprains are one of the most common ailments in the physically active population.[1] An estimated 40% of lateral ankle sprains lead to chronic ankle instability (CAI) at least 1 year after the initial injury.[2] Chronic ankle instability is primarily characterized by episodes of giving way, recurrent sprains, and feelings of instability.[3] Another frequent characteristic of CAI is impaired sensorimotor control.[4] Pain, perceived instability, kinesiophobia, and reduced somatosensation, self-reported function, and health-related quality of life are evidence of sensory-perceptual impairments in individuals with CAI.[4] These changes contribute to and can be exacerbated by motor-behavioral impairments, such as altered reflexes, neural inhibition, muscle weakness, altered movement patterns, and decreased physical activity.[4] Reduced balance performance is among the most commonly identified sensorimotor impairments in the population with CAI.[4] This was further supported by previous authors[5–10] who reported balance training was effective in improving both patient-reported and clinician-oriented outcome measures in those with CAI. Other modes of exercise, such as strength training, have also exhibited positive effects on balance performance.[11]

Most often, rehabilitation protocols aimed at improving balance focus on the involved extremity with the goal of restoring normal function to that leg.[5–10] However, recent findings[12] indicate that among individuals with CAI, balance training of the uninvolved limb is an effective means of improving balance performance of the involved limb; this phenomenon is known as cross-education. More broadly, *cross-education* is defined as adaptation of an untrained limb after unilateral training of the contralateral limb. Cross-education is possible because of the interhemispheric communication in the brain, primarily through the corpus callosum.[13] This interhemispheric communication causes unilaterally performed activities to stimulate the ipsilateral motor cortex, which corresponds to the untrained limb.[14] Cross-education effects have been widely observed in strength and conditioning research.[15,16] Patients with neurologic disorders that result in unilateral neuromuscular deficits (eg, stroke) have also shown benefits from cross-education training, particularly when paired with mirror therapy.[17] Despite the benefits to healthy and injured populations, the applicability of cross-education to CAI rehabilitation is less established.

Balance cross-education could potentially aid individuals with CAI in multiple ways. Providing therapeutic exercises for the uninvolved limb could offer a method for improving sensorimotor control in an involved limb that may be unable to engage in such activity because of swelling, range-of-motion deficits, or pain with weight-bearing. Furthermore, training the involved limb could improve balance deficits in the uninvolved limb.[18] Although numerous authors have studied the effects of therapeutic exercise on balance performance in individuals with CAI,[19] none have thoroughly reviewed the literature to determine how cross-education affects balance performance in the population with CAI. Therefore, the purpose of our study was to conduct a systematic review of the literature that has examined the cross-education effects of unilateral exercise on balance performance in those with CAI.

METHODS

We conducted a systematic review in accordance with guidelines established by the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; https://www.prisma-statement.org/) statement to examine the effect of unilateral exercise on balance performance in individuals with CAI. On October 27, 2020, we searched the PubMed, SPORTDiscus, and CINAHL online databases for relevant studies using the following terms: *ankle instability* AND *rehabilitation* OR *therapy* OR *exercise* OR *intervention* OR *training*.

After the duplicates were removed, 2 authors (B.L.-P. and S.C.) eliminated additional studies based on the titles and abstracts. The same authors reviewed the full texts of the remaining studies to ensure they met the inclusionary criteria. Any disagreements were settled by a third author (R.S.M.). To be included, each study must have met the following criteria:

1. Study was published in English.
2. Study participants had either CAI or a similar condition, such as functional ankle instability or mechanical ankle instability.
3. Study participants must have undergone a unilateral lower extremity exercise program.
4. Study participants must have undergone testing of balance performance of their untrained limbs before and after the intervention.

Because a preliminary search resulted in few studies that met our criteria, we opted to include randomized controlled trials and nonrandomized intervention studies.

Certainty of Evidence and Risk-of-Bias Assessment

Each study's certainty of evidence was assessed via the Downs and Black checklist[20] by 2 authors (B.L.-P. and S.C.), with a third author (R.S.M.) acting as a tiebreaker. The checklist has 27 items that evaluate the reporting, external validity, bias, confounding, and power. A score of 24 to 28 indicates *excellent* or *a very low risk of bias*; 19 to 23, *good* or *a low risk of bias*; 14 to 18, *fair* or *a moderate risk of bias*; and <14 *poor* or *a high risk of bias*.[21]

Data Extraction and Statistical Analysis

Together, the 2 authors extracted information directly from each article regarding design, participant characteristics, inclusion criteria, independent and dependent variables, intervention, and results. Extracted participant characteristics were sample size, age, height, and mass. Extracted intervention characteristics were exercise mode, frequency, duration, and training limb. Only dependent variables and results that pertained to balance performance were extracted. When available, we obtained baseline and postintervention balance performance data for participants' untrained limbs to calculate Hedges g effect sizes and 95% CIs (*negligible*, <0.2; *small*, 0.2–0.49; *moderate*, 0.5–0.79; *large*, >0.8).[22] Effect sizes were compiled in a forest plot.

Heterogeneity

We compiled the data to examine heterogeneity and gauge the appropriateness of meta-analysis. We calculated the I^2 statistic and classified *high heterogeneity* as a value >75%.[23] A value above this threshold indicated the data would not be compiled for meta-analysis.[24]

RESULTS

Search Results

Full results of the literature search are outlined in Figure 1. The database searches yielded 3 texts that fit the inclusion criteria, and we added 3 articles from a hand search to bring the total to 6. The hand search consisted of reviewing the reference lists of related articles to find articles that were not identified by the database search. Our database search returned 86 additional studies that explored the effects of therapeutic exercise in populations with ankle injuries. Most failed to meet multiple inclusionary criteria; 2 studies initially appeared to be eligible but were ultimately excluded. One investigation[25] examined the balance performance of the involved and uninvolved limbs after rehabilitation, but the intervention was applied bilaterally. Other researchers[26] evaluated the balance performance of the involved and uninvolved limbs after unilateral rehabilitation among participants described as having a history of acute ankle sprain, not CAI. Two studies were funded by external sources,[27,28] 1 received no external funding,[12] and 3 groups did not report whether funding was received.[29–31]

Certainty of Evidence and Risk of Bias

Each article's score on the Downs and Black checklist is presented in Table 1. The articles' risk of bias ranged from high to low. One article[29] exhibited a low risk of bias with a score of 19, 1 article[12] exhibited a moderate risk of bias with a score of 17, and the remaining 4 articles[27,28,30,31] exhibited a high risk of bias with scores <14.

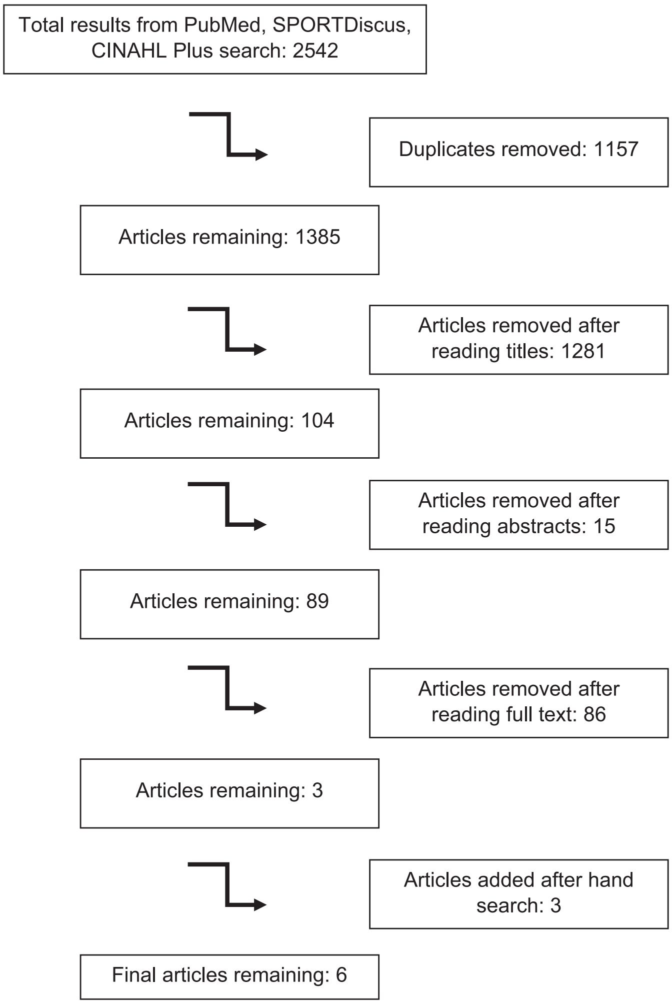

Figure 1. Literature search strategy.

Study Findings

Information extracted from each study is reported in Table 2. Hedges *g* effect sizes for the untrained limb ranged from small to large, and 9 of 14 comparisons had CIs that crossed 0 (Figure 2). Three studies[12,27,29] demonstrated large effect sizes and CIs that did not cross 0. Each of those comparisons indicated a positive effect on balance in the untrained limb.

Training Limb

The 6 studies varied by how the participants were trained. In 4 studies,[27,28,30,31] only the involved limb was trained; in 1 study,[29] only the uninvolved limb was trained, and 1 study[12] had 3 groups in which the uninvolved limb, the involved limb, or neither limb was trained. In 3 studies,[27,28,31] limb-to-limb comparisons were conducted; in 2 studies,[29,30] a trained group was compared with a control group; and in 1 study,[12] cross-education (training-uninvolved side), traditional training (training-involved side), and control groups were compared. Of the 4 studies in which only the involved limb was trained, a positive cross-education effect for balance was reported in 3.[27,30,31] In the 2 studies[12,29] in which the uninvolved limb was trained, cross-education effects were also observed.

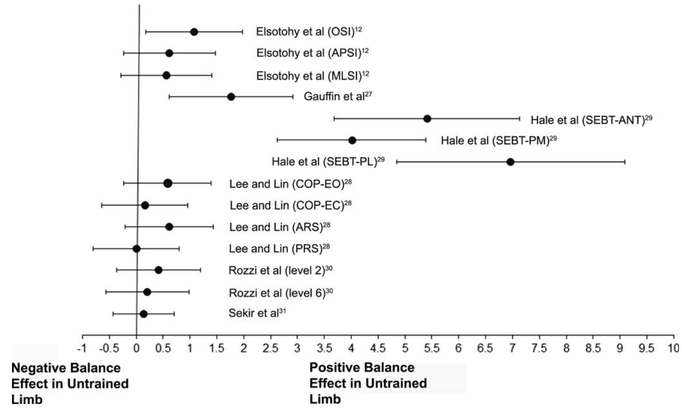

Figure 2. Effect sizes of balance changes in the untrained limb. Abbreviations: ANT, anterior; APSI, anterior-posterior stability index; ARS, active reposition sense; COP, center of pressure; EO, eyes open; EC, eyes closed; MLSI, medial-lateral stability index; OSI, overall stability index; PL, posterolateral; PM, posteromedial; PRS, passive reposition sense; SEBT, Star Excursion Balance Test.

Interventions

A variation of single-limb balance training was an intervention in 5 studies.[12,27–30] Of these, cross-education effects were seen in 4 studies.[12,27,29,30] In another study,[31] participants completed isokinetic strength training for the ankle-invertor and -evertor muscles, and cross-education effects for balance occurred. The different interventions targeting balance performance all resulted in improvements in the untrained limbs, but the groups that used single-limb balance training[12,27,29] displayed the strongest effect sizes for cross-education of balance outcomes. In the only investigation[28] in which no cross-education effect was demonstrated in the untrained limb, a Biomechanical Ankle Platform System (BAPS) board training protocol was used.

Outcomes

A variety of balance outcome measures were used for pretest and posttest comparisons. In 2 studies,[12,30] balance was assessed with stability indices via a Biodex Balance

Table 1. Certainty of Evidence Assessment

	Downs and Black Checklist Item[20]																											
Authors, Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	Total
Elsotohy et al,[12] 2021	X	X	X	X	X	X	X			X				X	X		X	X	X	X			X	X			X	17
Gauffin et al,[27] 1988	X	X	X	X	X	X	X											X	X	X							X	11
Hale et al,[29] 2014	X	X	X	X	X	X	X	X	X	X							X	X	X	X	X	X	X			X	X	19
Lee et al,[28] 2008	X	X	X	X	X	X	X											X	X	X							X	11
Rozzi et al,[30] 1999	X	X	X	X	X	X	X											X	X	X					X		X	12
Sekir et al,[31] 2007	X	X	X	X	X	X	X			X								X	X	X							X	12

Table 2. Study Characteristics

Authors, Year	Study Design and Setting	Participants	Inclusion Criteria	Independent Variables	Dependent Variables	Intervention	Results
Elsotohy et al,[12] 2021	RCT, research laboratory	32 F with CAI (age = 20.96 ± 1.69 y, height = 162.03 ± 5.45 cm, mass = 69.37 ± 12.73 kg)	≥1 previous ankle sprain that occurred ≥1 y prior, feelings of giving way, and ≥2 *yes* answers on questions 4–8 on the Modified Ankle Instability Instrument	Time: pretraining and posttraining Group: A, trained uninvolved limb; B, trained involved limb; C, did no training	Biodex Balance System OSI, APSI, MLSI of involved limb	Exercises included various activities during single-limb stance. Exercises were completed 3 times/wk x 6 wk. Each week's first session was supervised; the other 2 were done at home.	Groups A and B improved OSI, APSI, and MLSI of involved limb. Group C did not improve any balance outcomes.
Gauffin et al,[27] 1988	Case series, research laboratory	10 M with FAI (24 ± 3 y)	FAI, recurrent ankle sprains, and feelings of giving way	Time: pretraining and posttraining	Area of confidence ellipse and root mean square of COP data of involved limbs	Balance-disk training of involved limb for 10 min, 5 times/wk x 8 wk.	8 participants showed improved balance performance of untrained limb via reduced area of confidence ellipse.
Hale et al,[29] 2014	Cohort study, research laboratory	34 with CAI (M = 8, F = 26, age = 24.3 ± 5.0 y, height = 167.0 ± 9.5 cm, mass = 77.5 ± 23.8 kg)	≥1 ankle sprain, no ankle sprain in 6 mo before study, age = 13–35 y, and had feelings of giving way	Time: pretraining and posttraining Group: rehabilitation and control	SEBT and BESS of both limbs	The rehabilitation group did 30 min of supervised training 2 times/wk x 4 wk. Stable ankle was trained with single-legged stance, wobble board, steamboats, single-legged hops, quadrant hops, single-legged ball catch, toe touchdowns, & hop ups and downs. Control group resumed normal activities.	Rehabilitation group improved SEBT scores when combining data of both ankles. BESS scores improved at posttraining when data were combined for both groups and both ankles.
Lee et al,[28] 2008	Case series, research laboratory	12 with FAI (F = 4, M = 8, age = 20.1 ± 1.4 y, height = 172.3 ± 4.5 cm, mass = 67.7 ± 4.9 kg)	≥1 ankle sprain, inability to bear weight after sprain, 1 repeated injury with feeling of giving way, no formal rehabilitation of injured ankle, no evidence of mechanical instability, no previous fracture of either ankle	Time: pretraining and posttraining	Mean radius of COP excursion during eyes-open and eyes-closed single-legged stance for both limbs	Participants completed a progressive balance program with a BAPS board on the involved limb. All sessions lasted 20 min and were completed 3 times/wk for 12 wk.	Trained limb experienced improved mean radius of COP, but untrained limb did not.
Rozzi et al,[30] 1999	Non-RCT, research laboratory	13 with FAI (F = 5, M = 8, age = 21.9 ± 3.1 y, height = 172.9 ± 10.4 cm, mass = 72.2 ± 18.0 kg) 13 in control group (F = 6, M = 7, age = 21.2 ± 2.5 y, height = 169.4 ± 11.3 cm, mass = 73.2 ± 19.1 kg)	FAI group: ≥2 unilateral inversion ankle sprains, unilateral ankle weakness and/or instability Control group: No ankle sprain history All groups: AROM of 15° dorsiflexion and 45° of plantar flexion and ability to complete tests	Time: pretest and posttest Group: FAI and control Limb: trained and untrained	Stability indices of Biodex Stability System for both limbs	Both groups did single-legged balance training with static and dynamic conditions 3 times/wk x 4 wk on Biodex Stability System. Experimental group trained involved limb, and control group trained randomly chosen limb.	The FAI and control groups' untrained limbs exhibited improved stability index during stable and moderately unstable conditions, respectively.
Sekir et al,[31] 2007	RCT, research laboratory	24 M with unilateral FAI (age = 21 ± 2 y)	≥1 ankle sprain to same ankle and feelings of giving way before study	Time: pretraining and posttraining Side: injured and uninjured ankles	Number of errors on the 1-legged standing test for both limbs	Participants completed concentric isokinetic ankle-inversion and -eversion strength training on involved side. They did 3 sets of 15 repetitions at 120°/s 3 times/wk x 6 wk.	Errors on the 1-legged standing test were reduced for trained and untrained limbs.

Abbreviations: APSI, anterior-posterior stability index; AROM, active range of motion; BAPS, Biomechanical Ankle Platform System; BESS, Balance Error Scoring System; CAI, chronic ankle instability; COP, center of pressure; F, females; FAI, functional ankle instability; M, males; MLSI, medial-lateral stability index; OSI, overall stability index; RCT, randomized controlled trial; SEBT, Star Excursion Balance Test.

System, which requires participants to keep a mobile standing platform level while maintaining a single-legged stance. In 2 studies,[27,28]center-of-pressure metrics were examined while participants maintained a single-limb stance on a force plate, but a cross-education effect in the untrained limb of a subset of participants was reported in only 1. In a study[31] in which a 1-legged standing test was used, errors in the trained and untrained limbs after intervention were reduced. In a study[29] using a similar test, the Balance Error Scoring System (BESS), scores improved when data were combined for the training and control groups as well as both ankles. Similarly, these authors[29] also identified improved scores on the Star Excursion Balance Test (SEBT) when the data for both ankles were combined.

Heterogeneity

Analysis of the studies' heterogeneity revealed an I^2 value of 86%. Because of the high level of heterogeneity, we did not conduct a meta-analysis.[24]

DISCUSSION

We aimed to conduct a systematic review of the existing literature to examine the effects of unilateral lower extremity rehabilitation on balance performance of the untrained limb in the population with CAI. Our main finding was that in 5 of the 6 studies, unilateral lower extremity rehabilitation resulted in improved balance performance of the untrained limb from baseline to postintervention testing. Furthermore, researchers[12,27,29] in 3 studies observed that cross-education effects were associated with large, statistically significant effect sizes, indicating that a clinically meaningful change likely occurred. Although comparisons of these results with those of an untrained control group would strengthen the evidence of a cross-education effect, 4 of 6 studies[27,28,30,31] did not include an untrained control group. In 1 investigation[12] that included an untrained control group, balance performance did not improve from baseline to postintervention testing. Similarly, the control group in another study[29] failed to exhibit the improved balance performance demonstrated by the experimental group. We are unaware of any other systematic review that has examined cross-education effects on balance performance in participants with a lower extremity musculoskeletal injury. However, our findings support those of other researchers[32,33] who found that unilateral balance training in healthy individuals resulted in improved balance performance of the untrained limb. Our results also agree with those of a systematic review[34] whose authors concluded that cross-education effects can occur in healthy adults after unilateral resistance training, but the results might ultimately depend on the training protocol.

The studies in the current systematic review varied in terms of which limb was chosen for training. Generally, the authors found cross-education effects whether the involved limb or the uninvolved limb was trained. Clinically, patients with CAI could benefit from cross-education balance effects in the involved or uninvolved limb. In patients with CAI who have experienced a recurrent ankle sprain, balance training of the uninvolved limb could be an effective means of enhancing postural control before resuming weight-bearing activity on the involved side. Conversely, balance training of the involved side might be beneficial to a patient with CAI who presents with bilateral balance deficits. Although the authors[35] of a previous systematic review and meta-analysis determined that individuals with CAI did not experience bilaterally impaired balance, subsequent work[18] suggested that some might experience central nervous system alterations that reduce postural stability of the uninvolved limb.

Most of the cross-education effects on balance performance were generated by a form of balance training. Because we only evaluated investigations that analyzed cross-education effects, naturally each balance-training study was focused on single-legged stance exercises. Another important similarity was that all balance-training protocols were long term, lasting 4 to 12 weeks with 2 to 5 sessions per week. Aside from these similarities, the protocols varied in their use of dynamic movements, unstable surfaces, and visual feedback. Balance training in various modes, frequencies, and durations has consistently demonstrated benefits to the balance performance of individuals with CAI.[19] However, variations in exercise intensity, fatigue, and movement pacing might affect the cross-education of the untrained limb after unilateral training.[34] The reasons why the authors[28] of 1 study did not find a cross-education effect remain unclear, especially because it included a 12-week progressive balance-training protocol. A possible explanation is that the participants did not appear to have bilateral balance deficits at baseline, and thus, had little room for improvement of the untrained limb. Isokinetic strength training of the ankle joint was explored in only 1 study[31] and improved the balance performance of the untrained healthy limb. Others[36] found that strength training resulted in improved balance performance of the trained limb in people with CAI. Therefore, enhanced motor control might be experienced bilaterally in this population. This assertion is further supported by a study[37] of healthy participants in which unilateral isokinetic hip strengthening improved static balance performance of the contralateral limb.

Multiple balance outcomes, including stability indices, postural sway, 1-legged standing test, BESS, and SEBT, were effective in detecting cross-education effects for balance performance among individuals with CAI. However, the effectiveness of some outcomes for identifying cross-education effects remains uncertain. Although investigators[27,28] in 2 studies examined postural sway using center-of-pressure data, only 1 noted a cross-education effect. Additionally, the authors[29] of the study that included the BESS and SEBT combined the data for limbs, groups, and times, which might have obscured the true strength of the cross-education effects. Postural sway and the BESS and SEBT have all demonstrated the ability to detect balance performance improvements after rehabilitation,[19] but their value in assessing cross-education needs to be explored further.

Clinical Application

Our findings are directly applicable to clinicians caring for patients with CAI. The results suggest that cross-education effects on balance performance can be achieved in this population in numerous ways. Clinicians can use a variety of therapeutic exercise protocols to achieve improvements in the untrained limb. Additionally, cross-education benefits are possible from training the involved or uninvolved limb. When a patient with CAI sustains a recurrent ankle sprain, use of the involved limb is often limited. Still, the patient can begin improving balance by exercising the uninvolved limb. The clinical application also extends to further stages of rehabilitation, when exercise difficulty can increase. Once exercise for the involved limb can begin, rest intervals can be an opportune time to train the uninvolved limb and continue improvement. Clinicians must also consider the possible presence of bilateral balance deficits in patients with unilateral CAI; training the involved limb might correct these deficits, but thorough evaluation is needed to be sure.

Limitations

This study had several limitations that must be acknowledged. First, our systematic review included a small number of studies that varied widely in design, participant characteristics, and procedures. Because of the small volume of literature on our specific subject, we opted to include studies of lower quality. These lower-quality studies often did not involve an untrained control group for comparison, which diminished our ability to determine if cross-education was truly beneficial to individuals with CAI. Future authors should build on our current knowledge of cross-education and CAI with randomized controlled trials. Four of the 6 studies we included were published before the International Ankle Consortium's recommended guidelines[3] for selecting research participants with CAI. Thus, some studies' participants might not have represented the contemporary CAI definition. Subsequent researchers should follow the International Ankle Consortium's guidelines closely to ensure that comparisons of studies can be made confidently. Lastly, the wide ranges of training modes, frequencies, and durations inhibit our ability to recommend specific training protocols that can optimize cross-education effects for individuals with CAI.

CONCLUSIONS

Our primary finding in this systematic review was that unilateral therapeutic exercise can improve the balance performance on the untrained limb of individuals with CAI. The majority of included studies indicated that balance training was an effective technique, but additional evidence suggests that unilateral ankle-joint strengthening can also improve contralateral balance performance. Because of the limited volume of research on this topic, future investigators must determine which training protocols are most effective in this population.

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