doi: 10.4085/1062-6050-0682.24

Title: Electrotherapy as a Rehabilitation Modality for Chronic Ankle Instability: A Systematic Review

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PROSPERO Registration number: CRD42022328704
crd.york.ac.uk/prospero/display_record.php?ID=CRD42022328704

Electrotherapy as a Rehabilitation Modality for Chronic Ankle Instability: A Systematic Review

Abstract

Objective

To assess whether combining electrotherapies with therapeutic exercise (TEx) for chronic ankle instability (CAI) is more effective than TEx alone.

Data Sources

PubMed, MEDLINE, SPORTDiscus, and Web of Science were searched to ascertain studies relevant to this review published from inception until September 2024.

Study Selection

Studies included were randomized control trials, including human participants with no restriction on sex, age, or setting, with an intervention of electrotherapy in combination with TEx compared with TEx alone for treating CAI.

Data Extraction

Each article was reviewed to establish if a type of electrotherapy was used with TEx for rehabilitating CAI and compared to TEx alone.

Data Synthesis

3118 articles were found for review, with 7 studies meeting the inclusion criteria. The 7 studies were then divided into 4 groups: Stochastic Resonance Stimulation (SRS), Transcutaneous Electrical Nerve Stimulation (TENS), Transcranial Direct Current

Stimulation (aTDCS), and Neuromuscular Electrical Stimulation (NMES) for comparison.

Conclusion

The findings from the studies included in this review suggested that combining electrotherapy with TEx has preferable functional outcome measures than TEx alone when rehabilitating CAI.

Keywords: stochastic resonance stimulation, transcutaneous electrical nerve stimulation, transcranial direct current stimulation, neuromuscular electrical stimulation, therapeutic exercise, ankle instability, chronic ankle instability, functional ankle instability.

Key Points

For the most part, the current body of research suggests that combining electrotherapy with TEx has preferable functional outcomes than TEx alone in those with CAI. Future research must assess the long-term outcomes of combining electrotherapy with TEx in this population.

Introduction

Rationale

Ankle sprains are one of the most common injuries in sport,[1–3] and there is strong evidence that previous ankle sprains have a significant association with the likelihood of reoccurrence.[2,4] Studies have found that reoccurrence rates of ankle sprains can be anywhere between 12%-47%,[2] with regular reoccurrence of ankle sprains often leading to athletes developing some level of ankle instability (AI).[2,5] Musculoskeletal conditions of the ankle, including chronic ankle instability (CAI), osteochondral lesions (OCL),[6–8] cartilage damage,[9] and early-onset osteoarthritis[2,10] frequently develop as sequelae of ankle sprains and have been shown to impose a substantial long-term medical burden. As a result, some of these conditions can lead to the need for ankle arthrodesis or total ankle arthroplasty.[11]

Therapeutic exercise (TEx) and other treatment modalities are regularly used to treat lateral ankle sprains.[12] TEx programs often include exercise to help restore range of motion (ROM) and proprioception at the ankle joint and strengthen the surrounding musculature in injured athletes.[13–15] TEx, if completed thoroughly and incorporates the elements above, often results in a complete unrestricted return to sport for the injured athlete and aids in reducing injury reoccurrence[16] and therefore the possibility of CAI occurring. Restoring normal ankle function and functional stability during sports is paramount in reducing the risk of future ankle injuries. However, research has documented that reoccurrence rates within athletic populations remain high.[2,4] This is often due to constraints on the implementation of rehabilitation programs, such as a lack of coach education or time.[2]

An understanding of the mechanism of injury is required to rehabilitate an ankle sprain effectively. An inversion with an internal rotation mechanism at the ankle is the most common mechanism of injury for an ankle sprain. It often results in injury to one or more of the ligaments in the lateral ankle ligament complex.[17] The roles of the peroneus longus and brevis are to evert and plantarflex the ankle.[18] If this muscle group cannot inhibit the inversion mechanism effectively due to latency in their contraction time, they may be unable to protect the joint efficiently, and most likely cause a lateral ankle sprain.

Peroneal muscle group latencies are commonplace in those who have previously experienced an ankle sprain or have developed CAI.[19–21] If there is a latency in the muscle group, this may reduce the ankle joint stability, making those with previous injury to the ligaments more susceptible to recurrent ankle sprains. It has been found that arthrogenic muscle inhibition (AMI) often occurs in the peroneal muscles in those displaying CAI.[22] This can cause muscle activation failure because of neural inhibition, possibly increasing the risk of recurrent ankle sprains, which could subsequently lead to CAI. This is more likely if this has not been addressed effectively within the rehabilitation.

Rehabilitation of CAI can use many different modalities. Some electrotherapies as modalities have been found to have a degree of effectiveness in the rehabilitation of injuries and in reducing pain.[23–25] Electrotherapies that elicit muscular contractions have been used and found to be effective in increasing muscle strength at a higher rate than TEx alone within rehabilitation.[26,27] This may aid in reducing muscular atrophy, increasing muscle hypertrophy, and reducing AMI. However, there is often conflicting or limited evidence as to their effectiveness. The combination of TEx and the concurrent application of muscle stimulation has recently become more prevalent in rehabilitating musculoskeletal injuries.[24,25,28–36] Therefore, this review aims to identify whether TEx combined with electrotherapy improves functional ankle outcomes compared with TEx alone in those with CAI.

Objectives

The present study systematically reviews studies that use electrotherapies in combination with TEx to improve functional outcome measures in those with CAI, based on the current body of literature.

Method

Study Design

The Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science (PERSiST) guidelines[37] (Figure 1) were followed when conducting this systematic review, accompanied by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[38] and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses literature search extension (PRISMA-S).[39] The protocol of this systematic review was prospectively registered on PROSPERO (CRD42022328704).

Eligibility Criteria

Eligibility criteria were formulated using the Population, Intervention, Comparison, Outcome, and Study Design (PICOS) method[40] (Table 1). These were as follows: population: human participants without restriction on sex, age, or setting. Interventions: Electrotherapy in any form as part of rehabilitation for CAI in combination with TEx. Comparison: TEx for rehabilitation only. Outcome: The effectiveness of electrotherapy combined with TEx in functional outcome measures such as, but not limited to, balance, muscle strength, patient self-reported outcomes, muscle latency, and postural stability. Study design: Randomized controlled trials. All studies included were full-text articles published in English and peer-reviewed journals. All electrotherapy types were included to rehabilitate CAI when combined with TEx. Electrotherapy applications for acute ankle sprains or treatment of CAI without the inclusion of TEx were excluded.

Search Strategy

One reviewer independently searched PubMed, MEDLINE, SPORTDiscus, and Web of Science databases from inception to 16th September 2024 without language restrictions. After searching the databases, we exported them into Mendeley, and duplicates were removed. One reviewer screened titles and abstracts; the entire paper was reviewed where the title and abstract could not determine study eligibility. All eligible full-text papers were in English. The reference lists from the eight full texts selected to be included within this study were manually searched to identify studies not found through the electronic database searches. Still, no other texts appropriate to this study were extracted from this search. A Peer Review of Electronic Search Strategies (PRESS)[41] was implemented before conducting the search strategy. The search strategy included three strings of key terms joined with 'AND', the terms within the strings were joined with 'or' (Table 2).

Quality Assessment

One reviewer reviewed all studies for risk of bias using the Physiotherapy Evidence Database (PEDro) Scale[42] (Table 3) adapted from the Delphi list.[43]

Data extraction

The inclusion criteria included an electrotherapy intervention in rehabilitating CAI in combination with TEx therapies. The full text of eligible papers was retrieved and reviewed. The following data were extracted: electrotherapy intervention used, exercise therapy used, outcome measures, and findings.

Data Analysis

Due to the heterogeneity of studies, direct comparison and meta-analysis were not possible, so a narrative review was undertaken in line with the Synthesis without Meta-analysis (SWiM) guidelines.[44]

Results

The search strategy identified 3118 publications after duplicates were removed. After exclusions based on publication title, abstract, and published language, 87 studies were reviewed in full, and a final 7 were included in this systematic review. The 7 papers were split into 4 groups depending on which electrotherapy intervention had been applied, and then split into subsections based on functional outcome measures.

Stochastic resonance stimulation (SRS)

Three studies examined TEx combined with stochastic resonance stimulation (SRS) in participants with AI.[30,33,35] Two of these studies[30,33] used the same pool of participants with functional ankle instability (FAI) and interventions; however, they looked at different outcome measures for balance.

Ross and Guskiewicz[33] and Ross *et al*.[30] combined SRS stimulation to the lateral soleus, peroneus longus, tibialis anterior, anterior talofibular ligament, and deltoid ligament, combined with 6 weeks of coordination training (CT) in individuals with FAI. Participants completed 5 x 10-minute training sessions per week. Both studies found that combining SRS with CT to assess outcomes related to balance.

Ross and Arnold[35] looked at similar outcome measures to Ross *et al*.[30] but with some changes to the therapeutic exercise program, in that it was reduced from 6 weeks as per Ross and Guskiewicz[33] and Ross *et al*.[30] to 4 weeks with balance and resistance exercises added. It should be noted that they combined participants with CAI into the same experimental groups as those who had never previously been injured.

Balance Outcome Measures. Ross and Guskiewicz[33] found improvements in both anterior-posterior (A/P) and medial-lateral (M/L) balance in participants with FAI following a six-week intervention. Participants who received SRS combined with CT demonstrated greater and earlier improvements in time-to-stabilization (TTS) during single-leg jump landings compared to those who received CT alone. Specifically, the SRS-CT group improved on both A/P and M/L TTS by week 4, whereas the CT-only group showed smaller improvements and plateaued earlier. These improvements were reported as percentage change from baseline; no means or standard deviations were provided. Table S1 (supplementary materials) provides a summary of percentage improvements and associated outcomes for both groups across test sessions. The control group made no significant improvements.

Ross *et al*.[30] found that participants who received SRS combined with CT demonstrated significant improvements in balance outcomes, compared to pooled results from the control (CG) and CT-only groups. Specifically, the SRS group showed significant reductions in anterior-posterior (A/P) and medial-lateral (M/L) center of pressure velocity (COPvel), M/L center of pressure standard deviation (COPsd), M/L maximum excursion (COPmax), and center of pressure area (COParea). The effect size for A/P COPvel was large, with moderate effects observed for M/L COPvel, COPsd, and COParea, and a small effect for COPmax. No significant pre- to post-test changes were observed in the CG or CT-only group. A summary of p-values and effect sizes comparing the SRS group to pooled CG and CT results is provided in Table S2 (supplementary materials)

Ross and Arnold[35] found improvement in all balance-related outcome measures in all the groups within their study. The magnitude of improvement ranged from small to large, with large effects seen in A/P COPvel by week 4. In comparison, the CT-only group also showed improvements in all 4 outcomes, though all effect sizes were small, except for M/L COPvel at week 2, which reached a small-to-moderate level. Notably, outcome data were drawn from a combined sample of participants with CAI and those without previous injury, which limits the generalizability of results. However, effect sizes were reported specifically for the CAI subgroup, supporting the added benefit of SRS when used alongside balance training. Table S3 (supplementary materials) provides a summary of percentage improvements and effect sizes for each group across both time points.

Transcutaneous Electrical Nerve Stimulation (TENS)

Two studies examined TEx combined with transcutaneous electrical nerve stimulation (TENS) in participants with FAI,[45] and CAI.[25] They used different methods of TEx, limiting any comparison between the findings.

Yoshida *et al.*[45] examined the acute effects of combining TEx with TENS on balance in individuals with FAI, specifically during jump landing. One group received TEx with concurrent TENS applied to the common peroneal nerve, while the comparison group completed the same TEx protocol without TENS. The exercises were outlined for this study, however, detailed methods for the exercise protocol were limited.

Gottlieb *et al.*[25] had two experimental groups within their study in which the participants had CAI. They combined balance TEx with TENS in one group and with NMES (See NMES section below) in the other group, to assess balance and self-reported outcome measures. In both groups, the assigned electrical stimulation was applied to the peroneal group to compare outcomes. Participants were required to complete 2-3 treatment sessions per week with a total of 12 treatment sessions across a 4–6-week period at home. It should be noted that the images used to report the Y-balance test

(YBT) direction described posteromedial and posterolateral the wrong way around, indicating the need for caution when comparing these results with other findings, as the application is not in line with the Picot *et al*.[46] referenced by the authors.

Balance Outcome Measures. Yoshida *et al*.[45] found that balance improved in the TENS with TEx group, as indicated by a significant reduction in center of pressure (COP) on the affected ankle following the intervention. In contrast, the exercise-only group showed no significant change in COP. These outcomes were observed after just a single therapy session, making it unclear whether the improvements have long-term rehabilitative value. However, the findings suggest potential short-term benefits of combining TENS with exercise, warranting further investigation over the length of a full rehabilitation program. Table S4 (supplementary materials) presents pre-post means and SDs for COP in both groups.

Gottlieb *et al*.[25] did not observe any significant changes in balance as indicated by the Y-balance scores and TTS during a single-legged drop jump (SLDJ) in the TEx-TENS group from baseline to post-treatment. Effect sizes are discussed in comparison to NMES in the NMES section below. Table S5 (supplementary materials) provides a list of baseline-post means, SDs, and effect sizes for each respective group for outcome measures related to balance.

Patient Self-Reported Outcome Measures. Gottlieb *et al.*[25] found significant improvements in the self-reported outcome measures at 12 months post-intervention for the TEx-TENS group, these measures being the chronic ankle instability tool (CAIT), the sports component of the foot and ankle ability measure (FAAMsport), and the identification of functional ankle instability (IdFAI). Effect sizes are discussed in comparison to NMES in the NMES section below. Table S5 (supplementary material) provides a list of baseline-post means, SDs, and effect sizes for each respective group for outcome measures related to self-reported outcomes.

Transcranial Direct Current Stimulation (aTDCS)

Only one study examined TEx combined with transcranial direct current stimulation (aTDCS) in participants with CAI.[32]

Bruce *et al*.[47] combined transcranial direct current stimulation (aTDCS) and eccentric strength training for participants with CAI. They allocated the participants to 2 groups, the first combining aTDCS and an eccentric strengthening program using an isokinetic dynamometer, and the second completing the eccentric-only program with a sham intervention. The program lasted 4 weeks, and 10 sessions were completed per participant.

Motor Control Outcome Measures. Significant improvements were found in motor control of the PL as indicated by the primary motor cortex excitability (resting motor threshold (RMT) and intensity at peak slope (I_{50})). These improvements were found in RMT from week 2 to week 6 ($p = 0.024$) in the aTDCS group and $I_{50,}$ where week 6 values were lower than baseline (p = 0.025) and week 4 (p = 0.001). No significant changes were noted in the sham group from baseline to week 6, however, it should be noted that significant improvements were found at week 2 in comparison to the baseline (p = 0.007), where an increased excitability was seen, this then decreased again at all other time points but not quite as low as baseline. No significant difference was found in RMT and I_{50} for the TA. Table S6 (supplementary materials) provides a list of baseline-post means and SDs for each respective group for outcome measures related to motor control.

Balance Outcome Measures. Improvements in balance, as indicated by the Postural Stability Indices (PSI), were observed in the aTDCS group from baseline to week 6 (p = 0.010), while no significant change was found between any other time points and in the sham group. However, individually, the anteroposterior stability index (APSI), mediolateral stability index (MLSI), vertical stability index (VSI), and composite dynamic postural stability index (DPSI) found no significant differences between any time points for both groups. Changes in muscle activation were noted in balance-based tasks; this is discussed in the muscle activation section below. Table S6 (supplementary materials) provides a list of baseline-post means and SDs for each respective group for outcome measures related to balance.

Muscle Activation Outcome Measures. Changes in muscle recruitment were also noted during a hop-to-stabilization task. Tibialis anterior (TA) activity at 250ms pre-landing decreased significantly from baseline to post-test in both the aTDCS group and the sham group. TA activity in the sham group also decreased significantly at 250ms post-landing. In contrast, peroneus longus (PL) activation increased significantly at 250ms post-landing in the aTDCS group. These findings suggest a possible shift in muscle activation strategy in balance-based tasks, with TA activation decreasing pre-landing and PL activation increasing post-landing. No significant changes were found for the soleus (SOL) in either group. Table S6 (supplementary materials) provides a list of baseline-post means and SDs for each respective group for outcome measures related to muscle activation.

Patient Self-Reported Outcome Measures. No significant difference was found in patient self-reported outcomes for either group for the foot and ankle ability measure ($FAAM_{ADL}$), FAAMsport, and Tampa scale for kinesiophobia (TSK). However, the aTDCS group score decreased, and improved significantly from week 2 to week 4 ($p = 0.046$) as indicated by the disablement in physical activity questionnaire (DPA), with an increase in score being noted in the sham group occurring from baseline to week 2 ($p = 0.047$) meaning there was a significant worsening here. No other differences were found in either group for the DPA. S6 (supplementary materials) provides a list of baseline-post means and SDs for each respective group for outcome measures related to patient self-reported outcomes.

Muscle Strength Outcome Measures. No significant differences were found for either group in concentric and eccentric strength in either inversion or eversion between any time points for this study (mean & SDs not reported).

Neuromuscular Electrical Stimulation (NMES)

Two studies examined TEx combined with neuromuscular electrical stimulation (NMES) in participants with CAI.[25,31] There are some similarities in the TEx programs used in that balance training is included in both studies; however, one also provides strength training within the program.[31]

Choi and Jun[31] incorporated NMES to Gastrocnemius (GAS) and flexor digitorum longus (FDL) with a 6-week TEx program, including balance training and strength exercises to treat those with CAI. Participants were split into four groups: CG, TEx only, NMES only, and NMES-TEx combined.

Gottlieb *et al*.[25] had two experimental groups within their study, both of which defined the participants as having CAI. They combined balance TEx with TENS (See TENS section above) in one group and NMES in the other. In both instances, the assigned electrical stimulation was applied to the peroneal group to compare their outcomes. Participants were required to complete 2-3 treatment sessions per week with a total of 12 treatment sessions across a 4–6-week period at home. It should be noted that the images used to report the Y-balance test (YBT) direction described posteromedial and posterolateral the wrong way around, indicating the need for caution when comparing these results with other findings, as the application is not in line with the Picot *et al*.[46] referenced by the authors.

Muscle Strength Outcome Measures. Choi and Jun[31] found that a significant increase in muscle strength occurred in all groups except the CG, as indicated by an increase in thickness of the FDL, GAS-M, GAS-L, and SOL, all with large effect sizes. With the cross-sectional area (CSA) of the FDL, GAS-M, GAS-L, and SOL all also significantly increasing, with large effect sizes. However, no significant differences were found for any group for flexor hallucis longus (FHL) in both muscle thickness and CSA. Table S7 (supplementary materials) provides a list of baseline-post means, SDs, and effect sizes for each respective group for outcome measures related to muscle strength.

Balance Outcome Measures. Choi and Jun[31] found dynamic balance significantly improved, as indicated by improvements for all groups except for the CG in YBT scores in all directions: ANT, PM, and PL, from pre- to post-testing, as well as composite YBT scores, all with a large effect size. Improvements in dynamic balance were observed further as indicated by the square hop test (SHT) with all groups, except for the CG, significantly improving their speed to complete the SHT from pre- to post-test, again all with large effect sizes. Table S7 (Supplementary Materials) provides a list of baseline-post means, SDs, and effect sizes for each respective group for outcome measures related to muscle strength.

Gottlieb *et al.*[25] found no significant changes were observed in balance as indicated by the YBT scores and TTS during a single-legged drop jump (SLDJ) in the NMES group from baseline to post-treatment. The magnitude of improvement ranged from small to moderate based on the respective effect sizes in favor of the TEx-NMES group compared to the TEx-TENS group. Table S5 (supplementary materials) provides a list of baseline-post means, SDs, and effect sizes for each respective group for outcome measures related to muscle balance.

Patient Self-Reported Outcome Measures. Gottlieb *et al*.[25] found significant improvements were observed in the self-reported outcome measures at 12 months post-intervention in comparison to the baseline; these measures were CAIT, FAAMsport, and IdFAI. The magnitude of improvement ranged from small to moderate based on the respective effect sizes in favor of the TEx-NMES group compared to the TEx-TENS group. Table S5 (supplementary materials) provides a list of baseline-post means, SDs, and effect sizes for each respective group for outcome measures related to muscle balance.

Discussion

The purpose of this systematic review was to determine if using electrotherapies alongside TEx in those who have CAI is more effective at improving functional outcomes in rehabilitation than TEx alone. There was enough literature to meet the objectives of the study. However, the existing studies varied significantly in their design, the type of electrotherapy used, the location where it was applied, and the design of the prescribed TEx. No systematic review, to our knowledge, has previously reported on the use of electrotherapies combined with TEx and its outcomes for effectiveness in ankle rehabilitation.

Based on the body of literature discussed in this review, evidence suggests that combining TEx with different electrotherapies may positively affect some outcome measures in those with CAI, compared to TEx alone. However, some findings suggest that no significant changes were observed within functional outcome measures.

Balance Outcome Measures. There was some variation in findings when looking at balances as an outcome measure, all studies combining SRS with TEx,[30,33,35] one[45] of the two studies using TENS with TEx, the study looking at aTDCS combined with TEx, and one[31] of the two studies combining NMES with TEx found that there were significant improvements in balance-related outcome measures, with a majority consensus suggesting electrotherapies may affect rehabilitation positively. **Muscle Strength Outcome Measures.** Two studies[31,32] specifically looked at muscle strength in their outcome measures, one[31] found significant improvements, and the other [32] did not, they implemented different electrotherapies with TEx so comparison here is challenging, but the consensus sways towards positive outcomes because of electrotherapy application, with further research needed. **Patient Self-Reported Outcome Measures.** There was some variation in findings when looking at patient self-reported outcome measures, one study[25] found positive outcomes for both TENS and NMES combined with TEx. The study that looked at aTDCS[32] found significant improvements in one of the DPA but not in the other methods that they implemented. Further research is certainly needed here to ascertain these findings. **Motor Control and Muscle Activation Outcome Measures.** Only one study[32] specifically looked at motor control and muscle activation, combining TEx with aTDCS. Positive outcomes were found in motor control for the PL but not the TA and muscle recruitment strategies were seen in both muscles pre- to post-intervention in both muscles, suggesting a positive influence of aTDCS with the need for further research certainly needed here to observe these outcome measures further with aTDCS and with other alternative applications of electrotherapy combined with TEx.

All the studies discussed in this review applied relatively low-impact TEx programs in their methods, and all the exercises presented within these studies arguably have a place in the rehabilitation of CAI. However, sport is rarely low impact, particularly when it comes to the mechanisms of injury for ankle sprain, and further consideration is needed, as recommended by Wagemans *et al*.[48] for rehabilitation programs to reflect the established mechanisms of reinjury of ankle sprain to help prevent future reoccurrences. Therefore, future research comparing higher impact and more functional rehabilitative techniques both with and without the application of electrotherapy would be beneficial to assess functional outcome measures and long-term effects on the reoccurrence of injury and therefore the incidences of CAI occurring.

Only 1[25] of the 7 studies observed any long-term outcome measures following their intervention. The outcome measures observed over a more extended period here were self-reported outcome measures by the participants, which benefit from the perceived nature of how the participant sees their function but do not allow for an understanding of any functional changes that could be observed following the post-test findings. It would be beneficial for future research to observe the long-term outcomes of the interventions used to determine if there are any long-term, lasting positive effects of the combined use of electrotherapies and TEx. None of the studies followed up to assess if their interventions impacted injury reoccurrence rates.

Limitations

Some of the search terms used in this study may have been too broad, such as 'ankle' and 'interferential', which may explain the large number of papers found in our initial search process.

The studies presented in this review were heterogeneous and thus, conclusions about the effectiveness may be limiting.

Conclusion

Due to the heterogeneity of the studies included in this review, drawing definitive conclusions about the effectiveness of the electrotherapies used within the studies is challenging. This study's findings suggest that using some electrotherapies combined with TEx may benefit rehabilitation outcome measures for those with CAI. Further research is recommended to clarify the long-term outcomes of combining electrotherapies with TEx to establish their effect on reinjury rates and participant-perceived outcomes combined with more sports-specific functional rehabilitative techniques.

Not all the electrotherapy interventions used within this systematic review would always have an easy practical application in clinical or sports rehabilitation environments due to the costings of the equipment and the practicality for application during functional TEx activities. However, with some consideration, all could be adapted to become more applied in nature to these settings, with the potential for favorable outcomes for individuals with CAI.

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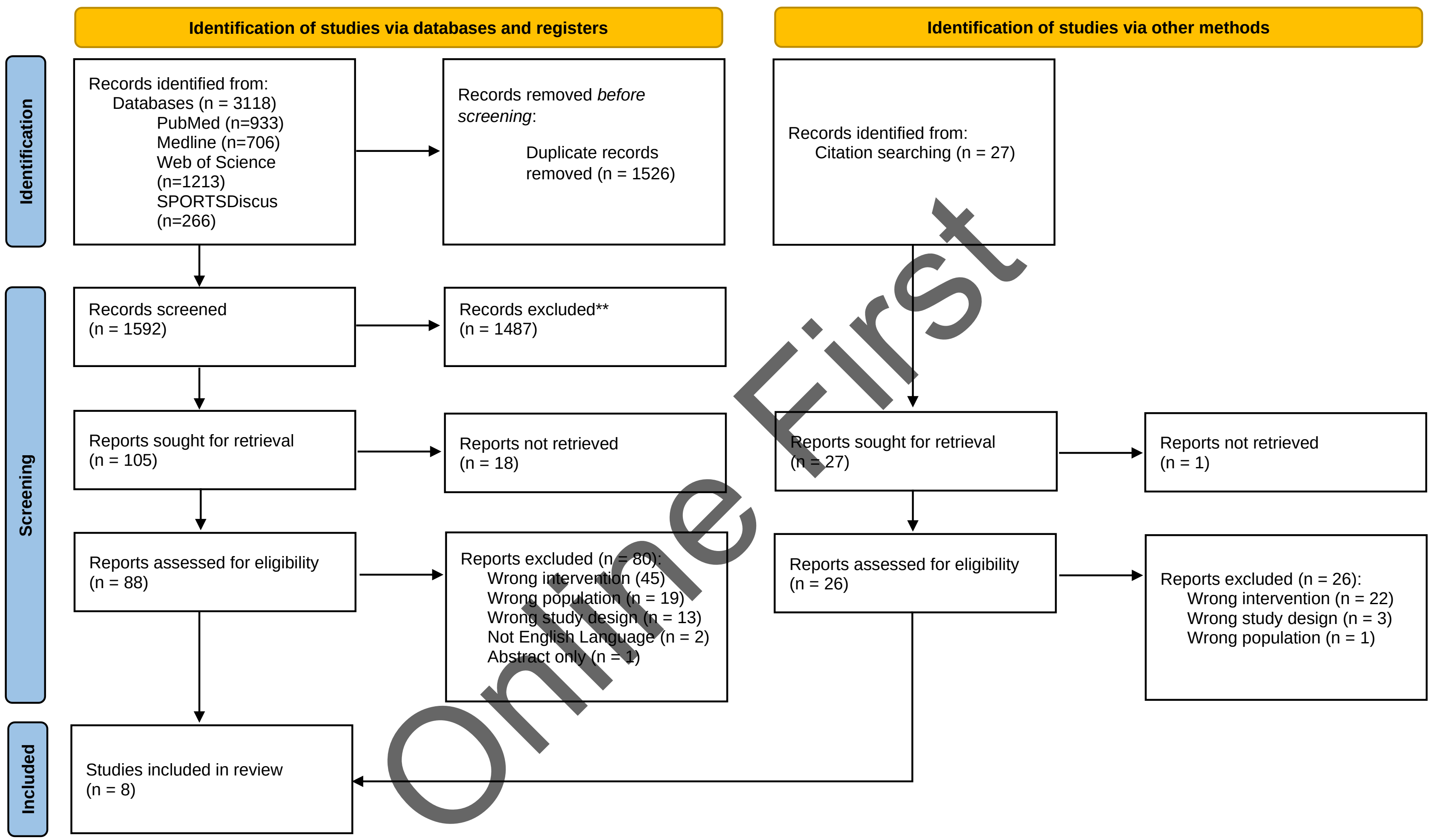
PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

Source: Page MJ, et al. BMJ 2021;372:n71. doi: 10.1136/bmj.n71.

Figure 1: PRISMA Flow Diagram

Table 1. PICOS Method used to Formulate Eligibility Criteria.

PICOS Component	Criterion
Population	Human participants, with no restrictions on sex, age or setting.
Intervention	Electrotherapy in any form as part of rehabilitation for AI in combination with TEx.
Comparison	TEx for rehabilitation only.
Outcome	The effectiveness of electrotherapy combined with TEx in functional outcome measures such as, but not limited to, balance, muscle strength, patient self-reported outcomes, muscle latency, and postural stability
Study Design	Randomized control trials.

Table 2: Search Syntax

Search string	Search Terms
1	(“chronic ankle instability” OR “ankle sprain” OR “ankle Injury*” OR “unstable ankle” OR “ankle joint instability” OR “ankle joint laxity” OR “subtalar joint” OR “talocrural joint” OR “talocalcaneal joint” OR “ankle joint” OR “ankle” OR “functional ankle instability” OR “functionally unstable ankle”)
2	AND (“interferential electrical stimulation” OR “transcutaneous electrical nerve stimulation” OR “electrical stimulation” OR “TENS” OR “neuromuscular electrical stimulation” OR “muscle stimulation” OR “NMES” OR “electrotherapy” OR “stochastic resonance stimulation” OR “neurostimulation” OR “transcutaneous stimulation” OR “functional electrical stimulation” OR “electrostimulation” OR “electromyostimulation” OR “biomechanical muscle stimulation” OR “interferential”)
3	AND (“landing” OR “jump landing” OR “balance” OR “proprioception” OR “rehabilitation” OR “exercise” OR “training” OR “therapy” OR “rehabilitative medicine” OR “treatment” OR “exercise therapy” OR “physical medicine” OR “strength” OR “exercise rehabilitation” OR “therapeutic exercise”)

Table 3: PEDro Scale Criteria

Author (year)	PEDro Scale Criteria											Score
	Criteria 1*	Criteria 2	Criteria 3	Criteria 4	Criteria 5	Criteria 6	Criteria 7	Criteria 8	Criteria 9	Criteria 10	Criteria 11	
Alahmari *et al.* [34]**	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7
Bruce *et al.*[32]***	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	7
Choi & Jun[31]***	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
Gottlieb *et al.*[25]***	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	7
Ross *et al.*[35]***	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	4
Ross & Guskiewicz[33]***	Yes	No	No	Yes	No	No	No	Yes	No	No	Yes	3
Ross *et al.*[30]**	No	Yes	No	No	No	No	No	No	No	Yes	Yes	3
Yoshida *et al.*[36]***	Yes	No	No	Yes	No	No	No	Yes	No	No	Yes	3

PEDro scale criteria:
(1) Eligibility criteria were specified; (2) Random allocation; (3) Concealed allocation; (4) Baseline comparability; (5) Blind subjects; (6) Blind therapists; (7) Blind assessors; (8) Adequate follow-up; (9) Intention-to-treat analysis; (10) Between-group comparisons; (11) Point estimates and variability.

* Does not contribute to total score.

** Score as confirmed in PEDro database.

*** Score determined by reviewer, as not available in the PEDro database.

Appendix A – Supplementary Material

Table S1 4. A Summary of Percent Change in TTS from Pre-Test in FAI Participants

Time Point	Group	A/P TTS Improvement (%)	M/L TTS Improvement (%)
Week 2	SRS & CT	16%	16%
	CT Only	16%	8%
Week 4	SRS & CT	25%	22%
	CT Only	18%	8%
Week 6	SRS & CT	22%	22%
	CT Only	18%	8%

Table S2 5. A Summary of P-Values and Effect Sizes Comparing the SRS Group to Pooled CG and CT-Group Results.

Outcome Measure	p-value - SRS Vs CG&CT (pooled)	Effect size (*d*) SRS	Effect Size (*d*) CG&CT (pooled)
A/P COPvel	0.036	0.87	0.18
M/L COPvel	0.049	0.71	0.21
M/L COPsd	0.013	0.77	-0.34
M/L COPmax	0.015	0.45	-0.10
COParea	0.043	0.63	0.25

Table S3 6. A Summary of Percentage A/P And M/L COPvel Improvements with Effect Size (*d*)

Time Point	Group	A/P COPvel Improvement (%)	A/P Effect Size (*d*)	M/L COPvel Improvement (%)	M/L Effect Size (*d*)
Week 2	SRS & CT	75%	0.18	83%	0.40
	CT Only	83%	0.38	80%	0.62
Week 4	SRS & CT	88%	0.40	88%	0.22
	CT Only	92%	1.10	80%	0.60

Table S4 7. A Summary of Pre-Post COP Measures for TEx-Only and TENS-Ex Groups

Group	Time Point	Mean COP (mm) ± SD
TEx Only	Pre-test	585.6 ± 158.9
	Post-test	562.6 ± 150.6
TENS with TEx	Pre-test	627.0 ± 235.4
	Post-test	551.8 ± 172.1

Table S5 8. A Summary of Means, Standard Deviation and Effect Sizes (*d*) for Outcome Measures

Outcome Measure	Group	Baseline	Pre-treatment	Post-treatment	6-month Follow-up	12-month Follow-up
ANT YBT (cm)	TEx-TENS	69.6±8.3	72.0±7.7	71.9±7.2		
	TEx-NMES	69.0±8.3	72.4±6.3	73.9±7.2		
Between-group (*d*)				0.59		
PL YBT (cm)	TEx-TENS	78.6±7.9	80.9±7.7	83.3±5.4		
	TEx-NMES	81.9±5.9	82.7±5.2	86.9±4.3		
PM YBT (cm)	TEx-TENS	76.6±9.3	78.9±9.3	81.6±7.1		
	TEx-NMES	80.5±6.6	82.1±5.6	86.0±4.4		
Between-group (*d*)				0.38		
TTS (ms)	TEx-TENS	2.7±3.3	2.2±3.0	2.0±2.8		
	TEx-NMES	2.1±2.8	2.2±2.6	1.2±0.8		
Between-group (*d*)				-0.26		
CAIT	TEx-TENS	13.7±6.5	13.3±5.8	15.1±6.6	15.6±5.9	18.0±7.1
	TEx-NMES	14.3±6.1	14.9±6.0	18.4±5.0	21.5±6.2	20.8±5.5
Between-group (*d*)				0.1	0.43	0.13
IdFAI	TEx-TENS	25.1±4.1	25.8±4.8	24.6±5.6	23.7±5.1	21.4±5.8
	TEx-NMES	24.2±5.8	24.5±5.8	20.4±5.1	17.5±6.9	15.9±6.5
Between-group (*d*)				-0.24	-0.50	-0.36
FAAM-Sport	TEx-TENS	64.1±17.1	64.2±16.8	68.5±20.3	70.5±18.6	71.8±20.0
	TEx-NMES	55.4±17.5	62.8±17.2	68.2±17.1	77.3±15.8	80.9±9.3
Between-group (*d*)				-0.03	0.40	0.55

Table S6 9. A Summary of Means and Standard Deviations for Outcome Measures

Outcome Measure	Group	Baseline Mean & SD	Week 2 Mean & SD	Week 4 Mean & SD	Week 6 Mean & SD
PL RMT (%2T)	aTDCS	36.92± 11.53	39.02± 9.30	37.46± 9.22	32.91± 12.33
	Sham	36.67± 12.74	27.86± 14.69	35.63± 13.10	35.99± 13.52
TA RMT (%2T)	aTDCS	38.54± 13.91	34.83± 13.63	36.55± 6.02	32.90± 7.97
	Sham	30.75± 10.20	29.41± 13.90	36.57± 13.68	37.31± 15.76
PL I_{50} (%2T)	aTDCS	51.97± 6.47	51.35± 9.38	55.89± 7.63	47.42± 5.63
	Sham	51.11± 11.27	45.47± 10.62	52.31± 11.30	53.91± 12.04
***TA* I_{50} (%2T)**	aTDCS	53.42± 6.19	54.67± 11.92	52.05± 7.33	49.26± 5.93
	Sham	49.06± 10.40	44.62± 12.96	53.08± 8.01	54.14± 11.42
DPSI	aTDCS	0.50± 0.07	0.49± 0.06	0.49± 0.04	0.47± 0.05
	Sham	0.50± 0.05	0.52± 0.07	0.51± 0.05	0.51± 0.06
APSI	aTDCS	0.12± 0.04	0.11± 0.04	0.13± 0.02	0.10± 0.05
	Sham	0.12± 0.03	0.10± 0.05	0.10± 0.05	0.11± 0.04
MLSI	aTDCS	0.04± 0.02	0.04± 0.02	0.03± 0.01	0.04± 0.01
	Sham	0.04± 0.01	0.04± 0.01	0.04± 0.01	0.04± 0.01
VSI	aTDCS	0.48± 0.07	0.47± 0.06	0.47± 0.04	0.46± 0.06
	Sham	0.47± 0.05	0.50± 0.07	0.49± 0.06	0.50± 0.07
TA 250ms pre-landing	aTDCS	0.31± 0.12	0.22± 0.09	0.22± 0.08	0.26± 0.10
	Sham	0.31± 0.10	0.27± 0.10	0.23± 0.07	0.25± 0.08
TA 250ms post-landing	aTDCS	0.46± 0.16	0.47± 0.15	0.49± 0.16	0.46± 0.16
	Sham	0.58± 0.11	0.51± 0.12	0.48± 0.09	0.46*0.12
PL 250ms pre-landing	aTDCS	0.49± 0.12	0.52± 0.12	0.48± 0.07	0.48± 0.09
	Sham	0.46± 0.12	0.55± 0.12	0.52± 0.12	0.50± 0.11
PL 250ms post-landing	aTDCS	0.51± 0.12	0.61± 0.10	0.58± 0.14	0.60± 0.11
	Sham	0.56± 0.16	0.57± 0.12	0.47± 0.11	0.58± 0.10
SOL 250ms pre-landing	aTDCS	0.58± 0.09	0.59± 0.13	0.63± 0.06	0.59± 0.12
	Sham	0.66± 0.12	0.61± 0.14	0.60± 0.11	0.57± 0.14
SOL 250ms post-landing	aTDCS	0.49± 0.16	0.47± 0.19	0.42± 0.17	0.44± 0.21
	Sham	0.51± 0.14	0.45± 0.14	0.46± 0.16	0.44± 0.16
$FAAM_{ADL}$	aTDCS	93.69± 5.33	94.52± 5.59	95.83± 4.13	95.95± 3.64
	Sham	92.74± 7.26	91.54± 8.92	91.54± 8.06	92.85± 7.36
FAAMsport	aTDCS	84.37± 12.88	84.38± 13.33	88.35± 9.38	88.92± 10.67
	Sham	79.37± 18.05	78.44± 19.57	79.37± 17.50	80.93± 15.27
TSK	aTDCS	32.91± 4.68	33.00± 4.90	31.91± 5.07	29.91± 4.11
	Sham	31.18± 6.82	31.36± 7.19	32.73± 7.40	30.91± 6.86
DPA	aTDCS	18.09± 5.45	18.09± 6.41	15.55± 4.82	15.45± 5.48
	Sham	17.91± 4.59	21.00± 8.52	21.09± 8.77	22.00± 8.23

Table S7 10. A Summary of Means, Standard Deviation and Effect Sizes (*d*) for Outcome Measures

Outcome Measure	Group	Pre (Mean & SD)	Post (Mean & SD)	Effect size (*d*)
FDL Thickness (cm)	TEx	0.83 ± 0.07	0.99 ± 0.13	1.54
	NMES	0.84 ± 0.08	0.98 ± 0.13	1.21
	NMES-TEx	0.81 ± 0.07	1.04 ± 0.12	2.43
GAS-M Thickness (cm)	TEx	1.64 ± 0.12	1.90 ± 0.17	1.83
	NMES	1.64 ± 0.11	1.82 ± 0.15	1.38
	NMES-TEx	1.64 ± 0.23	1.96 ± 0.21	1.48
GAS-L Thickness (cm)	TEx	1.36 ± 0.25	1.63 ± 0.24	1.12
	NMES	1.37 ± 0.21	1.59 ± 0.12	1.36
	NMES-TEx	1.36 ± 0.11	1.66 ± 0.15	2.26
SOL Thickness (cm)	TEx	1.52 ± 0.14	1.80 ± 0.15	1.94
	NMES	1.53 ± 0.13	1.76 ± 0.16	1.59
	NMES-TEx	1.53 ± 0.16	1.83 ± 0.20	1.64
FDL CSA (cm^2)	TEx	0.86 ± 0.10	1.21 ± 0.21	2.07
	NMES	0.87 ± 0.07	1.19 ± 0.15	2.76
	NMES-TEx	0.86 ± 0.08	1.25 ± 0.27	2.02
GAS-M CSA (cm^2)	TEx	6.78 ± 0.57	7.47 ± 0.83	0.96
	NMES	6.77 ± 0.71	7.37 ± 0.65	0.89
	NMES-TEx	6.78 ± 1.05	7.57 ± 0.76	0.87
GAS-L CSA (cm^2)	TEx	5.02 ± 0.92	6.16 ± 1.39	0.97
	NMES	5.06 ± 0.56	5.97 ± 0.74	1.39
	NMES-TEx	5.03 ± 0.57	6.32 ± 0.45	2.50
SOL CSA (cm^2)	TEx	5.82 ± 0.60	6.95 ± 0.56	1.94
	NMES	5.90 ± 0.82	6.68 ± 0.80	0.96
	NMES-TEx	5.93 ± 0.42	6.98 ± 0.51	2.26
YBT-ANT (cm)	TEx	45.18 ± 3.06	55.97 ± 5.03 cm	2.59
	NMES	44.86 ± 3.08	53.31 ± 5.76 cm	1.83
	NMES-TEx	46.81 ± 3.52	55.23 ± 5.65 cm	1.79
YBT-PM (cm)	TEx	86.82 ± 6.18	98.77 ± 8.22 cm	1.64
	NMES	87.18 ± 8.45	96.32 ± 4.84 cm	1.33
	NMES-TEx	84.24 ± 9.86	97.92 ± 7.61 cm	1.55
YBT-PL (cm)	TEx	83.90 ± 9.93	94.86 ± 7.10 cm	1.27
	NMES	81.75 ± 13.47	94.97 ± 3.39 cm	1.35
	NMES-TEx	79.34 ± 13.34	95.60 ± 5.70 cm	1.59
YBT-COMP (%)	TEx	80.96 ± 6.87	93.55% ± 5.67	2.00
	NMES	79.40 ± 8.37	90.96% ± 6.40	1.55
	NMES-TEx	79.94 ± 8.53	94.60% ± 5.70	2.02
SHT (secs)	TEx	24.80 ± 8.11	18.06 ± 1.86	-1.15
	NMES	28.07 ± 10.39	20.00 ± 5.17	-0.98
	NMES-TEx	29.51 ± 11.49	18.44 ± 3.08	-1.32