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What is the effect of ankle disk training and taping on proprioception deficit after lateral ankle sprains among active populations? – A systematic review

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ABSTRACT

Objective: To investigate the effect of disk training and tape application on diminished proprioception after Lateral Ankle Sprain (LAS) in active populations.
Eligibility criteria: Only clinical trials investigating the effectiveness of disk training and ankle tape on proprioception deficits following LAS by assessing JPS or kinaesthesia were included.
Information sources: Electronic databases of PubMed, MEDLINE, SPORTDiscus, CINAHL, Web of Science, Cochrane and PEDro were searched. The main search was conducted in February 2022.
Risk of bias: The physiotherapy Evidence Database (PEDro) scale was utilised to assess the methodological quality of each article.
Result: The search yielded six studies investigating the effects of disk training and four studies investigating the effects of inelastic tape. Five articles showed a significant improvement on JPS after disk training. However, no difference across different intervention groups was observed in one study. Only one trial presented an immediate significant improvement when taped, while another study showed that external ankle supports significantly improved JPS after 2 weeks and after 2 months. Three of four studies found no immediate improvement on proprioceptive deficits by the use of tape.
Conclusions: This review found that disk training may improve impaired proprioception after LAS, whilst the efficacy of inelastic tape was not evident due to methodological quality of the few available studies. Further studies are needed to establish whether these interventions can be used clinically with sufficient evidence.

1. Introduction

Proprioception is a commonly debated topic in rehabilitation. It has been defined as a subsystem that integrates the sensory information supplied by various mechanoreceptors located in connective tissues including skin, ligaments and joint capsules, and muscle tissue (Han et al., 2015; Röijezon et al., 2015). Electrical impulses derived from proprioceptors are transformed into relative position and movement parameters at both conscious (cerebral cortex) and unconscious (cerebellum) levels of the central nerve system (CNS) (Ogard, 2011). Therefore, a considerable number of previous studies (Hughes and Rochester, 2008; Lephart et al., 1997; Winter et al., 2015) have been discussing proprioception as joint position sense (JPS) and joint movement sense (kinaesthesia), related to sensory deficit and rehabilitation treatment. Proprioception plays a crucial role in balance ability because integrated sensory input contributes to the motor programming for accurate movement pattern and to muscle relaxation, which results in providing dynamic stability during activities (Lephart et al., 1997). Steinberg et al. (2019a,b) have shown that current sport participation level with joint position reproduction (JPR) error significantly correlated with less error in higher-level performers ($r = 0.49$, $p = 0.001$). Han et al. (2014) revealed that compared with

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other joints, ankle proprioception was most highly correlated with competition level in elite athletes of sports dancing, football and aerobic gymnastics ($r = 0.45$, $p < 0.001$).

Lateral ankle sprain (LAS) is one of the most common injuries in sports such as basketball, football and volleyball (Handoll et al., 2001) and it has been found that the rate of ankle sprains ranges from 15 to 20% in all sports injuries (Petersen et al., 2013). The occurrence rate for athletes is as high as 70–80%, frequently leading to functional ankle instability (FAI) and/or chronic ankle instability (CAI) (Webster and Gribble, 2010). Webster and Gribble (2010) also explained that proprioception deficit is one of the features of CAI due to injury to the nervous and musculotendinous tissue. Willems et al. (2002) found that the CAI group had significantly less accurate JPS and lower muscle strength than the control group ($p < 0.05$), thus suggesting that a combination of diminished proprioception and reduced muscle strength are maladaptive features typically found in CAI. Therefore, it is recommended to consider appropriate evaluation and rehabilitation of proprioception in order to prevent CAI and enhance better performance of sports specific movements (Postle et al., 2012; Röijezon et al., 2015). To assess proprioception, the threshold to detection of passive motion (TTDPM) method for kinaesthesia, the JPR test for JPS, the active movement extent discrimination assessment (AMEDA) method for JPS, and the slope box test for JPS are commonly used (Halasi et al., 2005; Han et al., 2016; Symes et al., 2010; Willems et al., 2002; Yasuda et al., 2014).

Regarding rehabilitation for proprioception deficit, interventions can be divided into two categories: passive and active. Passive interventions refer to manual therapy, taping/bracing, and shoe insoles, while active interventions include any active exercise, which can be considered ‘proprioceptive training’, such as active JPR training, force sense training, co-ordination training and disk (wobble board/balance board/unstable surface) training (Clark et al., 2015; Han et al., 2015). Disk training has been widely used because of the efficacy ($p < 0.01$) of improving the balance ability and preventing re-injury after ankle sprains (Waddington et al., 1999).

However, it is still not known which proprioceptive intervention is most effective. Ogard (2011) pointed out that many studies were conducted without a clear definition of proprioception or the details of exercises. Röijezon, Clark and Treleaven (2015) explained that any active interventions targeting JPS and kinaesthesia may ameliorate proprioception because they involve learning motor skills, explicitly (the cortico-striatal system: conscious and unconscious proprioception) or implicitly (the cortico-cerebellar system: unconscious proprioception). Ashton-Miller et al. (2001) discussed the term “ankle proprioception” and highlighted that many studies investigating the effect of proprioceptive exercises have assessed only the balance system embracing the elements of muscle strength and flexibility. Moreover, questions have been raised about the efficacy of taping because of the lack of high-quality evidence to support its effectiveness (Ashton-Miller et al., 2001; Hughes and Rochester, 2008). This has been investigated, albeit with conflicting results. Some studies advocated the use of tape with supporting theories claiming that the close contact of the tape to the skin might provoke sensory inputs derived from the cutaneous receptors, thus leading to an increase in the excitability of the motoneuron pool (Refshauge et al., 2009; Röijezon et al., 2015).

The ability of balance includes two aspects, sensory input (proprioception) and motor output, and many studies investigated ankle proprioception (de Vasconcelos et al., 2018; Konradsen, 2002; Schiftan et al., 2015). There are few systematic reviews focusing on the outcome of treatments using disk training or taping with the measurements of JPS and kinaesthesia in subjects with LAS, FAI or CAI. The purpose of this systematic review was to determine whether disk training and taping together or alone improve proprioceptive deficit after LAS in active populations.

2. Methods

2.1. Protocol

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 guidelines were followed in the presentation, conduct, and reporting of this review (Page et al., 2021).

2.2. Eligibility criteria

The journal articles were selected according to PICO framework (Populations, Interventions, Comparisons, and Outcomes) (Huang et al., 2006). Randomised control trials and clinical trials investigating proprioception following disk training and taping in active populations were considered. The participants were subjects who sustained LAS, FAI or CAI. The interventions were disk training and tape application together or alone for improvement on proprioception deficit, and the effect of those two interventions was investigated. The outcome measures were the assessments of proprioceptive (JPS or kinaesthesia) error measured with the TTDPM test, the JPR test, the AMEDA method, or the slope box test.

2.3. Information sources

Seven electronic databases (PubMed, MEDLINE, SPORTDiscus, CINAHL, Web of Science, Cochrane and PEDro) were searched for the available studies published. The literature search was conducted on 21st Feb 2022.

All databases were searched via library databases provided by Middlesex University (MDX). MEDLINE, SPORTDiscus and CINAHL were cross-searched via EBOSC.

2.4. Search strategy

The principal investigator (SO) developed a systematic search strategy following the PICO framework (Huang et al., 2006) and identified all suitable studies using a computer search algorithm and manual search. Each database search used the terms displayed in Table 1. The search was limited to literature published prior February 2022, peer-reviewed and in English language only. With Web of Science, the search was refined by Web of Science categories: Sport Sciences, Rehabilitation and Orthopedics.

2.5. Selection process

The principal investigator screened titles and abstracts to identify relevant studies. Title and abstracts investigating the effect of disk training and ankle taping, which included the assessment of ankle proprioception, were considered. The same screening was performed by one of the authors (KP). Disagreements were discussed with a third member of the team (LM) until agreement was reached. Full-text manuscripts of remaining eligible studies were evaluated for inclusion in this review. The additional inclusion criteria were: (1) subjects who sustained LAS, FAI or CAI; (2) the assessment of JPS or kinaesthesia using the TTDPM method, the JPR test, the AMEDA method, or the slope box test; (3) using a disk (balance/wobble board) to provide proprioceptive input; (4) using ankle tape to provide proprioceptive input; (5) comparison of before/after intervention.

Studies were excluded for the following reasons: (1) subjects who had no history of ankle sprain; (2) the assessment of proprioception testing only balance ability, force sense, velocity, or posture; (3) the intervention which is not therapeutic; (4)

Table 1
The search strategy.

Search strategy for PubMed, MEDLINE, SPORTDiscus, CINAHL, Web of Science and Cochrane
1 lateral ankle sprain; OR ankle ligament injur*; OR ankle injur*; OR LAS; OR ankle instability
2 dis* train*; OR dis* exercise*; OR wobble board*; OR balance board*; OR wobble dis*; OR balance dis*; OR stability dis*; ankle platform*; OR propriocept* exercise*; OR propriocept* train*; OR balance exercise*; OR balance train*; OR sensory re-educat*; OR sensory rehabilitation; OR tilt board*
3 tap*; OR kinesio tap*; OR kinesiology tap*; physio tap*
4 propriocept*; OR deficit*; OR position sense; OR movement sense; OR discrimination; OR kinaesthesia
1 AND 2 OR 3 AND 4
Search strategy for PEDro
1 Abstract & Title: wobble propriocep* Body Part: foot or ankle Method: clinical trial When searching: Match any search term (AND)
2 Abstract & Title: disk propriocep* Body Part: foot or ankle Method: clinical trial When searching: Match any search term (AND)
3 Abstract & Title: balance propriocep* Body Part: foot or ankle Method: clinical trial When searching: Match any search term (AND)
4 Abstract & Title: propriocep* Therapy: orthoses, taping, splinting Body Part: foot or ankle Method: clinical trial When searching: Match any search term (AND)

proprioceptive training without disk; (5) subjects with multiple or concomitant injuries; (6) non-experimental study; (7) non-peer-reviewed study.

2.6. Data collection process

Data extraction was conducted by the principal investigator (SO).

2.7. Data items

Information was extracted from each included trial on: (1) characteristics of trial participants (including gender, age, height, weight, BMI, history of LAS/FAI/CAI and level of sporting participation), and the trial's inclusion and exclusion criteria; (2) type of intervention (including disk training or taping; duration and frequency of intervention; or versus another intervention; or versus no treatment); (3) type of control group (randomised allocation, healthy group without history of ankle injury or without control group); (4) type of outcome measurement (including the TTDPM test, the JPR test, the AMEDA method or the slope box test).

2.8. Study risk of bias assessment

In order to ascertain the validity of the methodological quality of each article, the Physiotherapy Evidence Database (PEDro) scale was used because a total score can be treated as interval level measurement (de Morton, 2009; Verhagen et al., 1998). 11 items are rated ‘yes’ (1) or ‘no’ (0) according to if each study clearly satisfies each criterion, counting the total score between 0 and 10 with exception of item 1. It has been suggested that scores of <4 are considered ‘poor’, 4 to 5 are ‘fair’, 6 to 8 are ‘good’ and 9 to 10 are ‘excellent’ (Cashin and McAuley, 2020).

2.9. Effect measure

The chosen summary effect measure for each outcome differed from that used in some of the included studies. Thus, this review used either the difference in means (parametric analysis) or the difference in median (non-parametric analysis) as a principal summary measure ($p < 0.05$) to determine the significance of each study and to summarise the measure.

2.10. Reporting bias assessment

For each trial, the principal investigator assessed the possibility of publication bias by comparing each publication between articles. The possibility that the available data are biased (selective reporting bias) was considered. It was also investigated if each trial obtained any financial support for its research project.

3. Results

3.1. Study selection

The search on databases yielded a total of 2739 articles [MEDLINE; SPORTDiscus; CINAHL 717, PubMed 58, Web of Science 650, Cochrane 1256, PEDro 58]. After duplicates ($n = 1650$) were removed, 648 articles were removed through screening of title. In the next stage, 441 studies were screened, and 391 articles were excluded after reviewing the abstracts. Among the 50 potentially eligible studies, forty articles did not meet the inclusion criteria as described in Fig. 1. Ten articles fulfilled the criteria and were included in the review (Fig. 1).

3.1.1. Study characteristics

(1) Participants

The results of each study's cohort characteristics are summarised in Table 2.

(2) Summary of each study (PICO)

Table 3 shows each PICO of six studies used disk training as a part of training protocol aiming to improve diminished proprioception. The summary of PICOs of four articles investigated the effect of the use of tape on proprioception deficit were displayed in Table 4. There was no study including both disk training and taping. All studies included in this review were experimental design.

3.2. Risk of bias in studies

The PEDro score for each study can be found in Table 5. The risk of bias score was from 3 to 9, the average score was 5.6 and the median was 5.0.

4. Results of individual studies

(1) The effects of disk training

Overall, most studies showed that the improvement of JPS after balance and proprioceptive exercises was significant at the $p < 0.05$ level (Table 6). Lee and Lin (2008) ($n = 12$) reported that the FAI limb was more improved than the Non-injured limb (active JPS: $F = 19.87$, $p < 0.05$, $Eta = 0.56$; passive JPS: $F = 9.31$, $p < 0.05$, $Eta = 0.42$).

However, there was no significant difference ($F = 0.01$, $p = 0.97$, $p\eta^2 = 0.001$) in plantar flexion (PF) direction between before and

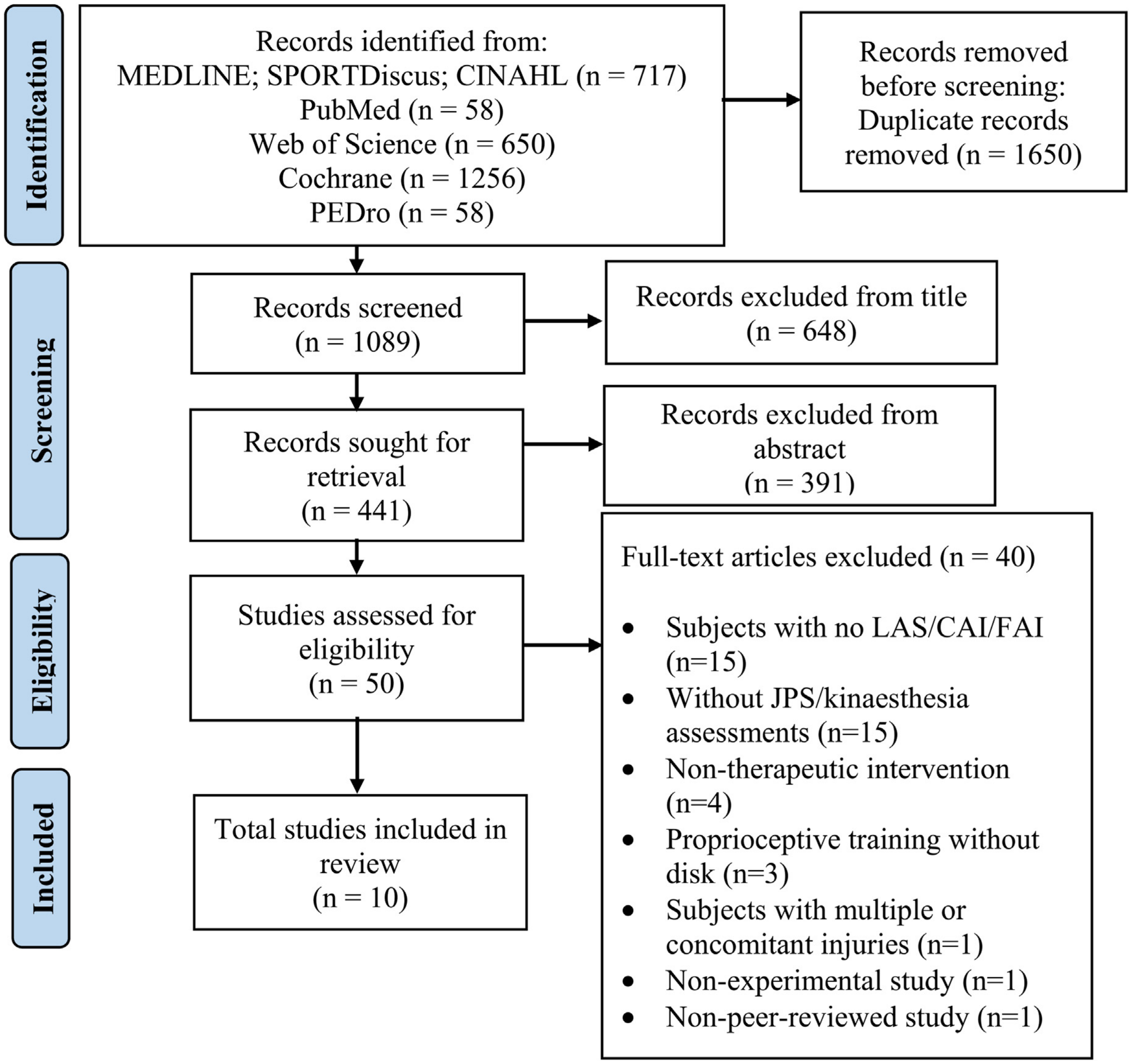

Fig. 1. Flow chart for study inclusion.

after 6-week training among CAI subjects (n = 12) in one study (Sefton et al., 2011). Bernier and Perrin (1998) (n = 45) showed no main effect or interactions among groups, which suggests there is no effect of balance and proprioceptive training on JPS. Kynsburg et al. (2006) reported that overall the training group (n = 10) significantly improved diminished proprioception (T = 103.00, Z = 3.32, $p < 0.001$), whereas the result of three subjects (i.e. group B) was worse than the control group which did not receive any intervention (mean: U = 116.50, Z = 2.68, p = 0.0073). In other words, there was no main effect of the proprioception training on JPS for some subjects with CAI.

(2) The effects of taping

Table 7 presents the results of each trial investigating the effect of tape application. Spanos, Brunswic and Billis (2008) (n = 20) found immediate significant differences in JPS of PF and inversion directions between taped and untaped conditions (10°PF: t = 2.716, p = 0.014; 30°PF; t = 2.279, p = 0.034; 5°inversion: t = 2.8986, p = 0.009; 20°inversion: t = 2.953, p = 0.008). Alawna and Mohamed (2020) (n = 100) revealed that there was no immediate significant effect of ankle supports, (i.e. taping, bandaging and placebo taping), on JPS ($p > 0.05$), whilst all subjects improved JPS two weeks after and two months after the initial test ($p < 0.02$). Significant differences were observed between taping and control groups ($p < 0.02$) and between bandaging and control groups ($p < 0.02$); however, no difference was found between taping and bandaging groups ($p > 0.05$) (Alawna and Mohamed, 2020).

One study (Refshauge et al., 2009) revealed that the use of tape decreased the ability to detect inversion and eversion movements (kinaesthesia) in subjects who sustained recurrent LAS (n = 16) (F = 6.387, p = 0.023). Refshauge, Kilbreath and Raymond (2000) (n = 43) also investigated kinaesthesia and reported that there was no significant difference between taped and untaped conditions for dorsiflexion (DF) and PF movements (F = 1.220, p = 0.28) and no difference between sprainers and non sprainers (F = 1.279, p = 0.27).

4.1. Certainty of evidence

None of all studies claimed any conflicts of interest. One study divided one group into two in order to show a significant improvement in a group, however, there was no selective data reported in other studies. Three articles reported that they have obtained financial support for their research.

Table 2
Population characteristics of included studies.

Reference	n	Male/ female	Mean age (years)	Mean Height (cm)	Mean weight (Kg)	Mean BMI (kg/m^2)	Presenting condition	Level of sporting participation
Bernier and Perrin (1998)	45	N/C	18 to 32	N/C	N/C	N/C	CAI	N/C
Eils and Rosenbaum (2001)	30	EG 6/14; CG 6/4	EG 27.0; CG 26.4	EG 176.6; CG 179.7	EG 69.6; CG 75.7	EG 22.3; CG 23.4	CAI	EG 5.2; CG 4.5 (per week)
Kynsburg et al. (2006)	20	EG 5/5; CG 5/5	EG 23.3; CG 23.0	EG 174.0; CG 172.8	EG 69.1; CG 66.5	EG 22.7; CG 22.1	EG: CAI; CG: no LAS	EG regular sporting activity; CG athletes
Lazarou et al., 2017	20	PBG 3/7; PNF 3/7	PBG 22; PNF 22	N/C	N/C	N/C	Post-acute LAS	PBG 5; PNF 5 (per week)
Lee and Lin (2008)	12	8/4	20.1	172.3	67.7	22.8	Unilateral FAI	N/C
Sefton et al. (2011)	21	EG 4/8: CG 3/6	EG 21.2; CG 20.8	EG 165.1; CG 167.3	EG 67.2; CG 62.8	EG 24.7; CG 22.4	EG: CAI; CG: no LAS	N/C
Alawna and Mohamed (2020)	100	TG 18/15; BG 19/14; PG 19/15	TG 22.3; BG 23.6; PG 23.0	N/C	N/C	N/C	CAI	Volleyball players from the national sports clubs
Refshauge et al. (2000)	61	N/C	EG 21.6; CG 21.3	EG 167.0; CG 166.1	EG 65.2; CG 63.1	EG 23.4; CG 22.9	EG: Recurrent LAS; CG: no LAS	EG 2.8; CG 2.4 (per week)
Refshauge et al. (2009)	16	2/14	22	166	62	22.5	Recurrent LAS	N/C
Spanos et al. (2008)	20	16/4	23.2	177.5	72.3	22.9	Previous LAS	Amateur athletes
	Total 345	Total 117/122	Mean 22.7	Mean 172.3	Mean 63.4	Mean 22.8		

EG: Experimental group, CG: Control group, PBG: Proprioceptive balance exercise group, PNF: PNF group.
TG: Taping group, BG: Bandaging group, PG: Placebo group, N/C: No comment.

5. Discussion

This review investigated the effect of disk training as active intervention and taping as passive intervention on proprioception deficit after LAS. The findings of this review indicated the possibility of the efficacy of proprioception exercise using disk (Table 6) and the paucity of the effectiveness of taping (Table 7) on impaired proprioception.

(1) Disk training

Five of six studies (Eils and Rosenbaum, 2001; Kynsburg et al., 2006; Lazarou et al., 2017; Lee and Lin, 2008; Sefton et al., 2011) included in this review found significant improvements on JPS after disk training. In addition to these six trials which targeted the subjects with CAI/FAI, many other studies investigated healthy athletes, such as ballet dancers, handball players and rugby players, with the same method and supported the effectiveness of disk training from their studies (Kynsburg et al., 2010; Steinberg et al., 2019a,b; Waddington et al., 1999).

Bernier and Perrin (1998) showed that the observed difference across three groups, (i.e. control, sham and experimental), was not statistically significant. Kynsburg et al. (2006) also found no difference after the disk training period in three subjects with CAI. This indicated the probability of no significant influence of disk training on proprioception, but this result might have been related to methodological quality such as the contents of the training protocol, the sample size and how the trial was conducted.

One study investigated two proprioceptive training programs, (i.e. balance and PNF), but the JPS results of these two programs were not compared statistically (Lazarou et al., 2017). The included articles in this review could not demonstrate the superiority of disk training in improving proprioception, compared to different proprioceptive exercises. Additional studies are needed to identify whether disk training could be a more effective treatment for restoring proprioception deficit than other therapeutic interventions.

(2) The use of taping

Only four trials (Alawna and Mohamed, 2020; Refshauge et al., 2000; Refshauge et al., 2009; Spanos et al., 2008) utilising inelastic tape were included in this review. The evidence is not sufficiently robust to determine whether the use of inelastic tape is effective on diminished proprioception. Only one of four showed the positive outcomes of the use of tape (Spanos et al., 2008). Another important finding was that only 1 study followed immediate responses as well as long-term outcomes and showed that JPS was improved 2 weeks after and 2 months after the initial test (Alawna and Mohamed, 2020). This indicates that external supports such as inelastic tape and bandage may have only the effect of the long-term application on proprioception. Further research is needed to determine the effectiveness of the long-term use of external ankle supports.

Contrary to expectations, Refshauge et al. (2009) showed that movement detection sense was aggravated when taped. A recent study examining the effect of kinesio and athletic taping in healthy participants found that taping worsened JPS of the group who had above-average good proprioception, whilst below-average JPS group improved when taped ($p = 0.008$) (Long et al., 2017). A possible explanation for this might be that tape application may increase sensory input, covering the deficiency of JPS and kinaesthesia. Meanwhile, the excessive increase in input from proprioceptors can result in failing to perceive these position and movement sense accurately. Another hypothesis is that comparing different senses, (i.e. JPS and kinaesthesia), can lead to conflicting results. Two studies (Refshauge et al., 2000; Refshauge et al., 2009) assessed kinaesthesia, showing negative outcomes of tape application. On the other hand, the other two studies (Alawna and Mohamed, 2020; Spanos et al., 2008) tested JPS, showing a significant improvement. It can therefore be assumed that assessing JPS and kinaesthesia should be considered separately.

This review included only four trials and none of them used elastic tapes. Some studies reported the effectiveness of elastic tape in healthy subjects (Brogden et al., 2018; Miralles et al., 2010). So far, however, there has been little evidence to indicate that applying either inelastic or elastic tape can ameliorate the ankle proprioceptive deficit after LAS.

Table 3
Summary of trials investigating proprioceptive exercise rehabilitation.

Reference and study design	Participants		Intervention			Comparisons	Outcome measures
	Characteristics	n	Intervention	Frequency	Duration		
Bernier and Perrin (1998) Pre-post treatment, quasi-experimental design	CAI	45	6-week training protocol consists of coordination and balance training program on proprioception. 13 strategies used: fixed surface, tilt board, wobble board, functional hop with eyes open/closed.	Three times per week for 10 min each day (Group 3)	6 weeks	1. Control group (n = 14): no treatment 2. Sham group (n = 14): a sham treatment of electrical stimulation to the peroneus longus and brevis 3. Experimental group (n = 17): balance and coordination training	1. Active and passive (5°/sec velocity) JPR test using isokinetic dynamometer with inversion/eversion footplate in supine position 2. Postural stability measured by the force plate of the Balance System
Eils and Rosenbaum (2001) Quasi-experimental design	CAI	30	The physiotherapeutic program consists of 12 different exercises, which use: exercise mats, swinging platform, ankle disk, Pedalo, exercise bands, air squab, wooden inversion-eversion boards (customised), mini trampoline, aerobic step, uneven walkway (customised), swinging and hanging platform, Biodex.	N/C	6 weeks	1. Exercise group (EG) (n = 20): 6-week exercise program 2. Control group (CG) (n = 10): no intervention Many subjects revealed bilateral instability so that 48 feet were evaluated (EG, n = 31; CG, n = 17)	1. Passive JPR test for JPS of DF/PF using a Penny & Giles electrogoniometer in sitting position 2. Postural sway using a force plate in single-limb stance 3. Muscle reaction times measured with the platform and bipolar electrodes
Kynsburg et al. (2006) Experimental design	CAI	10	Proprioceptive training: dynamic or static exercise including ankle disk training.	45 min training 3 days per week (Group 1 and 2)	7.9 weeks on average	1. Training group A (n = 7): patients with any significant improvements in any direction 2. Training group B (n = 3): patients showed no response to the intervention 3. Control group (n = 10): healthy athletes with no previous LAS. No intervention.	1. Slope box test on a single leg to assess JPS. A total of 11 wooden platforms inclined at various angles from 0 to 25°, positioned in four different directions (a total of 4x11 different testing positions). Subjects were asked to tell the direction and the amplitude of the slope they were stepping on. In control group the test was performed only once.
Lazarou et al., 2017 Randomised two group, pre-post treatment design	Post-acute LAS (mean: 11 weeks since sprain)	20	1. Balance protocol: consisted of wobble board, firm surface and soft surface activities, with the eyes open 2. PNF protocol: comprised two different techniques: rhythmic stabilization and combination of isotonics	Each session lasted 50–60 min	6 weeks	1. Balance group (n = 10): conducted the balance protocol 2. PNF group (n = 10): received the PNF treatment	1. Active JPS was assessed by an isokinetic dynamometer at three angles, 10° of DF, 15° of PF and 30° of PF 2. Muscle strength was measured by the Biodex dynamometer. Peak torque scores were recorded. 3. Electromyographic activity was assessed by recording the surface EMG data of peroneus longus and tibialis anterior muscles.
Lee and Lin (2008) Pre-post treatment, same-subject controlled design	University students with unilateral FAI	12	The biomechanical ankle platform system (BAPS) training procedures: consists of 5 exercises (anterior-posterior/medial-lateral cycles; clockwise/counter clockwise rotation; single-leg stability) and 2 progressions (board control/level).	20 min x three times per week	12 weeks	1. The injured limb (FAI) (n = 12) 2. The non-injured limb (NI) (n = 12): had no history of LAS or lower extremity pathology	1. Active and passive (2°/s) JPR test were conducted to assess JPS using isokinetic dynamometer at three angles, 15° of inversion, 0° subtalar neutral, and 10° of eversion. Each subject was in supine position in the chair with the lower limb parallel to the floor. 2. Postural stability was assessed using a force plate.
Sefton et al. (2011) 2x2 repeated-measures quasi-experimental design	CAI	12	The balance training: used a balancing platform containing a marble maze that provided 4 levels of difficulty.	3 times a week. Each session included four 3-min balancing periods. (Group 1)	6 weeks	1. CAI group (n = 12): conducted the balancing training 2. Control group (n = 9): Healthy participants who had no previous history of LAS, previous lower extremity injuries. No intervention.	1. JPS was assessed by active JPR test with an isokinetic dynamometer (1) PF/DF movements were tested in prone position. (2) Inversion/eversion movements were tested in seated position. 2. Dynamic balance was assessed by the Star Excursion Balance Test grid. 3. Static balance was measured by computing centre-of-pressures with a strain gauge force platform. 4. Motorneuron Pool Excitability was assessed by measuring the soleus Hoffmann reflex.

DF: Dorsiflexion; PF: Plantar flexion; CAI: Chronic Ankle Instability; LAS: Lateral Ankle Sprain; FAI: Functional Ankle Instability; JPR: Joint Position Reproduction; JPS: Joint Position Sense.

(3) Management of LAS

In terms of the management of acute LAS, a brief period of immobilisation with an elastic tape, inelastic tape or bandage is recommended (McCriskin et al., 2015; Renström and Lynch, 1998). In the systematic review of Seah and Mani-Babu (2011) it has been found that inelastic taping supports were effective for functional treatment, resulting in less persistent swelling. It is possible,

Table 4
Summary of trials investigating effects of taping on proprioception.

Reference and study design	Participants		Intervention			Comparisons	Outcome measures
	Characteristics	n	Intervention	Frequency	Duration		
Alawna and Mohamed (2020) Single-blinded randomised controlled design	Volleyball players with CAI	100	Three ankle supports were used, while usual athletic training activity sessions were conducted. 1. Ankle taping: used a hard preventive Zinc oxide tape). 2. Placebo taping: used the same tape but taping procedures were different 3. Ankle bandaging: a standard 4 inches width elastic bandage was used with 8-figure shape method	Every two weeks: assessment; the external support was removed and replaced by a new one.	Two months	1. Taping group (n = 33): used ankle tapings 2. Bandaging group (n = 33): used ankle bandages 3. Control group (n = 34): received placebo tapings	1. Active JPR test using the custom-made wooden sloops with four different positions (10° DF; neutral position; 10° PF; 20° PF). The ankle ROMs which subjects reproduced were measured by a universal goniometer in sitting position. 2. The Y-balance test was used to evaluate balance. 3. The vertical jump tester was used to measure the vertical jump height. Outcome measures were taken at the baseline, two weeks and two months.
Refshauge et al. (2000) Single-blinded randomised controlled design	Recurrent LAS	43	An inelastic tape was applied as a combination of ankle locks, stirrups and figure-of-6 applications.	1.5-h test: The taped or untapped conditions each day	N/C	1. Sprainers (n = 43) 2. Non sprainers (control group) (n = 18): had no history of an ankle injury.	1. TTDPM was used to test movement detection sense at 3 velocities: 0.1°/s, 0.5°/s, and 2.5°/s. At each velocity, PF and DF movements were imposed. A footplate connected to a linear servomotor was used. The order of testing the taped and untapped conditions was randomised.
Refshauge et al. (2009) Controlled design	Recurrent LAS	16	An inelastic tape (Leuko) was used with a standard inversion taping technique, consisting of a combination of heel locks, figure-of-6, and stirrups.	1.5-h test: The taped or untapped conditions each day	N/C	1. Taped condition (n = 16) 2. Untaped condition (n = 16)	1. TTDPM was used to test movement detection sense at 3 velocities: 0.1°/s, 0.5°/s, and 2.5°/s. At each velocity, inversion and eversion movements were imposed. A footplate connected to a linear servomotor was used. The test sessions were separated by less than a week.
Spanos et al. (2008) Pretest-posttest, quasi-experimental, same-subject design	Amateur athletes who had previously sustained at least one unilateral LAS	20	An inelastic tape (Leuko) was used. The closed basket weave with double heel lock was used as the taping method.	N/C	N/C	1. Taped condition (n = 20) 2. Untaped condition (n = 20)	1. Active JPR test was used to assess JPS. The electrogoniometer's sensors were used in a sitting non-weight-bearing position. Four target angles were tested; 5° and 20° of inversion, and 10° and 30° of PF.

TTDPM: The Threshold to Detection of Passive Motion; DF: Dorsi Flexion; PF: Plantar Flexion; LAS: Lateral Ankle Sprain; CAI: Chronic Ankle Instability; ROM Range Of Motion.

therefore, that due to the little effect of inelastic tape on JPS and kinaesthesia inelastic tape can be beneficial for functional improvement by immobilising the joints and preventing from further damage while not disrupting proprioception.

Applying the findings of this review to clinical practice, disk training can be an effective proprioception training after the acute phase and during chronic phase. Proprioceptive exercise including disk training also can enhance single leg balance and peroneal muscle reaction time (Fong et al., 2009; Hughes and Rochester, 2008). Thus, disk training may offer specific benefits following LAS.

6. Limitations

This systematic review reported different effect estimates in the result in order to determine each treatment effects. The main limitation of this review was the differences in the population and in the intervention including the training protocol, the training frequency and follow-up duration, the comparisons, the outcome measurement, and the statistical processing across studies. Thus, it is difficult to properly compare each result across studies.

The PEDro scale can investigate inherent study limitations which affected the methodological quality (Maher et al., 2003). Most of the studies were not high-quality randomised trials, which may result in biased estimates of intervention effectiveness (Cashin and McAuley, 2020; Maher et al., 2003). This bias can lead to an overestimation of the outcomes.

7. Conclusions

This review found that disk training possibly may be effective as

Table 5
PEDro scores.

Intervention	Reference	1	2	3	4	5	6	7	8	9	10	11	Total score
Intervention including disk training	Bernier and Perrin (1998)	✓	✓	X	✓	X	X	X	✓	✓	✓	✓	6/10
	Eils and Rosenbaum (2001)	✓	X	X	✓	X	X	X	✓	✓	✓	✓	5/10
	Kynsburg et al. (2006)	✓	✓	X	✓	X	X	X	✓	✓	✓	✓	6/10
	Lazarou et al., 2017	✓	✓	✓	✓	✓	X	✓	✓	✓	✓	✓	9/10
	Lee and Lin (2008)	✓	X	X	✓	X	X	X	✓	✓	✓	✓	5/10
	Sefton et al. (2011)	✓	X	X	✓	X	X	X	✓	✓	✓	✓	5/10
Taping	Alawna and Mohamed (2020)	✓	✓	✓	✓	✓	X	X	✓	✓	✓	✓	8/10
	Refshauge et al. (2000)	X	✓	X	X	X	X	X	X	X	✓	✓	3/10
	Refshauge et al. (2009)	✓	X	X	✓	X	X	X	✓	✓	✓	✓	5/10
	Spanos et al. (2008)	✓	✓	X	X	X	X	X	✓	X	✓	✓	4/10

"Yes": √; "No": X.

Table 6
Summary of trials investigating proprioceptive exercise rehabilitation.

Reference	Outcome measures			Summary data for each intervention				
	Test & position	Device	Movement	Statistics			Effect estimates	p value
Bernier and Perrin (1998)	Active and passive JPR test Supine position	Isokinetic dynamometer	Inversion/eversion with 0°PF or 25°PF	ANOVA	Main effect involving group			NS
					Main effect for test (the post-test scores were better than the pre-test)		F (1,42) = 5.46	p = 0.024*
				Tukey post hoc analysis	Passive JPS was significantly better than active position sense in the maximum inversion position		–	p < 0.05*
Eils and Rosenbaum (2001)	Passive JPR test Sitting position	Electrogoniometer	DF/PF	The nonparametric Wilcoxon test	EG: Main effect for test (the post-test scores were better than the pre-test)	10° DF	–	NS
						20° DF	–	p < 0.05*
						15° PF	–	p < 0.01**
						30° PF	–	p < 0.01**
						Mean error	–	p < 0.01**
					CG: Main effect for test	All directions	–	NS
Kynsburg et al. (2006)	Slope box test (Subjects were asked to tell the direction and the amplitude of the slope) Standing position	Wooden slopes	Inversion/eversion/DF/PF	Wilcoxon matched pairs test	Main effect for test (the post-test scores were better than the pre-test) in the training-group (A + B)	Mean	T = 103.00, Z = 3.32	p < 0.001**
				Mann-Whitney *U* test	Main effect for group (Group A was more improved than Group B	Mean	U = 34.00, Z = 3.95	p < 0.0001**
						PF	U = 0.00, Z = 2.39	p = 0.0167*
				Kruskal-Wallis test	Absolute estimate errors of CG were lower than the training group (A + B) (before training)	Mean	H = 17.1943	p = 0.0002**
				Mann-Whitney *U* test	Main effect for group (Group A (post-test) were better than Group B (post-test) & CG)	Mean	U = 335.50, Z = −2.80	p = 0.0051**
						DF	U = 7.00, Z = −2.73	p = 0.0063**
				Mann-Whitney *U* test	Main effect for group (the post-test scores of Group B were worse than CG)	Mean	U = 116.50, Z = 2.68	p = 0.0073**
						Eversion	U = 3.00, Z = 2.03	p = 0.0425*
						PF	U = 1.00, Z = 2.37	p = 0.0180*
Lazarou et al., 2017	Active JPR test Sitting position	Isokinetic dynamometer	DF/PF	Post hoc Wilcoxon test -Follow-up 1: at the end of training -Follow-up 1: 8 weeks after follow-up 1	BG	15° of PF at follow-up 1	r = 0.54	p = 0.016*
						15° of PF at follow-up 2	r = 0.55	p = 0.015*
					PNF	10° of DF at follow-up 1	r = 0.39	p = 0.012*
						15° of PF at follow-up 1	r = 0.25	p = 0.307
Lee and Lin (2008)	Active and passive JPR test Supine position	Isokinetic dynamometer	Inversion/eversion	ANOVA	Active	For training (post-training was better than pre-training)	F = 14.70, Eta = 0.50	p < 0.05*
						For limb (the FAI limb was more improved than the NI limb)	F = 19.87, Eta = 0.56	p < 0.05*
						For training x limb	F = 5.37, Eta = 0.33	p < 0.05*
					Passive	For training	F = 10.21, Eta = 0.43	p < 0.05*
						For limb	F = 9.31, Eta = 0.42	p < 0.05*
						For training x limb	F = 10.83, Eta = 0.44	p < 0.05*
Sefton et al. (2011)	Active JPR test DF/PF: prone Inversion/eversion: sitting	Isokinetic dynamometer	DF/PF/Inversion/eversion	ANCOVA	Main effect for group (The post-training scores of CAI was better than CG)	PF	F = 0.01, $p\eta^2 = 0.001$	p = 0.97
						Inversion	F = 7.0, $p\eta^2 = 0.3$	p = 0.017*

NS: No significance; *Significant difference ($p < 0.05$); **Significant difference ($p < 0.01$); -: No data; PF: Plantar Flexion; DF: Dorsi Flexion; JPS: Joint Position Sense; FAI: Functional Ankle Instability; JPR: Joint Position Reproduction.

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Table 7
Summary of trials investigating effects of taping on proprioception.

Reference	Outcome measures			Summary data for each intervention				
	Test & position	Device	Movement	Statistics			Effect estimates	p value
Alawna and Mohamed (2020)	Active JPR test Sitting position	Wooden slopes & goniometer	DF/PF	MANOVA	Comparison to the baseline measurements in all group (Taping; Bandaging; Control)	Immediately after support	–	$p > 0.05$
						2 weeks after support	–	$p < 0.01$**
						2 months after support	–	$p < 0.01$**
					Comparison between taping and bandaging	2 weeks after support	–	$p > 0.05$
						2 months after support	–	$p > 0.05$
					Comparison between taping and CG	2 weeks after support	–	$p < 0.02$*
						2 months after support	–	$p < 0.01$**
					Comparison between bandaging and CG	2 weeks after support	–	$p < 0.02$*
						2 months after support	–	$p < 0.01$**
Refshauge et al. (2000)	TTDPM (kinaesthesia) Sitting position	Footplate connected to a linear servomotor	DF/PF	3-way repeated measures ANOVA	Main effect for group (sprainers/CG) at any velocity		$F = 1.279$	$p = 0.27$
					Main effect for test (taped/untaped) at any velocity		$F = 1.220$	$p = 0.28$
Refshauge et al. (2009)	TTDPM (kinaesthesia) Sitting position	Footplate connected to a linear servomotor	Inversion/ eversion	3-way repeated measures ANOVA	Main effect for taping (Movement direction sense was worse when taped than untaped condition)		$F = 6.387$	$p = 0.023$*
					Main effect for direction		$F = 0.0015$	$p = 0.905$
Spanos et al. (2008)	Active JPR test Sitting position	Electrogoniometer	Inversion/ PF	T test (Taped/ untaped)	10° PF		$t = 2.716$	$p = 0.014$*
					30° PF		$t = 2.279$	$p = 0.034$*
					5° inversion		$t = 2.8986$	$p = 0.009$**
					20° inversion		$t = 2.953$	$p = 0.008$**

PF: Plantar Flexion; DF: Dorsi Flexion; JPR: Joint Position Reproduction; TTDPM: The Threshold to Detection of Passive Motion.

part of proprioceptive exercises in patients who sustained LAS, CAI or FAI. On the other hand, the few studies which used inelastic taping revealed poor effectiveness in improving impaired proprioception. Further studies with higher methodological quality are needed to elucidate the clinical effectiveness of disk training following LAS. Similarly, further investigations with sufficient sample size are required to assess the effectiveness of tape application on proprioceptive deficits after LAS.

CRediT authorship contribution statement

Shoko Otsuka: Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Roles, Writing – original draft. **Konstantinos Papadopoulos:** Supervision, Validation, Writing – review & editing. **Theodoros M. Bampouras:** Supervision, Validation. **Luca Maestroni:** Supervision, Validation, Writing – review & editing.

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