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Review article

Ankle Instability Patients Exhibit Altered Muscle Activation of Lower Extremity and Ground Reaction Force during Landing: A Systematic Review and Meta-Analysis

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Abstract

This review aimed to investigate characteristics of muscle activation and ground reaction force (GRF) patterns in patients with ankle instability (AI). Relevant studies were sourced from PubMed, CINAHL, SPORTDiscus, and Web of Science through December 2019 for case-control study in any laboratory setting. Inclusion criteria for study selection were (1) subjects with chronic, functional, or mechanical instability or recurrent ankle sprains; (2) primary outcomes consisted of muscle activation of the lower extremity and GRF during landing; and (3) peer-reviewed articles with full text available, including mean, standard deviation, and sample size, to enable data reanalysis. We evaluated four variables related to landing task: (1) muscle activation of the lower extremity before landing, (2) muscle activation of the lower extremity during landing, (3) magnitude of GRF, and (4) time to peak GRF. The effect size using standardized mean differences (SMD) and 95% confidence intervals (CI) were calculated for these variables to make comparisons across studies. Patients with AI had a lower activation of peroneal muscles before landing (SMD = -0.63, $p < 0.001$, CI = -0.95 to -0.31), greater peak vertical GRF (SMD = 0.21, $p = 0.03$, CI = 0.01 to 0.40), and shorter time to peak vertical GRF (SMD = -0.51, $p < 0.001$, CI = -0.72 to -0.29) than those of normal subjects during landing. There was no significant difference in other muscle activation and GRF components between the patients with AI and normal subjects ($p > 0.05$). Altered muscle activation and GRF before and during landing in AI cases may contribute to both recurrent ankle and ACL injuries and degenerative change of articular.

Key words: Ankle injury, non-contact injury, kinetic chain system, impact force, risk factor.

Introduction

A lateral ankle ligament sprain is one of the most common lower extremity injuries in activities and sports that consist of strenuous jumping and cutting maneuvers (Brown et al., 2004; Delahunt et al., 2006). Most (45% - 75%) individuals who have initially sprained their lateral ankle ligaments will be experience aggravation that progresses to chronic ankle instability (CAI), which is affected by functional instability (FI) or mechanical instability (MI) (Garrick and Requa, 1988; Tropp et al., 1985; Yeung et al., 1994). The characteristic symptoms of CAI including FI and MI are the recurrence of the ankle sprain, repeated “giving way” of the ankle joint, and constant complaints of pain, loss of function, structural alterations, and adaptations in the sensorimotor system (Gribble et al., 2013; 2016). These symptoms lead to decreased neuromuscular control, such as joint instability, strength deficit, nerve damage, and decreased proprioception (Boyle and Negus, 1998; Hertel, 2002; Theisen and Day, 2019).

Landing is one of the dynamic tasks that associated with injury mechanisms of the ankle or other lower extremity (e.g. anterior cruciate ligament injury) (Konradsen and Voigt, 2002; Olsen et al., 2004). Previous studies reported that greater peak ground reaction force (GRF) leads to either knee abduction moment or generate supination moment, which can cause non-contact ankle and knee injuries during landing (Hewett et al., 2005; Simpson et al., 2018). CAI may alter the kinetic-chain linkage system, providing altered transfer of force from distal to proximal in the lower extremity (Hertel, 2002; Terada et al., 2013). Therefore, a review of biomechanical analysis in the landing can provide insight into the progression to the pathological state of ankle instability (AI) or risk of other lower extremity injuries.

These changes in the proximal and distal joint mechanism in lower extremity may result from altered muscle activation patterns surrounding the ankle joint and further change in ground reaction patterns. Both of these factors have adverse effects on knee joint protection mechanism and may result in anterior cruciate ligament damage as well. Similarly, a previous study (Theisen and Day, 2019) performed a systematic review that found that CAI causes lower extremity kinematic changes during landing. It has also been demonstrated that individuals with CAI have decreased knee flexion as compared with those with ankle stability. However, the new model of CAI described by Hiller et al., (2011) showed that individuals with perceived instability, including MI, FI, and CAI, had several impairments as compared with the control group. Therefore, a review of previous studies is warranted to identify the causes of muscle activation patterns and GRF that result in kinematic changes in the AI group.

This review confirming an altered landing strategy for AI might lead to the development of more appropriate interventions, including treatment and rehabilitation protocols for clinicians in three aspects: First, reducing exacerbation possibility to chronic pathology results from ankle instability; second, preventing other injuries in lower

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extremity; and third, retraining movement pattern. Therefore, this meta-analysis aimed to clarify the muscle activation pattern and GRF of AI patients compared with normal subjects during landing. We hypothesize that patients with AI adopt different muscle activation and GRF before and during landing that result in altered muscle activation and GRF.

Methods

A systematic search was conducted to investigate the differences in landing strategies between patients with AI and individuals without instability by following the Preferred Reporting Items for Systemic Review and Meta-Analysis (PRISMA) guidelines (Moher et al., 2009).

Literature search

Comprehensive literature searches were performed to identify peer-reviewed journal articles on muscle activation or GRF during landing in patients with AI. Two independent authors (S.H. and H.G.J.) systematically searched the electronic databases PubMed, CINAHL, SPORTDiscus, and Web of Science from inception through December 2019 using a keyword search and Medical Subject Headings vocabulary (Table 1). The search was limited to studies involving humans, written in English, and reported in peer-reviewed journals. A hand search for relevant references was also performed on all systematically retrieved studies and identified articles were screened.

Eligibility criteria

The eligibility of the articles identified in the systematic search was assessed by two investigators (S.H. and H.G.J.) using the inclusion and exclusion criteria described in the following paragraphs.

Inclusion criteria

The inclusion criteria used to select and screen studies were as follows:

- The primary purpose of the study was to investigate the effect of patients with AI on GRF and muscle activation in landing.
- Task using anterior or vertical directions. Only the anterior or vertical direction task in the sagittal plane was included because this study intends to focus on lower extremity injuries, not ankle sprain, which occurred in patients with AI.
- Patients with AI were described as having CAI, FI, MI, or recurrent ankle sprains.
- The primary outcomes consisted of GRF and muscle activation during landing.
- The article reported descriptive points such as means, standard deviations, and sample size.
- Landing strategies of patients with AI were compared with those of normal subjects or copers. Copers were currently classified as normal for further data analysis because they do not have persistent symptoms or instability (e.g., pain and dysfunction in the lower extremity including the knee as well as the ankle joint; Jeon et al., 2021; Wikstrom and Brown, 2014).

Exclusion criteria

The exclusion criteria used to screen out studies was as follows:

- Task using lateral or diagonal directions.
- The authors did not use landing tasks on a flat surface.
- The study was a case study, guideline, systematic review, meta-analysis, or abstract.

Assessment of methodologic quality

The Critical Appraisal Skills Programme (CASP) case-control study checklist was used to assess the quality of the included studies. The checklist includes 12 questions and indicates total scores as a percentage. Two authors (S.H. and H.G.J.) independently reviewed the full text of the selected studies for quality analysis. Discrepancies in screening and scoring were addressed through collaboration between the authors until a consensus was reached.

Data extraction and analysis

Two independent authors performed the initial review and data extraction (S.H. and H.G.J.); the review process included assessing the aims and quality of studies, participant characteristics, inclusion criteria, intervention procedures, and outcome variables. The reviews discussed any discrepancies in data interpretation until a consensus was reached. If consensus could not be reached, any conflict of opinions was resolved through a third reviewer (S.E.P. and S.Y.L.).

The primary results for the meta-analysis were landing strategy, muscle activation of the lower extremity, magnitude of peak GRF, and time to peak GRF. The standardized mean differences (SMD) with 95% confidence intervals (CI) were calculated for the outcomes by subtracting patients with AI from normal subjects and are presented through a forest plot and funnel plot using R-Studio (version 1.2.1335, R-Studio, Inc.). Overall homogeneity was assessed to determine if every effect was from the same population. A fixed-effects model was used to estimate the overall effect, when the homogeneity test statistics were insignificant. When the heterogeneity was less than $p = 0.05$, a random-effects model was used that included the restricted maximum likelihood estimation method.

Table 1. Search keywords and relevant articles extracted from the search databases.

Search terms	PubMed	CINAHL	SPORTDiscus	Web of Science
1. Ankle instability OR CAI OR ankle sprain	64,128	2,838	2,772	9,370
2. Biomechanics OR kinetic OR electromyography OR EMG	1,833	362	519	819
3. Landing	54	49	84	123
4. Language [English]	54	49	84	122
5. Excluded duplicate study	136			
Total identified	173			

Muscle activations of the lower extremity

Muscle activations of the lower extremity refer to the surface integral before and during landing. The muscle activations of the lower extremity were sorted as follows: (1) gastrocnemius before landing (Brown et al., 2004; Suda et al., 2009), (2) peroneus before landing (Brown et al., 2004; Caulfield et al., 2004; Delahunt et al., 2006; Lin et al., 2011; Suda et al., 2009), (3) soleus before landing (Brown et al., 2004; Caulfield et al., 2004; Delahunt et al., 2006;), (4) tibialis anterior before landing (Brown et al., 2004; Caulfield et al., 2004; Delahunt et al., 2006; Suda et al., 2009), (5) gastrocnemius during landing (Brown et al., 2004; Suda et al., 2009), (6) peroneus during landing (Brown et al., 2004; Caulfield et al., 2004; Delahunt et al., 2006; Lin et al., 2011; Suda et al., 2009), (7) soleus during landing (Brown et al., 2004; Caulfield et al ., 2004; Delahunt et al., 2006), and (8) tibialis anterior during landing (Brown et al., 2004; Caulfield et al., 2004; Delahunt et al., 2006; Suda et al., 2009).

Magnitudes of peak GRF

Magnitudes of peak GRF refers to the maximum GRF during landing. The magnitudes of peak GRF were sorted as follows: (1) peak anterior GRF (Brown et al., 2008; Caulfield and Garrett, 2004), (2) peak posterior GRF (Brown et al., 2008; Caulfield and Garrett, 2004), (3) peak medial GRF (Brown et al., 2008; Caulfield and Garrett, 2004; Zhang et al., 2012), (4) peak lateral GRF (Brown et al., 2008; Caulfield and Garrett, 2004), and (5) peak vertical GRF (Brown et al., 2008; Caulfield and Garrett, 2004; De Ridder et al., 2015; Doherty et al., 2015; Lee et al., 2017; Zhang et al., 2012).

Times to peak GRF

Times to peak GRF refers to the time from the initial contact with the ground to maximum GRF in each direction. The times to peak GRF were sorted as follows: (1) time to peak anterior GRF (Brown et al., 2008; Caulfield and Garrett, 2004), (2) time to peak posterior GRF (Brown et al., 2008; Caulfield and Garrett, 2004; Delahunt et al., 2006), (3) time to peak medial GRF (Brown et al., 2008; Caulfield and Garrett, 2004; Delahunt et al., 2006), (4) time to peak lateral GRF (Brown et al., 2008; Caulfield and Garrett, 2004; Delahunt et al., 2006), and (5) time to peak vertical GRF (Brown et al., 2008; Caulfield and Garrett , 2004; De Ridder et al., 2015; Delahunt et al., 2006; Zhang et al., 2012).

Assessment of publication bias

After reviewing the meta-analysis data through the forest plot, the asymmetry of the effect size was first judged visually through the funnel plot. In addition, the relationship between the effect size and the standard error was verified using Egger's regression to determine whether the funnel plot was asymmetric or not. In the case of asymmetry, we calculated the average effect size obtained by adjusting the asymmetry through the trim-and-fill method and compared it with the original average effect size.

Level of evidence and strength of recommendation

The Strength of Recommendation Taxonomy (SORT) was used in the quality assessment of the individual studies and the body of evidence (Ebell et al., 2004). Pooled studies were classified from level 1 to 3 as per the study quality. In the present study, level 1 evidence was considered as CASP scores ≥ 80%, level 2 evidence was considered as 50% < CASP scores < 80%, and level 3 evidence was considered as CASP scores ≤ 50% (Ebell et al., 2004). The strength of recommendation of the SORT was used to determine the pooled body of evidence. The SORT reports grade A as "consistent and good quality patient-oriented evidence," B as "inconsistent or limited quality patient-oriented evidence," and C as "consensus, usual practice, opinion, disease oriented evidence, and case series for studies of diagnosis, treatment, prevention or screening" (Ebell et al., 2004).

Results

Study selection

Three hundred nine articles were identified from PubMed, SPORTDiscus, CINAHL, and Web of Science. Of these, 136 were eliminated because of study duplication. Among these 173 papers, 85 were not related to patients with AI or functional landing task, as determined by review of the title. Thirty-nine articles were eliminated based on their abstracts. Forty-two articles were eliminated after reviewing the full text. Repeated-measures papers were excluded because of the lack of a normal comparison to patients with AI. Eventually, after the elimination of articles, seven full-text articles met the criteria for the meta-analysis. Furthermore, 4 additional papers were found through cross-referencing, and ultimately, 11 papers were selected. These articles were used to determine whether patients with AI alter GRF and muscle activation during landing. Figure 1 shows the step-by-step process of article exclusion.

Eleven studies were included in the current research synthesis. Of the 11 studies selected by 2 investigators (S.H. and H.G.J.), 5 studies (Brown et al., 2004; Caulfield and Garrett e, 2004; Caulfield et al., 2004; Delahunt et al., 2006; Suda et al., 2009) compared FI to the control group, 3 studies (Lin et al 2011;Lee et al 2017;Zhang et al 2012) compared CAI to the control group. Another study (Brown et al., 2008) investigated the relationship among FI, MI, and the coper group. One study (De Ridder et al., 2015) investigated the relationship among patients with CAI, copers, and control group. One study (Doherty et al., 2015) investigated the association between CAI and copers. Specifically, one study (Zhang et al., 2012) demonstrated the effects of the brace in patients with CAI compared with the control group, but we included only the data before brace intervention in the present study. Table 2 presents a methodologic summary of the included studies.

Methodologic quality assessment

The average methodologic quality of the included studies was 8.3 out of a possible 12 (range, 6 - 9; Table 3). All studies had case-control designs and were thus classified as level 2 evidence according to SORT (Brown et al., 2004; 2008; Caulfield and Garrett, 2004; Caulfield et al., 2004; Lin et al., 2011; De Ridder et al., 2015; Delahunt et al., 2006; Doherty et al., 2015; Lee et al., 2017; Suda et al., 2009; Zhang et al., 2012). Because studies did not describe the effects of treatment and controlling for confounding factors, they were unable to receive a maximum score on the CASP.

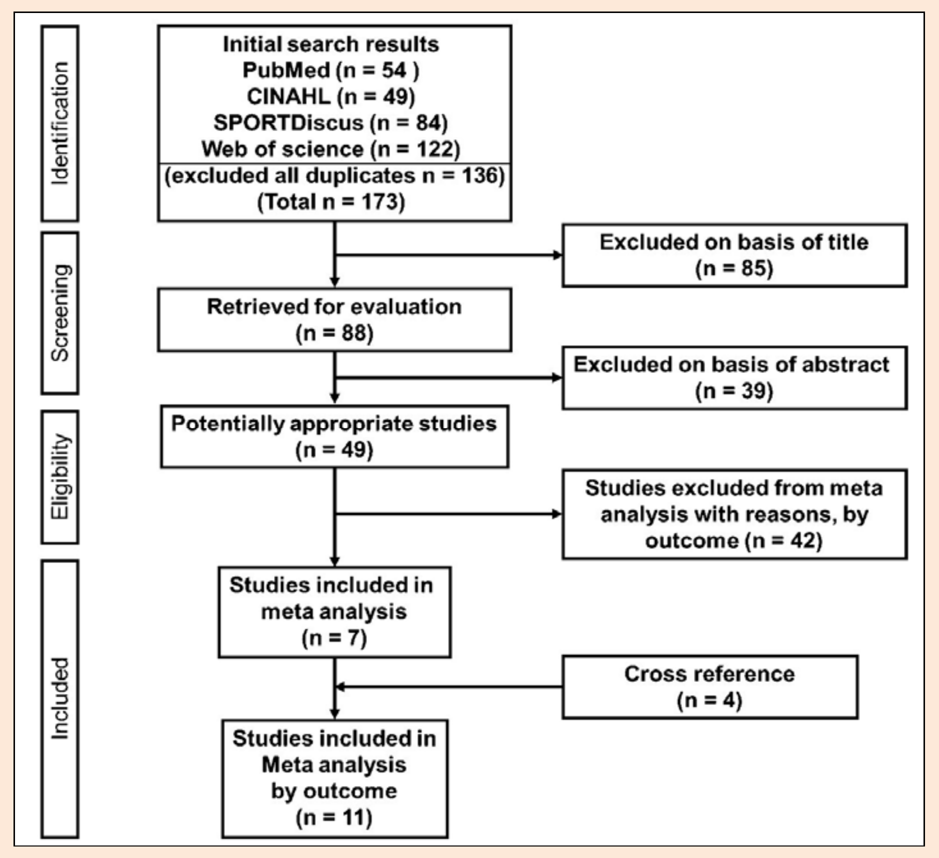

Figure 1. Flow chart of the selection process for studies. Overall selection process for systematic review in compliance with the PRISMA flow diagram.

Data Synthesis

Muscle activation before landing

The effect of muscle action before landing was evaluated: gastrocnemius ($k = 2$), peroneus ($k = 6$), soleus ($k = 4$), and tibialis anterior ($k = 5$). Figure 2 shows the overall effect size measures found to be with an overall mean effect size for gastrocnemius ($I^2 = 40\%$, $Q(1) = 1.68$, $p = 0.19$), peroneus ($I^2 = 31.17\%$, $Q(5) = 7.26$, $p = 0.20$), soleus ($I^2 = 0\%$, $Q(3) = 0.22$, $p = 0.97$), and tibialis anterior ($I^2 = 0\%$, $Q(4) = 3.40$, $p = 0.50$). Therefore, a fixed-effects model was used to estimate the overall effect of muscle activation on patients with AI before landing. Under the fixed-effects model, the overall difference in activation in the peroneal muscle was found to be statistically significant ($d = -0.63$, $SE = 0.16$, 95% CI = -0.95 to -0.31), indicating that the peroneal muscle was less activated in patients with AI compared with normal subjects before landing ($z = -3.87$, $p < 0.001$).

Muscle activation during landing

The effect of muscle action during landing was evaluated: gastrocnemius ($k = 2$), peroneus ($k = 6$), soleus ($k = 4$), and tibialis anterior ($k = 5$). Figure 3 shows the overall effect size measures found to be with an overall mean effect size for gastrocnemius ($I^2 = 6\%$, $Q(1) = 1.07$, $p = 0.30$), peroneus ($I^2 = 0\%$, $Q(5) = 1.42$, $p = 0.92$), soleus ($I^2 = 43\%$, $Q(3) = 5.30$, $p = 0.15$), and tibialis anterior ($I^2 = 0\%$, $Q(4) = 1.48$, $p = 0.83$). Therefore, a fixed-effects model was used to estimate the overall effect of muscle activation in patients with AI during landing. There was no difference in any muscle activation of the lower leg during landing between patients with AI and controls.

Magnitude of peak GRF during landing

The effect of peak GRF during landing was evaluated: anterior GRF ($k = 5$), posterior GRF ($k = 5$), medial GRF ($k = 6$), lateral GRF ($k = 5$), and vertical GRF ($k = 9$). Figure 4 shows the overall effect size measures found to be from the same population with an overall mean effect size for anterior GRF ($I^2 = 0\%$, $Q(4) = 1.35$, $p = 0.85$), posterior GRF ($I^2 = 0\%$, $Q(4) = 0.65$, $p = 0.96$), medial GRF ($I^2 = 0\%$, $Q(5) = 1.64$, $p = 0.90$), lateral GRF ($I^2 = 0\%$, $Q(4) = 0.98$, $p = 0.91$), and vertical GRF ($I^2 = 0\%$, $Q(8) = 4.02$, $p = 0.86$). Therefore, a fixed-effects model was used to estimate the overall effect of peak GRF in patients with AI during landing. Under the fixed-effects model, the overall difference in peak vertical GRF was found to be statistically significant ($d = 0.21$, $SE = 0.10$, 95% CI = 0.01 to 0.40), indicating that peak vertical GRF was greater in patients with AI as compared with normal subjects during landing ($z = 2.11$, $p = 0.03$).

Table 2. Methodologic summary of the studies included in the review (continued on next page).

Author	Study design	Comparison group	Ankle instability group inclusion criteria	Exclusion criteria	Task	Outcome measures	Results
Brown et al (2004)	Case-control study	FI (n = 10) CON (n = 10)	Skill level from recreational to club sport who perform 30 minutes, 3 times per week Recurrent ankle sprain at least 2 in the 1 year Feeling of "giving way" with activity AJFAT $\leq$ 20	Had lower extremity injury in 3 months before History of lower extremity surgery	Single-leg jump landing (50% of maximum jump height)	Percentage of mean EMG amplitude for TA, PL, GCM, SOL in pre-landing (200 ms before) and during landing phase (1000 ms after)	No significant differences between groups were found in the 200 ms before landing for any muscle Only the SOL exhibited significant differences between groups in the 1000 ms after landing. The CON had significantly higher mean EMG amplitude after landing compared with the FI group
Brown et al (2008)	Case-control study	FI (n = 21) MI (n = 21) Coper (n = 21)	Recreational activity at least 1.5 total hours of cardiovascular, resistance, sport-related, or other physical activity per week. History of acute inversion ankle sprain requiring immobilization or non–weight bearing for at least 3 days. Repeated episodes of "giving way" Complaints of ankle instability secondary to the initial sprain, with a minimum of 2 episodes of giving way or spraining in the past 12 months Positive anterior drawer and/or talar tilt test (MI) Negative anterior drawer and/or talar tilt test (FI)	History of surgery or any ankle fracture Had lower extremity injury in the past 3 months Obvious swelling or discoloration Ankle pain, gross limitations in ankle ROM, self-reported instability of the knee or hip Current enrollment in a rehabilitation program	Single-leg drop jump landing (from 32 cm height) & running stop jump landing	Normalized magnitude of peak V, A, P, M, L GRF (xBW) TTP V, A, P, M, L GRF (ms)	Drop jump landing: No significant difference between groups in peak GRF and TTP GRF Running stop jump: No significant difference between groups in peak GRF and TTP GRF
Caulfield et al (2004)	Case-control study	FI (n=12) CON (n=10)	Involved in sporting activities History of a minimum of 2 inversion injuries requiring a period of protected weight bearing and/ or immobilization Chronically weaker, more painful, and less function Complaints are reported to be secondary to past history of inversion sprain	History of fracture to the lower extremity History of neurological or vestibular illness	Single-leg jump landing (from 40 cm height) & forward jump landing (from 100 cm distance)	IEMG for SOL, PL, TA in pre-landing (150 ms before) and during landing phase (150 ms after)	No significant differences between the groups in terms of SOL or TA IEMG activity before or after impact in either jumping activity Increase in TA activity before impact in downward jump and a decrease in TA before impact in the jump for distance in the FI group compared with controls The FI group exhibited a statistically significant reduction in PL IEMG compared with the control group during the pre-impact period in both jumping activities

A, anterior; ADL, activity of daily living; AII, ankle instability instrument; AJFAT, ankle joint junctional assessment tool; ATSF, anterior tibial shear force; xBW, normalized to multiple of body weight; CAI, chronic ankle instability; CAIT, Cumberland ankle instability tool; CON, control group; EMG, electromyography; FI, functional instability; GCM, gastrocnemius; GRF, ground reaction force; IC, initial contact; IEMG, integrated electromyography; L, lateral; M, medial; MI, mechanical instability; P, posterior; PL, peroneus longus; RMS, root mean square; SOL, soleus; TA, tibialis anterior; TTP, time to peak; V, vertical.

Table 2. **Continue...**

Author	Study design	Comparison group	Ankle instability group inclusion criteria	Exclusion criteria	Task	Outcome measures	Results
Caulfield and Garrett (2004)	Case-control study	FI (n=10) CON (n=14)	Participants in recreational sporting activities History of a minimum of 2 inversion injuries Chronically weaker, more painful, and less function of ankle Giving way during sporting activities	Receiving rehabilitation at the time of the study History of fracture to the lower extremity	Single-leg jump landing (from 40 cm height)	Normalized magnitude of peak V, A, P, M, L GRF (%BM) TTP V, A, P, M, L GRF (ms)	Peak L and A peak GRF occurred significantly earlier in subjects with FI. Significant differences in time-averaged vertical, frontal and sagittal components of GRF
Delahunt et al (2006)	Case-control study	FI (n = 24) CON(n = 21)	History of a minimum of 2 inversion injuries requiring a period of protected weight-bearing and/or immobilization Chronically weaker, more painful, and less function Reports a tendency for the ankle to give way during sporting activities Complaints are reported to be secondary to past history of inversion sprain	History of fracture to the lower extremity History of neurological or vestibular impairments Receiving formal rehabilitation program	Single-leg drop landing(from 35 cm height)	IEMG activity for SOL, PL, TA in pre-landing (200 ms before) and during landing phase (200 ms after) TTP V L, M, P GRF (ms)	Significant decrease in pre-landing of PL IEMG FI subjects had an increase in the V GRF during the time period of 35–60 ms after IC and a more medially directed GRF during the time period of 85–105 ms after IC FI subjects had an increased P GRF during the time period after IC and reached their TTP P GRF earlier than CON
De Ridder et al (2015)	Case-control study	CAI (n = 30) CON (n = 30) Coper (n = 28)	History of at least one ankle sprain which resulted in pain, swelling and stiffness prohibiting participation in sport, recreational or other activities for at least 3 weeks Repeated ankle sprains Presence of giving way Feeling of weakness around the ankle Decreased functional participation as result of ankle sprains	History of ankle fracture or surgery, lower-limb pain Having equilibrium deficits	Single-leg drop landing (from 40 cm height)	Normalized magnitude of peak V GRF TTP V GRF (sec)	The CAI group displayed a higher peak vertical GRF and reached this vertical peak faster than the CON for the vertical drop
Doherty et al (2015)	Case-control study	CAI (n = 28) Coper (n = 42)	CAIT < 24	Severe lower extremity injury in the past 6 months History of ankle fracture and surgery History of neurological disease, vestibular or visual disturbance	Single-leg drop landing (from 40 cm height)	Normalized magnitude of peak V GRF	No significant differences for peak V GRF
Lee et al (2017)	Case-control study	CAI (n = 19) CON (n = 19)	History of at least 1 acute lateral ankle sprain that resulted in swelling, pain, and temporary loss of function At least 1 episode of the ankle giving wayin the previous 6–24 months CAIT < 27	History of lower extremity injury History of other lower extremity injury within the past 6 months History of lower extremity fracture or surgery	Single-leg drop landing (from 40 cm height)	Normalized magnitude of peak V GRF	The peak V GRF was significantly reduced at post fatigue in both athletes with CAI and control

A, anterior; ADL, activity of daily living; AII, ankle instability instrument; AJFAT, ankle joint junctional assessment tool; ATSF, anterior tibial shear force; xBW, normalized to multiple of body weight; CAI, chronic ankle instability; CAIT, Cumberland ankle instability tool; CON, control group; EMG, electromyography; FI, functional instability; GCM, gastrocnemius; GRF, ground reaction force; IC, initial contact; IEMG, integrated electromyography; L, lateral; M, medial; MI, mechanical instability; P, posterior; PL, peroneus longus; RMS, root mean square; SOL, soleus; TA, tibialis anterior; TTP, time to peak; V, vertical.

Table 2. Continue...

Author	Study design	Comparison group	Ankle instability group inclusion criteria	Exclusion criteria	Task	Outcome measures	Results
Lin et al (2011)	Case-control study	CAI (n = 15) CON (n = 15)	Having at least 1 ankle sprain that resulted in swelling, pain, and protected weight bearing and/or immobilization of the injured ankle Having episodes of the ankle “suddenly giving way” and at least 2 ankle sprains within the past 2 years Suffering from ankle sprain at least once in the past 6 months CAIT ≤ 27 The ligamentous integrity of the ankle joint was evaluated for each participant via an anterior drawer test, a posterior drawer test, and a talar tilt test.	History of lower extremity fractures or any serious orthopedic injury Acute inflammation in the lower extremities	Double-leg running stop jump landing	RMS of PL in pre-landing (100 ms to IC) and during landing (IC to 100 ms) phase	No significant differences for RMS of PL in both phase
Suda et al (2009)	Case-control study	FI (n = 21) CON (n = 19)	History of at least 1 sprain needing practice leave more than 3 months Instability complaints: tendency for the ankle to give way during sports activities Difficulties in walking and running on irregular surfaces Difficulty to jump and change directions and sprain recurrence. Negative results in the ADT	No information	Double-leg vertical jump landing after volleyball blocking	RMS values for TA, PL, GCM in pre-landing (200 ms before) and during landing (200 ms after) phase	The RMS value of PL was significantly lower in FI in the before landing phase, and the RMS value of the TA muscle was significantly higher in the after landing phase
Zhang et al (2012)	Case-control study	CAI (n = 10) CON (n = 10)	Screening use AJFAT Arch index measurements Multiple ankle sprains in past 12 months and beyond	Ankle sprains in past 3 months	Double-leg drop landing (from 60 cm height)	Normalized magnitude of peak V GRF TTP V GRF (sec)	The peak V GRF for no brace was smaller than a semi rigid ankle brace The TTP V GRF was significantly shorter in semi rigid ankle brace compared with no brace and a soft ankle brace and in a soft ankle brace compared with no brace

A, anterior; ADL, activity of daily living; AII, ankle instability instrument; AJFAT, ankle joint junctional assessment tool; ATSF, anterior tibial shear force; xBW, normalized to multiple of body weight; CAI, chronic ankle instability; CAIT, Cumberland ankle instability tool; CON, control group; EMG, electromyography; FI, functional instability; GCM, gastrocnemius; GRF, ground reaction force; IC, initial contact; IEMG, integrated electromyography; L, lateral; M, medial; MI, mechanical instability; P, posterior; PL, peroneus longus; RMS, root mean square; SOL, soleus; TA, tibialis anterior; TTP, time to peak; V, vertical.

Table 3. **Methodological quality score using the CASP scale of relevant studies.**

CASP scale	Brown et al (2004)	Brown et al (2008)	Caulfield & Garrett (2004)	Caulfield et al (2004)	Delahunt et al (2006)	De Ridder et al (2015)	Doherty et al (2016)	Lee et al (2017)	Lin et al (2011)	Suda et al (2009)	Zhang et al (2012)
1. Did the study address a clearly focused issue?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Did the authors use an appropriate method to answer their question?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Were the cases recruited in an acceptable way?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4. Were the controls selected in an acceptable way?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
5. Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	CT
6. Aside from the experimental intervention, were the groups treated equally?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7. Have the authors taken account of the potential confounding factors in the design and/or in their analysis?	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
8. How large was the treatment effect?	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
9. How precise was the estimate of the treatment effect?	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT	CT
10. Do you believe the results?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11. Can the results be applied to the local population?	Yes	Yes	Yes	Yes	CT	CT	Yes	CT	Yes	Yes	Yes
12. Do the results of this study fit with other available evidence?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	CT
Yes score (%) *	9 (75)	9 (75)	9 (75)	9 (75)	8 (67)	8 (67)	9 (75)	8 (67)	8 (67)	9 (75)	6 (50)
Level of evidence	2	2	2	2	2	2	2	2	2	2	2

* Scores are based on items 1 thorough 12. CASP, Critical Appraisal Skills Programme; CT, cannot tell.

Time to peak GRF during landing

The effect of peak GRF during landing was evaluated: time to peak anterior GRF ($k = 5$), time to peak posterior GRF ($k = 6$), time to peak medial GRF ($k = 6$), time to peak lateral GRF ($k = 6$), and time to peak vertical GRF ($k = 8$). Figure 5 shows the overall effect size measures found to be from the same population with an overall mean effect size for time to peak anterior GRF ($I^2 = 71\%$, $T(4) = 0.24$, $Q(4) = 12.84$, $p = 0.01$), time to peak posterior GRF ($I^2 = 72\%$, $T(5) = 0.28$, $Q(5) = 18.26$, $p < 0.01$), time to peak medial GRF ($I^2 = 0\%$, $Q(5) = 1.51$, $p = 0.91$), time to peak lateral GRF ($I^2 = 33\%$, $Q(5) = 5.02$, $p = 0.41$), and time to peak vertical GRF ($I^2 = 0\%$, $Q(7) = 6.11$, $p = 0.53$). Therefore, a fixed-effects model was used to estimate the overall effect of time to peak GRF on patients with AI during landing, except for time to peak anterior and posterior GRF. Under the fixed-effects model, the overall difference in the time to peak vertical GRF was found to be statistically significant ($d = -0.51$, $SE = 0.11$, 95% CI = -0.72 to -0.29), indicating that time to peak vertical GRF was faster in patients with AI as compared with normal subjects during landing ($z = -4.65$, $p < 0.001$).

Publication bias

The likelihood of publication bias was assessed using a funnel plot (Figures 2 - 5) and Egger's regression. Additional analysis using the trim-and-fill method also indicated that publication bias was not likely to have influenced the overall result.

Level of evidence and strength of recommendation

Grade B evidence indicated nonconsensus effects of area of muscle activation both before and during landing between the patients with AI and normal subjects. Because the studies that included a variable for muscle activation all had a case-control design, this recommendation was classified as level 2 (Brown et al., 2004; Caulfield et al., 2004; Lin et al., 2011; Delahunt et al., 2006; Suda et al., 2009). For the peak GRF and time to GRF variables, grade B evidence was observed between the patients with AI and normal subjects. This recommendation was also classified as level 2 (Delahunt et al., 2006; Brown et al., 2008; Caulfield and Garrett, 2004; De Ridder et al., 2015; Doherty et al., 2015; Lee et al., 2017; Zhang et al., 2012).

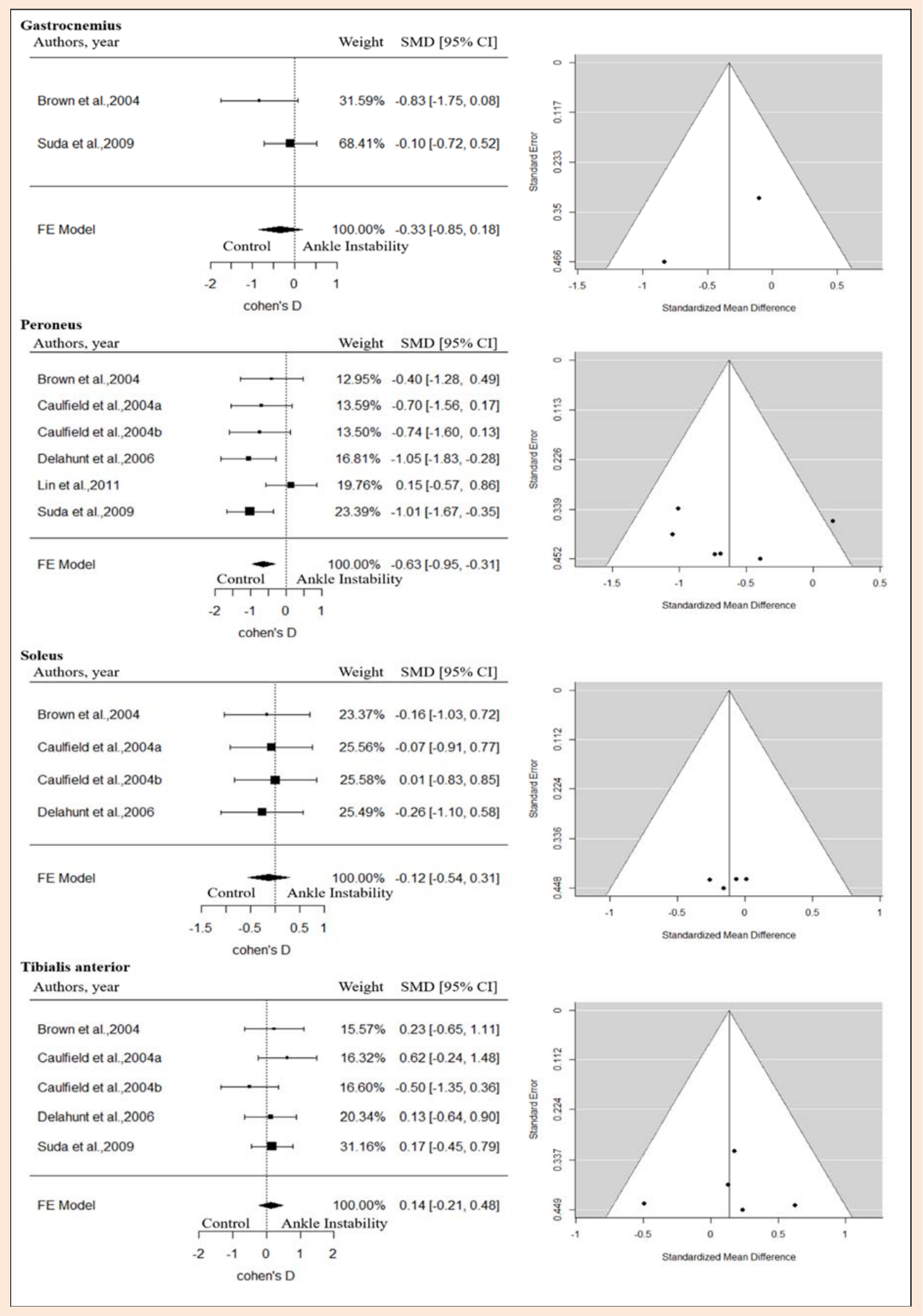

Figure 2. Forest plots of the meta-analysis for SMD in area of muscle activation of the lower leg before landing (left side) and funnel plots of standard error by each muscle for the studies included in the meta-analysis (right side). For Caulfield et al. 2004a and 2004b refer to two different landing conditions by the same study: a was identified muscle activity from initial contact to 150 ms during sing leg jump landing from 40 cm height; b was identified muscle activity from initial contact to 150 ms during sing leg jump landing from 100 cm distance. Abbreviations: CI, confidence interval; FE, fixed-effects; SMD, standardized mean difference

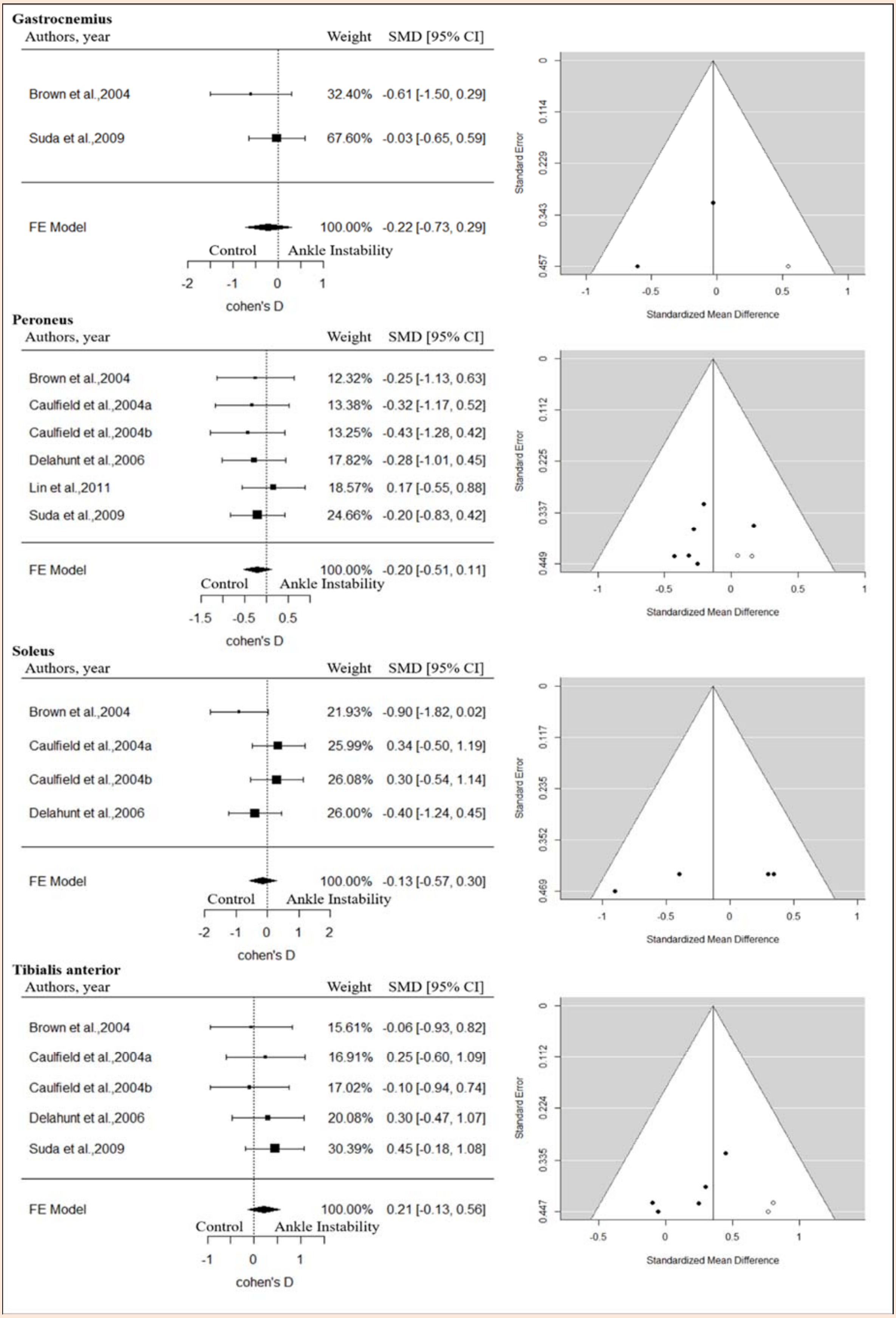

Figure 3. Forest plots of the meta-analysis for SMD in area of muscle activation of the lower leg during landing (left side) and funnel plots of standard error by each muscle for the studies included in the meta-analysis (right side). For Caulfield et al 2004 *a* and *b* refer to two different landing conditions by the same study: *a* was identified muscle activity from initial contact to 150 ms during sing leg jump landing from 40 cm height; *b* was identified muscle activity from initial contact to 150 ms during sing leg jump landing from 100 cm distance. Abbreviations: CI, confidence interval; FE, fixed-effects; SMD, standardized mean difference.

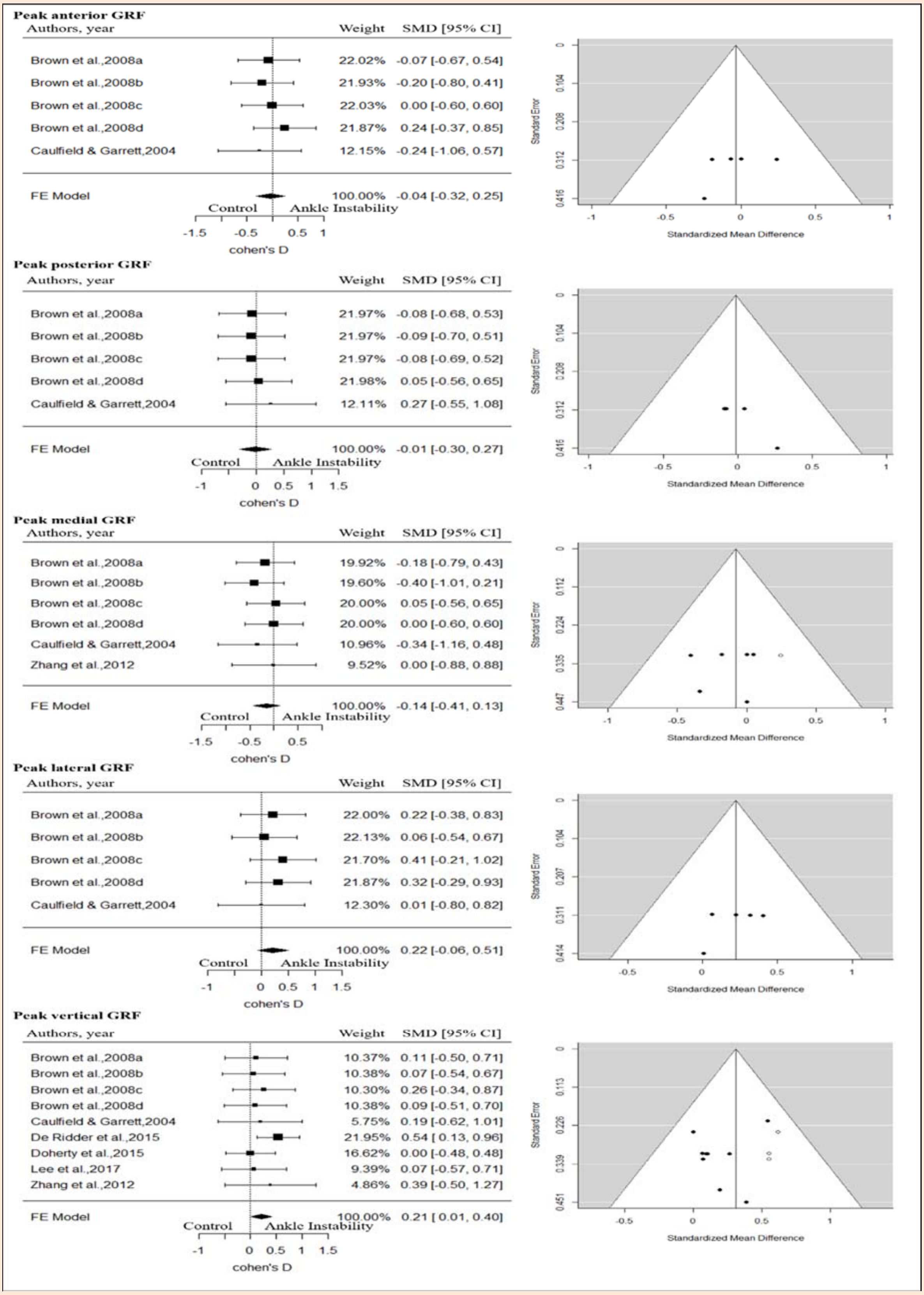

Figure 4. **Forest plots of the meta-analysis for SMD in the magnitude of peak GRF during landing (left side) and funnel plots of standard error by each direction of peak GRF for the studies included in the meta-analysis (right side).** For Brown et al 2008 *a*, *b*, *c*, and *d* refer to two different landing tasks and three groups (MI, FI, and coper) by the same study: *a* was compared FI and coper during single-leg drop jump landing; *b* was compared FI and coper during running stop jump landing; *c* was compared MI and coper during single-leg drop jump landing; *d* was compared MI and coper during running stop jump landing. Abbreviations: CI, confidence interval; FE, fixed-effects; FI, functional instability; MI, mechanical instability; SMD, standardized mean difference.

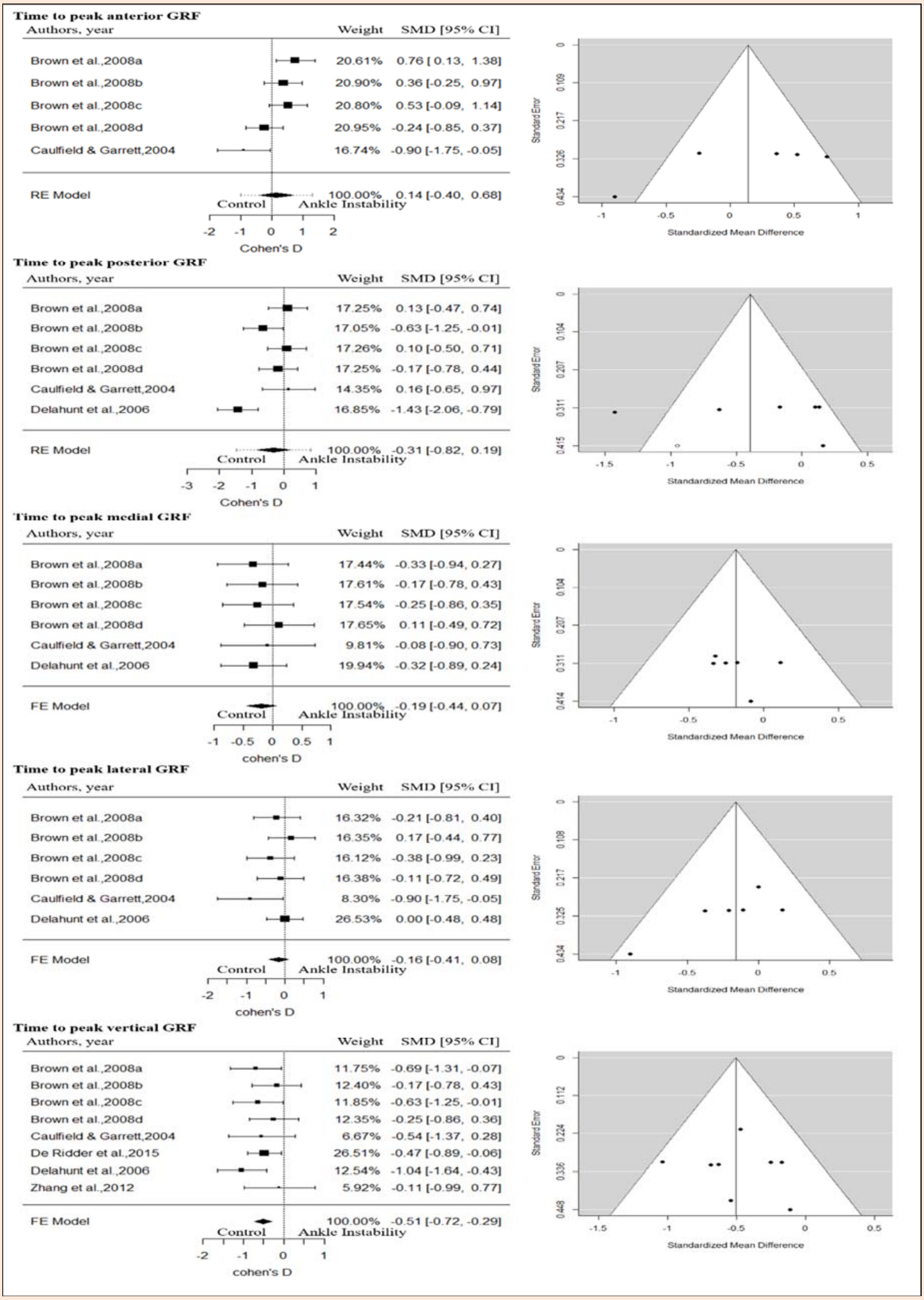

Figure 5. Forest plots of the meta-analysis for SMD in time to peak ground reaction force during landing (left side) and funnel plots of standard error by each direction of time to peak GRF for the studies included in the meta-analysis (right side). For Brown et al 2008 *a, b, c,* and *d* refer to two different landing tasks and three groups (MI, FI, and coper) by the same study: *a* was compared FI and coper during single-leg drop jump landing; *b* was compared FI and coper during running stop jump landing; *c* was compared MI and coper during single-leg drop jump landing; *d* was compared MI and coper during running stop jump landing. Abbreviations: CI, confidence interval; FE, fixed-effects; FI, functional instability; MI, mechanical instability; RE, random-effects; SMD, standardized mean difference.

Discussion

This study aimed to conduct a systematic review and meta-analysis to observe whether the altered muscle activation and GRF of patients with AI associate with ACL injury and degenerative change of ankle and knee articular cartilage during landing task. This meta-analysis extracted data from 11 studies that compared outcomes between patients with AI and normal subjects. The major finding of this study were as follows: (1) peroneal muscle activation was lower in patients with AI than that in normal subjects before landing, (2) patients with AI demonstrated a greater peak vertical GRF than normal subjects during landing, and (3) patients with AI had an earlier time to peak vertical GRF than normal subjects during landing. The results of this systematic review and meta-analysis could provide significant evidence that AI could be a risk factor not only for recurrent ankle sprain but also for ACL injury and degenerative change of ankle and knee articular cartilage when compared with normal subjects. This altered landing strategy may represent a potential impaired lower extremity neuromuscular in patients with AI. Grade B evidence supported the current findings indicated by consistent level 2 evidence.

Area of the muscle activation of the lower leg

We found grade B evidence that peroneal muscle activation (SMD = -0.63, CI = -0.95 to -0.31) was lower before landing in patients with AI as compared with normal subjects. Evaluation of AI effects produced strong effects on peroneal muscle activation with CI that did not cross 0 during landing. Peroneal muscle and its surrounding tissue are both passive and neurological structures in the lateral ankle complexes that are primarily damaged after an initial lateral ankle sprain. Recurrent lateral ankle sprains occurred in all types of AI, including MI, FI, and CAI (Hiller et al., 2011). Structural damage, functional deficit, or a combination of both has been hypothesized as a cycle of repetitive pathological ankle injury occurrence. In general, the activated peroneal muscles in individuals with normal stability can be interpreted as an activity that brings about the inversion of the foot into a neutral position upon landing (Ashton-Miller et al., 1996; Konradsen and Voigt, 2002; Suda et al., 2009). However, patients with AI could not activate the peroneal muscle due to an impairment or deficit of the proprioceptive system and/or muscle. The previous studies reported AI patients observed increased inversion of the subtalar joint before landing (Caulfield and Garrett, 2002; Delahunt et al., 2006). Thus, it may be caused by the altered peroneal muscle activation based on the results of this study. The altered neuromuscular system of the lower extremity resulting from damaged tissue after initial and/or recurrent ankle sprain may lead to the decrease of both appropriate efferent responses before landing and afferent feedback during a landing task. Eventually, episodes of instability and ankle sprain could repeatedly occur because incomplete or decreased activation of peroneal muscle could not adequately control the ankle joint. Moreover, the ankle sprain is caused by unexpected situations in sports. Thus, the role of the peroneal muscle is to position a neutral or pronation of the subtalar joint before the foot comes in contact with the ground, which is important to prevent a lateral ankle sprain.

The laboratory environment or setting (e.g., the starting height of the jump, the landing position, and the landing maneuvers) considerably varied in each study pooled for use in the current study. There was no agreement in landing tasks between studies in which a statistically significant effect size was observed (Delahunt et al., 2006; Suda et al., 2009). Suda et al. 2009 reported significant results of the peroneal muscle with lower activity in the FI group before landing. Because they investigated high-level tasks, such as volleyball blocking by recruiting athletes, compared with other studies (Brown et al., 2004; Caulfield et al., 2004; Delahunt et al., 2006; Lin et al., 2011) investigating peroneal muscle, the peroneal activation can be a key factor to prevent recurrent ankle sprain in the task requesting high performance. In addition, the group composition of the study that constituted the results was composed of FI and CAI, but the group was not clearly defined through the special test except for one study (Suda et al., 2009). A special test was performed in the study in which the subjects were selected as the CAI group, but FI and MI were not distinguished and defined as one group (Lin et al., 2011). In the study defined as the remaining FI group, the special test was not performed, so information on FI and MI was omitted (Brown et al., 2004; Caulfield and Garrett, 2002; Delahunt et al., 2006). Additionally, the definition of analysis intervals before and after landing, EMG data processing methods (mean, root mean square or integral EMG), and standardization methods (maximum voluntary isometric contraction or maximum voluntary contraction from the maximum value of the task) were also observed in considerable variety. However, despite various studies, decreased peroneal muscle in patients with AI indicates that ankle instability may be affected by muscles located in the lateral compartment of the lower leg.

Although grade B evidence was found on the overall summary effects of other muscle activations including gastrocnemius (SMD = -0.33, CI = -0.85 to 0.18), soleus (SMD = -0.12, CI = -0.54 to 0.31), and tibialis anterior (SMD = 0.14, CI = -0.21 to 0.48), all of these muscle activations were associated with CI that crossed 0 before landing, unlike the peroneal muscle. However, no difference in lower extremity muscle activity according to AI was demonstrated in this review during landing. These muscles are among the important components contributing to the stability of the lower extremities including the knee joint. The activation of lower leg muscles could affect proximal joint kinematics because the knee joint movement is caused by the rolling and gliding of the lower leg relative to the thigh or the thigh relative to the lower leg. Gastrocnemius, one of the crossings of the knee joint in the lower leg muscle groups, contributes especially to the anteroposterior knee joint stability during the task-preparation phase (Klyne et al., 2012). Moreover, Terada et al. (2014) have demonstrated that CAI patients have greater preactivation in vastus medialis compared with the control. These results partially supported the compensatory mechanism of the lower extremity kinetic chain for decreased ankle stability. Thus, an increase in the activation of vastus medialis in landing may be related to an increase in mediolateral knee movement that threatens damage to the knee joint in the frontal plane because of the attachment of the medial border of the patellar (Toumi et al., 2007).

Grade B evidence showed that the overall summary effects of all muscle activations including gastrocnemius (SMD = -0.22, CI = -0.73 to 0.29), peroneus (SMD = -0.20, CI = -0.51 to 0.11), soleus (SMD = -0.13, CI = -0.57 to 0.30), and tibialis anterior (SMD = 0.21, CI = -0.13 to 0.56) were found to be associated with CI that crossed 0 during landing. The findings suggested the absence of inter-group differences with regard to muscle activations of the lower leg during landing. These may be attributable to the fact that somatosensory information increases more as the feet touch the ground during landing than before landing. The result of muscle activation in the lower leg suggests that muscle activation patterns before landing may be more important and valuable compared with those during landing as preprogrammed motor control. In addition, peroneal muscle activation before ground contact is a factor to compensate for ankle instability. Regarding the subjects with AI in this study, a compensatory mechanism may exist not only in the lower leg muscles but also in the muscle that crosses the knee joint for ankle instability in the lower extremity kinetic-chain system. Although this review searched and pooled previous studies regarding landing tasks, limited variables were included to observe the effect of AI on the muscles of the proximal joint. Therefore, this study could not present significant evidence or levels for the muscles of the proximal joint to support the AI effects on the knee joint.

The muscles in the lower extremity kinetic system need to be examined overall because the femoral or hip muscle group could activate to compensate for distal joint instability. To support this possibility, several studies are needed to examine the gluteus and quadriceps muscles and the ratio of these muscles in AI patients during the landing task. Consequently, the possibility of the importance of the neuromuscular control system before landing compared with during landing was supported to provide adequate stabilization of joint and prevent lower extremity injuries because all studies reported significant differences in the muscles of the proximal joint precontact phase (Delahunt et al., 2006; Terada et al., 2014).

Ground reaction force

We found grade B evidence that the magnitude of peak vertical GRF (SMD = 0.21, CI = 0.01 to 0.40) was greater in patients with AI than normal subjects. Evaluation of AI effects produced weak effects on the magnitude of peak vertical GRF with CI that did not cross 0. Additionally, we found grade B evidence that time to peak vertical GRF (SMD = -0.51, CI = -0.72 to -0.29) was shorter in patients with AI than normal subjects. Evaluation of AI effects produced moderate effects on time to peak vertical GRF with CI that did not cross 0. These increased GRF parameters could be interpreted as the effects of AI that deficit the ability to control weight acceptance, maintenance, and absorption. Insufficient neuromuscular control of the foot/ankle complex in the preparatory contact phase of a dynamic task in patients with AI may result in inadequately controlling and accommodating their body weight (De Ridder et al., 2015). The increased loading rates due to abnormal strategy could increase the risk of injuries of the lower extremities by transferring a greater amount of impact force to the tissue. Therefore, higher loading rates could increase the risk for restraining ankle injuries and degenerative changes in ankle and knee joints. Potentially the most concerning long-term outcome of lateral ankle sprains or AI is not only long-lasting symptoms including pain, swelling, and dysfunction but also the development of posttraumatic osteoarthritis. Moreover, several studies suggested that ankle ligament lesions caused by lateral ankle sprain are one of the main factors of posttraumatic ankle osteoarthritis (Valderrabano et al., 2006; Anandacoomarasamy and Barnsley, 2005).

Ankle injury and/or instability could affect degenerative changes of articular cartilage in the knee joint. The results of this study, which present greater vertical GRF parameters, support this hypothesis. An abnormal GRF magnitude or timing is one of the common biomechanics characteristics in patients with AI (Brown et al., 2008; De Ridder et al., 2015; Delahunt et al., 2006). In a laboratory setting, vertical GRF is a useful and noninvasive method for predicting internal joint loading, and this increased GRF parameter increased impact force transmitted to the knee joint as well as the ankle joint. The effects of AI have been currently unclear. However, this review believe that abnormal GRF magnitude and timing have significant evidence to explain whether AI could increase the risk of other injuries and how AI affects the kinetic-chain system of the lower extremities.

The altered patterns of the aforementioned peroneal muscle activation could have a potential link with increased vertical GRF magnitude and earlier time to peak. Thus, GRF cannot be independently explained or understood. For example, human movement strategy (e.g., walking and running), in general, activating the peroneal muscles reflects the efforts of patients with AI to prevent recurrent sprains. This effort of AI patients to compensate for ankle instability or protect from inversion injuries could emerge as abnormal peroneal muscle activation and GRF. The peroneal muscle showed greater activation before initial contact in CAI when compared with the normal subject (Koldenhoven et al., 2016). This may be the preactivation of the peroneal to overcome the reduced vertical foot–floor clearance in patients with AI owing to the damaged structural or decreased function. However, Bigouette et al. (2016), who evaluated the difference in kinetic variables for AI patients, revealed that the side effects of CAI have increased GRF magnitude and timing.

However, the compensatory strategy in AI patients seems to be task specific, similar to the current findings. In dynamic and rapid tasks (e.g., landing), AI patients could not control the pre-program of the lower extremity muscles. The altered distal-to-proximal linkage could not play an efficient role in supporting transfer impact force in the lower extremity kinetic-chain system. Since the action of the peroneus is plantar flexion and eversion, landing on the forefoot relies on a strategy of reducing the impact of the body at the ankle joint (Lam et al., 2019). Nevertheless, AI patients could not utilize this landing strategy in rapid and dynamic tasks, resulting in increased impact force in greater and earlier GRF parameters.

Another contributor to the abnormal GRF parameters is the range of motion. Limiting the range of motion of the ankle joint in AI patients may be one of the compensating strategies to protect from lateral ankle sprains. Limiting the range of motion in the ankle joint is related to the stiff landing including the increased GRF magnitude, which is a risk factor for noncontact lower extremity injuries (Fong et al., 2011). It is thought that normal subjects showed greater activation of peroneal muscles than patients with AI in order to maintain a range of motion of the ankle joint before landing. Moreover, the dorsiflexion range of motion of patients with CAI was less than in the control group, resulting in a stiffer landing pattern, an increase in maximum vertical GRF, and a shorter time to peak vertical GRF (De Ridder et al., 2015; Williams et al., 2004). These differences in GRF magnitude and time in the AI group could affect the occurrence of not only acute but also chronic injuries (e.g., articular cartilage degeneration and osteoarthritis; Brown et al., 2008). Greater and faster impact force transmission to the joint structure is a high-risk factor in areas where the tolerance of joint cartilage has decreased because of recurrent ankle sprain (Brown et al., 2008; Valderrabano et al., 2009). Therefore, the prevention strategy of AI after initial sprain may be the first step in both acute and chronic injuries of the lower extremity.

In contrast, although grade B evidence was found on the overall summary effects of GRF magnitude in anterior (SMD = -0.04, CI = -0.32 to 0.25), posterior (SMD = -0.01, CI = -0.30 to 0.27), medial (SMD = -0.14, CI = -0.41 to 0.13), and lateral directions (SMD = 0.22, CI = -0.06 to 0.51), all of these directions in GRF magnitude was associated with CI that crossed 0 before landing, unlike the vertical direction. In case of time to peak GRF, although grade B evidence was found on the overall summary effects in anterior (SMD = 0.14, CI = -0.40 to 0.68), posterior (SMD = -0.31, CI = -0.82 to 0.19), medial (SMD = -0.19, CI = -0.44 to 0.07), and lateral directions (SMD = -0.16, CI = -0.41 to 0.08), all of the time to peak GRF was associated with CI that crossed 0 before landing. These findings suggested the absence of intergroup differences regarding GRF magnitude and time to peak except for the vertical direction during landing when compared with normal subjects.

Posterior GRF parameters, which were not significantly different in this review, are the major factors for interpreting ACL injury-occurring mechanisms during a landing task. The muscles of the lower extremity should activate for a large deceleration, and this mechanism posteriorly enables GRF through the tibia (Chappell et al., 2007). Additionally, the peak posterior GRF significantly affects the peak proximal tibial anterior shear force (Sell et al., 2007; Markolf et al., 1995). Moreover, several researchers demonstrated the maximal ACL strain occurring at the peak GRF in vivo study (Cerulli et al., 2003; Lamontagne et al., 2005), and this posterior GRF parameter correlates with the vertical direction value (Yu et al., 2006). Although the synthesized effect could not provide significant results, a study reported an abnormal medial GRF increase in AI patients (Delahunt et al., 2006). They explained that abnormal medial GRF values are one of the main factors contributing to the increased incidence of degenerative changes in the articular cartilage over the medial half of the talar and tibial surfaces of the ankle joint resulting from overload transmission by inefficient impact absorption system in AI patients (Delahunt et al., 2006; Harrington, 1979). Additionally, Caulfield and Garrett (2004) demonstrated that peak lateral GRF recorded approximately 13 ms faster in AI patients when compared with normal subjects. Even with the same impact force occurrence, a potential possibility exists that the rapid incidence of this initial stage of ground contact may increase the load transmission to the lateral foot/ankle complex (e.g., peroneal muscles and lateral ligaments). Therefore, we speculated that the altered movement pattern caused by AI may be related to the injury of the proximal joint by affecting the vertical load magnitude and absorption duration rather than in other directions.

Clinical Implications

Based on our results, pre-activation of the peroneal muscles before landing in patients with AI may affect the peak vertical GRF and time to peak vertical GRF. This can result in other injuries of the lower extremity throughout the kinetic chain (Theisen and Day, 2019; Kramer et al., 2007). Therefore, patients with AI require neuromuscular training of the peroneal muscles and relearning about landing strategy because of the characteristics of muscle activity and GRF during landing.

Limitations

This review had some limitations. Most of the studies selected in the search strategy analyzed muscles of the ankle joint. A few studies (Sadeghi et al., 2011; Terada et al., 2014) analyzed muscles such as quadriceps, hamstrings, and gluteus muscles, but the lack of evidence preventing us from determining the inter-group differences during landing. Further research is needed on this topic, including the effects of patients with AI on the biomechanics of the knee and hip joints during landing. In addition, epidemiology studies are warranted to determine whether patients with AI demonstrate higher rates of lower extremity injury in sports involving a landing task as compared with individuals who have normal ankle stability.

Conclusion

Muscle recruitment training of the peroneal muscle may diminish the risk of recurrent ankle sprain in addition to other lower-limb injuries. The peroneal muscle could provide a sufficient range of plantar flexion to decrease vertical GRF and eversion of the subtalar joint. Therefore, peroneal muscle training may be a key re-training factor of a modified landing strategy to prevent the occurrence of AI.

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Key points

- Patients with ankle instability have a lower activation of peroneal muscles before landing.
- Additionally, patients with ankle instability have greater peak vertical GRF and shorter time to peak vertical GRF than those of normal subjects during landing.
- Altered landing strategy in cases of ankle instability may contribute both to the recurrent ankle and other injuries of the lower extremity (e.g., ACL tear and degenerative change of articular cartilage).

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