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Research article

Effects of Prophylactic Ankle Supports on Vertical Ground Reaction Force during Landing: A Meta-Analysis

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Abstract
There has been much debate on how prophylactic ankle supports (PASs) may influence the vertical ground reaction force (vGRF) during landing. Therefore, the primary aims of this meta-analysis were to systematically review and synthesize the effect of PASs on vGRF, and to understand how PASs affect vGRF peaks (F1, F2) and the time from initial contact to peak loading (T1, T2) during landing. Several key databases, including Scopus, Cochrane, Embase, PubMed, ProQuest, Medline, Ovid, Web of Science, and the Physical Activity Index, were used for identifying relevant studies published in English since inception to April 1, 2015. The computerized literature search and cross-referencing the citation list of the articles yielded 3,993 articles. Criteria for inclusion required that 1) the study was conducted on healthy adults; 2) the subject number and trial number were known; 3) the subjects performed landing with and without PAS; 4) the landing movement was in the sagittal plane; 5) the comparable vGRF parameters were reported; and 6) the F1 and F2 must be normalized to the subject's body weight. After the removal of duplicates and irrelevant articles, 6, 6, 15 and 11 studies were respectively pooled for outcomes of F1, T1, F2 and T2. This study found a significantly increased F2 (.03 BW, 95% CI: .001, .05) and decreased T1 (-1.24 ms, 95% CI: -1.77, -.71) and T2 (-3.74 ms, 95% CI: -4.83, -2.65) with the use of a PAS. F1 was not significantly influenced by the PAS. Heterogeneity was present in some results, but there was no evidence of publication bias for any outcome. These changes represented deterioration in the buffering characteristics of the joint. An ideal PAS design should limit the excessive joint motion of ankle inversion, while allowing a normal range of motion, especially in the sagittal plane.

Key words: Ankle brace, athletic tape, ankle sprain, anterior cruciate ligament.

Introduction

The ankle is the second most common joint to suffer sports injuries, and ankle sprains are the most common type of ankle injury (Fong et al., 2007). About 10~28% of all sports injuries are ankle sprains, which cause the longest absence from athletic activity among all types of injuries (Dizon and Reyes, 2010). To protect the relatively weak collateral ligaments of the ankle joint, athletes often use prophylactic ankle supports (PASs). A systematic review by Dizon and Reyes (2010) showed that using a PAS reduced the incidence of ankle sprains by about 70% in previously injured athletes.

Ankle injuries often occur when athletes perform high-impact landing movements. During landing, the vertical ground reaction force (vGRF) is typically much greater than GRFs in the anterior-posterior or medial-lateral directions, so it has been studied in greater detail (Niu et al., 2014). In a typical landing, the vGRF generally has two peaks (Ortega et al., 2010). The first peak force (F1) is produced by the impact of the forefoot and is always of lower magnitude than the second peak force (F2), which occurs when the heel contacts ground (Riemann et al., 2002). The time from initial contact to F1 (T1) and F2 (T2) has also been studied extensively (Cordova et al.; Distefano et al., 2008; Zhang et al., 2008; West et al., 2014).

Though it remains unknown how vGRF peaks influence the risk of injury during landing (Mills et al., 2010; Niu et al., 2010), numerous studies have shown close correlations between GRFs and kinematics of the lower-extremity joints and related muscle activities, because the GRF must be overcome or absorbed by supporting musculature of the ankle, knee, and/or hip joints (Devita and Skelly, 1992; Okamatsu, 2014). For example, the lower F2 in a soft landing corresponds with greater flexion angles in the hip and knee joints, and more energy absorbed by these two joints, but less energy absorbed by the ankle joint (Devita and Skelly, 1992).

Such correlations involve numerous biomechanical factors which must be interpreted and explained by the athletic trainers, biomechanists and rehabilitation therapists. High values of T1 or T2 are normally correlated with low vGRF peaks (Devita and Skelly, 1992; Schmitz et al., 2007), which mean that a longer buffering process may reduce the risk of injuries, including both chronic and acute injuries. However, all of these kinetic and kinematic parameters must be integrated together to construct a global view of the biomechanics surrounding a certain landing task. The vGRF parameters are the pivotal and favored indicators for evaluating landing performance, because of the ease of measurement and the accuracy of the obtained results.

Though PASs are commonly used in sports that involve high-energy impact landings, their effect on landing mechanics is still limited and even ambiguous. Contrasting results of various studies pose a real challenge for consensus and further investigation. For example, some authors have shown PASs to have no significant influence on F1 (Abián-Vicén et al., 2008; Riemann et al., 2002),

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while Hodgson et al. (2005) concluded that the use of a PAS significantly increased F1, and some others argued that PASs significantly decreased F1 (Cordova et al., 2010; Zhang et al., 2012).

Therefore, this study aimed to construct a systematic review of controlled studies to determine whether using a PAS significantly affects vGRF characteristics during landing. The subjects were defined as healthy adults because 1) PASs are often used by this group of people in sports, and 2) data from healthy adults is more readily available.

Methods

Search strategy

A computerized search was performed to compile peer-reviewed journals, conference articles and theses in English. Nine key databases were systematically searched for identifying relevant studies since inception to December 1, 2014. These databases included: Scopus, Cochrane, Embase, PubMed, ProQuest, Medline, Ovid, Web of Science, and the Physical Activity Index. Each database was searched using the following search terms: "ankle AND landing AND (brace OR tape OR support OR stabilizer)". Journal searches focused on those journals that were most likely to publish research related to athletic protection. Relevant articles were identified by cross-referencing the citation lists of the articles sourced from the electronic search. We also contacted other authors in the field.

Selection of studies

Relevant studies were identified by two independent authors based on their titles and abstracts. Full papers were retrieved if a decision could not be made. Disagreements were resolved by discussion and consensus with a third author. Randomized controlled trials or quasi-experimental designs were eligible if they met the following criteria: 1) the study was conducted on healthy adults; 2) the number of subjects and trials were known; 3) the subjects performed landing with and without PASs, including ankle tape or an ankle brace; 4) the landing movement was in the sagittal plane regardless of drop or jump landing, and landings in the lateral direction or cutting were excluded; 5) comparable vGRF parameters for PAS and non-PAS conditions were reported and had sufficient information for extraction and pooling, which referred to the number of participants, mean values, and standard deviations (SD); and 6) the F1 and F2 values were normalized to the subject's body weight (BW).

Data extraction

Two reviewers independently performed data extraction using standardized data extraction forms. General characteristics of the study (e.g. mean age, gender, number of subjects, and landing type and PAS type) were extracted. Then, the mean and SD of GRF parameters (F1, T1, F2 and T2) were extracted. Any disagreements were resolved by discussion or consensus with a third party. In addition to the data extraction, two reviewers also measured study quality using the Physiotherapy Evidence Database (PEDro) scale. Data from both reviewers were compared. If independent scores were different, the reviewers would meet and attempt to resolve the discrepancies. In case of non-resolution, a third reviewer would be consulted.

Statistical methods

Mean differences in results (for F1, T1, F2 and T2) between the control and PAS conditions were estimated for each study. Hedges' adjusted g was used for pooling. Any effects of clinical intervention were assessed before pooling using the DerSimonian-Laird estimate, whether they were varied or heterogeneous across the included articles. A Q statistic was used to check the heterogeneity of mean differences, and an I^2 statistic (Tau-square value) was used to quantify the degree of heterogeneity. If the P-value of heterogeneity (Q value) was greater than .05 or I^2 was less than 25%, all included articles were seen as within-study designs. Then a fixed effect model was applied to estimate the pooled standard mean difference. Otherwise, a random effect model was used. Before studies were pooled, an Egger's test was used to assess publication bias. All analyses were performed by the 'meta' version 3.1-2 of R language. $P < 0.05$ was considered to be statistically significant.

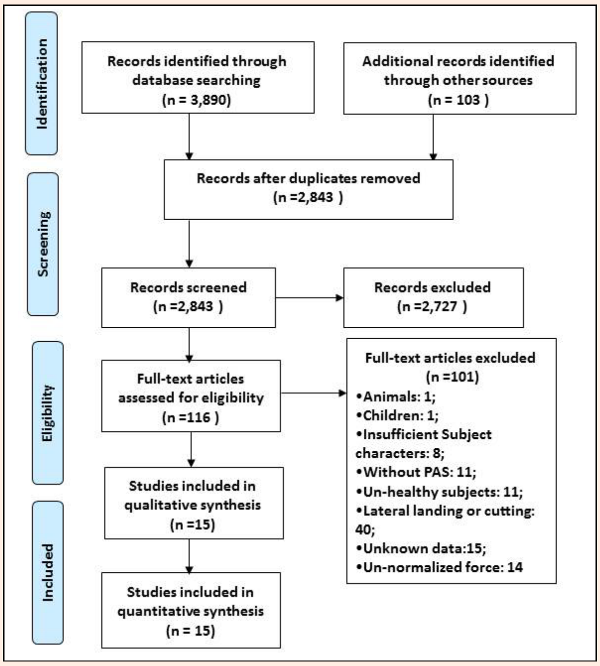

Figure 1. The PRISMA flow diagram depicting the number of articles present at each stage of selection including identification, screening, eligibility and inclusion.

Results

Descriptive statistics

The study selection process is detailed in Figure 1. The computerized literature search of all previously listed databases yielded 3,993 articles. After the removal of duplicates and irrelevant articles based on title and abstract screening, 116 articles remained, of which a further 101 articles were removed on the basis of inclusion/exclusion criteria, leaving a final yield of 15 articles.

The characteristics of all included articles are listed in Table 1. All studies were randomized controlled trials. Ankle braces were chosen as a PAS in 10 articles (Cordova et al., 2010; DiStefano et al., 2008; Hodgson et al., 2005; Kasturi et al., 2005; Niu et al., 2011; Okamatsu, 2014; Riemann et al., 2002; Simpson et al. 2013; Smith, 2011; Vanwanseele et al., 2014). In one article three different ankle braces were adopted (Kasturi et al., 2005), and both low-tension and high-tension lace-up ankle braces were adopted in one dissertation by Okamatsu (2014). Ankle tape was chosen as a PAS in 7 articles (Abián-Vicén et al., 2008; Cordova et al., 2010; Fayson et al., 2015; Huang et al., 2011; Niu et al., 2011; Riemann et al., 2002; Yi et al., 2003), and 1 article by Huang et al. (2011) used both elastic and non-elastic tapes. In 3 articles, both an ankle brace and tape were compared with a control condition (Cordova et al., 2010; Niu et al., 2011; Riemann et al., 2002).

Subject information and pooled parameters arelisted in Table 2. A total of 250 volunteers were measured. Most of them were college students and recreationally active subjects. In only one study, the volunteers were older than 28 years (Kasturi et al., 2005). In one study, the subjects were inactive without a habit of regular exercise (Huang et al., 2011), and in another two studies, the activity level was not reported (Fayson et al., 2015; Yi et al., 2003).

F1 outcomes

Six studies included 12 comparisons of the mean value of F1. This study used the funnel plot to show any bias in publication. As shown in Figure 2, the points are distributed symmetrically at two sides of the dotted triangle, and the result of Egger's test ($p > 0.05$) does not show any bias in this analysis. The heterogeneity of the test was < 0.01 ($tau^2 = 0.02$, H = 1.77 [1.31; 2.39], $I^2 = 68\%$ [41.6%;

Table 1. Characteristics of included articles

Reference	PAS condition	Landing task protocol	PEDro score	Footwear condition	GRF sample frequency (Hz)
Riemann et al. 2002	1. Semi-rigid AirSport ankle brace (AirCast, Inc.) 2. Ankle tape (Coach Athletic Tape, Johnson & Johnson)	Stiff and soft drop landings before and after a 20-minute treadmill exercise bout	6/10	Standard low-cut laboratory shoes (Mundial Team, Adidas America, Portland, OR)	1000
Yi et al., 2003	One and one half inch tape (Johnson & Johnson)	40-cm drop landing	6/10	Low-top sneakers	500
Kasturi et al., 2005	1. Internal laced ankle brace 2. Modified form fit ankle brace 3. Aircast ankle brace	Parachute landing fall	5/10	Bates boots	Unknown
Hodgson et al. 2005	Active Ankle T2 brace (Active Ankle Systems, Inc.)	61-cm hanging drop landing	6/10	Standardized footwear (Mizuno Wave Spike)	600
Abián-Vicén et al., 2008	A prophylactic taping, modified Gibney closed-basket-weave	Count-movement jump landing	6/10	Indoor court shoes.	500
DiStefano et al., 2008	ASO ankle brace (Medical Specialties, Inc.)	Count-movement jump landing	7/10	Own basketball or volleyball shoes	1440
Cordova et al., 2010	1. Semirigid ankle brace (Ultra ankle brace, McDavid, Inc.) 2. Ankle tape (Zonas, Johnson & Johnson Sports Medicine)	30.5-cm 1-legged drop landing	6/10	Low-cut cross-training shoes	1000
Smith, 2011	ASO brand ankle lace up brace (Medical Specialties, Inc.)	Forward 1-legged jump landing	6/10	Own Huskie basketball team shoes	2000
Niu et al., 2011	1. Semirigid ankle brace (McDavid A101, McDavid Knee Guard Inc.) 2. ShuangXing elastic ankle tape (Double Star Sports, Shuangxing Inc., China)	Simulated half-squat parachute landing	6/10	Barefoot	1000
Huang et al., 2011	1. Elastic tape (Kinesio Tex KT-X-050, Tokyo, Japan) 2. Non-elastic tape (Micropore, 3 M, St. Paul, USA)	Vertical jump landing	6/10	Unknown	1000
Simpson et al. 2013	ASO lace-up brace (Medical Specialties Inc., Charlotte, NC)	43-cm 2-legged drop landing	6/10	Own court shoes	1200
Vanwanseele et al., 2014	Lace-up brace (E-Professional)	1-legged jump landing	5/10	Standard netball shoes (Ignite3, Ascics)	1000
West et al., 2014	ActiveAnkle T2 brace	Volleyball-specific blocking and spiking jump landing	6/10	Own volleyball shoes	1000
Okamatsu, 2014	Low-tension and high-tension lace-up ankle braces (ASO® Ankle Stabilizer; Medical Specialties)	Drop-jump landing and forward-jump landing	6/10	Low-cut sports shoes	400
Fayson et al., 2015	Kinesio tape (Kinesio® Tex Gold™, Kinesio USA, Albuquerque, NM)	35-cm count-movement drop landing	6/10	Unknown	1000

Table 2. The subject information and parameters of included articles

Reference	Subject Number sex*	Age (years)	Body mass (kg)	Height (cm)	Activity level	Compared data pair	F1	T1	F2	T2
Riemann et al., 2002	9M, 5F	17~26	75±13	173±8	Recreationally active	8	√	√	√	√
Yi et al., 2003	4M 10F	26±2 24±2	Unknown	Unknown	Unknown to readers	1	√	√	√	√
Kasturi et al., 2005	7M	28~68	Unknown	Unknown	Had an appropriate fitness level and had prior experience in parachuting	3	√	√	√	√
Hodgson et al., 2005	12F	19.8±1.7	76.9±10.4	180.4±7.3	Division I college volleyball players	1	√	√	√	√
Abián-Vicén et al., 2008	7M, 8F	21.0±4.4	71.1±11.4	172±9	Are regularly involved in recreational sports, at least twice a week, but none of them had competed professionally	1	√	√	√	√
DiStefano et al., 2008	11M, 8F 11M, 7F	19.6±0.7 19.9±1.4	71.5±13.2 74.1±10.3	176.1±10.6 179.2±8.8	Recreational volleyball and basketball athletes	2 2			√ √	√ √
Cordova et al., 2010	13M	22±2	72±11	177±7	Recreational basketball at least 2 or more days per week	2	√	√	√	√
Smith, 2011	8F	21.4±2.2	67±7	171.5±6.1	Canadian Interuniversity Sport level female basketball players	1			√	
Niu et al., 2011	8M 8F	24.5±4.2 23.0±0.9	56.1±23.5 51.1±4.4	170.9±2.8 160.9±5.9	Recreationally active in a sport in which lower extremity movement is important	12			√	√
Huang et al., 2011	19M, 12F	25.3±3.8	64.1±6.2	169.4±7.3	Completely inactive without habit of regular exercise before the study	2			√	
Simpson et al., 2013	16F	21.2±2.9	57.9±8.2	164.8±7.6	Prior and/or current competitive experience in volleyball, basketball, and/or soccer	1			√	√
Vanwanseele et al., 2014	11U	18.3±1.8	70.1±8.2	178.5±4.1	High performance netball players	1			√	
West et al., 2014	15M	22.7±3.3	72.1±7.9	180±7	Current state- or national-level indoor volleyball players	2			√	√
Okamatsu, 2014	19F	20.2±1.1	65.7±8.0	170.0±7.2	Perform physical activity at least two times per week and minimum of 30 minutes in each session	2			√	
Fayson et al., 2015	10M, 12F	20.4±1.1	61.9±8.3	165.0±7.6	Unknown to readers	2			√	√

*, M: males; F: females; U: unknown to readers.

82.5%]), so a random effects model was used. Figure 2 also shows a forest plot using standard mean difference, which is a graphical display designed to combine the relative strength of treatment effects in multiple quantitative studies. The pooled mean difference was -.06 BW (95% CI: -.17, 0.06), but this difference was not significant (p = 0.32).

T1 outcomes

The same six studies also compared the mean values of T1. A forest plot and contour funnel plot of T1 pooling are shown in Figure 3. Neither the contour funnel plot nor Egger's test showed evidence of publication bias (bias = 2.42, bias.se = 2.30, p = 0.32). The homogeneity of included studies was significant (tau^2 = 0.19; H = 1.09 [1; 1.49]; I^2 = 15.1% [0%; 54.8%], p = 0.30). Using the fixed effect model, the value of T1 was found to be lower with the use of a PAS than the control, and the mean difference was -1.24 microseconds (ms) (95% CI: -1.77, -.71).

F2 outcomes

All fifteen studies, comprising 38 comparisons, reported on the differences for F2 between a control and PAS group. A forest plot using standard mean difference and contour funnel plot of F2 pooling is shown in Figure 4. The Egger's test and contour funnel plot did not suggest any evidence of publication bias (bias = 0.73, bias.se = 0.80, p = 0.37). The heterogeneity varied little across all studies (tau^2 = 0.002; H = 1.09 [1; 1.34]; I^2 = 15.9% [0%; 43.9%], p = 0.30). Using the fixed effect model, the value of F2 was significantly higher in the PAS condition than the control condition. The mean difference using a fixed model was .03 BW (95% CI: .001, 0.05), not including zero.

T2 outcomes

Eleven studies, which included 30 comparisons, reported mean values of T2 between the control and PAS conditions. A forest plot using standard mean difference and a contour funnel plot of T2 pooling are shown in Figure 5. No evidence of publication bias was found from the Egger's test or contour funnel plot (bias = -0.94, bias.se = 1.32, p = 0.48). Heterogeneity across all studies was not significant (tau^2 = 1.03; H = 1.05 [1; 1.3]; I^2 = 9.4% [0%;

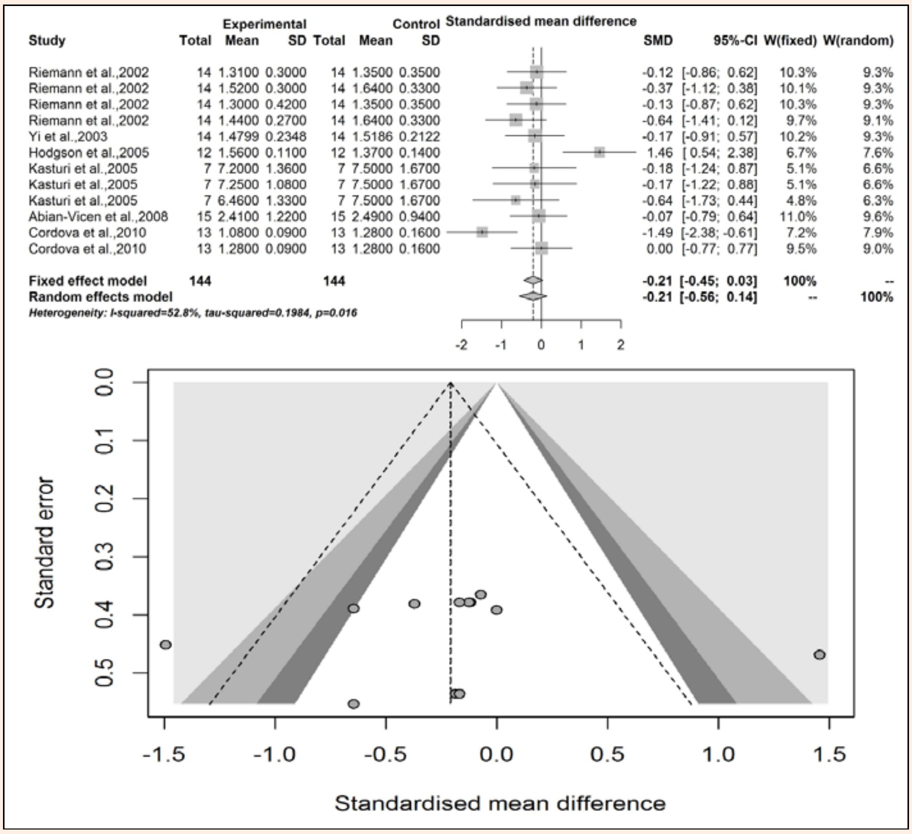

Figure 2. Forest plot and contour funnel plot of the F1 outcome.

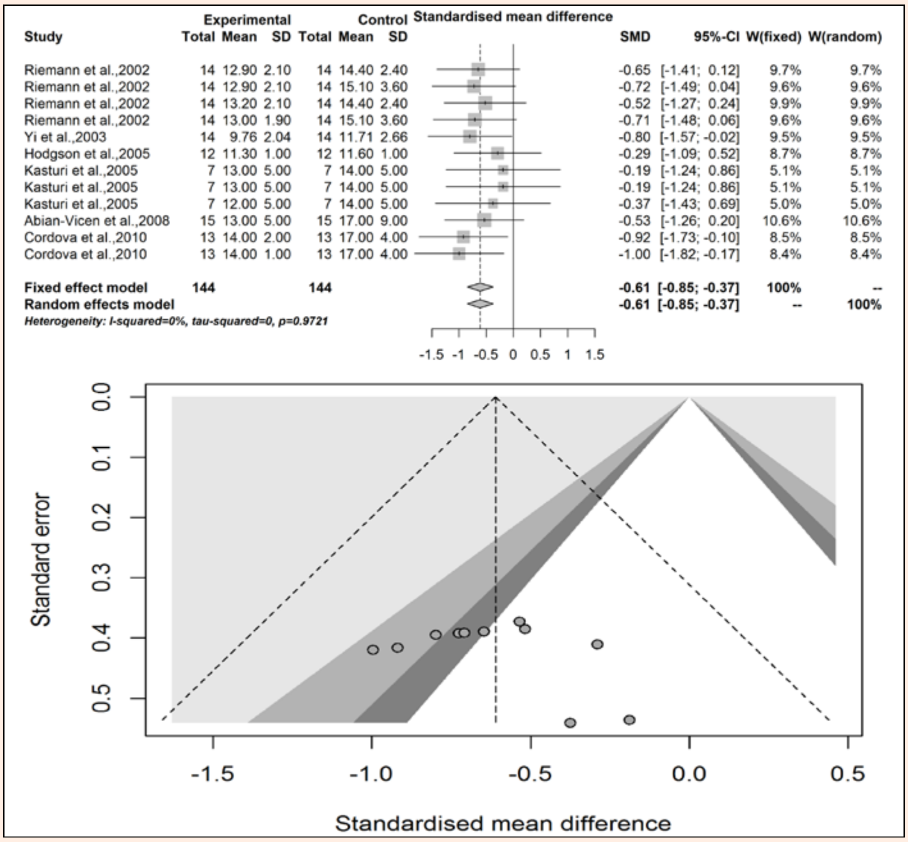

Figure 3. Forest plot and contour funnel plot of the T1 outcome.

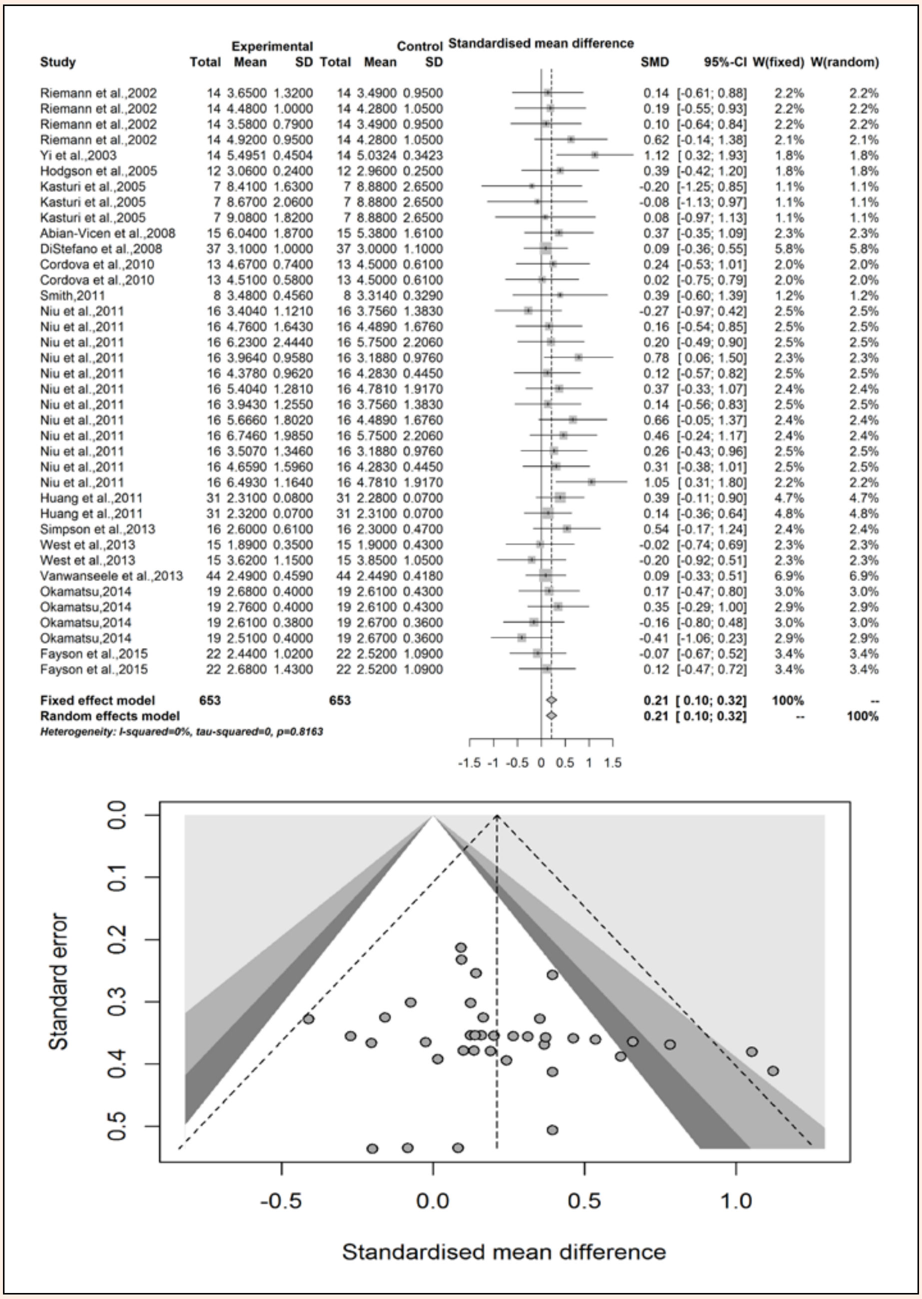

Figure 4. **Forest plot and contour funnel plot of the F2 outcome.**

41%], p = 0.32). The difference in means using a fixed model was -0.374 ms, while the 95% CI was from -0.83 to -2.65, not including 0. This suggested that the value of T2 was significantly less with the use of a PAS than the control condition.

Discussion

This meta-analysis showed that the use of a PAS noticeably decreased the value of T1. The same significant change was also seen in the referenced articles (Cordova et al., 2010; Riemann et al., 2002; Yi et al., 2003). Though the finding was not statistically significant, a similar tendency was also found in other studies (Abián-Vicén et al., 2008; Hodgson et al., 2005; Kasturi et al., 2005). These six studies did not report on plantar flexion at initial ground contact, but some other articles did show a significant decrease in ankle plantar flexion at initial contact while subjects were wearing PASs (Chen et al., 2012; DiStefano et al., 2008; McCaw and Cerullo, 1999; Smith, 2011). A more neutral position would lead to more rapid metatarsal head contact. One potential hypothesis for the decreased plantar flexion at contact is the cutaneous proprioceptive contribution of PASs (Chinn et al., 2014; Feuerbach et al., 1994).

Similarly, this study also found a decreased T2 with the use of a PAS. This change could also be associated with changes in ankle joint kinematics in the sagittal plane as the PAS significantly restrains dorsiflexion of the ankle joint during landing (Chen et al., 2012; DiStefano et al., 2008; McCaw and Cerullo, 1999). The greater joint motion may be a strategy for gaining more time for

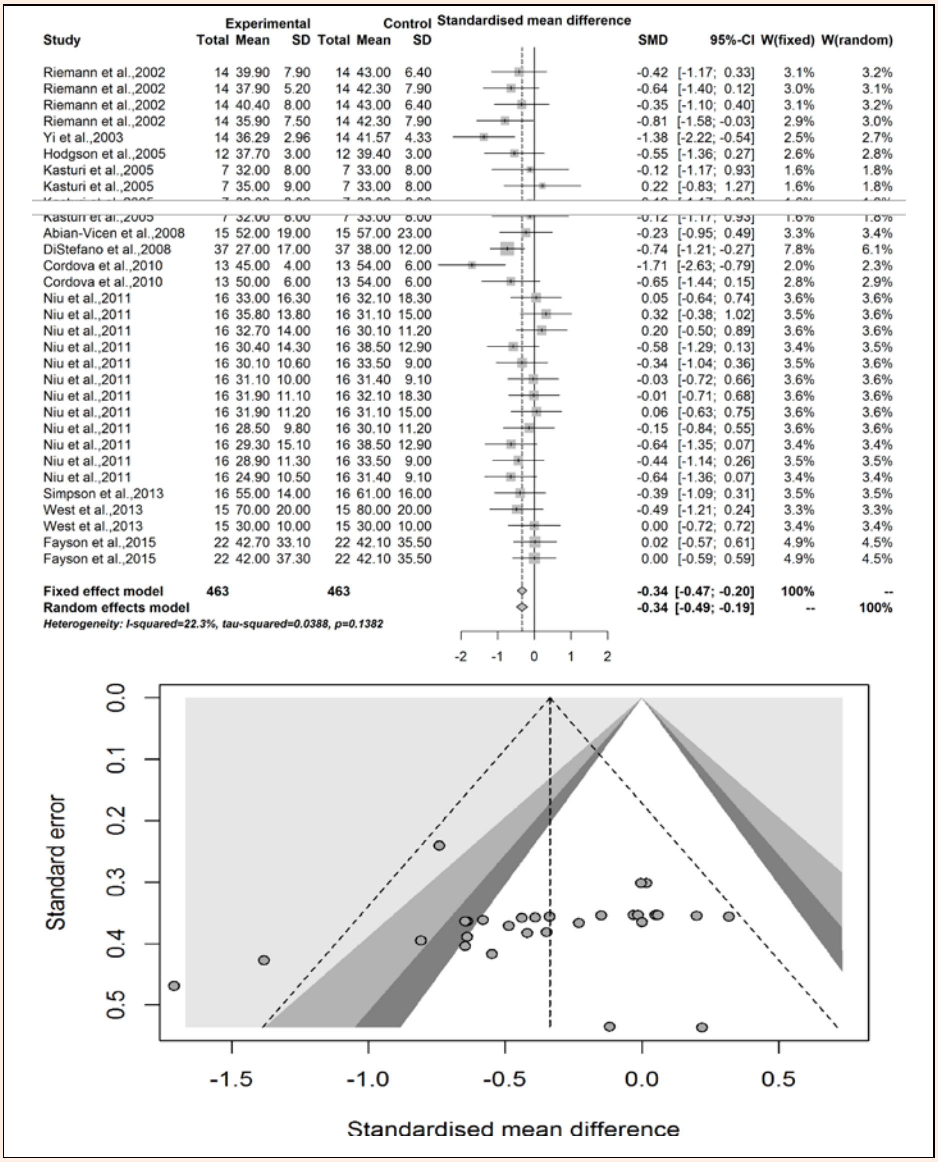

Figure 5. **Forest plot and contour funnel plot of the T2 outcome.**

buffering, and the lower angular displacement would reduce the motion time, which would then be reflected in the lower T2.

When a PAS is used, the body has a shorter time to adjust itself to a stable landing posture. The reduced buffering properties would require the body to absorb the energy within a shorter duration. According to the theorem of impulse, the impact force will increase as the duration is decreased. As seen in Figure 4, using a PAS increases the value of F2, which signifies a deteriorated buffering environment.

To evaluate the risk of injury, force plates are commonly used in kinematic laboratories to provide GRF measurements for amplitude, direction, and time. These parameters are readily available and are relatively easy to analyze, but the correlation between them and the related risk of injury isn't well understood (Mills et al., 2010; Nigg, 1997; Niu et al., 2010). There is a window of loading in which biologic tissue reacts positively to the applied impact load. Nigg (1997) concluded that the GRF levels during running are typically within an acceptable range for cartilage, bones, ligaments, and tendons. However, during high-velocity landing, GRFs may be greatly increased, which can lead to ankle sprain and other injuries. Further study is required to understand how the deteriorated buffering environment affects the risk of injury when a PAS is used during landing.

Most sports injuries to the ankle joint are sprains of the ligamentous structure (Dizon and Reyes, 2010). Therefore, PASs were originally designed to protect the ankle ligaments, especially the lateral ligament complex from spraining. The widely-accepted prophylactic effect of PASs for ankle sprains is down to their mechanical support (Lindley and Kernozek, 1995). Without a PAS, during landing, the kinetic energy is partly absorbed by ligaments, muscles and tendons. When a PAS is used, this pathway is limited and more energy has to be transferred to impact loading and absorbed by the skeletal system.

Abián-Vicén et al. (2008) attempted to associate the higher F2 values with a greater risk of injury when PASs are used, because of the accumulation of repeated impacts in sports where jumps are frequently performed. Two recent studies have shown that a greater F2 may be associated with an increased risk of the anterior cruciate ligament (ACL) injury (Fong et al., 2011; Malloy et al., 2015). Both Pappas et al. (2007) and Bates et al. (2013) also concluded that a shorter T2 may increase ligament strain and better represent the abrupt joint loading that is associated with ACL injury risk. All these evidences showed that PAS may affect the ACL injury risk.

F1 and F2 often reflect diametrically opposite tendencies during landing (Mill et al., 2010; Ortega et al., 2010). The present meta-analysis found that F1 was not significantly influenced by the use of a PAS. Though F1 is at a lower level than F2, F1 and T1 conjunctively may be useful for evaluating the subtle influence on the forefoot or metatarsophalangeal joints. Further investigation should be needed to elaborate on this finding using a more detailed multi-segment foot model.

There are many types of PAS, but they are generally classified into two main categories: ankle braced and taped. A systematic review concluded that no one was more superior to the other, and both could effectively reduce the incidence of ankle sprains among previously injured individuals (Dizon and Reyes, 2010). When comparing the influence of PASs on the vGRF, two previous studies also showed no significant difference between ankle brace and tape (Niu et al., 2011; Riemann et al., 2002). Therefore, this current meta-analysis pooled all types of PASs together to study their effects on vGRF characteristics. Some authors also took high-top shoe as one type of PAS (Fu and Liu, 2013), but only Brizuela et al. (1997) studied the influence of top height on GRF performances during level landing. To avoid bias, this article was not considered in this meta-analysis.

A limitation of this meta-analysis is that in the pooled studies, participants performed various types of landing, e.g. single-leg and two-legged landing, soft and stiff landing, drop landing, jump landing, and simulated parachute landing fall. For example, subjects performing a simulated parachute landing fall may have different GRF features in each leg because they would be instructed to fall to one side at the end of landing process (Kasturi et al., 2005). However, all these landings mainly involved movement in the vertical direction. Landings in the lateral direction or cutting were not considered because they had different GRF characteristics and the PAS played different roles. This may be another interesting future study, to analyze the effect of PASs during lateral landing.

Additionally, many other factors, such as footwear, sample frequency, fatigue, age, and activity level would potentially affect the analysis (Niu et al., 2014; Pappas et al., 2007). Certainly, it is very beneficial to evaluate the effect of different factors on biomechanical parameters during landing or other movements. With a comprehensive review and analysis of published data, this study provides a global and objective view of the influence of PASs on the characteristics of vGRF.

Conclusion

The data from 15 articles showed that using a PAS elevated F2 and reduced T1 and T2 during landing. These changes represented deterioration in the buffering characteristics of the joint. Undoubtedly, PASs can effectively protect the ligamentous structure from spraining by providing mechanical support and cutaneous proprioceptive benefits. An ideal PAS design should limit the excessive joint motion of the ankle inversion, while allowing a normal range of motion, especially in the sagittal plane.

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Key points

- PAS can effectively protect the ligamentous structure from spraining by providing mechanical support and cutaneous proprioceptive benefits.
- Using of PAS can significantly elevate F2 and reduce T1 and T2 during landing. These changes represented deterioration in the buffering characteristics of the joint.
- An ideal PAS design should limit the excessive joint motion of the ankle inversion, while allow normal range of motion, especially in the sagittal plane.

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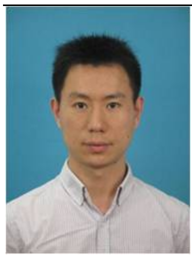

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