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ANKLE

Postural stability deficit could predict ankle sprains: a systematic review

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Abstract

Purpose To perform a systematic review aimed to determine (1) if the postural stability deficit represents a risk factor for ankle sprains; (2) the most effective postural stability evaluation to predict ankle sprains and (3) eventual confounding factors that could influence postural stability and ankle sprain risk.

Methods A systematic electronic search was performed in MEDLINE, EMBASE and CINAHL using the search terms (balance) OR (postural stability) matched with (lower limb) OR (ankle) OR (foot) and (sprain) OR (injury) on October 2 2017. All prospective studies that evaluated postural stability as risk factor for ankle sprains were included. The PRISMA Checklist guided the reporting and data abstraction. Methodological quality of all included papers was carefully assessed.

Results Fifteen studies were included, evaluating 2860 individuals. Various assessment tools or instruments were used to assess postural stability. The injury incidence ranged from 10 to 34%. Postural stability deficit was recognized as risk factor for ankle sprain (OR = 1.22–10.2) in 9 cases [3 out of 3 with Star Excursion Balance Test (SEBT)]. Among the six studies that measured the center-of-gravity sway, five were able to detect worse postural stability in athletes that sustained an ankle sprain. In nine cases, the measurement of postural stability did not show any statistical relationship with ankle sprains (four out of five with examiner evaluation). In the studies that excluded patients with history of ankle sprain, postural stability was reported to be a significant risk factor in five out of six studies.

Conclusions The ultimate role of postural stability as risk factor for ankle sprains was not defined, due to the high heterogeneity of results, patient's populations, sports and methods of postural stability evaluation. Regarding assessment instruments, measurement of center-of-gravity sway could detect athletes at risk, however, standardized tools and protocols are needed to confirm this finding. The SEBT could be considered a promising tool that needs further investigation in wider samples. History of ankle sprains is an important confounding factor, since it was itself a source of postural stability impairment and a risk factor for ankle sprains. These information could guide clinicians in developing screening programs and design further prospective cohort studies comparing different evaluation tools.

Level of evidence I (systematic review of prospective prognostic studies).

Keywords Ankle · Sprain · Athletes · Postural stability · Balance · SEBT · Sway · Prevention

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Introduction

Sport activity and physical exercise are considered to have long-term benefits for global heath. However, a certain risk of injury for ankle injury is present especially in young athletes performing high-impact, contact and pivoting activities but also in leisure-time activities performed by non-professional athletes. It has been estimated that almost 60% of sports injuries are sprains, luxation, and ligament tears [29], and involve extensively lower limbs, especially the ankle joint [2, 13, 21]. To try to reduce the incidence of ankle sprains, preventive programs have been introduced [6, 20, 30, 32]. However, the development of effective prevention programs is strongly related to the capacity of identifying those with a higher risk of sustaining an ankle sprain. Therefore, adequate screening tools may be a crucial component in preventing these injuries and could be used preseason to identify athletes that are at high risk of developing an ankle sprain, with the aim to adjust training programs to the individual athlete.

Systematic reviews suggested several risk factors for ankle sprains, such as generalized hyperlaxity, joints range of motion (ROM), muscle strength and balance or postural stability deficit [7, 14]. If the first could be easily quantifiable, the latter aspect represents instead a matter of debate and controversies, as no gold standard measurements are available in the literature for postural stability evaluation.

The postural stability, which has been defined as the ability to maintain and control one's center of gravity over a base of support, is a complex mechanism derived from the coordination and synergy between vestibular, visual and somatosensory systems [26, 36]. It could be quantified by means of direct evaluation by an examiner [9, 12, 18, 31, 36] or by force plates during static tasks such as single or double stance, or with dedicate tools that tries to capture and quantify difference during the executions of a broad spectrum of dynamic tasks such as jumps, regaining balance after perturbation, or complex movement with lower limbs during single leg stance [8, 15, 34, 35].

The broad spectrum of tools, tasks and measurement methods, coupled with the heterogeneity in patients populations regarding sex, sports, and previous injuries could be responsible of the lack of general agreement in considering alterations of postural stability as a risk factor for lower limb injuries [9, 37].

The aim of the present systematic review was, therefore, to determine (1) if postural stability deficit represents a risk factor for ankle sprains; (2) the most effective postural stability evaluation to predict ankle sprains and (3) eventual confounding factors that could influence postural stability and ankle injury sprains. The answer to these questions will guide clinicians in developing screening programs for ankle sprain, identify which athletes are at risk of sprain due to postural stability deficit and recommending which tools are more useful in this task.

Materials and methods

Study design

A systematic review was performed in accordance with the preferred reporting items for systematic reviews and meta-analysis guidelines [24].

Search strategy

A systematic electronic search, assisted by a librarian, was performed in MEDLINE, EMBASE and CINAHL databases on 2 October 2017. The search terms were mapped to Medical Subject Headings (MeSH) terms where possible. Search terms were entered under three concepts: concept 1—(balance) OR (postural stability); concept 2—(lower limb) OR (ankle) OR (foot); concept 3—(sprain) OR (injury). Each concept was then combined with the 'AND' operator to produce the search strategy and final yield. E-pub and ahead of print papers were included as well (Supplementary Appendix 1).

Selection criteria

The following inclusion criteria, modified from Onate et al. [25] were applied to the final yield:

1. Studies investigating ankle sprain prediction or risk factors;
2. Study population consists primarily of physically active individuals (athletes or military) of any level of experience (eg, recreational, college, professional, etc.);
3. Either populations with or without history of previous ankle injuries;
4. At least one of the sprain risk factor being studied is balance or postural stability measured with tools or examiner evaluation;
5. Study is peer-reviewed;
6. Prospective studies;
7. Study is reported in English.

Also the following exclusion criteria were applied:

1. Studies not reporting original research including review articles, expert opinion, or current concepts articles;
2. Posters or abstracts at annual meetings or masters theses without subsequent peer-reviewed publication of a article;

3. Studies investigating risk factors other than balance and postural stability;
4. Animal studies;
5. Studies drawing conclusions regarding risk of ankle sprain or injury prediction based on historical data.

Article selection

To select the articles to be included in the systematic review, two non-blinded authors reviewed the title and abstract of each article identified in the literature search. When eligibility was unclear from the title and abstract, the full text of the article was obtained and evaluated for eligibility. In the case of disputes, eligibility was obtained after consulting the senior author.

Data extraction

Regarding the population studied, the following information were obtained: number of patients enrolled, number of patients evaluated, inclusion\exclusion criteria, patient sex, mean age, sports practiced and the follow-up. Regarding the balance evaluation, the following information was extracted: details of the tool or devices used, test performed and parameter measured. Also, the information of additional measurements such as joint ROM, laxity, strength or injury history was noted. Regarding ankle sprains, the following information was extracted: definition of injury, total number of sprains and incidence. Finally, the statistical relationship between balance and ankle sprains was summarized. Other possible relations with the additional parameters evaluated were extracted as well.

Quality assessment

The methodological quality was evaluated according to a modified version of the Cochrane Group on Screening and Diagnostic Test Methodology (Cochrane methods) [10], according to Dallinga et al. [7]. Two authors assessed the quality of the included studies (X.X. and X.X.). The 11 items evaluated were: "Study design" (prospective = 1 point; retrospective = 0 point); "Level of Evidence" (level 1 = 5 points; level 2 = 4 points; level 3 = 3 points; level 4 = 2 points; level 5 = 1 point); "Selection criteria" (Inclusion and exclusion criteria clearly described = 1 point); "Setting" (Enough information to identify setting = 1 point); "Demographic information" (mean or median and standard deviation or range of age, and gender reported = 1 point); "Screening tool" (Description of screening tool had sufficient detail to permit replication of the test. Test device or instruments, protocol of screening tool(s) reported = 1 point each); "Statistical analysis" (For variable of interest details given on mean or median, standard deviation or confidence intervals and predictive value = 1 point); "Reliability of screening test" (Reliability reported = 1 point); "Percentage missing" (All included subjects measured and, if appropriate, missing data or withdrawals from study reported or explained = 1 point); "Outcome" (Outcome clearly defined and method of examination of outcome adequate = 1 point); "Confounders" (Most important confounders and prognostic factors identified and adequately taken into account in design study = 1 point). The maximal score that could be reached was, therefore, 16. Since no guidelines on how to rate this score are available, we considered an excellent quality in case of 16 points, good quality with 15−14 points, fair quality with 13−10 points and poor quality with < 10 points.

Statistical analysis

Due to the heterogeneity of the population regarding age, sport and patient sex, of the injuries evaluated and of the methods of balance evaluation, it was not possible to pool the data to perform a meta-analysis. The data were, therefore, presented in a narrative manner with best of synthesis approach, summarizing the main findings of each papers focused on balance evaluation and ankle injuries.

Results

Article selection

Forty-five articles were obtained in full text based on title and abstract screening. Eighteen articles were excluded, as they did not report the evaluation of balance or postural stability as a risk factor for ankle injuries. Twelve further studies were excluded because they reported the evaluation of lower limb injuries without performing a separate analysis of ankle sprains or because was retrospective. Finally, 15 studies were included in the final systematic review [1, 2, 8, 9, 12, 15, 16, 18, 19, 21, 22, 31, 33–35] (Fig. 1).

Quality assessment

The assessment of the methodological quality of the included studies is shown in Table 1. The mean score was 15.3 (range 13–16). Ten studies (67%) reported the maximum available score, therefore, representing an excellent quality, 3 studies (20%) had a good quality while only 2 (13%) presented fair quality. The items assessing the prospective study design, level of evidence I, adequate description of setting, tools, patient's population, statistical analysis, outcomes and missing patients were rated as the maximum in all the studies. The worst scoring area was the evaluation of confounders, where 5 studies (33%) failed to meet the quality requirements. Therefore, the overall quality of the

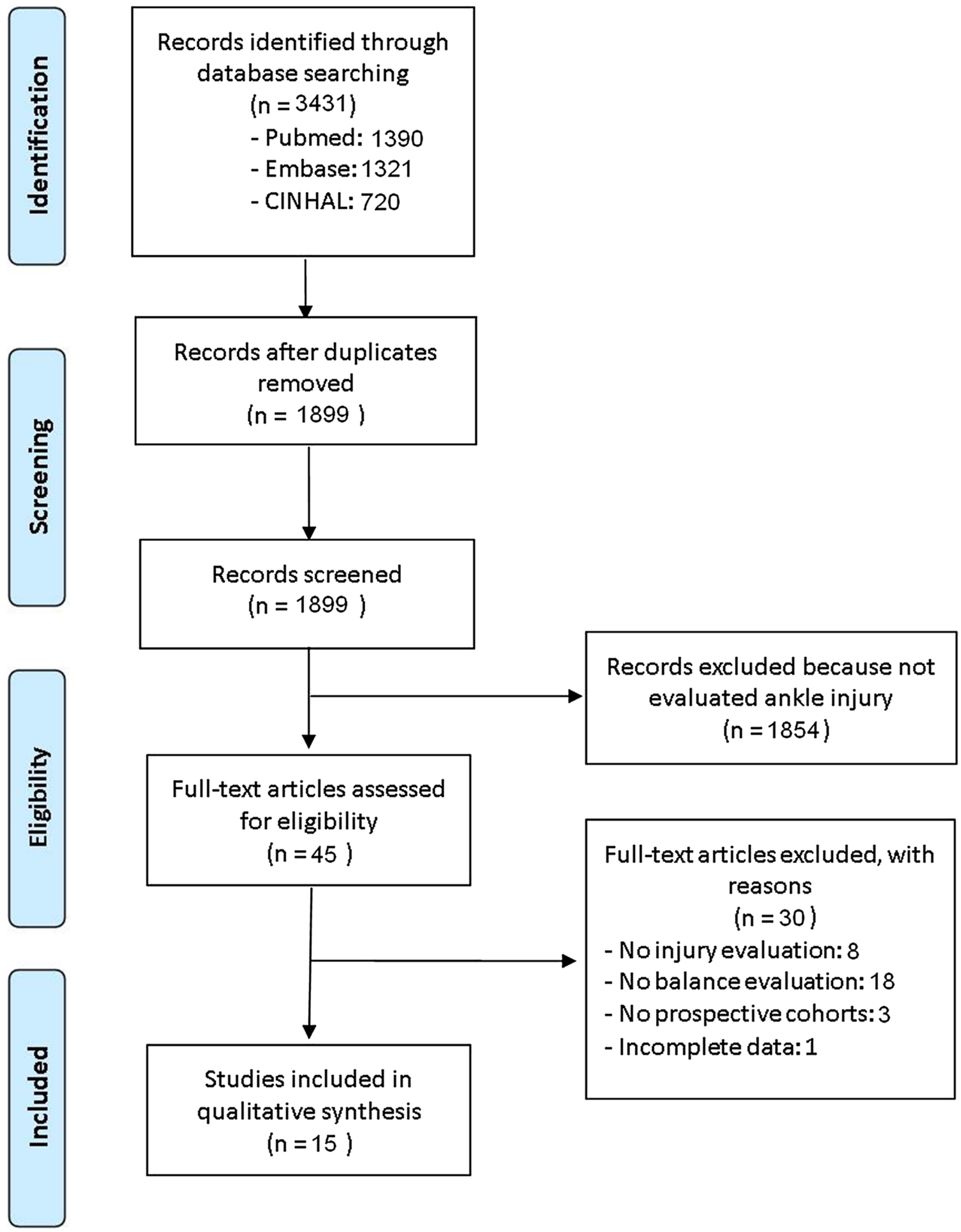

Fig. 1 Flow-chart of the systematic search in the different databases

studies included in this systematic review could be considered of good to excellent.

Patient's population

Overall, 2860 patients were screened for balance deficit as potential risk factor for ankle sprains within the 15 studies. Eleven studies (73%) evaluated patient populations > 100 athletes. Three studies (20%) analyzed athletes performing non-contact sports, 9 studies (60%) athletes involved in contact sports, and the remaining 3 studies (20%) athletes participating in both contact and non-contact sport activities. Exclusively male or female athletes were considered in 6 (40%) and 2 (13%) studies, respectively. The most relevant exclusion criteria were the presence of current injuries and the history of ankle fracture\sprain\injury (Table 2).

Postural stability evaluation

Various tool were used to assess balance: specific devices such as the New Balance Master, NeuroTest System or Neurocom Blance Master (NeuroCom International, Clackmas, OR, USA), the 3space Fastrak (Polhemus Inc, Colchester, VT, USA) and the Biodex Balance System (Biodex Medical System, Shirley, NY, USA) were used in six studies, force plates in three studies, the Star Excursion Balance Test (SEBT) in three studies, a tilt board in one study and direct

Table 1 Quality assessment of the included studies

Authors	Design	LOE	Selection crit	Setting	Demographic info	Screening tool	Statistic	Reliability	Missing	Outcome	Confounders	Total
	Pros = 1	LOE1 = 5	Inclus = 1	Info = 1	Age, sex = 1	Test + protocol = 1 + 1	Mean, SD = 1	Yes = 1	Reported = 1	Clear = 1	Identified = 1	
	Retro = 0	LOE5 = 1	No = 0	No = 0	No = 0	No = 0	No = 0	No = 0	Omitted = 0	No = 0	Omitted = 0	
McGuine et al.	1	5	1	1	1	2	1	1	1	1	1	16
Beynnon et al.	1	5	1	1	1	2	1	1	1	1	1	16
Willems et al.	1	5	1	1	1	2	1	1	1	1	1	16
Willems et al.	1	5	1	1	1	2	1	1	1	1	1	16
Wang et al.	1	5	1	1	1	2	1	1	1	1	0	15
McHugh et al.	1	5	0	1	1	2	1	0	1	1	0	13
Trojian and McKeag	1	5	1	1	1	2	1	1	1	1	1	16
Hrysomallis et al.	1	5	1	1	1	2	1	1	1	1	0	15
Hiller et al.	1	5	1	1	1	2	1	1	1	1	1	16
Hadzic et al.	1	5	0	1	1	2	1	0	1	1	0	13
Engebretsen et al.	1	5	1	1	1	2	1	0	1	1	0	14
de Noronha et al.	1	5	1	1	1	2	1	1	1	1	1	16
Dallinga et al.	1	5	1	1	1	2	1	1	1	1	1	16
Gribble et al.	1	5	1	1	1	2	1	1	1	1	1	16
Attenborough et al.	1	5	1	1	1	2	1	1	1	1	1	16
	0 = 0	0 to 4 = 0	0 = 2	0 = 0	0 = 0	0 and 1 = 0	0 = 0	0 = 3	0 = 0	0 = 0	0 = 5	Mean
	1 = 15	5 = 15	1 = 13	1 = 15	1 = 15	2 = 15	1 = 15	1 = 12	1 = 15	1 = 15	1 = 10	15.3

LOE level of evidence, *Pros* prospecitve, *Retro* retrospective, *Selection crit* selection criteria

Table 2 Demographic and study-design characteristics of the included studies

Authors	Year	Initial patients population	Patient evaluated	Sport activity	Sex	Age	Follow-up	Exclusion criteria
McGuine et al.	2000	223	210	High school	119 M	16.1 ± 1.1 M	1 season	Ankle\knee injuries (< 12 months)
				Basketball	91 F	16.3 ± 1.3 F		
Beynnon et al.	2002	118	118	NCAA	50 M	18–23	1 season	Previous ankle sprain
				Lacrosse	68 F			Foot\ankle surgery
				Soccer				Previous lower limb trauma
				Field hockey				Ankle support use
Willems et al.	2005	241	241	Physical education freshman at Ghent University	241 M	18.3 ± 1.1	1–3 academic years	Foot\ankle surgery (< 6 months)
								Previous grade II and III ankle sprain (< 6 months)
								Previous lower limb trauma (< 6 months)
Willems et al.	2005	159	159	Physical education freshman at Ghent University	159 F	18.3 ± 1.1	1–3 academic years	Foot\ankle surgery (< 6 months)
								Previous grade II and III ankle sprain (< 6 months)
								Previous lower limb trauma (< 6 months)
Wang et al.	2006	70	42	1st league High School	42 M	16.7 ± 1.2	1 season	Previous lower limb surgery
				Basketball			46.0 ± 2.5 weeks	History of lower limb pain\giving way (< 6 months)
								Leg-length discrepancy > 1.5 cm
								Genu varum (tibiofemoral angle < 4°)
								Foot arch overpronation
								Varus\valgus calcaneus
McHugh et al.	2006	169	169	High school	101M	16.0 ± 1.0	2 years	NA
				Football	68 F			
				Soccer				
				Basketball				
				Gymnastic				
Trojian and McKeag	2006	230	230	High school and College	150 M	NA	14 weeks	Not cleared for athletics
				Football	80 F			Previous ankle fracture
				Soccer				Previous ankle sprain (< 6 weeks)
				Volleyball				
Hrysomallis et al.	2007	210	210	Australian Football League	210 M	22.9 ± 3.8	1 season	Current low limb injuries
Hiller et al.	2008	141	115	Dance students	21 M	14.2 ± 1.8	13 months	NA
					94 F			

Table 2 (continued)

Authors	Year	Initial patients population	Patient evaluated	Sport activity	Sex	Age	Follow-up	Exclusion criteria
Hadzic et al.	2009	38	38	I/II division	38 M	21 ± 5.0	6 months	NA
				Volleyball				
Engebretsen et al.	2010	769	508	I/II/III division	508 M	NA	1 season	Currently injured
				Soccer				
de Noronha et al.	2013	125	121	University students	57 M	20.9 ± 2.7	1 year	Neurological\vestibular problems
				Regular exercise at least 2/week	64 F			Musculoskeletal problems
Dallinga et al.	2016	80	66	Elite and sub-elite	47 M	22.9 ± 3.9 M	1 season	Current ankle injury
				Basketball	19 F	21.5 ± 2.9 F		
				Volleyball				
				Korfball				
Gribble et al.	2016	606	539	NCAA division I	539 M	NA	1 season	Previous lower limb injuries (except ankle)
				Football				
Attenborough et al.	2017	96	94	Netball	94 F	21.5 ± 6.3	2 seasons	Lower limb surgery\fractures
								Ankle injuries < 6 months

M males, *F* females, *NCAA* National Collegiate Athletic Association, *NA* not available

evaluation by an examiner in five studies. Three studies combined two different methods.

Every study utilized different tasks, mostly dominant or non-dominant single-leg stance and bilateral stance (Table 3), except for two studies [34, 35] that applied the same protocol in male and female athletes. Therefore, many different measures were obtained to quantify the postural stability, mostly sway of center of gravity when tools were used [2, 19, 21, 33–35], and inability to maintain balance according to a predetermined protocol when an examiner observation was employed.

Eleven studies (73%) measured at least another parameter such as ankle ROM, general laxity, muscle strength or anatomical characteristics, other than postural stability, as risk factor for ankle sprain.

Injury evaluation

Each study provided a definition of ankle injury (Table 4). The incidence ranged from 10% in Australian Football male players [19] to 34% in division I–II volleyball male players [16], with a rate ranging from 0.3 sprains per 1000 [12] to 2.2 sprains per 1000 days of exposures [2].

According to the statistical methods used in each study, postural stability deficit was recognized as risk factor for ankle sprain in nine cases. Specifically, decreased postural stability measured with New Balance Master device had a OR = 10.2 of ankle sprain in basketball players [21], while decreased directional control and limit of stability measured with Neurocom Balance Master had higher rate of ankle sprain in freshmen athletes [34, 35]. Decreased balance on bilateral stance and increased medio-lateral and antero-posterior sway measured with force plates had an OR = 1.22–2.44 in 42 basketball [33] and Australian Football athletes, respectively [19]. Using the Star Excursion Balance Test (SEBT), a posterolateral distance < 80, ananterior distance < 63% compared to non-injured side and a posteromedial distance < 77.5% of leg length [1] were risk factors in various athletes [1, 9, 15]. Finally, failure to maintain balance as detected by an examiner was reported as risk factor for ankle sprain as well [31].

In nine cases, the measurement of postural stability did not show any statistical relationship with ankle sprain. Specifically, four studies that employed an examiner evaluation involving dance and University students [9, 18], soccer [12] and netball players, one study using the NeuroTest System [2], one study using the Biodex Balance System [16], one study employing balance on a tilt board [22], one study using the 3Space Fastrak [18] and one study using a force plate [8]. Among the six studies that measured a sway parameter [2, 19, 21, 33–35], five were able to detect worst postural stability in athletes that sustained an ankle sprain.

Table 3 Methods of postural stability evaluation and parameters measured in each study

Authors	Year	Tool\device	Tests performed	Measure of postural stability	Other parameters evaluated
McGuine et al.	2000	New Balance Master	Bilateral stance	Sway velocity of center of gravity	None
			Dominant leg stance		
			Non-dominant leg stance		
			(open and closed eyes)		
Beynnon et al.	2002	NeuroTest System	Fixed platform dominant leg stance	Antero-posterior center of gravity sway	Generalized ankle and joint laxity
			Fixed platform non-dominant leg stance		Anatomic alignment of foot and ankle (weight bearing and non-weight bearing)
			Sway-referenced platform two leg stance		Isokinetic ankle strength
			Sway-referenced platform dominant leg stance		Muscle
			Sway-referenced platform non-dominant leg stance		
			(closed eyes)		
Willems et al.	2005	Neurocom Balance Master	Bilateral stance	% of weight bearing of each leg	Anthropometric characteristics
			Dominant leg stance	Sway velocity of center of gravity	Functional motor performances
			Non-dominant leg stance	Sway velocity single leg stance	Joint position sense
			Voluntary forward, right, back, left sway	Limits of stability (reaction time, sway velocity, directional control, endpoint execution)	Muscle strength
			1 leg forward lunge	Forward lunge (distance, time, impact force, force impulse)	Lower leg alignment
			(open and closed eyes)		Muscle reaction time
Willems et al	2005	Neurocom Balance Master	Bilateral stance	% of weight bearing of each leg	Anthropometric characteristics
			Dominant leg stance	Sway velocity of center of gravity	Functional motor performances
			Non-dominant leg stance	Sway velocity single leg stance	Joint position sense
			Voluntary forward, right, back, left sway	Limits of stability (reaction time, sway velocity, directional control, endpoint execution)	Muscle strength
			1 leg forward lunge	Forward lunge (distance, time, impact force, force impulse)	Lower leg alignment
			(open and closed eyes)		Muscle reaction time
Wang et al.	2006	Force plate	Dominant leg stance	Antero-posterior sway	Isokinetic ankle strength
			Non-dominant leg stance	Medio-lateral sway	Ankle ROM
McHugh et al.	2006	Tilt board	Dominant leg stance	Time to out-of-balance	Muscle strength
			Non-dominant leg stance		Generalized ligamentous laxity
			(open and closed eyes)		
Trojian and McKeag	2006	Examinator evaluation	Dominant leg stance	Failure to maintain balance	None
			Non-dominant leg stance		

Table 3 (continued)

Authors	Year	Tool\device	Tests performed	Measure of postural stability	Other parameters evaluated
Hrysomallis et al.	2007	Force plate	Dominant leg stance on a unstable surface	Medio-lateral sway	Anthropometric characteristics
			Non-dominant leg stance on a unstable surface		Previous injuries
			(open eyes)		
Hiller et al.	2008	Examinator evaluation	Dominant leg stance (closed eyes)	Failure to maintain balance	Anthropometric characteristics
			Non-dominant leg stance (closed eyes)		Joint laxity
			Balance on demipointe (open eyes)		Ankle ROM
		3Space Fastrak	Dominant leg stance (closed eyes)	Medio-lateral ankle movement	Ankle instability
			Non-dominant leg stance (closed eyes)	Time taken to recover	Previous injuries
			Balance on demipointe (open eyes)		
			Single leg stance followed by a perturbation		
Hadzic et al.	2009	Biodex Balance System	Bilateral stance	Platform Antero-posterior degree of tilt	Ankle strength
			(open eyes)	Platform Medio-lateral degree of tilt	Ankle ROM
Engebretsen et al.	2010	Examinator evaluation	Dominant leg stance	Failure to maintain balance	Foot type
			Non-dominant leg stance		Rearfoot alignment
					Ankle ROM
					Anthropometric characteristics
					Previous injuries
de Noronha et al.	2013	Examinator evaluation	Dominant leg stance	Failure to maintain balance	Cumberland Ankle Instability Test
			Non-dominant leg stance		Motor imagery
		Star Excursion Balance Test	Anterior reach dominant leg	Maximal reach distance	Ankle ROM
			Anterior reach non-dominant leg		Previous injuries
			Posteromedial reach dominant leg		
			Posteromedial reach non-dominant leg		
			Posterolateral reach dominant leg		
			Posterolateral reach non-dominant leg		

Table 3 (continued)

Authors	Year	Tool\device	Tests performed	Measure of postural stability	Other parameters evaluated
Dallinga et al.	2016	Force plate	Forward jump dominant leg	Medio-lateral stability index	Previous injuries
			Forward jump non-dominant leg	Antero-posterior stability index	Anthropometric characteristics
			Diagonal jump dominant leg	Vertical stability index	
			Diagonal jump non-dominant leg	Dynamic postural stability index	
			Lateral jump dominant leg		
			Lateral jump non-dominant leg		
Gribble et al.	2016	Star Excursion Balance Test	Anterior reach dominant leg	Maximal reach distance	Functional movement screen
			Anterior reach non-dominant leg		Anthropometric characteristics
			Posteromedial reach dominant leg		Previous injuries
			Posteromedial reach non-dominant leg		
			Posterolateral reach dominant leg		
			Posterolateral reach non-dominant leg		
Attenborough et al.	2017	Examinator evaluation	Dominant leg stance	Failure to maintain balance	Muscular power
			Non-dominant leg stance		Ankle laxity
		Star Excursion Balance Test	Anterior reach dominant leg	Maximal reach distance	Cumberland Ankle Instability Test
			Anterior reach non-dominant leg		Previous sprains
			Posteromedial reach dominant leg		Anthropometric characteristics
			Posteromedial reach non-dominant leg		
			Posterolateral reach dominant leg		

ROM range of motion

Evaluation of confounding factors

Eleven studies (73%) identified at least one risk factor for ankle sprain other than postural stability deficit (Table 4). Overall, out of the nine studies that accounted history of previous ankle sprain in the statistical models, only five identified balance deficit as risk factor for ankle sprain. In three of the remaining four studies, a positive history of previous sprain was identified a risk factor.

In the studies that excluded patients with history of ankle sprain, or without episodes in the previous 6–12 months, postural stability deficit was reported to be a significant risk factor in five out of six studies (Table 5).

Discussion

The most important finding of the present systematic review was that it is not possible to certainly identify postural stability deficit as a risk factor for ankle sprain, due to the heterogeneity of the results. In fact, in nearly half of the cases, postural stability was not correlated to ankle sprains. Moreover, the identification of the most effective tool in identifying postural stability deficit to predict ankle injuries was unsuccessful. However, most of the studies that employed instruments measuring center-of-gravity sway and those employing the SEBT were able to identify postural stability deficit as risk factor for ankle sprain. Differently,

Table 4 Incidence of ankle injuries and correlation with postural stability evaluation

Authors	Year	Definition of injury	Incidence	Effect of postural stability deficit as risk factor for ankle sprain	Other findings
McGuine et al.	2000	Trauma that disrupts the structures of the ankle that occurs during a team-sponsored practice or competition session, and causes the athlete to miss the rest of practice or competition or miss the next scheduled team practice or competition	23/210 (11%) 1.56/1000 exposure 1.68/1000 exposure M 1.44/1000 exposure F	Higher injuries in decreased balance (OR = 10.2)	None
Beynnon et al.	2002	A grade I injury was defined as no loss of function, no loss of ligamentous stability, little or no hemorrhage, and point tenderness. Grade II injuries demonstrated some loss of function, decreased motion, a positive anterior drawer and negative talar tilt test, hemorrhage, swelling and point tenderness. Grade III injuries had nearly total loss of function, a positive anterior drawer and talar tilt test, diffuse swelling and hemorrhage, and extreme point tenderness	7/50 (14%) (M) 13/68 (19.1%) (F) 1.6/1000 person-days (M) 2.2/1000 person-days (F)	Not significant	Higher injuries in soccer (F) Higher injuries in varus tibia, calacaneal eversion (F) Higher injuries in talar rotation > 20° (M)
Willems et al.	2005	A reduction in the amount or level of sports activity, (2) a need for (medical) advice or treatment, or (3) adverse social or economic effects	44/241 (18%)	Higher injuries in decreased directional control ($p = 0.037$)	Higher injuries in worst motor performance Higher injuries in decreased dorsiflexion muscle strength Higher injuries in decreased dorsiflexion ROM Higher injuries in decreased anterior tibialis, gastrocnemius muscles reaction time
Willems et al.	2005	A reduction in the amount or level of sports activity, (2) a need for (medical) advice or treatment, or (3) adverse social or economic effects	32/159 (20%) 0.75/1000 h-exposure	Higher injuries in decreased endpoint excursion (HR = 0.96) Higher injuries in decreased maximal endpoint excursion (HR = 0.94) (tested by the limits of stability test)	Higher injuries in less accurate joint position sense Higher injuries in increased dorsiflexion muscle strength Higher injuries in increased first MTP ROM
Wang et al.	2006	Incident occurring in connection with basketball during training or competition that occurs at the ankle, handicaps the player from playing basketball or makes the player look for treatment to continue playing basketball	18/42 (43%)	Higher injuries in increased of ML sway (OR = 1.220) Higher injuries in increased of AP sway (OR = 1.216) Higher variation on ML sway in injured athletes ($p > 0.001$)	None
McHugh et al.	2006	Missed games and practice	20/169 (12%) 1.13/1000 exposures	Not significant	Higher injuries in higher BMI Higher injuries in previously injured athletes

Table 4 (continued)

Authors	Year	Definition of injury	Incidence	Effect of postural stability deficit as risk factor for ankle sprain	Other findings
Trojian and McKeag	2006	Trauma that disrupted the structures of the ankle and which occurred during a team sponsored practice or competition session, and caused the athlete to miss the rest of practice or competition, or miss the next scheduled team practice or competition	28/230 (12%)	Higher injuries in positive SLB test (RR = 2.43)	Higher injuries when no taping
Hrysomallis et al.	2007	Diagnosed by a medicl personnel and if it caused the athlete to cease participation in the current session and precluded participation in the next official training session game	21/210 (10%)	Higher ankle injuries in lower both limb balance (OR = 2.44)	None
Hiller et al.	2008	An inversion injury that had resulted in either swelling or bruising in the area and limping for more than 1 day	33/115 (29%)	Not significant	Higher injuries in previous contralateral ankle sprain (HR = 3.9)
Hadzic et al.	2009	Caused a player to miss a match or a training session were registere	13/38 (34%)	Not significant	Higher injuries in decreased dorsiflexion
			0.85/1000 h-exposure		Higher injuries in higher plantar flexion strength
Engebretsen et al.	2010	Any physical complaint sustained by a player that resulted from a soccer match or soccer training, forcing the player to miss or unable to take full part in future soccer training or match play	43/508 (8.5%)	Not significant	Higher injuries in previously injured
			0.5/1000 h-play		
			0.3/1000 h-train		
de Noronha et al.	2013	An inversion beyond the physiological limit followed by at least one of the following criteria: pain for more than a day, swelling for more than a day, hematoma lasting for more than a day, or absence from physical activity in at least one occasion	31/121 (25.6%)	Higher injuries in decreased posterolateral distance < 80 (HR = 0.96)	Higher injuries in previously injured
Dallinga et al.	2016	An injury of the ankle ligaments sustained by an athlete that results from a game or training, irrespective of the need for medical attention or time loss from activities	6/33 (18.2%) M	Not significant	None
			2/16 (12.5%) F		
Gribble et al.	2016	An injury occurred during a sanctioned team practice or competition, required medical attention from a health care professional (athletic trainer or physician), and resulted in at least 1 day of time loss from scheduled football activities	81/539 (15%)	Higher injuries in decreased anterior distance < 67.2% (OR = 0.674)	Higher injuries in BMI > 26.69

Table 4 (continued)

Authors	Year	Definition of injury	Incidence	Effect of postural stability deficit as risk factor for ankle sprain	Other findings
Attenborough et al.	2017	A lateral, medial or syndesmotic sprain to the ankle complex […] occurred during a netball training session or match […] that must have prevented the individual from participating in a full subsequent match or netball training session	11/94 (11.7%) 6.75/1000 h-play 0.40/1000 h-train	Higher incidence in decreased postero-medial distance < 77.5% of leg length (OR = 4.04)	None

M males, *F* females, *HR* hazard ration, *OR* odd ration, *AP* antero-posterior, *ML* medio-lateral, *BMI* body mass index, *MTP* metatarso-phalangeal

examiner evaluation failed in this task. Finally, after exclusion of patients with history of ankle injuries, a positive relation between postural stability deficit and ankle sprain was present.

Attempts to summarize the evidence of the postural stability role in lower limb injuries and, specifically, ankle sprain have been performed previously [7, 17, 25, 37]. Onate et al. [25] reported that there is a moderate evidence supporting multidirectional balance in high school-aged athletes as risk factor for future ankle sprains, however, based on the analysis of only three studies. Similarly, Witchalls et al. [37], analyzing four studies that measured postural sway with similar instrumented measures (New Balance Master, NeuroTest System, Neurocom Balance Master, force plates), identified higher postural sway and lower postural stability—together with lower eversion strength and higher plantar flexion strength—as risk factors for ankle sprains. Our systematic review was also able to highlight the center-of-gravity sway as risk factor for ankle sprain in five out of six studies. However, due to the limited number of studies included, the use of different tools and protocols, and the lack of discrimination regarding sports, sample size and sex, these finding need further confirmation in homogeneous populations using standardized tools, tests and measures of postural stability. In fact, force plates and similar technologies such as the New Balance Master, Neurocom Balance Master or Biodex Balance System, measure different parameters (e.g., sway velocity, antero-posterior center of gravity sway, directional control, degrees of platform tilt, etc.) and also involve an heterogeneous number of tasks that are grossly categorized as static or dynamic postural stability (e.g., leg stance, sway, jump, external perturbation, etc.). Therefore, their different intrinsic ability to detect a postural stability deficit could possibly mask the effective presence of an intrinsic postural stability deficit, further explaining the lack of agreement.

Regarding the evaluation by an examiner, Witchalls et al. [37] already reported its inability to adequately predict ankle sprains, confirming the findings of this review. They suggested that methods that tests postural stability by scoring the number of errors during a test, involve an increased subjectivity that might increase the variability in scores, rendering them less useful for the purpose of identifying postural stability deficit.

The Star Excursion Balance Test (SEBT) has been utilized in various tasks, including postural stability deficit detection and injury prediction. It has been demonstrated, which is able to differentiate pathological conditions such as chronic ankle instability (CAI), anterior cruciate ligament (ACL) reconstruction and Patellofemoral pain syndrome (PFPS), and to discriminate the effect of external influences such as taping, fatigue and various types of balance training [26]. Plisky et al. identified a composite score for lower limb

Table 5 Summary of the effect of the ankle injuries history in the development of further injuries

Authors	Year	Exclusion of ankle sprain	Evaluation of history of ankle sprain	Statistical method	History of ankle sprain as risk factor	Postural stability as risk factor
McGuine et al.	2000	Yes (< 12 months)	No	NA	NA	Yes
Beynnon et al.	2002	Yes	No	NA	NA	No
Willems et al.	2005	Yes (< 6 months)	No	NA	NA	Yes
Willems et al.	2005	Yes (< 6 months)	No	NA	NA	Yes
Wang et al.	2006	Yes (< 6 months)	No	NA	NA	Yes
McHugh et al.	2006	No	Yes	Logistic regression	Yes	No
Trojian and McKeag	2006	Yes (< 6 weeks)	Yes	Chi-square	No	Yes
Hrysomallis et al.	2007	No	Yes	Logistic regression	No	Yes
Hiller et al.	2008	No	Yes	Logistic regression	Yes (contralateral)	No
Hadzic et al.	2009	No	Yes	Logistic regression	No	No
Engebretsen et al.	2010	No	Yes	Logistic regression	Yes	No
de Noronha et al.	2013	Yes (< 1 month)	Yes	Logistic regression	Yes	Yes
Dallinga et al.	2016	No	No	NA	NA	No
Gribble et al.	2016	No	Yes	Chi-square	No	Yes
Attenborough et al.	2016	Yes (< 6 months)	Yes	Logistic regression	No	Yes

NA not available

difference less than 94% and an anterior reach difference of 4 cm or greater as a risk factor for lower limb injuries [28]. Limited to ankle sprains, a posterolateral distance < 80, an anterior distance < 63% compared to non-injured side and a posteromedial distance < 77.5% of leg length were identified as risck factors in 3 studies [1, 9, 14].

However, it should be taken into account that the tasks required to complete the SEBT could actually involve other characteristics than postural stability, such as supinated or pronated foot, joint ROM, flexibility, and muscle activation [5, 11]. Since bad motor performance [20], decreased ankle dorsiflexion [16, 34], increased calcaneal eversion [2], decreased muscle reaction time [34] and decreased dorsiflexion strength [34] have been identified as risk factors for ankle sprain, it could be possible that the results obtained with SEBT could not be related only to the mere capacity to evaluate postural stability. Thus, if the ability of SEBT to predict ankle sprains is strictly related to postural stability deficit or to other neuromuscular or anatomical features remains controversial. However, due to its high intratester (0.85–0.89) and intertester (0.97–1.00) reliability of both the original method and its simplified version (Y Balance test) [27], its simplicity and its limited cost, further studies are encouraged to confirm its ability to predict ankle injuries, possibly compared to other methodologies.

The last interesting consideration emerged from the findings of the present systematic review is the role of previous ankle injuries in the development of further injuries. As reported, only six studies evaluated athletes without history of ankle injuries in the previous 6 months. Since five out of this six studies reported postural stability as risk factor for ankle injuries, it is possible that the evaluation of postural stability deficit in patients without previous sprains is more effective and actually able to predict further injuries. Conversely, when a previous injury is present, a basal postural stability deficit could be already established due to the previous trauma, before the risk exposure. It has been in fact demonstrated a direct relationship between balance and history of ankle injuries or chronic ankle instability [4, 21, 22, 31]. Furthermore, three studies [12, 18, 22] performed a logistic regression with several independent variables in the same model, highlighting the history of previous ankle injuries but not postural stability deficit as risk factor for further ankle injuries. Therefore, this anamnestic detail should always be considered during athletes screening and in the study design of prospective studies. Finally, the results of the present systematic review could guide clinicians in developing screening programs and design further prospective cohort studies comparing different evaluation tools.

The present review has several important limitations. The most important is related to the high heterogeneity of the studies included regarding sex, sport, follow-up, methods of balance evaluation and data analysis. This did not allow the evaluation of the data through a meta-analysis; therefore, the findings obtained by the review of the available literature are based on qualitative evaluation and presented in a narrative form. Furthermore, confounding factors especially history of ankle injuries, despite acknowledged and investigated, could have masked the effect of intrinsic postural stability deficit and distort the reported evidences. Finally, the statistical methods to correlate postural stability evaluation and ankle injury were different between the studies, from multivariate analysis adjusted to confounders to simple Chi-square test, thus introducing a further source of variability.

Future studies should be aimed to evaluate postural stability through standardized instruments, protocols, tasks and measurements of center-of-gravity sway. Moreover, also the ability of SEBT to detect postural stability deficit and predict ankle sprains should be confirmed through further studies on wider and heterogeneous samples, possibly compared to instruments for center-of-gravity sway measurement.

Conclusions

The ultimate role of postural stability as risk factor for ankle sprains was not defined, due to the high heterogeneity of results, patient's populations, sports and methods of postural stability evaluation. Regarding assessment instruments, measurement of center-of-gravity sway could detect athletes at risk, however, standardized tools and protocols are needed to confirm this finding, while the SEBT could be considered a promising tool that needs further investigation in wider samples. History of ankle sprains is an important confounding factor, since it was itself a source of postural stability impairment and a risk factor for ankle sprains.

Compliance with ethical standards

Conflict of interest All the authors declare no conflict of interests related to the ideation, preparation and production of the present manuscript.

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