Ankle Instability Is Associated with Balance Impairments: A Meta-Analysis

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ABSTRACT

ARNOLD, B. L., S. DE LA MOTTE, S. LINENS and S. E. ROSS. Ankle Instability Is Associated with Balance Impairments: A Meta-Analysis. *Med. Sci. Sports Exerc.*, Vol. 41, No. 5, pp. 1048–1062, 2009. **Purpose**: Our primary purpose was to determine whether balance impairments were associated with functional ankle instability (FAI). **Methods**: Our literature search consisted of four parts: 1) an electronic search of PubMed, CINAHL, pre-CINAHL, and SPORTDiscus; 2) a forward search of articles selected from the electronic search using the Science Citation Index; 3) a hand search of the previously selected articles; and 4) a direct contact with corresponding authors of the previously selected articles. We initially identified 145 articles and narrowed these to 23 for inclusion in the meta-analysis. Identified outcomes were categorized by measurement units and balance task type (i.e., dynamic or static). Each study was coded based on whether inclusion or exclusion criteria were identified. Our statistical analysis included fixed, random, or mixed effect analyses based on the presence of within study heterogeneity and whether categories were being compared. **Results**: FAI was associated with poorer balance (standard difference of the mean [SDM] = 0.455, 95% confidence interval = 0.334–0.577, $Z = 7.34$, $P < 0.001$), but no difference existed between dynamic and static measure categories ($Q = 3.44$, $P = 0.063$). However, there was a significant difference between the dynamic measures ($Q = 6.22$, $P = 0.013$) with both time to stabilization and the Star Excursion Balance Test producing significant SDM and between static measures ($Q = 13.00$, $P = 0.012$) with the linear, time, velocity, and other measurement categories (but not area) producing significant SDM. Examination of individual outcomes revealed that time in balance and foot lifts produced very large SDM (3.3 and 4.8, respectively). **Conclusion**: FAI is associated with impaired balance. Due to the relatively large effect sizes and simplicity of use of time in balance and foot lifts, we recommend that further research should establish their clinical validity and clinical cutoff scores. **Key Words:** POSTUROGRAPHY, STABILITY, SPRAIN, CHRONIC, DYNAMIC, STATIC

Functional ankle instability (FAI) is common after ankle sprains and is characterized by feelings of "giving way" at the ankle and recurrent ankle sprains (35). Thirty to forty percent of patients with ankle sprains report recurrent sprains (11) or residual symptoms of instability (31,40). FAI has been shown to prevent approximately 6% of patients from returning to their occupation (40), and due to residual symptoms, 5–15% of patients remain occupationally handicapped from at least 9 months to 6.5 yr, respectively (31,40). Single-leg balance impairments, additionally, have been associated with FAI (1,3,4,6,15–17,20,21,38,39) and have predicted ankle sprain injury in physically active individuals (23,34,37,41). As a result of this association between balance deficits and ankle sprain injury, single-leg balance tests have been used as clinical and research examinations to assess postural instabilities associated with FAI.

One reason balance tests are used to evaluate postural instabilities associated with FAI is due to the work of Freeman et al. (9), who reported that FAI impaired static single-leg balance as measured by the Romberg test. Freeman et al. (9) proposed that disrupted sensorimotor pathways associated with FAI diminished postural reflex responses, causing single-leg balance deficits. Thus, clinicians and researchers have used noninstrumented static single-leg balance tests to assess FAI (6,17). To more objectively assess balance, researchers have used instrumented force plates to quantify static single-leg balance deficits associated with FAI (1–4, 12,15–17,19–21,25,29,36–39,44). However, the balance literature on FAI lacks consistency in reporting balance deficits associated with FAI, as some researchers have indicated that balance impairments exist with FAI, and other researchers have reported that balance deficits are not associated with FAI (24,27). Reasons for this disparity in the FAI literature are unclear. Several factors, however, may be affecting the outcomes of studies, making it difficult to conclude how FAI affects balance. Factors that may confound the balance literature on FAI include subject characteristics, inclusion/exclusion criteria, type of balance test used to examine

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postural stability, and/or type of balance measure (instrumented vs noninstrumented or static vs dynamic).

Balance tests that are more functional may be better than static single-leg balance tests at detecting balance impairments associated with FAI. Dynamic single-leg jump-landing tests and the Star Excursion Balance Test (SEBT) are alternative assessment techniques that may challenge balance greater than static single-leg balance tests. Researchers have reported dynamic balance deficits associated with FAI using time to stabilization (TTS) (2,29,30,43). The SEBT has also quantified dynamic single-leg balance, and researchers have reported balance impairments associated with FAI (14,26). Like static balance measures, however, some researchers have reported dynamic balance deficits with TTS and SEBT measures, whereas others have not (2,14,26,29,30,43). These conflicting results contribute to the confusion in determining if balance deficits exist with FAI.

Inconsistencies reported in the literature on the effects of FAI on static and dynamic balance measures may result from different balance assessment measures or tests. In examining the balance literature related to FAI, we cannot definitively conclude if balance deficits exist with FAI nor can we determine the degree to which various balance tests or balance measures impact previously reported results. Thus, the purpose of this meta-analysis was 1) to pool studies to determine an overall effect size difference between ankles with instability and uninjured ankles, 2) to determine whether effect sizes differed depending on the type of measure used, and 3) to determine whether effect sizes differed between studies with clear inclusion and exclusion criteria and those without criteria.

Hypothesis. On the basis of the above, we identified five hypotheses: 1) balance is impaired in subjects with ankle instability; 2) dynamic balance tests will be associated with greater balance impairments than static tests of balance; 3) within the categories of dynamic and static balance, different measures will produce different effect sizes; 4) studies with clearly stated inclusion criteria will report greater balance deficits than those without stated inclusion criteria; and 5) studies with clearly stated exclusion criteria will report greater balance deficits than those without exclusion criteria.

Description of outcomes. The outcomes used in this study were restricted to two broad categories of balance measures: dynamic and static. Static measures were defined as measures that required subjects to stand either single-legged or double-legged and maintain a quiet posture. We defined dynamic measures as those that required subjects to perform movement as the task (e.g., jump landings). The outcome(s) selected for each study is in Table 1. In both cases, the outcomes were restricted to measures of central tendency (e.g., not root mean squares, SD, etc.) and to those measured on a firm/stable surface.

Type of study designs used. We did not restrict our analysis to any particular study design or research question. Rather, we used any study that met our inclusion/exclusion criteria. The typical study included was a case–control study comparing subjects with stable and FAI ankles. However, experimental/randomized control trials and *ex post facto* designs were included when pretreatment data were available.

Study populations. As with study designs, no restriction was placed on study populations. Demographics for the study populations are in Table 2.

METHODS

Search Strategy and Manuscript Selection

Our effort to include all available studies consisted of four components: 1) the initial search and evaluation of the studies; 2) a forward search of the included articles from step one; 3) a hand search of included articles from steps 1 and 2; and 4) a direct contact with the corresponding authors of the included articles. The process flow is in Figure 1. In theory, steps 2 and 3 were iterative to the point that no further articles were located. In practice, only one repetition was necessary to identify the included studies.

Literature search. We searched the literature using PubMed (National Library of Medicine, Bethesda, MD), CINAHL, pre-CIHAHL, and SPORTDiscus through November 2007. The three latter databases were searched simultaneously using EBSCOhost (EBSCO Industries, Inc., Birmingham, AL). The search strategy and results are presented in Table 3. The literature search was directed by our senior research team member (BLA) who has 14 yr of research experience and expertise in the area of FAI. The search was assisted by two doctoral students in the area of rehabilitation and movement science and specializing in FAI. The search strategy was limited to the English language (five foreign language articles were excluded).

Article inclusion and exclusion. After the initial electronic search was complete (n = 145), three reviewers reviewed titles and abstracts and selected articles for detailed review. Articles were selected or eliminated based on the consensus of the three reviewers. For the detailed review, we used two criteria to determine whether the article should be included in the analysis: 1) tabular means and SD must have been reported for an injured group (or ankle) and an uninjured group (or ankle), or sufficient statistical detail (e.g., P values and group n) was reported to calculate an appropriate effect size; and 2) stated inclusion criteria required injured ankles to have episodes of giving way or frequent sprains, or "functional ankle instability" was described as the target pathology.

We did not include abstracts in this analysis. However, we did review theses and dissertations as part of the overall selection process. Provided the thesis/dissertation met the inclusion criteria and had not been previously published, they were included in the analysis.

Forward and hand search. Using the articles selected for inclusion from the initial search, we conducted a forward search using the Science Citation Index (The Thomson Corp., New York, NY). This search produced

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TABLE 1. Study inclusion criteria, quality score, measurement instrument, number of subjects (*n*), and outcome measures.

Authors	Quality Score	Stated Inclusion/Exclusion Criteria	Injured Subjects (*n*)	Uninjured Subjects (*n*)	Postural Control Instrument	Outcome Variables
Baier and Hopf (1)	27	Functional instability defined as recurrent ankle sprains (more than five per year) and a feeling of giving way	32	44	Force platform	A/P sway velocity ($mm \cdot s^{-1}$)
		No increased talar tilt or anterior drawer				Number of angular vectors (%)
						Number of linear vectors (%)
						M/L sway velocity ($mm \cdot s^{-1}$)
						Sway area (mm^2)
						Total horizontal sway ($mm \cdot s^{-1}$)
Brown et al. (2)	31	Recurrent ankle sprains (at least two in past year)	10	10	Force plate	TTS A/P (ms)
		Feeling of giving way during activity	10	10		TTS M/L (ms)
		Score of 20 or less on AJFAT				
		No acute lower extremity injury, lower extremity injury in past 3 months, or previous history of lower extremity surgery				
Brown and Mynark (3)	38	History of ankle giving way with activity	20	20	Force plate	COP area (mm^2)
		Minimum two ankle sprains	20	20		COP length (mm)
		OR	20	20		COP velocity ($mm \cdot s^{-1}$)
		Two giving ways in last year	20	20		TTS A/Pr (s)
		No history of lower extremity surgery, current signs or symptoms of ankle sprain, vestibular or balance disorders, or use of drug affecting the central nervous system	20	20		TTS M/L (s)
Chrintz et al. (4)	15	History of recurrent ankle sprains	29	41	N/A	Single-leg postural equilibrium test, eyes closed (s)
		Giving way incidents resistant to training guided by a physiotherapist				Single-leg postural equilibrium test, eyes open (s)
Docherty et al. (6)	32	History of at least one inversion sprain and repeated feeling of giving way or instability in the ankle	30	60	N/A	BESS (single leg—firm)
		No history of fracture or surgeries to the foot, ankle, or lower leg; cerebral concussion; vestibular; visual; equilibrium dysfunction; or symptoms of an acute ankle sprain (swelling, pain, etc.)				
Gauffin et al. (10)	9	Not specified	10	15	Force plate	Area of confidence ellipse (mm^2)
Hale et al. (12)	26	History of at least one unilateral ankle sprain with pain or limping for more than 1 d	29	19	N/A	SEBT anterior (% leg length)
		Chronic ankle weakness				SEBT anterolateral (% leg length)
		Pain or instability attributed to initial injury				SEBT anteromedial (% leg length)
		Self-reported giving way in last 6 months				SEBT lateral (% leg length)
		No bilateral ankle instability, history of ankle fracture, ankle injury within 3 months before participation, history of anterior cruciate ligament injury, history of balance disorders, or current participation in supervised physical rehabilitation				SEBT medial (% leg length)
						SEBT mean reach (% leg length)
						SEBT posterior (% leg length)
						SEBT posterolateral (% leg length)
						SEBT posteromedial (% leg length)
					Force plate	COP velocity, eyes open ($cm \cdot s^{-1}$)
						COP velocity, eyes closed ($cm \cdot s^{-1}$)
Hertel and Olmsted-Kramer (15)	20	Inclusion criteria not specified	15	9	Force plate	COP velocity M/L ($cm \cdot s^{-1}$)
		No history of ankle fracture, vestibular or neurological disorders, any acute or subacute lower extremity injuries within the previous 3 months that could adversely affect their balance				COP velocity A/P ($cm \cdot s^{-1}$)
						TTB A/P
						TTB M/L
Hertel et al. (14)	33	History of at least one ankle sprain on the involved ankle requiring medical care	48	39	N/A	SEBT anterior
		More than three episodes of ankle giving way on involved side in past 12 months				SEBT anterolateral

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		No history of fracture or surgery to the involved ankle or history of ankle sprain, fracture, or surgery on the uninvolved limb				SEBT anteromedial SEBT lateral SEBT medial SEBT posterior SEBT posterolateral SEBT posteromedial
Hiller et al. (16)	16	CAI that resulted from history of ankle inversion injury, which required protected weight bearing and/or immobilization CAI defined as the perception that the ankle was chronically weaker, more painful, and/or less functional than the other ankle or than before first injury Older than 16, trained in ballet to at least intermediate level to enable safe positioning on the demi-pointe, and female Required to be participating fully in dance classes and able to maintain the demi-pointe position without pain No lower limb fracture, central neurological deficit, ankle surgery, or modification of dance activity due to acute lower limb injury	16	26	3Space FASTRAK	Single-leg stance oscillation (mm)
Hiller et al. (17)	33	Ankle instability from past ankle inversion injury that resulted in modified weight bearing or use of ankle support No history of ankle surgery, ankle fracture, neurologic deficit, or an ankle sprain within last month	41	20	3Space FASTRAK	Single-leg stance, no. foot lifts, eyes closed Single-leg stance oscillation (mm)
Hubbard et al. (19)	44	Previous history of unilateral ankle sprain Frequent giving way of ankle Pain Feelings of instability Decreased function No acute ankle sprain within 6 wk of participation in study, history of surgery or fracture to either lower extremity, or any previous sprain on the limb contralateral to the chronically unstable ankle Controls had to be free of previous injury or surgery to either lower extremity	30	30	N/A Force plate	SEBT anterior SEBT posterolateral SEBT posteromedial COP velocity, eyes open ($cm \cdot s^{-1}$) COP area, eyes closed (cm^2) COP area, eyes open (cm^2) COP velocity, eyes closed ($cm \cdot s^{-1}$)
Konradsen and Ravn (20)	16	Not specified	15	15	Force plate	Transverse sway medial amplitude (mm)
Lee et al. (21)	23	At least one significant lateral ankle sprain of only one ankle after which subject was unable to bear weight or placed on crutches within last year Sustained at least one repeated injury or the experience of feelings of instability or giving way of one ankle No reported history of bone fracture to either ankle, Not undergoing any formal or informal rehabilitation of the unstable ankle or no evidence of mechanical instability as assessed by a physician using an anterior drawer test	8	8	Force plate	COP mean radius, eyes closed (cm) COP mean radius, eyes open (cm)
Michell et al. (25)	20	Multiple giving way sensations at ankle with physical activity Sustained at least two ankle sprains in last year For FAI subjects no score higher than 20 points on the AJFAT or ankle sprain within 6 months before this study For all subjects, no history of lower extremity fracture, knee injury, hip injury; visual impairment that affected balance; vestibular deficit; or neurologic dysfunction	16	16	Force plate	COP A/P (cm) COP M/L (cm)
Olmsted et al. 2002 (26)	31	At least one episode of an acute lateral ankle sprain but none within the past 6 wk Multiple episodes of giving way within past 12 months For the CAI group, no cerebral concussions, vestibular disorders, lower extremity injuries for past 3 months, ear infection, upper respiratory infection or head cold at time of study, prior balance training	20	20	N/A	SEBT anterior (cm) SEBT anterolateral (cm) SEBT anteromedial (cm)

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TABLE 1. *Continued*

Authors	Quality Score	Stated Inclusion/Exclusion Criteria	Injured Subjects (*n*)	Uninjured Subjects (*n*)	Postural Control Instrument	Outcome Variables
		For the uninjured group, no history of injury to either ankle, cerebral concussions, vestibular disorders, lower extremity injuries for 3 months before testing, ear infection, upper respiratory infection, head cold at the time of the study, or no prior balance training				EBT posterior (cm) SEBT lateral (cm) SEBT medial (cm) SEBT posterolateral (cm) SEBT posteromedial (cm)
Ross and Guskiewicz (29)	34	Inclusion criteria not specified For FAI subjects, no signs and symptoms of injury, such as pain or swelling, ankle sprain injury within 6 wk before their participation For all subjects, no history of lower extremity fractures, knee injuries, or hip injuries	14	14	Force plate	COP mean sway A/P (cm) COP mean sway M/L (cm) TTS A/P (s) TTS M/L (s)
Ross et al. (30)	25	History of a severe ankle sprain injury with at least 3 d of immobilization At least two additional ankle sprains and two giving way sensations with weight-bearing activity within the past year No history of lower extremity fracture, knee injury, hip injury, visual impairments that affected their balance, vestibular deficits, or neurologic dysfunctions For subjects with stable ankles, no history of ankle sprain injury or sensations of giving way at the ankle with weight-bearing activity	10	10	Force plate	TTS A/P (s) TTS M/L (s)
Tropp and Odernick (38)	0	Recurrent sprains or a feeling of giving way Exclusion criteria not specified	15	15	Force plate	Area of confidence ellipse (no units reported)
Wayne (42)	9	Had a history of two sprains and functional instability in the past 2 yr No experience with the BESS within the last year, lower extremity injury in the past 2 months, known neuromuscular deficits, head injury within the past 6 months, nor caffeine, alcohol, or any drugs that could alter balance within the last 12 h	19	21	Force plate	BESS single-leg mean sway speed X ($cm \cdot s^{-1}$) BESS single-mean sway speed XY ($cm \cdot s^{-1}$) BESS single-leg mean sway speed Y ($cm \cdot s^{-1}$)
Wikstrom et al. (43)	27	Sensations of weakness, 'looseness," and episodes of giving way during daily activity No fractures to ankle, injury within past 3 months, or no formal rehabilitation of the affected ankle	29	29	Force plate	TTS A/P (ms) TTS M/L (ms) TTS vertical (ms)
You et al. (44)	38	Feeling of giving way after one or more significant ankle inversion sprains within the past 12 months No injuries other than (ATFL or CFL) ligament injury were excluded	6	4	Force plate	A/P sway (cm) M/L sway (cm)
Zinder (45)	17	Score of 5 or higher on the ankle instability instrument Minimum of one give-way episode per month No history of ankle pathology in the last 6 wk, known neuromuscular dysfunction, or medication that would alter neuromuscular control at the time of testing	14	14	Force plate	Sway amplitude (mm) Sway velocity ($cm \cdot s^{-1}$)

A/P, anteroposterior; M/L, mediolateral; TTS, time to stabilization; COP, center of pressure; BESS, balance error scoring system; SEBT, Star Excursion Balance Test; TTB, time to boundary.

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TABLE 2. Reported subject characteristics of the included articles.

Authors	Giving way	Non–weight-Bearing/ Immobilization	Time Lost	Physical Activity	Mechanical Instability	History of Sprain	Age Injured	Height Injured (cm)	Weight Injured (kg)	Age Uninjured	Height Uninjured (cm)	Weight Uninjured (kg)
Baier and Hopf (1)	Yes	Not specified	Not specified	Physically active	Excluded	More than five per yr	26	Not specified	Not specified	25	Not specified	Not specified
Brown and Mynark (3)	Yes	Not specified	Not specified	Physically active	Not specified	At least two in the past year	21.45	173.16	69.34	22.10	173.69	72.10
Brown et al. (2)	Yes	Not specified	Not specified	Physically active	Not specified	At least two in past yr	22.50	176.53	82.64	21.90	181.86	72.88
Chrintz (4)	Yes	Not specified	Not specified	Not specified	Required	At least three in yr before operation	27	Not specified	Not specified	29	Not specified	Not specified
Docherty et al. (6)	Yes	Not specified	Not specified	Collegiate	Excluded	At least one	20	172.7	68.5	18.7	173.4	68.2
Gauffin et al. (10)	Mentioned	Not specified	Not specified	Physically active	Included	Recurrent sprains	24	Not specified	Not specified	22	Not specified	Not specified
Hale et al. (12)	Yes	Not specified	Not specified	Recreational athlete	Excluded	At least one	22.2 C, 21 R	Not specified	Not specified	21.1	Not specified	Not specified
Hertel and Olmsted-Kramer. (15)	Yes	Not specified	Not specified	Physically active	Not specified	At least one mean = 2.7	19.7	166.6	70	22.7	163.7	61.6
Hertel et al. (14)	Yes	Not specified	Not specified	Not specified	Not Specified	At least one	20.9	173.6	80.1	20.7	174.1	75.1
Hiller et al. (16)	No	Required	Not specified	Physically active	Not specified	CAI	21	164	57	23	165	55
Hiller et al. (17)	No	Not specified	Not specified	Physically active	Not specified	Ankle inversion injury	23.7 UI, 22.5 BI	171.9 UI, 171.9 BI	70.6 UI 67 BI	24.5	171.4	67.3
Hubbard et al. (19)	Yes	Not specified	Not specified	Not specified	Not specified	Mean = 5.8	20.3	172.5	72.9	21.3	172.6	71.9
Konradsen and Ravn (20)	No	Not specified	Not specified	Physically active	Mixed†	Severe complaints of FI	27	Not specified	Not specified	27	Not specified	Not specified
Lee et al. (21)	Or*	Required	Not specified	Not specified	No	At least one	19.21	174.25	69	19.58	170.71	65.14
Michell et al. (25)	Yes	Not specified	Not specified	Physically active	Not specified	At least two	20	190 M, 160 F	79 M, 57 F	20	190 M, 160 F	75 M, 57 F
Olmsted et al. (26)	Yes	Not specified	Not specified	Collegiate	Not specified	At least one	19.8	176.8	82.9	20.2	178.7	82.7
Ross and Guskiewicz (29)	Yes	Not specified	Required	Not specified	Mixed†	At least one severe and two additional	21.71	177.98	80.17	22	179.25	76.38
Ross et al. (30)	Yes	Not specified	Required	Recreational athlete	Not specified	At least one severe and two additional	22	175.2	73.4	20.8	175.8	74
Tropp and Odernick (38)	Yes	Not specified	Not specified	Physically active	Not specified	Recurrent sprains or a feeling of giving way	22.1	Not specified	Not specified	22.1	Not specified	Not specified
Wayne (42)	Yes	Not specified	Not specified	Not specified	Not specified	History of inversion ankle sprains and functional instability within past 2 yr	22.3	173.00	80.41	20.62	170.14	70.81
Wikstrom et al. (43)	Yes	Not specified	Not specified	Not specified	Not specified	Weakness, looseness, and giving way	21.8	173.6	77.8	21.2	170.5	67.9
You et al. (44)	Yes	Not specified	Not specified	Not specified	Excluded	At least one	23.3	170	68	20.5	170	60
Zinder (45)	Yes	Not specified	Not specified	Physically active	Not specified	Not specified	23.76	174.00	68.60	26.19	166.07	69.90

C, control; R, rehabilitation; UI, uninjured; BI, bilateral; M, male; F, female.
* Giving-way or repeated sprain.
† Included both mechanically stable and unstable ankles.

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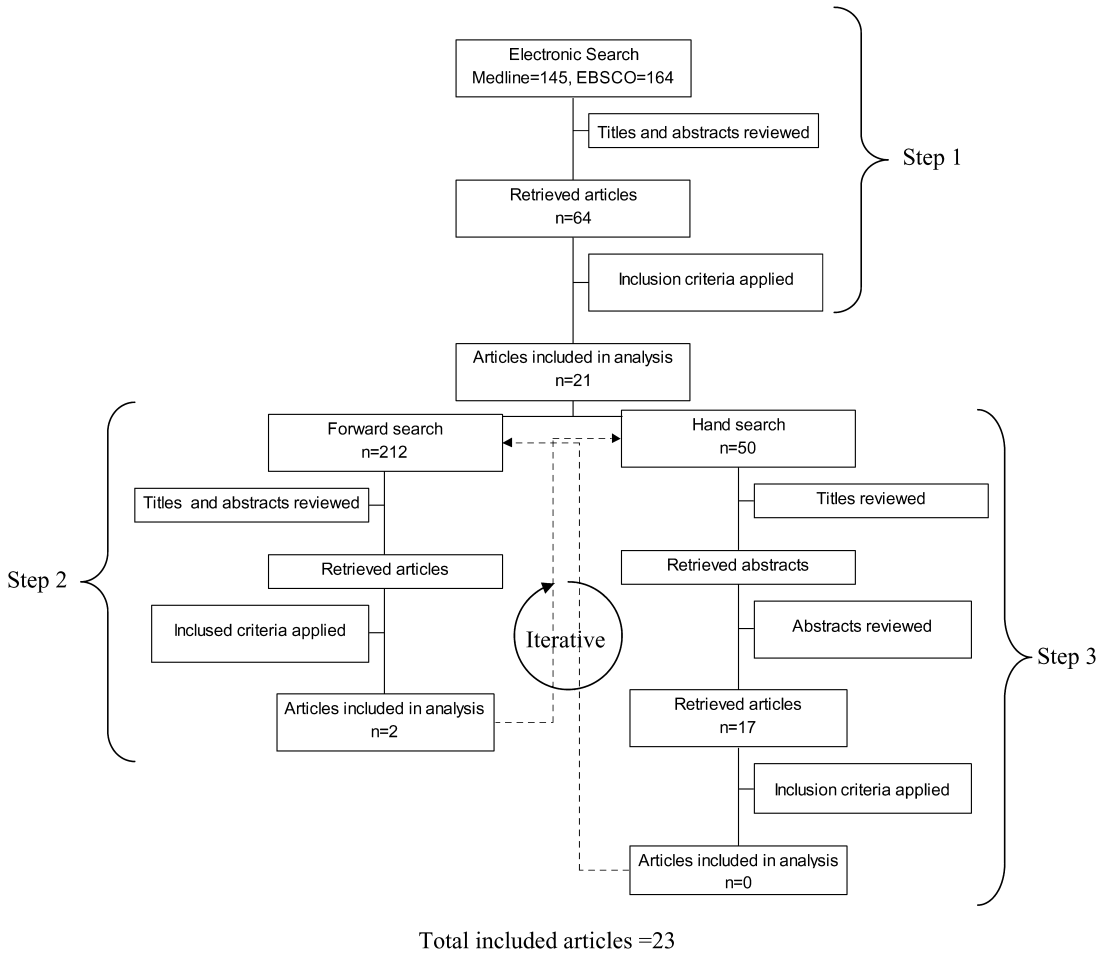

FIGURE 1—Flow chart for the manuscript review process. Steps 2 and 3 were iterative.

two additional articles for inclusion in the analysis, and we consequently conducted forward searches on these articles. From the articles selected from the initial and both forward searches, we conducted a hand search of each articles cited references. The hand search produced no additional articles.

Contact with authors. Additionally, the corresponding author of each of the included articles was contacted by letter or e-mail. A listing of their included articles was presented in the correspondence, and they were asked to identify any additional articles that might be eligible for inclusion.

Meta-Analysis

Data extraction. Three investigators extracted relevant data from each study. Specifically, we identified the means, SD, and group sample size for the FAI and the stable ankle groups (or ankles in the case of a contralateral comparison) for the selected outcomes. If only statistical test values were provided, those were extracted. In two cases (4,20), the median and the range were reported. These were converted to estimated means and SD (18). Each investigator extracted data independently. If discrepancies existed between investigators, we resolved those differences by reexamining the study and by agreeing on the final data by consensus. For studies that included a treatment, only the pretreatment values were used in the analysis.

Assessment of confounding. One concern for every meta-analysis is confounding of the results by factors and/or variables outside the focus of the included studies. For example, balance is affected by age. Mixing age groups without accounting for this confounder may bias the results in a particular direction or produce a null result. How to assess confounding can be a challenge in that many confounders may exist simultaneously. We assessed confounding from two separate perspectives: anthropometric similarity of injured and uninjured subjects and comparability of FAI definitions, inclusion criteria, and exclusion criteria. The former was assessed as an item in our quality assessment with studies statistically comparing subjects' anthropometrics being given a higher score. The latter was assessed with regard to the studies reporting inclusion criteria/FAI definitions and exclusion criteria. Each of these

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TABLE 3. Search strategy for meta-analysis.

Step	Strategy	EBSCO Result	PubMed Central Result
28	S27 and S18	164	82
27	S26, S25, S24, S23, S22, S21, S20, or S19	17239	96207
26	TI TTB or AB TTB	9	59
25	TI COP or AB COP	793	2653
24	TI BESS or AB BESS	70	77
23	TI TTS or AB TTS	123	1124
22	TI SEBT or AB SEBT	37	11
21	TI entropy or AB entropy	132	9525
20	TI postural sway or AB postural sway	381	758
19	TI balance or AB balance	16248	83005
18	S17, S10, and S4	1129	1133
17	S16, S15, S14, S13, S12, or S11	136088	1770820
16	TI multiple or AB multiple	39268	457447
15	TI repetitive or AB repetitive	3025	33616
14	TI functional* or AB functional*	36451	545870
13	TI recurrent* or AB recurrent*	12476	239173
12	TI chronic* or AB chronic*	51564	566587
11	SU 'recurrence'	7873	117396
10	S9, S8, S7, S6, or S5	12260	104954
9	TI inversion or AB inversion	1212	17721
8	TI instability or AB instability	5388	44779
7	TI sprain* or AB sprain*	2731	2516
6	TI unstable or AB unstable	2908	39169
5	(SU "sprains" and SU "strains") or SU "joint instability"	2395	11935
4	S3, S2, or S1	11749	24851
3	TI ankle* or AB ankle*	11621	22721
2	SU "lateral ligament, ankle"	21	191
1	SU "ankle joint"	748	6854

S, step; TI, title; AB, abstract; SU, subject; TTS, time to stabilization; COP, center of pressure; BESS, balance error scoring system; SEBT, Star Excursion Balance Test; TTB, time to boundary.

were coded separately as "yes" or "no" and included in the analysis as separate moderator variables. Due to highly variable reporting of inclusion/exclusion criteria by the respective studies, a more detailed analysis of these was not considered possible.

Quality assessment. Quality was assessed using a questionnaire developed for this analysis (Fig. 2). The questionnaire was developed from the threats to construct, internal, and external validity identified by Cooke and Campbell (5) and tailored to issues associated with ankle instability research. We elected to use our own scale rather than a similar scale developed for randomized control trials, for example, the PEDro scale, because these scales specifically penalize for not randomizing. For this meta-analysis, all of the data were extracted from observational (i.e., not randomized) studies or from time points before randomization. All studies were assessed by three reviewers on a 20-point scale. Three items were eligible for the rating "not applicable." Thus, the final quality score was calculated as the percentage of points possible, that is, 20 minus any not applicable items. Initially, we reviewed all studies independently. After the initial review, we compared scores and identified large discrepancies among the reviewers. Studies with large discrepancies (scores greater than ±1 SD above the mean) were again independently reviewed. We used these final results as the quality score. The study quality was then regressed on the mean outcome standard difference of the mean (SDM) for each study to determine the effect of quality on SDM.

Statistical methods. All statistical analyses were completed using Comprehensive Meta-analysis version 2.2.034 (Biostat, Inc., Englewood, NJ). Depending on the data available from each study, data were entered as means and SD (n = 21), as SDM (n = 1), or as means and P values (n = 1). From these data, the SDM was calculated and used for the analysis. The statistical significance of individual and category SDM was tested using the Z statistic, which follows the normal distribution and tests whether the observed SDM differs from zero (13).

Test of the overall effect. The first hypothesis was initially assessed for heterogeneity using the Q statistic. The Q statistic approximates the chi-square distribution and tests whether the observed effect size variance is greater than chance expectations, that is, heterogeneous (32). If the Q statistic was significant, the random-effects analysis was used to account for this heterogeneity in the analysis.

Comparisons between categories. For hypotheses 2–5 (e.g., dynamic versus static balance), if the Q statistic was significant, the random-effects model was extended to a mixed-effects model. The mixed-effects model combines studies within each category using the random-effects model, and the categories are subsequently compared using the fixed-effects model.

Treatment of multiple outcomes. All of the studies included in this analysis used multiple outcomes. Because we viewed hypotheses 1 through 3 as largely exploratory and believed it important to study the effects of all of the potential variables used, we elected to treat each variable as independent. The effects of this are 1) the SE (and confidence interval [CI]) for the overall effect is too small, 2) the statistical test for the overall effect is likely to be liberal, and 3) the statistical comparisons between/among outcomes are conservative. For hypothesis 3, we tested the static and dynamic measures separately. On the basis of the outcomes' units, we grouped the static outcomes into five categories: area, linear, time, velocity, and other. Similarly, we divided the dynamic measures into two categories: SEBT and TTS.

For hypotheses 4 and 5, we averaged the effect sizes across outcomes within each study to produce one effect size per study. We felt this was appropriate because 1) it is likely that the inclusion and exclusion criteria would affect all of the outcomes within a study, and 2) the hypotheses were directed at differences between studies rather than between outcomes. Bias was assessed using Duval's (7) fixed effect trim and fill as well as Sterne and Egger's (33) regression intercept on the averaged outcomes.

RESULTS

Identification of Subject Characteristics

Study and subject characteristics are reported in Tables 1 and 2, respectively. These qualities were extracted either

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Construct validity			
1.	Was more than one outcome measure used? (mono-operational bias) E.g. proprioception, strength, balance (dynamic and static conditions would count as separate outcomes), etc.	+1	
2.	Were outcome measures randomly ordered or counterbalanced?	+1	N/A
3.	Were multiple levels of the target outcome variable(s) randomly ordered or counterbalanced? Does not include measures collected simultaneously, e.g. multiple COP excursion measures, EMG w/ force, etc.	+1	N/A
4.	Were subjects blinded to the research hypothesis?	+1	
5.	Were data collectors blinded to groups, i.e. unstable and comparison?	+1	
External Validity			
6.	Was the population defined (i.e. from where was the sample recruited)?	+1	
7.	Were the groups constructed using a representative sampling procedure? (Was it purposively sampled across target groups? Groups may be age, sport, activity level, etc.)	+1	
8.	Was more than one criteria used as inclusion criteria? (e.g. # of sprains, time on crutches, immobilization, time since last sprain)	+1	
9.	Was a minimum # of sprains required?	+1	
10.	Was the number of ankle sprains reported?	+1	
11.	Was a minimum # of give-ways required?	+1	
12.	Was the number of giving-way episodes reported?	+1	
13.	Was mechanical instability measured, eliminated, or included? (manually, arthrometry, or radiographs)	+1	
14.	Were acute symptoms excluded?	+1	
15.	Was the degree of the initial sprain reported or controlled?	+1	
16.	Was the setting described?	+1	
17.	Were copers and non-copers included?	+1	
Internal Validity			
18.	Was the comparison and unstable group equal relative to reported demographics/anthropometrics? (Selection bias) This is "no" if not statistically tested.	+1	
19.	Was/were calibration procedures reported for the variable(s) of interest? (Instrumentation) N/A for surveys, etc.	+1	N/A
20.	Was measurement reliability reported for the variable of interest? (May be referenced to another study or included in current study.)	+1	

Scoring:

A=Sum _____

B=20-N/A ___

A/B*100=____

FIGURE 2—Quality assessment tool used to rate study quality.

from reported subject characteristics or from reported inclusion/exclusion criteria. As the tables indicate, multiple factors were identified by the investigators and recorded. It is also apparent from the tables that there is no consistency in reporting of subject characteristics. Although we did not make direct comparisons for equality among studies, studies received credit for statistical comparisons of subjects' anthropometric characteristics as part of our quality assessment.

Quality Assessment

To compare our agreement among reviewers, we calculated the intraclass correlation coefficient (ICC), form (2,1). The ICC value was 0.735 with a 95% CI ranging from 0.547 to 0.868 and is higher than the reported value for the PEDro scale (22). The mean quality score was 24.3% ± 11.0% with a range from 0% to 43.7%. We found no relationship between study quality and SDM (slope = −0.011, $P = 0.09$).

Meta-Analysis

Due to the large heterogeneity between balance measures ($Q = 257.0$, $P < 0.001$), we used a random-effects analysis to determine whether balance was impaired in FAI subjects. This revealed that FAI was associated with poorer balance (SDM = 0.455, 95% CI = 0.334–0.577, $Z = 7.34$, $P < 0.001$).

Differences between dynamic and static measures. For the comparison between static and dynamic measures, there was significant within-group heterogeneity ($Q = 254.6$, $P < 0.001$). Thus, we computed a mixed-effects analysis and found no difference between dynamic and static measures ($Q = 3.44$, $P = 0.063$).

Comparison among static measures. There was significant within-group heterogeneity ($Q = 147.71$, $P < 0.001$) for the static measures. Thus, we computed a mixed-effects analysis to compare the static measurement groups (i.e., area, linear, time, velocity, and other). The overall SDM for the static measures was significant (0.324, 95% CI = 0.189–0.459, $Z = 4.71$, $P < 0.001$), indicating that FAI ankles had impaired balance as measured by static balance. Furthermore, we found that the static measure groups' SDM were significantly different from each other ($Q = 12.85$, $P = 0.012$). The individual SDM and the group values are presented in Figure 3.

Comparison among dynamic measures. For the dynamic measures (i.e., SEBT and TTS), no significant

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within-group heterogeneity was found (Q = 26.86, P = 0.836). Thus, a fixed-effects analysis was completed. The overall SDM was significant (0.336, Z = 7.28, P < 0.001, 95% CI = 0.246–0.410), indicating that FAI ankles had impaired balance as measured by the dynamic measures. The comparison between SEBT and TTS was significant (Q = 6.22, P = 0.013), indicating a significant difference between the two categories of dynamic measures. The individual SDM and the group values are presented in Figure 4.

Effects of inclusion criteria. Due to significant within-group heterogeneity (Q = 84.4, P < 0.001), we conducted a mixed-effects analysis. We found no significant difference (Q = 0.428, P = 0.513) between studies with inclusion criteria versus those without inclusion criteria. The individual SDM and the group values are presented in Figure 5.

Effects of exclusion criteria. Due to significant within-group heterogeneity (Q = 62.7, P < 0.001), we conducted a mixed-effects analysis. We found no significant difference (Q = 3.20, P = 0.074) between studies with exclusion criteria versus those without exclusion criteria. The individual SDM and the group values are presented in Figure 6.

Bias Assessment

The bias funnel plot including filled studies is presented in Figure 7. Egger's regression intercept was 3.00 (P = 0.048, two tailed), suggesting that bias was present. The trim and fill procedure identified six studies to be trimmed and filled. The SDM before filling was 0.594 (95% CI = 0.489–0.387) and after filling was 0.361 (95% CI = 0.237–0.486). This suggests that unpublished or "fugitive" (28) studies may exist and that if they were included, the SDM would approximate the filled value.

DISCUSSION

Our initial analysis of outcomes measures revealed that ankles with FAI exhibited poorer balance performance than stable ankles. Although from a historical perspective the literature has been equivocal (27), these results clearly indicate that balance is impaired and that the average effect across outcomes is rather large (SDM = 0.455). What remains unclear is whether these differences preexisted or were the result of injury. Comparisons between the FAI

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Group by Units	Study name	Outcome	Std diff in means	Standard error	Lower limit	Upper limit	Z-Value	p-Value
			Statistics for each study					
Area	Baier & Hopf 1998	Stabilometry, confidence elipse area (mm^2) in shoes	0.250	0.233	-0.207	0.707	1.072	0.284
Area	Brown & Mynark 2007	Stabilometry, COP excursion area (mm^2)	-0.183	0.317	-0.804	0.438	-0.579	0.563
Area	Gauffin et al 1988	Stabilometery, confidence ellipse area (mm^2)	0.679	0.419	-0.143	1.501	1.618	0.106
Area	Hubbard et al. 2007	Stabilometry, COP area, eyes closed (cm^2)	0.013	0.258	-0.493	0.519	0.050	0.960
Area	Hubbard et al. 2007	Stabilometry, COP area, eyes open (cm^2)	0.042	0.258	-0.464	0.549	0.164	0.869
Area	Tropp & Odernick 1988	Stabilometry, confidence ellipse area	1.099	0.392	0.331	1.866	2.804	0.005
Area			0.243	0.164	-0.078	0.565	1.482	0.138
Linear	Brown & Mynark 2007	Stabilometry, COP excursion length (mm)	-0.257	0.318	-0.880	0.365	-0.810	0.418
Linear	Hiller et al. 2004	Single leg stance, baseline oscillation (mm)	0.229	0.319	-0.395	0.854	0.720	0.472
Linear	Hiller et al. 2007	Single leg stance, baseline oscillation (mm)	0.108	0.273	-0.427	0.643	0.395	0.693
Linear	Konradsen & Ravn 1991	Stabilometry, transverse sway median amplitude (mm) (converted to mean)	1.009	0.388	0.249	1.769	2.603	0.009
Linear	Lee et al. 2006	Stabilometry, COP mean radius, eyes closed (cm)	1.429	0.560	0.331	2.526	2.550	0.011
Linear	Lee et al. 2006	Stabilometry, COP mean radius, eyes open (cm)	1.961	0.608	0.769	3.154	3.223	0.001
Linear	Michell et al. 2006	Stabilometry, COP Excursion, anterior/posterior (cm)	0.124	0.354	-0.570	0.817	0.350	0.727
Linear	Michell et al. 2006	Stabilometry, COP Excursion, medial/lateral(cm)	0.395	0.357	-0.305	1.094	1.106	0.269
Linear	Ross & Guskiewicz 2004	Stabilometry, COP mean sway anterior/posterior (cm)	0.413	0.382	-0.335	1.162	1.082	0.279
Linear	Ross & Guskiewicz 2004	Stabilometry, COP mean sway medial/lateral (cm)	0.199	0.379	-0.544	0.942	0.525	0.599
Linear	You et al. 2004	Stabilometry, anterior/posterior sway (cm)	1.329	0.711	-0.064	2.722	1.870	0.061
Linear	You et al. 2004	Stabilometry, medial/lateral sway (cm)	0.626	0.660	-0.669	1.920	0.947	0.344
Linear	Zinder 2002	Stabilometry, Sway amplitude (mm)	0.354	0.381	-0.393	1.101	0.929	0.353
Linear			0.451	0.147	0.163	0.738	3.068	0.002
Other	Baier & Hopf 1998	Stabilometry, angulrar movement >175 deg/.01sec (%) in shoes	0.238	0.233	-0.219	0.695	1.022	0.307
Other	Baier & Hopf 1998	Stabilometry, linear movement <5deg/.01sec (%) in shoes	0.096	0.232	-0.359	0.552	0.415	0.678
Other	Brown & Mynark 2007	TTS anterior/posterior (s)	0.660	0.325	0.024	1.296	2.032	0.042
Other	Brown & Mynark 2007	TTS medial/lateral (s)	0.080	0.316	-0.540	0.700	0.253	0.801
Other	Docherty et al. 2006	BESS, Single leg firm	0.808	0.232	0.354	1.262	3.491	0.000
Other	Hiller et al. 2007	Single leg stance, eyes closed (# foot lifts in 30 sec)	4.845	0.517	3.833	5.857	9.380	0.000
Other			1.035	0.458	0.137	1.933	2.258	0.024
Time	Chrintz et al. 1991	Single leg postural equilibrium test, eyes closed (s)	1.623	0.279	1.077	2.170	5.823	0.000
Time	Chrintz et al. 1991	Single leg postural equilibrium test, eyes open (s)	3.304	0.370	2.579	4.029	8.931	0.000
Time	Hertel & Olmsted-Kramer 2007	Time to Boundary, anterior/posterior (s)	1.459	0.471	0.535	2.383	3.096	0.002
Time	Hertel & Olmsted-Kramer 2007	Time to Boundary, medial/lateral (s)	0.820	0.438	-0.038	1.679	1.873	0.061
Time			1.818	0.518	0.802	2.834	3.506	0.000
Velocity	Baier & Hopf 1998	Stabilometry, anterior/posterior sway velocity (mm/sec) in shoes	0.557	0.237	0.093	1.021	2.352	0.019
Velocity	Baier & Hopf 1998	Stabilometry, medial/lateral sway vel (mm/s) in shoes	0.536	0.236	0.072	0.999	2.266	0.023
Velocity	Baier & Hopf 1998	Stabilometry, tot horiz sway (mm/s) in shoes	0.576	0.237	0.112	1.041	2.432	0.015
Velocity	Brown & Mynark 2007	Stabilometery, COP velocity (mm/s)	-0.256	0.318	-0.878	0.366	-0.806	0.420
Velocity	Hale et al. 2007	Stabilometry COP velocity, eyes open (cm/s)	0.309	0.297	-0.272	0.891	1.043	0.297
Velocity	Hale et al. 2007	Stabilometry, COP velocity, eyes closed (cm/s)	0.295	0.297	-0.286	0.876	0.994	0.320
Velocity	Hubbard et al. 2007	Stabilometry COP velocity, eyes open (cm/s)	0.105	0.258	-0.401	0.612	0.407	0.684
Velocity	Hubbard et al. 2007	Stabilometry, COP velocity, eyes closed (cm/s)	0.000	0.258	-0.506	0.506	0.000	1.000
Velocity	Zinder 2002	Stabilometry, Sway velocity (cm/s)	0.182	0.379	-0.560	0.925	0.482	0.630
Velocity	Hertel & Olmsted-Kramer 2007	Stabilometry, COP velocity medial/lateral (cm/s)	0.614	0.431	-0.230	1.459	1.426	0.154
Velocity	Hertel & Olmsted-Kramer 2007	Stabilometry, COP velocity, anterior/posterior (cm/s)	0.813	0.438	-0.045	1.671	1.857	0.063
Velocity	Wayne 2004	Stabilometry, COP velocity medial/lateral (cm/s)	-0.220	0.318	-0.842	0.402	-0.693	0.489
Velocity	Wayne 2004	Stabilometry, COP velocity, anterior/posterior (cm/s)	-0.244	0.318	-0.867	0.379	-0.767	0.443
Velocity	Wayne 2004	Stabilometry, Sway velocity (cm/s)	-0.147	0.317	-0.768	0.475	-0.463	0.643
Velocity			0.225	0.092	0.045	0.405	2.452	0.014
Overall			0.324	0.069	0.189	0.459	4.707	0.000

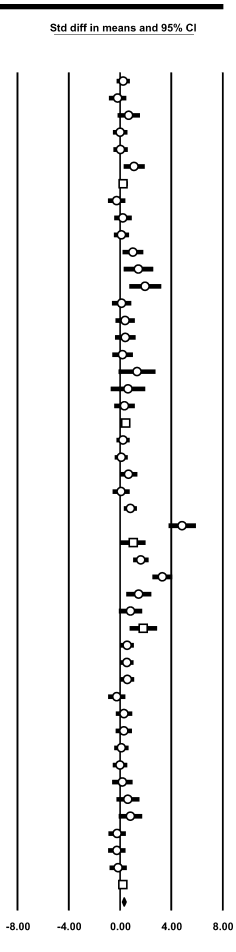

FIGURE 3—Forrest plot for static outcome measures. Studies are grouped (column 1) based on the type of measure reported. COP = center of pressure; BESS = balance error scoring system; ◆ = SDM for the overall effect (diamond width represents SE); □ = group mean.

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Group by Units	Study name	Outcome	Std diff in means	Standard error	Lower limit	Upper limit	Z-Value	p-Value
SEBT	Hale et al. 2007	SEBT anteriolateral involved (% leg length)	0.333	0.297	-0.249	0.916	1.122	0.262
SEBT	Hale et al. 2007	SEBT anterior involved (% leg length)	0.100	0.295	-0.479	0.679	0.339	0.735
SEBT	Hale et al. 2007	SEBT anteromedial involved (% leg length)	0.319	0.297	-0.263	0.901	1.074	0.283
SEBT	Hale et al. 2007	SEBT lateral involved (% leg length)	0.092	0.295	-0.486	0.671	0.313	0.754
SEBT	Hale et al. 2007	SEBT mean reach (% leg length)	0.222	0.296	-0.358	0.802	0.751	0.453
SEBT	Hale et al. 2007	SEBT medial involved (% leg length)	0.520	0.300	-0.068	1.107	1.733	0.083
SEBT	Hale et al. 2007	SEBT posterior involved (% leg length)	0.333	0.297	-0.249	0.916	1.122	0.262
SEBT	Hale et al. 2007	SEBT posterolateral involved (% leg length)	0.266	0.296	-0.315	0.847	0.898	0.369
SEBT	Hale et al. 2007	SEBT posteromedial involved (% leg length)	0.344	0.297	-0.238	0.927	1.158	0.247
SEBT	Hertel et al. 2006	SEBT anterior involved (cm/cm leg length)	0.250	0.216	-0.174	0.674	1.155	0.248
SEBT	Hertel et al. 2006	SEBT anterolateral involved (cm/cm leg length)	0.314	0.217	-0.111	0.739	1.446	0.148
SEBT	Hertel et al. 2006	SEBT anteromedial involved (cm/cm leg length)	0.400	0.218	-0.027	0.827	1.837	0.066
SEBT	Hertel et al. 2006	SEBT lateral involved (cm/cm leg length)	0.335	0.217	-0.090	0.761	1.544	0.123
SEBT	Hertel et al. 2006	SEBT medial involved (cm/cm leg length)	0.418	0.218	-0.009	0.845	1.919	0.055
SEBT	Hertel et al. 2006	SEBT posterior involved (cm/cm leg length)	0.277	0.217	-0.148	0.701	1.278	0.201
SEBT	Hertel et al. 2006	SEBT posterolateral involved (cm/cm leg length)	0.161	0.216	-0.263	0.584	0.744	0.457
SEBT	Hertel et al. 2006	SEBT posteromedial involved (cm/cm leg length)	0.385	0.218	-0.042	0.811	1.768	0.077
SEBT	Hubbard et al. 2007	SEBT anterior involved (cm/cm leg length)	0.460	0.262	-0.053	0.973	1.759	0.079
SEBT	Hubbard et al. 2007	SEBT posterolateral involved (cm/cm leg length)	0.001	0.258	-0.505	0.507	0.005	0.996
SEBT	Hubbard et al. 2007	SEBT posteromedial involved (cm/cm leg length)	0.364	0.260	-0.147	0.874	1.397	0.162
SEBT	Olmsted et al. 2002	SEBT anterior involved (cm)	0.275	0.318	-0.348	0.898	0.866	0.387
SEBT	Olmsted et al. 2002	SEBT anterolateral involved (cm)	0.281	0.318	-0.342	0.903	0.883	0.377
SEBT	Olmsted et al. 2002	SEBT anteromedial involved (cm)	0.250	0.317	-0.372	0.872	0.787	0.431
SEBT	Olmsted et al. 2002	SEBT lateral involved (cm)	0.284	0.318	-0.339	0.907	0.893	0.372
SEBT	Olmsted et al. 2002	SEBT medial involved (cm)	0.284	0.318	-0.339	0.907	0.894	0.372
SEBT	Olmsted et al. 2002	SEBT posterior involved (cm)	0.109	0.316	-0.511	0.729	0.345	0.730
SEBT	Olmsted et al. 2002	SEBT posterolateral involved (cm)	0.093	0.316	-0.527	0.713	0.295	0.768
SEBT	Olmsted et al. 2002	SEBT posteromedial involved (cm)	0.351	0.319	-0.274	0.976	1.101	0.271
SEBT			0.287	0.050	0.189	0.386	5.712	0.000
TTS	Brown et al. 2004	TTS anterior/posterior (ms)	2.251	0.572	1.131	3.371	3.938	0.000
TTS	Brown et al. 2004	TTS medial/lateral (ms)	0.494	0.454	-0.396	1.384	1.088	0.277
TTS	Ross & Guskiewicz 2004	TTS anterior/posterior (s)	1.678	0.440	0.817	2.540	3.819	0.000
TTS	Ross & Guskiewicz 2004	TTS medial/lateral (s)	0.828	0.394	0.056	1.600	2.102	0.036
TTS	Ross et al. 2005	TTS anterio/posterior (s)	0.801	0.465	-0.110	1.712	1.724	0.085
TTS	Ross et al. 2005	TTS medial/lateral (s)	0.966	0.473	0.040	1.892	2.044	0.041
TTS	Wikstrom et al. 2005	TTS anterior/posterior(ms)	0.015	0.263	-0.500	0.529	0.056	0.956
TTS	Wikstrom et al. 2005	TTS medial/lateral (ms)	0.471	0.266	-0.051	0.992	1.768	0.077
TTS	Wikstrom et al. 2005	TTS vertical (ms)	0.368	0.265	-0.151	0.887	1.391	0.164
TTS			0.608	0.118	0.376	0.839	5.138	0.000
Overall			0.336	0.046	0.246	0.427	7.267	0.000

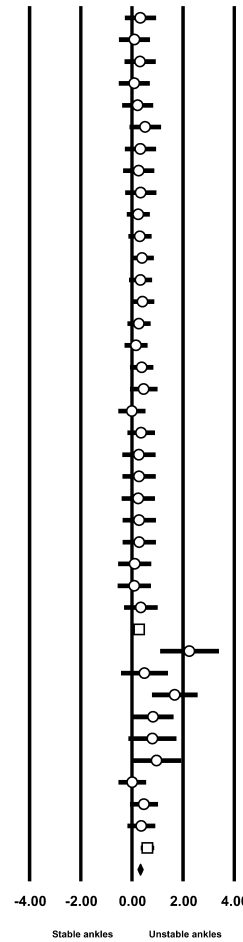

FIGURE 4—Forrest plot of dynamic outcome measures. Studies are grouped (column 1) based on the type of measure reported. SEBT = Star Excursion Balance Test; TTS = time to stabilization; ◆ = SDM for the overall effect (diamond width represents SE); □ = group mean.

ankles and the contralateral normal ankle have failed to produce differences (36,38,39). Tropp (36) suggested that the lack of differences between contralateral ankles may represent a preexisting condition or a central organizational change due to pain and immobilization. Because our data set predominantly includes studies with case–control designs rather than prospective designs, we cannot answer this specific question.

Differences between Dynamic and Static Balance

One of the clear distinctions in the outcomes was the use of either a dynamic or a static measure of balance. For our purposes, static balance was defined as balancing on a stable surface without intentional movement by the subject, for example, postural sway on a force plate. Conversely, dynamic measures were defined as balance tasks that required the subject to perform some movement (e.g., leg reaching with the SEBT) or a task (e.g., jumping with TTS). We believed it important to determine whether differences existed between these two broad categories of outcomes. In fact, there was no statistical difference, but the *P* value was quite low ($P = 0.063$) and close to the criterion value of 0.05. It is worth noting that for this part of the analysis, the outcomes from each study were treated as being independent of each other. This is very likely not the case but was done because we wanted to make direct comparisons among different balance measures. When comparing differences in SDM among groups, this will tend to increase the SE and CI and make the statistical comparison conservative. Thus, we suspect that a difference between dynamic and static measures does exist with dynamic measures producing a smaller SDM than static measures.

Static measures. Examination of the static measures (Fig. 3) reveals that three of the four categories of measurement (linear, time, velocity, and other) produced significant SDM. The area group did not produce a significant difference, nor were any of the individual study SDM for area significant. This was surprising to us because this was one of the first stabilometry measures used to study ankle injury and has been described as indicative of ankle

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Group by Inclusion criteria?	Study name	Outcome	Std diff in means	Standard error	Lower limit	Upper limit	Z-Value	p-Value
No	Gauffin et al 1988	Stabilometery, confidence ellipse area (mm^2)	0.679	0.419	-0.143	1.501	1.618	0.106
No	Hertel & Olmsted-Kramer 2007	Combined	0.927	0.445	0.055	1.798	2.084	0.037
No	Konradsen & Ravn 1991	Stabilometry, transverse sway median amplitude (mm) (converted to mean)	1.009	0.388	0.249	1.769	2.603	0.009
No	Ross & Guskiewicz 2004	Combined	0.780	0.399	-0.003	1.562	1.952	0.051
No			0.851	0.206	0.448	1.254	4.141	0.000
Yes	Baier & Hopf 1998	Combined	0.376	0.235	-0.085	0.836	1.600	0.110
Yes	Brown & Mynark 2007	Combined	0.009	0.319	-0.616	0.633	0.027	0.978
Yes	Brown et al. 2004	Combined	1.372	0.516	0.361	2.384	2.659	0.008
Yes	Chrintz et al. 1991	Combined	2.464	0.328	1.822	3.106	7.522	0.000
Yes	Docherty et al. 2006	BESS, Single leg firm	0.808	0.232	0.354	1.262	3.491	0.000
Yes	Hale et al. 2007	Combined	0.285	0.297	-0.297	0.867	0.960	0.337
Yes	Hertel et al. 2006	Combined	0.317	0.217	-0.108	0.743	1.462	0.144
Yes	Hiller et al. 2004	Single leg stance, baseline oscillation (mm)	0.229	0.319	-0.395	0.854	0.720	0.472
Yes	Hiller et al. 2007	Combined	2.476	0.413	1.667	3.286	5.995	0.000
Yes	Hubbard et al. 2007	Combined	0.141	0.259	-0.367	0.649	0.544	0.587
Yes	Lee et al. 2006	Combined	1.695	0.585	0.549	2.841	2.898	0.004
Yes	Michell et al. 2006	Combined	0.259	0.355	-0.437	0.956	0.729	0.466
Yes	Olmsted et al. 2002	Combined	0.241	0.318	-0.381	0.863	0.758	0.448
Yes	Ross et al. 2005	Combined	0.884	0.469	-0.035	1.802	1.885	0.059
Yes	Tropp & Odernick 1988	Stabilometry, confidence ellipse area	1.099	0.392	0.331	1.866	2.804	0.005
Yes	Wayne 2004	Combined	-0.204	0.317	-0.826	0.419	-0.641	0.521
Yes	Wikstrom et al. 2005	Combined	0.285	0.265	-0.234	0.803	1.075	0.282
Yes	You et al. 2004	Combined	0.977	0.686	-0.367	2.322	1.425	0.154
Yes	Zinder 2002	Combined	0.268	0.380	-0.476	1.013	0.706	0.480
Yes			0.680	0.163	0.359	1.000	4.161	0.000
Overall			0.746	0.128	0.495	0.997	5.834	0.000

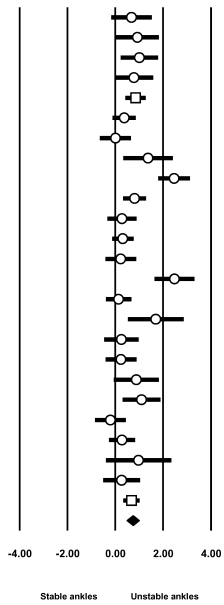

FIGURE 5—Forrest plot of studies with and without inclusion criteria (column 1). Outcomes within a study are averaged (i.e., "combined" in column 3) for comparisons across the two groups. BESS = balance error scoring system; □ = group SDM; ˆ = individual study SDM; ◆ = SDM for the overall effect (diamond width represents SE); □ = group mean.

instability (39). However, other work by Tropp et al. (37) found no differences. Thus, our results are consistent with the latter but not the former findings.

Our examination of the SDM revealed that the greatest SDM (1.818) was for the time measures (time in balance, i.e., postural equilibrium test [4], and time to boundary

Group by Exclusion criteria?	Study name	Outcome	Std diff in means	Standard error	Lower limit	Upper limit	Z-Value	p-Value
No	Chrintz et al. 1991	Combined	2.464	0.328	1.822	3.106	7.522	0.000
No	Gauffin et al 1988	Stabilometery, confidence ellipse area (mm^2)	0.679	0.419	-0.143	1.501	1.618	0.106
No	Konradsen & Ravn 1991	Stabilometry, transverse sway median amplitude (mm) (converted to mean)	1.009	0.388	0.249	1.769	2.603	0.009
No	Tropp & Odernick 1988	Stabilometry, confidence ellipse area	1.099	0.392	0.331	1.866	2.804	0.005
No			1.336	0.425	0.502	2.170	3.141	0.002
Yes	Baier & Hopf 1998	Combined	0.376	0.235	-0.085	0.836	1.600	0.110
Yes	Brown & Mynark 2007	Combined	0.009	0.319	-0.616	0.633	0.027	0.978
Yes	Brown et al. 2004	Combined	1.372	0.516	0.361	2.384	2.659	0.008
Yes	Docherty et al. 2006	BESS, Single leg firm	0.808	0.232	0.354	1.262	3.491	0.000
Yes	Hale et al. 2007	Combined	0.285	0.297	-0.297	0.867	0.960	0.337
Yes	Hertel & Olmsted-Kramer 2007	Combined	0.927	0.445	0.055	1.798	2.084	0.037
Yes	Hertel et al. 2006	Combined	0.317	0.217	-0.108	0.743	1.462	0.144
Yes	Hiller et al. 2004	Single leg stance, baseline oscillation (mm)	0.229	0.319	-0.395	0.854	0.720	0.472
Yes	Hiller et al. 2007	Combined	2.476	0.413	1.667	3.286	5.995	0.000
Yes	Hubbard et al. 2007	Combined	0.141	0.259	-0.367	0.649	0.544	0.587
Yes	Lee et al. 2006	Combined	1.695	0.585	0.549	2.841	2.898	0.004
Yes	Michell et al. 2006	Combined	0.259	0.355	-0.437	0.956	0.729	0.466
Yes	Olmsted et al. 2002	Combined	0.241	0.318	-0.381	0.863	0.758	0.448
Yes	Ross & Guskiewicz 2004	Combined	0.780	0.399	-0.003	1.562	1.952	0.051
Yes	Ross et al. 2005	Combined	0.884	0.469	-0.035	1.802	1.885	0.059
Yes	Wayne 2004	Combined	-0.204	0.317	-0.826	0.419	-0.641	0.521
Yes	Wikstrom et al. 2005	Combined	0.285	0.265	-0.234	0.803	1.075	0.282
Yes	You et al. 2004	Combined	0.977	0.686	-0.367	2.322	1.425	0.154
Yes	Zinder 2002	Combined	0.268	0.380	-0.476	1.013	0.706	0.480
Yes			0.543	0.126	0.297	0.789	4.322	0.000
Overall			0.607	0.120	0.370	0.843	5.035	0.000

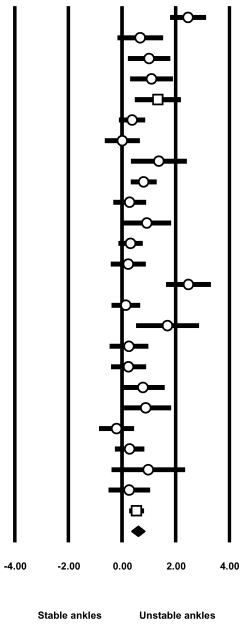

FIGURE 6—Forrest plot of studies with and without exclusion criteria (column 1). Outcomes within a study are averaged (i.e., "combined" in column 3) for comparisons across the two groups. BESS = balance error scoring system; □ = group SDM; ○ = individual study SDM; ◆ = SDM for the overall effect (diamond width represents SE); □ = group mean.

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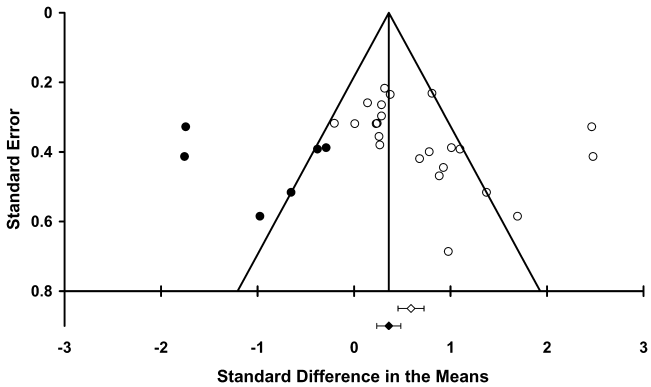

FIGURE 7—Funnel plot with the SDM plotted against SE. ○ = observed studies; ● = imputed studies from the trim and fill procedure; <> = SDM for the observed studies (± SE); ◆ = SDM for the observed and imputed studies (± SE).

[15]). Of these, the highest SDM was produced by the time in balance, eyes open condition (4). We believe that this is an interesting finding because the time-in-balance measure is simple and could be easily used clinically. However, these results should be viewed cautiously because the mean difference had to be estimated using the median and range, and no reliability of the measure was reported. We recommend further study of this measure to establish its reliability and determine a clinical cutoff score using the receiver operating characteristic (ROC) analysis.

The Other category also produced the second largest SDM greater than one (1.035). Of these measures, the number of foot lifts of Hiller et al. (17) produced the largest SDM (4.845). Similar to time in balance, foot lifts can be easily counted in the clinical setting. Furthermore, the reported reliability of this test was fair to good (ICC = 0.73, 95% CI = 0.40–0.89). Thus, we would suggest that future investigations should include this measure to better establish its usefulness and that ROC curves with cutoff scores should be developed.

Dynamic measures. On the basis of the group SDM, the TTS measure produced the greatest SDM (0.555) with time to stabilization (TTS) in the anterior/posterior direction producing the greatest effects (2,29). In contrast, the Star Excursion Balance Test (SEBT) produced an SDM (0.287) approximately one half that of TTS, suggesting that TTS is the better of the two measures. However, TTS requires availability of a force plate and processing software to generate the measures. This makes TTS less clinically convenient than the SEBT. On the basis of this and the very similar SDM between static and dynamic measures, we would recommend future studies focus on convenient static measures (e.g., foot lifts) for clinical use.

The Effects of Inclusion and Exclusion Criteria

As can be seen from Tables 1 and 2, the reported inclusion criteria and subject characteristics vary greatly from study to study. Our initial examination of the selected studies suggested that in fact very few studies actually reported true inclusion criteria and instead reported only subject characteristics. On the basis of this, we hypothesized that those studies that reported clear inclusion criteria would find larger effects than those that did not. However, further examination of the studies revealed that in lieu of clearly identified inclusion criteria, most studies at least had clear definitions of FAI. On the basis of this, we subsequently included FAI definitions as inclusion criteria and grouped studies as either having FAI definitions/inclusion criteria or not. We found only four studies that did not use inclusion criteria or had a clear definition of FAI. This was far fewer than we had initially expected. Furthermore, the comparison between the two groups of studies failed to find a significant difference, which was also counter to our expectation. We doubt that this finding means that inclusion criteria are not important. Rather, we suspect that studies not stating inclusion criteria were actually reporting inclusion criteria as part of their subject characteristics. If that was the case, then in fact all studies had inclusion criteria. Nevertheless, our experience was that the lack of clearly stated inclusion criteria and/or the use of a separate definition of pathology as part of the inclusion criteria made our task more difficult. We would recommend to all authors that future studies should use *a priori* inclusion criteria and that these criteria should be stated as such and listed together in the methods section of the manuscript.

Exclusion criteria were more clearly reported in all studies but similar to the inclusion criteria varied across studies. Similar to the inclusion criteria, we found no difference between those studies that reported exclusion criteria and those that did not. However, the P value ($P = 0.074$) was close to the criterion value, and the SDM for the studies without exclusion criteria was nearly three times larger than that for studies with exclusion criteria. This suggests to us that researchers should give more careful attention to exclusion criteria because they may have an important influence on the results.

Quantitative Assessment of Bias

On the basis of Egger's regression intercept, our data demonstrated some degree of bias, and the trim and fill procedure identified six studies for trimming. The adjusted SDM was smaller after the fill procedure, indicating that the SDM was sensitive to this bias. These results suggest that the smaller studies in our data set have larger SDM than expected and that there may be missing studies. This may be because smaller studies without significant differences tend to be under represented or missing in the reported literature (i.e., publication bias). However, publication bias is not the only cause of bias (8). It is also possible that smaller studies truly have larger effect sizes. This may be due either to more potent treatments or to better quality measures that can be provided in smaller studies. Because

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we did not focus this analysis on treatment effects, the former cause is not relevant. Whether measurement quality is associated with the existing bias is unclear. On the basis of the variety of measures used to assess balance, this seems possible, but we could not discern a pattern indicating that smaller studies used different or better quality measures than larger studies.

Assessment of Quality of Included Studies

Our rating of quality was lower than we had expected with a range that did not go above 44 (out of 100). However, our meta-regression revealed that study quality did not impact SDM size. We should emphasize that study quality as we measured it was dependent on at least two factors: study quality and study reporting. All three reviewers felt that it was often difficult to distinguish between poor quality and poor reporting. Thus, we suspect that several studies probably merited higher quality scores but were penalized due to poor reporting. This fact emphasizes the importance good reporting of study details, especially the methods, on the part of authors, reviewers, and editors.

CONCLUSION

On the basis of our results, it appears that individuals with ankle instability have deficits in their balance. These deficits appear to exist regardless of whether balance is assessed with static or dynamic tests. However, our analysis is probably conservative based on our processing of the data, and it may be that static measures actually perform better than dynamic measures. Because our data is from observational studies, it is not possible to determine whether these differences were preexisting or the result of injury.

Select dynamic and static measures produced larger SDM than others. Within the static measures, time-based measures (time in balance [4] and time to boundary [15]) performed best as well as measures within the miscellaneous Other category. Further analysis of the Other category suggested that the number of foot lifts (17) produced the largest SDM. Because time in balance and foot lifts are measures that can be easily completed in the clinical setting, we believe further study should focus on these measures to establish their clinical validity.

Within the dynamic category, TTS measures performed better than the SEBT and suggest TTS would be preferred to the SEBT. However, although TTS may be useful in the laboratory setting, its setup is more complicated than the SEBT and requires a force plate and appropriate analytical software. Thus, it may be viewed as less desirable for the clinical setting.

Finally, neither inclusion nor exclusion criteria affected the results. However, there was inconsistent reporting of inclusion and exclusion criteria making comparisons difficult. Furthermore, some inclusion criteria were reported as part of the definition of FAI. We would suggest that future reports combine FAI definitions and inclusion criteria into a specific section of the methods.

One caution that should be added is that most of the studies included in the analysis were conducted on relatively physically active individuals. This is because most of the research on FAI is conducted by sports medicine specialists, either medical or allied health. Whether these results apply to more sedentary populations is unknown. Thus, additional FAI research may want to focus on nonphysically active populations. It remains possible that different measures may better apply to different populations.

The results of this study are not an endorsement by the American College of Sports Medicine.

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