Article

Foot & Ankle International®
1–16

DOI: 10.1177/10711007251339483
journals.sagepub.com/home/fai

Reliability of Dynamometric Measurements for Ankle Muscle Strength: A Systematic Review

Cristina Jiménez-Ávila, PT[1], Andrés Felipe Villaquiran-Hurtado, PT[1], Daniel Jerez-Mayorga, PhD[2,3], and Guido Contreras-Diaz, PhD[4]

Abstract

Background: Strength assessment is crucial for enhancing physical fitness, health, and injury prevention, particularly for the ankle joint, which is frequently injured in athletic activities. Despite technological advances, the reliability of dynamometric measurements for ankle strength varies because of differences in test procedures, equipment, and methodologies. This systematic review aimed to (1) examine the reliability of dynamometric strength measurements for ankle muscles in healthy individuals and athletes, (2) identify the most valid and reliable positions for strength measurement, and (3) determine the most reliable velocities for assessing ankle muscle strength.

Methods: A comprehensive search of 4 electronic databases (Web of Science, SCOPUS, EBSCO, and PubMed) identified 556 studies, of which 13 met the inclusion criteria for this meta-analysis. The reliability of the measurements was assessed using intraclass correlation coefficients (ICCs). Data extraction and analysis followed PRISMA guidelines, with methodologic quality evaluated using the Critical Appraisal Tool and the Quality Appraisal tool for Reliability Studies.

Results: Most studies assessed ankle movements in a seated position, reporting ICC values between 0.42 and 0.97, with the majority showing good to excellent reliability (0.78-0.99). Dorsiflexion and plantarflexion movements demonstrated high reliability, whereas inversion and eversion showed greater variability (ICC 0.47-0.96). The most reliable velocities for isokinetic assessments were between 40 and 90 degrees/second. Eccentric and concentric strength measurements also exhibited good to excellent reliability.

Conclusion: Dynamometric measurements of ankle strength are generally reliable, especially in seated positions and at specific velocities (40-90 degrees/second). Standardizing assessment protocols can improve measurement consistency and accuracy, enhancing their utility in injury prevention and rehabilitation programs.

Keywords: reproducibility, muscle strength dynamometer, ankle joint, muscle contraction

Introduction

Strength is widely recognized as a key strategy for improving physical fitness, health maintenance, and overall well-being.[23] In the sports domain, it is directly linked to performance enhancement and injury prevention, serving as a fundamental component of preventive programs, surpassing proprioceptive training, flexibility, and multicomponent strategies.[3,11,21]

The ankle is one of the most frequently injured orthopaedic joints,[13] affecting sports such as football, wrestling, and field hockey, resulting in 15.8% with a restriction in participation of more than 21 days,[28] affecting between 1.5 and 2.0 million athletes in the United States alone.[29] A significant proportion of people who sustain ankle injuries may experience chronic ankle instability or recurrent injuries at the bony, muscular, or tendon level.[39] The prescription of

[1]Facultad Ciencias de la Salud, Universidad del Cauca, Popayán, Colombia
[2]Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain
[3]Exercise and Rehabilitation Sciences Institute, Faculty of Rehabilitation Sciences, Universidad Andres Bello, Santiago, Chile
[4]Escuela de Kinesiología, Facultad de Ciencias de la Rehabilitación y Calidad de Vida, Universidad San Sebastián, Puerto Montt, Chile

Corresponding Author:
Daniel Jerez-Mayorga, PhD, Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Cam. de Alfacar, 21, Granada, 18071, Spain.
Email: djerezmayorga@ugr.es

strength exercises for the plantar flexors, dorsiflexors, inverters, and evertors of the ankle are fundamental for rehabilitation and prevention processes in sports,[18] because of the complexity of the different motor actions,[7] which require strength, speed and coordination.[30]

Therefore, the evaluation of ankle muscle strength can provide information on the functional capacity of an individual to perform activities of daily living and sports actions and reduce the risk of injury.[9] Dynamometry, encompassing both isokinetic and handheld devices, remains a cornerstone in clinical and research practice because of its widespread adoption and established utility.[14] However, several factors have been shown to influence the reliability of these tests, including differences in test application, procedures, protocol specificity, methodologies for test-retest studies, isolation of muscle groups,[26] equipment calibration, measurement parameters, stabilization procedures, and software adaptability.[3]

Therefore, the aims of this systematic review were as follows: (1) to examine the reliability of dynamometric strength measurements for the ankle musculature in healthy subjects and athletes; (2) to determine the most valid and reliable position for measuring strength; and (3) to determine the most reliable velocity for assessing ankle muscle strength.

Methods

Experimental Approach to the Problem

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines. Before initiating the review, the protocol was registered on the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY; registration number INPLASY202450068). The principal aims were (1) to summarize current knowledge on the reliability of ankle muscle strength tests using a dynamometer in healthy adults and athletes, as measured primarily by the intraclass correlation coefficient (ICC); (2) to identify the most valid and reliable position for measuring ankle strength; and (3) to determine the most reliable velocity for assessing ankle muscle strength. We included both quantitative and qualitative analyses, focusing on a quantitative synthesis of ICC values and a qualitative examination of factors that might influence reliability. A PRISMA flow diagram was used to document the identification, screening, eligibility, and inclusion of studies.[38]

Search Strategy. We searched 4 major electronic databases (Web of Science, SCOPUS, EBSCO, and PubMed) for quantitative studies evaluating the reliability of isokinetic, isometric, concentric, or eccentric ankle muscle strength tests. Searches combined Medical Subject Headings (MeSH) and keywords ("Strength," "Dynamometer," "Ankle," "Reliability," and "Reproducibility") with Boolean operators (AND, OR). Reference lists from relevant reviews and included articles were also screened to identify additional studies. Further evidence was sought by contacting authors directly via email when necessary. Two reviewers independently screened all titles and abstracts; full texts of potentially eligible articles were retrieved and assessed for inclusion. Any disagreements were resolved through discussion.

Eligibility criteria. Eligible studies for the systematic review were required to (1) be written in English or Spanish; (2) involve healthy, physically active adults and athletes; (3) include isokinetic, isometric, concentric, and/or eccentric ankle strength tests; and (4) clearly report mean ICC values, as well as the number of participants and tests used to estimate variance. Articles meeting these criteria were retrieved in full for further evaluation.

Exclusion Criteria

We excluded (1) observational or cross-sectional case reports or case series, (2) studies involving injured participants or individuals with medical conditions, and (3) investigations that did not report the interval between test and retest sessions. If a study presented multiple ICC values, the most representative was included in the quantitative analysis—generally one that reflected a test duration of 10-15 minutes, an interval of 1 day to 1 month between sessions, or a median outcome when multiple pipelines were provided.

Evaluation of the methodological quality of the studies. Two tools were used to assess methodologic quality: the Critical Appraisal Tool (CAT)[5] and the Quality Appraisal for Reliability Studies (QAREL).[22] The CAT scale comprises 13 criteria—4 on validity and 9 on reliability—and generates a percentage score; a study scoring above 45% was considered high quality.[33]

QAREL includes 11 items on sample representativeness, masking, randomization of testing order, appropriateness of the time interval between tests, and adequacy of statistical analysis. Each study's overall percentage was calculated, with scores approaching 110% indicating higher methodologic quality.[22] Two reviewers independently applied both CAT and QAREL. Disagreements were resolved by discussion; if unresolved, a third reviewer acted as arbiter. Because CAT focuses on internal validity and applicability and QAREL on robustness and reproducibility, their combined use was deemed an effective strategy.

Data extraction. The data extraction process included the collection of participant characteristics (eg, number of

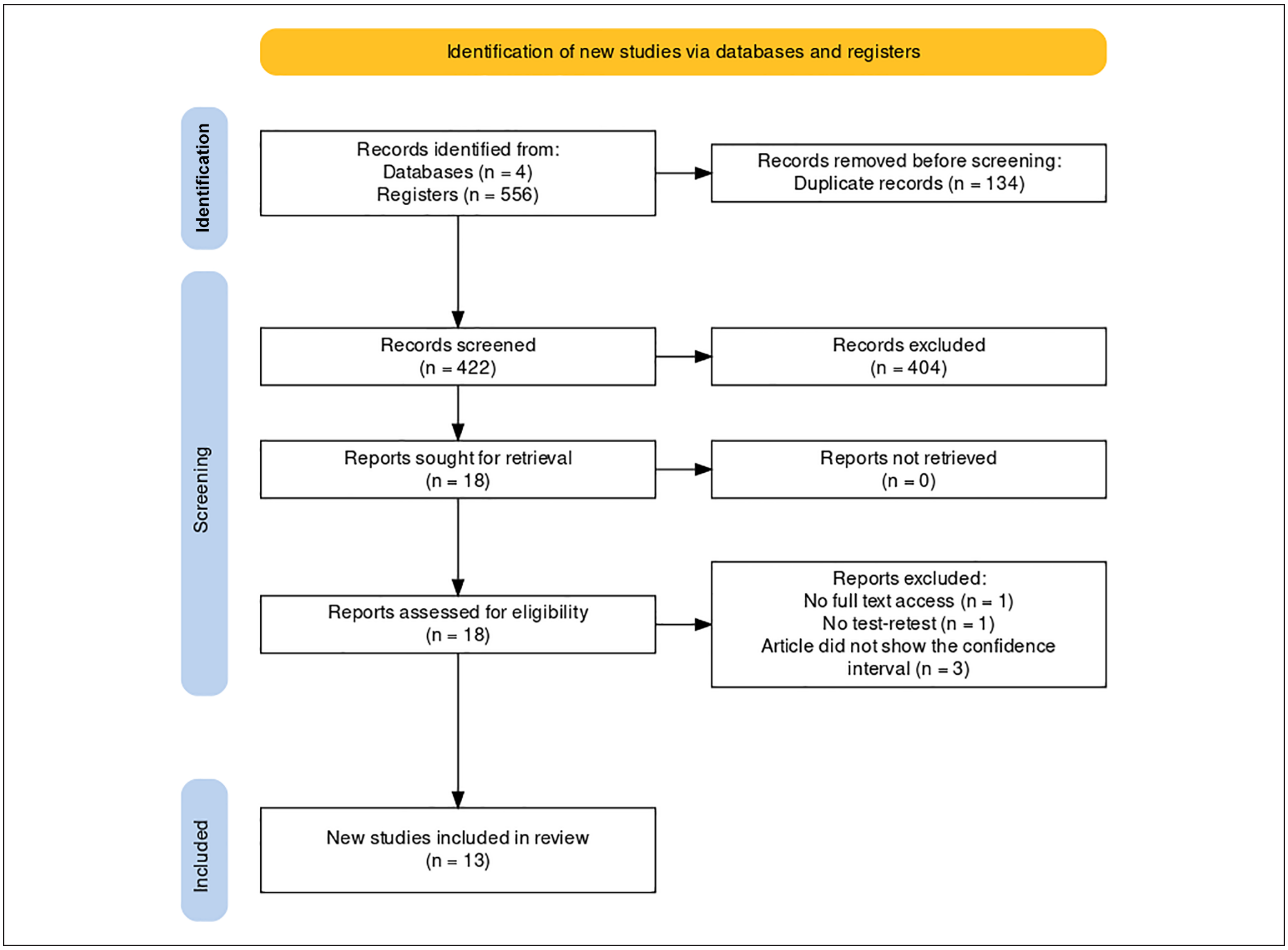

Figure 1. PRISMA flow diagram.

subjects, gender, age, and level of athletic involvement), study design details (eg, type of subject, unilateral or bilateral ankle evaluation, and the time interval between test and retest sessions), testing protocols (eg, testing positions such as seated, supine, or standing; dynamometry modes including isometric or isokinetic; and velocity ranges), and reliability metrics (eg, ICCs, CIs, and SE of measurement). Two authors independently performed the data extraction. Any discrepancies between the reviewers were resolved through discussion or, when necessary, by consulting a third reviewer

Data Analysis

A narrative synthesis was conducted by categorizing studies based on testing position (seated vs nonseated), velocity range (30-180 degrees/second), and muscle contraction type (concentric, eccentric, isometric). The primary outcome of interest was the ICC, along with any reported CIs or SEs, which allowed for comparisons of reliability across different testing protocols. Because of significant heterogeneity in sample characteristics and testing procedures, a meta-analysis was not feasible. Instead, we report and interpret ranges of ICC values to identify patterns in measurement consistency across the included studies.

Results

Study Selection

A total of 556 studies (PubMed, n=144; Web of Science, n=192; EBSCO, n=70; and Scopus, n=150) were identified through an electronic database search, of which 134 duplicate articles were identified and eliminated from the study. After reading the title and abstract, 422 articles were eliminated, leaving 19 studies for full reading, but one was deleted because the full text could not be obtained. Therefore, 13 studies on ankle strength assessment were included in this systematic review (Figure 1)

Table 1. Evaluation of the Quality of Studies Using the Critical Appraisal Tool (CAT).[a]

Author	1	2	3	4	5	6	7	8	9	%
O'Neill et al[33]	Y	N	N	Y	N	N	Y	N	Y	44
Webber and Porter[43]	Y	Y	N	Y	N	N	Y	N	Y	56
Tavakkoli et al[40]	Y	N	N	N	N	N	Y	N	Y	33
Spink et al[39]	Y	N	N	N	Y	N	Y	N	Y	44
van Cingel et al[42]	Y	N	N	N	N	N	Y	N	Y	33
Morrison and Kaminski[30]	Y	N	N	N	N	N	Y	N	Y	33
Aydoğ et al[2]	N	N	N	N	N	N	Y	N	Y	22
Man et al[24]	Y	Y	N	N	N	N	Y	N	Y	44
Holmbäck et al[15]	Y	N	N	N	N	N	Y	N	Y	33
Kaminski and Dover[18]	Y	Y	N	N	N	N	Y	N	Y	44
Morris-Chatta et al[29]	Y	Y	N	N	Y	N	Y	N	Y	56
Porter et al[35]	N	N	N	N	N	N	Y	N	Y	22
Holmbäck et al[16]	Y	N	N	N	N	N	Y	N	Y	33

Annreviations: N, no; Y, yes.
[a]Items: 1. If human subjects were used, did the authors provide a detailed description of the sample of subjects used to perform the test? 2. Did the authors clarify the qualification or competence of the rater(s) who performed the test? 3. If interrater reliability was tested, were the raters blinded to the findings of other raters? 4. If intrarater reliability was tested, were the raters blinded to their own prior findings of the test under evaluation? 5. Was the order of examination varied? 6. Was the stability (or theoretical stability) of the variable being measured considered when determining the suitability of the time interval between repeated measures? 7. Was the execution of the test described in sufficient detail to permit replication of the test? 8. Were withdrawals from the study explained? 9. Were the statistical methods appropriate for the study? %: final percentage of reliability.

Risk of Bias in the Studies

The quality of studies evaluated through the CAT scale obtained a score between 22% and 56%, of which 8 articles had a high-quality evaluation (Table 1). The quality of the studies evaluated through QAREL obtained a score between 18% and 55% (Table 2).

Characteristics of the Studies

The sample size of the selected studies ranged from 10 to 65 subjects aged between 18 and 77 years, who were healthy and/or physically active. The times between tests ranged from 60 minutes to 6 months, and the assessment was mainly performed on a single ankle. The dynamometers used for the assessments were as follows: C-Station,[34] Biodex System 3 Pro,[43] Citec,[39] Humac Norm,[42] Kin Com 125 AP,[30] Biodex Medical Systems,[2] Biodex Multi-Joint System 2,[15,16] Cybex II+,[29] KIN-COM 500H.[35] In turn, 2 studies developed 2 measuring dynamometers mentioning their manufacturing characteristics[24,40] (Table 3).

Anatomical Plane and Movement

Eight studies included assessment of plantarflexion movement,[24,29,30,33,35,39,40,43] whereas 5 studies performed sagittal plane assessment with plantarflexion and dorsiflexion movements.[24,29,30,35,43] Three studies developed frontal plane assessment,[2,18,42] using inversion and eversion movements, but only 1 study performed assessment of all 4 movements.[39]

Muscle Contraction

In 7 studies, isokinetic ankle strength measurements were included in their assessment protocol,[2,15,24,29,30,35,42] whereas 3 studies opted for isometrics assessments.[33,39,40] On the other hand, another focused exclusively on eccentric contractions,[15] and 1 more on concentric contractions.[18] Only 1 study has addressed strength measurements using 3 different modalities: isometric, isotonic, and isokinetic.[43]

Position

All possible movements of the ankle joint were evaluated, dorsiflexion, plantarflexion, inversion, and eversion. In most articles, the position most used to evaluate these movements was seated.[2,15,16,18,24,29,30,33,40,42,43] One study evaluated all 4 movements in supine[39] and another used the standing position to evaluate dorsiflexion and plantiflexión.[35]

Velocity

The velocity used for isokinetic force measurement in most of the reviewed articles ranged from 30 to 180 degrees/second. Specifically, 2 studies opted for speeds up to 180

Table 2. Evaluation of the Quality of Studies Using the QAREL Scale.[a]

Autor	1	2	3	4	5	6	7	8	9	10	11	%
O'Neill et al[33]	UC	UC	UC	Y	NA	UC	UC	N	Y	Y	Y	36
Webber and Porter[43]	Y	Y	N	Y	NA	UC	UC	N	Y	Y	Y	55
Tavakkoli et al[40]	UC	UC	UC	UC	NA	UC	UC	N	Y	Y	Y	27
Spink et al[39]	UC	UC	N	UC	NA	UC	UC	Y	Y	N	Y	27
van Cingel et al[42]	UC	UC	NA	UC	NA	UC	UC	N	Y	Y	Y	27
Morrison and Kaminski[30]	UC	UC	UC	UC	NA	UC	UC	N	N	Y	Y	18
Aydoğ et al[2]	UC	UC	UC	UC	NA	UC	UC	N	Y	Y	Y	27
Man et al[24]	UC	Y	NA	UC	NA	UC	UC	N	Y	Y	Y	36
Holmbäck et al[15]	UC	UC	NA	UC	NA	UC	UC	N	Y	Y	Y	27
Kaminski and Dover[18]	UC	Y	NA	UC	NA	UC	UC	N	Y	Y	Y	36
Morris-Chatta et al[29]	UC	Y	UC	UC	NA	UC	UC	Y	Y	Y	Y	45
Porter et al[35]	UC	UC	UC	UC	NA	UC	UC	N	Y	Y	Y	27
Holmbäck et al[16]	UC	UC	UC	UC	NA	UC	UC	N	Y	Y	Y	27

Abbreviations: N, no, does not comply; NA, not applicable; QAREL, Quality Appraisal for Reliability Studies; UC, unclear; Y, yes, complies.
[a]Items: 1. Was the test evaluated in a sample of subjects who were representative of those to whom the authors intended the results to be applied? 2. Was the test performed by raters that were representative of those to whom the authors intended the results to be applied? 3. Were the raters blinded to the findings of other raters during the study? 4. Were the raters blinded to their own prior findings of the test under evaluation? 5. Were the raters blinded to the results of the reference standard for the target disorder (or variable) being evaluated? 6. Were the raters blinded to clinical information that was not intended to be provided as part of the testing procedure or study design? 7. Were the raters blinded to additional cues that were not part of the test? 8. Was the order of examination varied? 9. Was the time interval between repeated measurements compatible with the stability (or theoretical stability) of the variable being measured? 10. Was the test applied correctly and interpreted appropriately? 11. Were appropriate statistical measures of agreement used? %: final percentage of reliability.

degrees/second,[2,29] whereas only 1 article limited the maximum speed to 150 degrees/second.[16] In addition, 2 investigations were identified that used a single measurement speed: one[35] at 30 degrees/second and one[24] at 40 degrees/second. In the case of eccentric force measurement, the use of speeds of 30 and 90 degrees/second was observed,[15] whereas for concentric measurements, speeds of 30 and 120 degrees/second were recorded.[18]

Reliability

In this review, values below 0.50 indicate poor reliability, between 0.50 and 0.75 indicate moderate reliability, 0.75 to 0.90 indicate good reliability, and values above 0.90 indicate excellent reliability.

Most research in the field assesses ankle movements while the subject is in a seated position. ICCs have been found to range from 0.42 to 0.97 in these studies.[2,15,16,18,24,29,30,33,40,42,43] However, a closer analysis reveals that most articles report ICCs within the range of 0.78 to 0.99, indicating good to excellent reliability. Only a limited number of investigations have exhibited lower ICCs, ranging from 0.42 to 0.95,[29] 0.54 to 0.92,[18] and 0.47 to 0.94.[42] In contrast, one study[29] has addressed the assessment of ankle movements with the subject in a standing position, finding ICCs ranging between 0.26 and 0.90. In this case, the heterogeneity of the data is notably greater. In addition, another study used the supine position to measure ankle strength, obtaining ICC values between 0.78 and 0.91.[39] These results show a reliability ranging from good to excellent in the measurement of strength in this position.

Within the set of movements evaluated for the ankle, which include dorsiflexion, plantarflexion, inversion, and eversion, a consistency in the reliability of the first two was observed. Specifically, dorsiflexion and plantarflexion movements have demonstrated reliability ranging from good to excellent, with ICC limits between 0.78 and 0.99.[15,16,24,33,39,40,43] However, 2 individual studies[29,35] presented minimum cut-offs of 0.26 and 0.42 respectively, evidencing variability in the results in these cases.

On the other hand, inversion and eversion movements exhibit reliability limits between 0.47 and 0.96.[2,18,39,42] It is crucial to highlight that the heterogeneity of the data is considerably greater among the articles that address the measurement of these last 2 movements, which may indicate a greater variability in the results obtained in comparison with those of dorsiflexion and plantarflexion.

In relation to the velocities used in the ankle motion assessments, there was variability in the intraclass correlation coefficients (ICC) obtained. The studies reviewed employed various velocities, from 30 to 180 degrees/second. It was found that the 30-degrees/second speed presented ICCs ranging from 0.26 to 0.95, indicating reliability ranging from poor to excellent.[15,16,18,29,30,35,42,43] On the other hand, the 40-degrees/second velocity, which was addressed in a single article, demonstrated an ICC of 0.96, indicating

Table 3. Relative and Absolute Reliability of Ankle Strength Assessment.

Study	Ankle Movement	Position	Velocity (degrees/second)	1-Degree Test, Mean (SD)	2-Degree Test, Mean (SD)	3-Degree Test, Mean (SD)	4-Degree Test, Mean (SD)	ICC	Limits ICC	SEM	SEM (%)
O'Neill et al[33]	Isometric plantarflexion (N)	Seated	(–)	1575.89 (398.50)	1562.50 (389.09)	(–)	(–)	0.91	0.86-0.94	52.79	(–)
Webber and Porter[46]	Dorsiflexion										
	Isometric results										
	Peak torque (Nm)	Seated	(–)	21.6 (5.1)	21.2 (5.5)	(–)	(–)	0.97	0.94-0.99	1.30	(–)
	RTDb (0%-50%; Nm/s)	Seated	(–)	97.8 (28.6)	95.3 (34.9)	(–)	(–)	0.86	0.71-0.94	15.80	(–)
	RTD (40%-80%; Nm/s)	Seated	(–)	62.3 (18.6)	59.3 (23.1)	(–)	(–)	0.84	0.67-0.92	11.00	(–)
	Isotonic results										
	Peak velocity (1-Nm load; degrees/second)	Seated	(–)	160.9 (31.0)	158.5. (28.9)	(–)	(–)	0.96	0.92-0.98	8.00	(–)
	Average acceleration (1-Nm load. degrees/second^2)	Seated	(–)	685.5 (183.0)	662.0 (176.7)	(–)	(–)	0.97	0.93-0.98	43.70	(–)
	Peak power (1-Nm load; degrees/second^2)	Seated	(–)	14.7 (6.1)	13.8 (5.6)	(–)	(–)	0.90	0.79-0.95	2.50	(–)
	Peak velocity (50% of maximum isometric load; degrees/second)	Seated	(–)	78.2 (18.5)	80.0 (15.0)	(–)	(–)	0.76	0.50-0.89	10.60	(–)
	Average acceleration (50% of maximum isometric load; degrees/second^2)	Seated	(–)	345.2 (95.3)	350.9 (81.9)	(–)	(–)	0.90	0.79-0.95	37.90	(–)
	Peak power (50% of maximum isometric load; W)	Seated	(–)	15.7 (6.3)	15.5 (6.2)	(–)	(–)	0.95	0.90-0.98	1.90	(–)
	Isokinetic results										
	Peak torque (30 degrees/second; Nm)	Seated	30	14.0 (4.6)	13.9 (4.8)	(–)	(–)	0.95	0.89-0.98	1.50	(–)
	Peak torque (90 degrees/second; Nm)	Seated	90	10.5 (4.2)	10.6 (4.1)	(–)	(–)	0.96	0.92-0.98	1.20	(–)
	Peak power (30 degrees/second; Nm)	Seated	30	7.2 (2.3)	7.1 (2.5)	(–)	(–)	0.94	0.88-0.97	0.80	(–)
	Peak power (90 degrees/second; Nm)	Seated	90	11.2 (4.5)	10.9 (4.4)	(–)	(–)	0.97	0.94-0.99	1.00	(–)
	Plantar flexion										
	Isometric results										
	Peak torque (Nm)	Seated	(–)	71.0 (21.5)	77.5 (24.0)	(–)	(–)	0.90	0.74-0.95	9.20	(–)
	RTD (up to 50% of peak torque; Nm/s)	Seated	(–)	113.5 (60.1)	142.0 (65.3)	(–)	(–)	0.63	0.20-0.82	44.70	(–)
	RTD (40%-80% of peak torque; Nm/s)	Seated	(–)	68.9 (30.1)	90.3 (48.8)	(–)	(–)	0.58	0.12-0.80	29.90	(–)
	Isotonic results										
	Peak velocity (15-Nm load; degrees/second)	Seated	(–)	275.2 (47.8)	274.8 (50.1)	(–)	(–)	0.93	0.85-0.97	18.20	(–)
	Average acceleration (15-Nm load; degrees/second^2)	Seated	(–)	1686.4 (477.2)	1698.3 (460.5)	(–)	(–)	0.93	0.86-0.97	168.20	(–)
	Peak power (15-Nm load; W)	Seated	(–)	171.3(73.0)	180.0 (460.5)	(–)	(–)	0.92	0.83-0.96	27.60	(–)
	Peak velocity (50%; degrees/second)	Seated	50	224.6 (44.2)	217.9 (43.6)	(–)	(–)	0.77	0.51-0.89	27.00	(–)
	Average acceleration (50%; degrees/second)	Seated	(–)	1304.7 (334.8)	1235.6 (318.5)	(–)	(–)	0.79	0.56-0.90	192.00	(–)
	Peak power (50%; W)	Seated	(–)	158.9 (59.1)	162.7 (57.0)	(–)	(–)	0.92	0.68-0.93	22.20	(–)
	Isokinetic results										
	Peak torque (30 degrees/second; Nm)	Seated	30	66.7 (20.0)	69.7 (20.2)	(–)	(–)	0.89	0.77-0.95	8.70	(–)
	Peak torque (90 degrees/second; Nm)	Seated	90	61.4 (15.8)	62.0 (18.5)	(–)	(–)	0.85	0.68-0.93	8.90	(–)
	Peak power (30 degrees/second; Nm)	Seated	30	35.0 (10.3)	37.1 (10.6)	(–)	(–)	0.88	0.75-0.95	4.60	(–)
	Peak power (90 degrees/second; Nm)	Seated	90	76.2 (18.0)	77.8 (21.2)	(–)	(–)	0.86	0.71-0.93	9.80	(–)

(continued)

Table 3. (Continued)

Study	Ankle Movement	Position	Velocity (degrees/second)	1-Degree Test, Mean (SD)	2-Degree Test, Mean (SD)	3-Degree Test, Mean (SD)	4-Degree Test, Mean (SD)	ICC	Limits ICC	SEM	SEM (%)
Tavakkoli et al[40]	Isometric Plantar flexion (Nm)										
	Torque max (Nm)	Seated	(–)	200.64 (78.29)	197.62 (83.75)	(–)	(–)	0.99	0.98-0.99	(–)	(–)
	RTD 0-25 (Nm/s)	Seated	(–)	143.23 (92.66)	150.69 (110.56)	(–)	(–)	0.92	0.68-0.98	(–)	(–)
	RTD 0-50 (Nm/s)	Seated	(–)	198.20 (120.15)	197.37 (119.38)	(–)	(–)	0.93	0.73-0.98	(–)	(–)
	RTD 0-100 (Nm/s)	Seated	(–)	282.88 (151.83)	278.12 (135.19)	(–)	(–)	0.95	0.80-0.99	(–)	(–)
	RTD 0-150 (Nm/s)	Seated	(–)	316.98 (158.29)	313.65 (132.39)	(–)	(–)	0.97	0.86-0.99	(–)	(–)
	RTD 0-200 (Nm/s)	Seated	(–)	319.08 (149.31)	320.52 (123.24)	(–)	(–)	0.97	0.88-0.99	(–)	(–)
	RTD 50-100 (Nm/s)	Seated	(–)	365.99 (194.40)	357.44 (164.85)	(–)	(–)	0.95	0.81-0.99	(–)	(–)
	RTD 100-200 (Nm/s)	Seated	(–)	355.73 (161.53)	363.26 (131.19)	(–)	(–)	0.96	0.84-0.99	(–)	(–)
	nRTD 0-25 (% torque max)	Seated	(–)	78.17 (46.60)	74.35 (48.99)	(–)	(–)	0.90	0.58-0.97	(–)	(–)
	nRTD 0-50 (% torque max)	Seated	(–)	109.49 (57.96)	100.92 (55.09)	(–)	(–)	0.93	0.72-0.98	(–)	(–)
	nRTD 0-100 (% torque max)	Seated	(–)	160.75 (75.55)	149.49 (71.92)	(–)	(–)	0.96	0.86-0.99	(–)	(–)
	nRTD 0-150 (% torque max)	Seated	(–)	183.21 (81.27)	170.83 (75.78)	(–)	(–)	0.98	0.89-0.99	(–)	(–)
	nRTD 0-200 (% torque max)	Seated	(–)	184.09 (72.62)	173.18 (68.62)	(–)	(–)	0.97	0.88-0.99	(–)	(–)
	nRTD 50-100 (% torque max)	Seated	(–)	211.03 (103.99)	197.20 (101.39)	(–)	(–)	0.97	0.88-0.99	(–)	(–)
	nRTD 100-200 (% torque max)	Seated	(–)	207.71 (82.51)	197.12 (79.17)	(–)	(–)	0.94	0.75-0.98	(–)	(–)
Spink et al[39]	Ankle dorsiflexion (N)										
	Rater 1	Supine	(–)	165.8 (46.2)	166.8 (47.2)	(–)	(–)	0.91	0.86-0.94	(–)	(–)
	Rater 2	Supine	(–)	132.2 (54.1)	141.7 (58.8)	(–)	(–)	0.90	0.85-0.94	(–)	(–)
	Ankle plantar flexion (N)										
	Rater 1	Supine	(–)	237.0 (57.6)	237.2 (57.2)	(–)	(–)	0.89	0.83-0.93	(–)	(–)
	Rater 2	Supine	(–)	213.3 (77.8)	225.0 (78.7)	(–)	(–)	0.84	0.76-0.90	(–)	(–)
	Ankle inversion (N)										
	Rater 1	Supine	(–)	159.9 (45.4)	160.5 (44.2)	(–)	(–)	0.90	0.85-0.94	(–)	(–)
	Rater 2	Supine	(–)	124.5 (44.2)	130.3 (48.7)	(–)	(–)	0.87	0.80-0.92	(–)	(–)
	Ankle eversion (N)										
	Rater 3	Supine	(–)	153.6 (43.4)	157.3 (45.6)	(–)	(–)	0.88	0.82-0.92	(–)	(–)
	Rater 4	Supine	(–)	123.4 (38.4)	127.6 (39.2)	(–)	(–)	0.78	0.67-0.86	(–)	(–)
Morrison and Kaminski[30]	Plantar flexion isokinetic strength right ankle (Nm)										
	Concentric muscle action peak torque (Nm)	Seated	30	149.73 (52.75)	150.77 (51.95)	(–)	(–)	0.92		14.76	9.8
	Concentric muscle action peak torque (Nm)	Seated	120	92.87 (41.2)	92.35 (38.86)	(–)	(–)	0.85		15.85	17.1
	Concentric muscle action average torque (Nm)	Seated	30	106.19 (36.67)	102.19 (35.16)	(–)	(–)	0.89		11.70	11.2
	Concentric muscle action average torque (Nm)	Seated	120	66.31 (26.63)	65.81 (27.64)	(–)	(–)	0.90		9.03	13.17
	Eccentric muscle action peak torque (Nm)	Seated	30	240 (81.57)	234.65 (81.31)	(–)	(–)	0.89		25.38	10.7
	Eccentric muscle action peak torque (Nm)	Seated	120	208.35 (75.32)	199.81 (75.93)	(–)	(–)	0.93		19.19	9.4
	Eccentric muscle action average torque (Nm)	Seated	30	152.85 (45.18)	145.12 (46.42)	(–)	(–)	0.90		14.08	9.5
	Eccentric muscle action average torque (Nm)	Seated	120	129.58 (42.39)	126.46 (43.61)	(–)	(–)	0.86		15.22	11.9
	Dorsiflexion isokinetic strength right ankle (Nm)										
	Concentric muscle action peak torque (Nm)	Seated	30	39.77 (15.81)	44.12 (14.17)	(–)	(–)	0.88		4.58	10.9
	Concentric muscle action peak torque (Nm)	Seated	120	25.65 (10.3)	28.46 (9.76)	(–)	(–)	0.84		4.51	16.7
	Concentric muscle action average torque (Nm)	Seated	30	32.69 (12.59)	35.65 (12.49)	(–)	(–)	0.90		3.96	11.6
	Concentric muscle action average torque (Nm)	Seated	120	16.46 (8.09)	19.92 (8.66)	(–)	(–)	0.78		4.02	22.1

(continued)

Table 3. (Continued)

Study	Ankle Movement	Position	Velocity (degrees/second)	1-Degree Test, Mean (SD)	2-Degree Test, Mean (SD)	3-Degree Test, Mean (SD)	4-Degree Test, Mean (SD)	ICC	Limits ICC	SEM	SEM (%)
	Eccentric muscle action peak torque (Nm)	Seated	30	61.88 (20.94)	67.19 (19.38)	(–)	(–)	0.94		4.81Nm	7.5
	Eccentric muscle action peak torque (Nm)	Seated	120	62.46 (18.86)	67.88 (19.82)	(–)	(–)	0.93		5.26	8.1
	Eccentric muscle action average torque (Nm)	Seated	30	52.27 (17.66)	57.23 (17.74)	(–)	(–)	0.95		3.84	7
	Eccentric muscle action average torque (Nm)	Seated	120	47.96 (14.74)	51.73 (16.68)	(–)	(–)	0.92		4.50	9
	Plantar flexion isokinetic strength left ankle (Nm)										
	Concentric muscle action peak torque (Nm)	Seated	30	144.27 (36.19)	152 (48.6)	(–)	(–)	0.86		15.71	10.6
	Concentric muscle action peak torque (Nm)	Seated	120	88.85 (33.15)	91.5 (29.23)	(–)	(–)	0.83		12.66	14
	Concentric muscle action average torque (Nm)	Seated	30	103.85 (26.04)	104.54 (34.89)	(–)	(–)	0.83		10.43	10
	Concentric muscle action average torque (Nm)	Seated	120	61.77 (22.63)	65.27 (20.07)	(–)	(–)	0.80		9.60	14.3
	Eccentric muscle action peak torque (Nm)	Seated	30	245.54 (84.85)	233.42 (79.64)	(–)	(–)	0.91		24.51	10.2
	Eccentric muscle action peak torque (Nm)	Seated	120	228.23 (73.85)	222.31 (72.54)	(–)	(–)	0.93		19.73	8.8
	Eccentric muscle action average torque (Nm)	Seated	30	156.5 (47.15)	145.69 (46.59)	(–)	(–)	0.90		14.85	9.9
	Eccentric muscle action average torque (Nm)	Seated	120	131.46 (36.9)	123.31 (31.96)	(–)	(–)	0.87		12.56	9.9
	Dorsiflexion isokinetic strength left ankle (Nm)										
	Concentric muscle action peak torque (Nm)	Seated	30	43.46 (13.52)	40.96 (13.5)	(–)	(–)	0.89		4.50	10.7
	Concentric muscle action peak torque (Nm)	Seated	120	28.77 (11.02)	25.88 (11.26)	(–)	(–)	0.90		3.45	12.6
	Concentric muscle action average torque (Nm)	Seated	30	35.65 (11.54)	33.42 (10.2)	(–)	(–)	0.84		4.36	12.6
	Concentric muscle action average torque (Nm)	Seated	120	19.42 (8.76)	17.38 (9.33)	(–)	(–)	0.87		3.25	17.7
	Eccentric muscle action peak torque (Nm)	Seated	30	66.38 (17.47)	64.81 (18.1)	(–)	(–)	0.91		5.20	7.9
	Eccentric muscle action peak torque (Nm)	Seated	120	66.38 (17.2)	64.35 (15.94)	(–)	(–)	0.89		5.53	8.5
	Eccentric muscle action average torque (Nm)	Seated	30	54.69 (17.94)	55.27 (15.09)	(–)	(–)	0.86		6.23	11.3
	Eccentric muscle action average torque (Nm)	Seated	120	50.62 (15.87)	49.23 (12.05)	(–)	(–)	0.82		5.99	12
Aydoğ et al[2]	First tester										
	Eversion (Nm)	Seated	60	12.85 (3.89)	17.01 (4.23)	17.26 (5.58)	18.29 (4.86)	0.94 (0.81)	(–)	(–)	(–)
		Seated	180	9.96 (2.86)	13.16 (5.27)	12.26 (3.76)	13.26 (4.72)	0.88 (0.88)	(–)	(–)	(–)
	Inversion (Nm)	Seated	60	15.62 (4.95)	21.95 (6.45)	23.86 (8.26)	23.62 (7.89)	0.92 (0.86)	(–)	(–)	(–)
		Seated	180	12.26 (3.58)	16.85 (6.26)	17.59 (7.52)	16.81 (5.56)	0.95 (0.88)	(–)	(–)	(–)
	Second tester										
	Eversion (Nm)	Seated	60	19.05 (6.59)	19.43 (5.56)	18.26 (4.99)	(–)	0.94			
		Seated	180	12.21 (5.68)	11.65 (3.94)	11.99 (3.42)	(–)	0.87	(–)	(–)	(–)
	Inversion (Nm)	Seated	60	22.26 (7.56)	23.63 (7.14)	23.81 (6.26)	(–)	0.96	(–)	(–)	(–)
		Seated	180	16.05 (5.29)	15.65 (4.82)	15.56 (4.95)	(–)	0.95	(–)	(–)	(–)
Man et al[24]	Dorsiflexion /plantar flexion (Nm/deg)										
	Between-day	Seated	40	(–)	(–)	(–)	(–)	0.96	0.83-0.99	(–)	(–)
	Within-day	Seated	40	(–)	(–)	(–)	(–)	0.96	0.85-0.99	(–)	(–)

(continued)

Table 3. (Continued)

Study	Ankle Movement	Position	Velocity (degrees/second)	1-Degree Test, Mean (SD)	2-Degree Test, Mean (SD)	3-Degree Test, Mean (SD)	4-Degree Test, Mean (SD)	ICC	Limits ICC	SEM	SEM (%)
Kaminski and Dover[18]	Concentric ankle inversion and eversion peak torque (Nm)										
	Right eversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.54		6.38	(–)
	Left eversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.76		4.52	(–)
	Right inversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.87		2.37	(–)
	Left inversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.84		2.88	(–)
	Right eversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.68		2.10	(–)
	Left eversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.77		3.27	(–)
	Right inversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.92		1.28	(–)
	Left inversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.82		2.14	(–)
	Concentric ankle inversion and eversion average-torque (Nm)										
	Right eversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.55		6.12	(–)
	Left eversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.68		3.64	(–)
	Right inversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.84		2.36	(–)
	Left inversion (Nm)	Seated	30	(–)	(–)	(–)	(–)	0.75		3.14	(–)
	Right eversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.73		2.81	(–)
	Left eversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.73		3.26	(–)
	Right inversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.91		1.23	(–)
	Left inversion (Nm)	Seated	120	(–)	(–)	(–)	(–)	0.83		1.76	(–)
Morris-Chatta et al[29]	Plantarflexion (Nm)										
		Seated	30	33.5 (13.2)	35.5 (13.1)	36.5 (14.3)	(–)	0.88	0.72-0.91	(–)	(–)
		Seated	60	25.9 (10.0)	26.4 (9.0)	26.5 (15.1)	(–)	0.90	0.75-0.93	(–)	(–)
		Seated	120	14.6 (5.6)	13.8 (6.4)	14.4 (8.0)	(–)	0.87	0.69-0.90	(–)	(–)
		Seated	180	5.8 (5.1)	3.9 (5.0)	5.4 (6.7)	(–)	0.66	0.35-0.75	(–)	(–)
	Dorsiflexion (Nm)									(–)	(–)
		Seated	30	14.3 (6.8)	12.5 (7.4)	14.5 (6.2)	(–)	0.95	0.87-0.97	(–)	(–)
		Seated	60	9.6 (4.4)	8.6 (4.2)	8.9 (4.7)	(–)	0.92	0.80-0.94	(–)	(–)
		Seated	120	2.5 (3.2)	2.2 (3.7)	2.2 (3.1)	(–)	0.75	0.48-0.83	(–)	(–)
		Seated	180	0.2 (0.9)	0.0 (0.0)	0.3 (1.1)	(–)	0.42	0.09-0.57	(–)	(–)
Porter et al[35]	Concentric dorsiflexion (Nm)	Stand	30	16 (7)	17 (5)	(–)	(–)	0.85	(–)	(–)	(–)
	Eccentric dorsiflexion (Nm)	Stand	30	29 (7)	30 (6)	(–)	(–)	0.55-0.86	(–)	(–)	(–)
	Concentric plantar flexion (Nm)	Stand	30	69.9 (19)	73 (18)	(–)	(–)	0.80	(–)	(–)	(–)
	Eccentric plantar flexion (Nm)	Stand	30	108 (24)	111 (29)	(–)	(–)	0.90	(–)	(–)	(–)
	Dorsiflexion eccentric/concentric (Nm)	Stand	30	2.1 (0.8)	1.9 (0.5)	(–)	(–)	0.33	(–)	(–)	(–)
	Plantar flexion eccentric/concentric (Nm)	Stand	30	1.6 (0.4)	1.5 (0.3)	(–)	(–)	0.26	(–)	(–)	(–)

Abbreviations: ICC, intraclass correlation coefficient; nRTD, normalised RTD; RTD, rate of torque development; SEM, standard error of the mean.

Table 4. Characteristics of the Participants.

Study	N	Sex	Subjects	Bilateral	Rest	Dynamometer
O'Neill et al[33]	65	Men/women	Healthy	No	2 d	C-Station
Webber and Porter[43]	30	Women	Healthy older adults	No	7 d	Biodex System 3 Pro
Tavakkoli et al[40]	10	Women	Healthy	No	60 min	Torque transducer (JNNT-T1, Bengbu Sensor System, China)
Spink et al[39]	72	Men/women	Healthy	No	7 d	Citec (CIT Technics, Haren, Netherlands)
van Cingel et al[42]	30	Men/women	Healthy	Yes	7 d	Humac Norm
Morrison and Kaminski[30]	26	Men/women	Healthy	Yes	7 d	Kin Com 125 AP
Aydoğ et al[2]	25	Men/women	Healthy	No	2 d	Biodex Medical Systems
Man et al[24]	19	Men	Athletes	No	Group 1: No rest Group 2: 2 d	The console consists of a swing cradle, driven by a motor-sensor unit, which includes a computer-controlled servo motor (Cool Muscle Inc, model: RCM1-C-23L20-C-RT3) gearbox (Cool Muscle Inc, model: RGP60-80-NEMA23, Ratio 80:1 and 3-stage), a torque limiter (R+W Inc, model: SK2/ 15/75(W)), a calibrated torque transducer (Mountz Inc; Type RTSX 200 IA II, range 2.3-22.6 Nm and sampling frequency 100 Hz) and a pair of vertical laser line projectors
Holmbäck et al[15]	30	Men/women	Healthy	No	7 d	Biodex Multi-Joint System 2
Kaminski and Dover[18]	35	Men/women	Healthy	Yes	7 d	Biodex System 3
Morris-Chatta et al[29]	24	Men/women	Healthy older adults	No	3 mo	Cybex II+
Porter et al[35]	22	Men/women	Healthy older adults	No	7 d	KIN-COM 500 H
Holmbäck et al[16]	30	Men/women	Healthy	No	7-10 d	Biodex Multi-Joint System 2

excellent reliability.[24] Likewise, speeds such as 60 and 90 degrees/second exhibited ICCs between 0.85 and 0.96, indicating good to excellent reliability.[2,15,16,29,43] However, the 120-degrees/second speed showed ICCs between 0.47 and 0.93, ranging from moderate to good reliability.[16,18,29,30,42] Only 1 article used a speed of 150 degrees/second, obtaining an ICC of 0.80, suggesting good reliability.[16] Finally, the highest speed evaluated, 180 degrees/second, showed ICC limits between 0.42 and 0.95, reflecting variability in reliability from poor to excellent, depending on the specific study (Tables 4 and 5).[2,29]

Regarding the type of muscle contraction used to measure ankle strength, a diversity of approaches was observed in the reviewed studies, each with its corresponding level of reliability. Isokinetic measurement of strength, which encompasses a range of movements at constant velocity, showed coefficients ranging from 0.26 to 0.96.[2,16,24,29,30,35,42,43] These values reflect a reliability ranging from poor to excellent, depending on the specific study. On the other hand, isometric measurement demonstrated much more consistent reliability, with ICCs between 0.78 and 0.99, indicating reliability ranging from good to excellent in most cases.[33,39,43] Only 1 article[15] assessed strength eccentrically, obtaining an ICC of 0.90 to 0.96, suggesting good to excellent reliability. Similarly, only one other study[18] measured strength concentrically, with ICCs between 0.54 and 0.92, reflecting reliability ranging from moderate to good.

Discussion

The aims of this systematic review were as follows: (1) to examine the reliability of dynamometric strength measurements for the ankle musculature in healthy subjects and athletes, (2) to determine which position is the most

Table 5. Relative and Absolute Reliability of Ankle Strength Assessment by Sex.

Study	Ankle Movement	Position	Velocity (degrees/second)	1-Degree Test, Mean (SD)	2-Degree Test, Mean (SD)	3-Degree Test, Mean (SD)	4-Degree Test, Mean (SD)	ICC	Limits ICC	SEM	SEM (%)
van Cingel et al[42]	Inversion, men (Nm)										
	Dominant leg (peak torque)	Seated	30	36.73 (11.68)	37.60 (12.24)	(–)	(–)	0.65	0.22-0.87	6.92	(–)
	Nondominant leg (peak torque)	Seated	30	33.80 (7.66)	33.60 (9.83)	(–)	(–)	0.55	0.07-0.82	5.14	(–)
	Dominant leg (peak torque)	Seated	120	27.26 (9.61)	26.53 (9.22)	(–)	(–)	0.47	-0.37-0.78	7.00	(–)
	Nondominant leg (peak torque)	Seated	120	26.53 (9.80)	29.46 (11.84)	(–)	(–)	0.68	0.28-0.88	5.54	(–)
	Eversion, men (Nm)					(–)					
	Dominant leg (peak torque)	Seated	30	30.00 (8.40)	30.93 (8.03)	(–)	(–)	0.61	0.16-0.85	5.25	(–)
	Nondominant leg (peak torque)	Seated	30	27.86 (7.84)	27.46 (5.51)	(–)	(–)	0.67	0.25-0.87	4.51	(–)
	Dominant leg (peak torque)	Seated	120	22.40 (8.36)	22.00 (9.99)	(–)	(–)	0.82	0.55-0.94	3.55	(–)
	Nondominant leg (peak torque)	Seated	120	21.33 (8.30)	20.66 (6.51)	(–)	(–)	0.53	0.38-0.81	5.69	(–)
	Inversion, women (Nm)					(–)					
	Dominant leg (peak torque)	Seated	30	29.93 (11.20)	29.26 (10.06)	(–)	(–)	0.89	0.71-0.96	3.71	(–)
	Nondominant leg (peak torque)	Seated	30	31.00 (11.30)	29.33 (8.40)	(–)	(–)	0.83	0.56-0.94	4.66	(–)
	Dominant leg (peak torque)	Seated	120	21.20 (9.12)	21.26 (8.89)	(–)	(–)	0.79	0.48-0.92	4.20	(–)
	Nondominant leg (peak torque)	Seated	120	20.20 (7.36)	21.20 (7.42)	(–)	(–)	0.70	0.31-0.89	4.04	(–)
	Eversion, women (Nm)					(–)					
	Dominant leg (peak torque)	Seated	30	27.13 (13.58)	26.66 (11.68)	(–)	(–)	0.94	0.82-0.98	3.33	(–)
	Nondominant leg (peak torque)	Seated	30	26.13 (13.05)	26.20 (16.50)	(–)	(–)	0.91	0.75-0.97	3.92	(–)
	Dominant leg (peak torque)	Seated	120	19.20 (10.49)	22.80 (16.49	(–)	(–)	0.83	0.58-0.94	4.33	(–)
	Nondominant leg (peak torque)	Seated	120	18.46 (10.41)	18.00 (10.77)	(–)	(–)	0.85	0.61-0.95	4.03	(–)
Holmbäck et al[15]	Dorsiflexion (Nm)										
	Men peak torque (Nm)	Seated	30	35.0 (7.5)	35.5 (6.7)	(–)	(–)	0.91		2.01	(–)
		Seated	60	28.0 (7.3)	28.6 (7.2)	(–)	(–)	0.93		1.69	(–)
		Seated	90	23.9 (5.1)	23.9 (6.4)	(–)	(–)	0.9		1.71	(–)
		Seated	120	20.0 (4.5)	20.2 (5.7)	(–)	(–)	0.78		2.16	(–)
		Seated	150	17.4 (4.4)	18.4 (6.0)	(–)	(–)	0.8		2.15	(–)
	Women peak torque (Nm)	Seated	30	28.8 (4.8)	28.3 (4.8)	(–)	(–)	(–)		(–)	(–)
		Seated	60	23.3 (4.8)	23.8 (5.1)	(–)	(–)	(–)		(–)	(–)
		Seated	90	19.5 (4.4)	20.2 (4.9)	(–)	(–)	(–)		(–)	(–)
		Seated	120	7.3 (4.0)	17.1 (4.8)	(–)	(–)	(–)		(–)	(–)
		Seated	150	15.3 (4.3)	15.7 (4.9)	(–)	(–)	(–)		(–)	(–)
Holmbäck et al[16]	Eccentric dorsiflexion (Nm)	Seated									
	Men	Seated	30	52. 1 (9.5)	50.7 (10.1)	(–)	(–)	0.95	(–)	(–)	(–)
	Women	Seated	30	35.5 (4.4)	35.0 (5.0)	(–)	(–)	0.92	(–)	(–)	(–)
	Men	Seated	90	53.6 (9.2)	53.0 (9.9)	(–)	(–)	0.96	(–)	(–)	(–)
	Women	Seated	90	36.9 (4.8)	36.1 (4.9)	(–)	(–)	0.90	(–)	(–)	(–)

Abbreviations: ICC, intraclass correlation coefficient; SEM, standard error of the mean.

valid and reliable for measuring strength, and (3) to determine the most reliable velocity for assessing ankle muscle strength.

The main findings of this study are as follows:

1. Most research evaluates ankle movements with the subject in a seated position. The ICCs obtained in these studies range from 0.42 to 0.97, with most articles reporting ICCs within the range of 0.78 to 0.99, indicating reliability ranging from good to excellent.
2. As for the movements evaluated, dorsiflexion and plantarflexion exhibited reliability ranging from good to excellent, with ICCs between 0.78 and 0.99. In contrast, inversion and eversion movements exhibited variability in reliability, with ICCs ranging from 0.47 to 0.96.
3. The measurement of eccentric and concentric strength showed reliability ranging from good to excellent, with ICCs between 0.54 and 0.92 and between 0.90 and 0.96, respectively.
4. Variability was observed in the ICCs obtained for the different velocities used in the ankle movement evaluations. Although some velocities, such as 40 and 60 degrees/second, showed excellent reliability, others, such as 30 and 120 degrees/second, exhibited reliability ranging from poor to excellent.

Anatomical Plane, Movement, and Position

Regarding the position used for the assessment of ankle muscle strength, sedentary is the most used posture for the assessments,[2,15,16,18,24,29,30,33,40,42,43] although the supine[39] and standing[35] positions have also been reported. In this regard, Chamorro et al[6] recommend standardizing the body position for strength assessment, because a lack of consensus may vary the results and decrease the consistency and reliability of intra- and interevaluator tests. Regarding the seated position, Cho et al[8] used this arrangement during testing, concluding that the use of a single posture may contribute to greater accuracy and validity. However, subject comfort is another variable to consider because they found reports of hamstring strain during prolonged sitting. Conversely, Kimura et al[19] found excellent reliability when limiting compensatory movements during the assessment of the dorsiflexor using a handheld device in the seated position.

Mentiplay et al[28] used the supine position to assess the isometric strength of the plantarflexor and dorsiflexor muscles, reporting good to excellent reliability, although with poor validity—a situation that may be related more to the use of the handheld device (stabilization and adjustment to the joint) than to the position of the individual. Furthermore, Marinho et al[25] concluded that hip and knee positions can vary ankle joint mechanics by force transmission through the muscle fascia, which reinforces the importance of establishing consensus in the ankle strength assessment position.

With reference to the movements evaluated, most studies evaluated strength in plantarflexion and dorsiflexion; few studies evaluated anterior movements in addition to inversion and eversion. Regarding the above, Witchalls et al[44] demonstrated that poor eccentric inversion strength in tests with low movement speeds increases the risk of ankle injury. Similarly, Kobayashi et al[20] found that greater eccentric inversion strength and increased concentric strength in plantarflexion increase the risk of lateral ankle ligament sprain. In addition, alterations in peroneus longus activation during eversion have been found in individuals with chronic ankle instability.[27] Moreover, an increase in the torque ratio between dorsiflexion and plantarflexion and a decrease in the same ratio between eversion and inversion at angular velocities of 60 and 120 degrees/second have also been reported. This suggests that the inclusion of frontal plane assessment with plantarflexion and dorsiflexion movements should be included in ankle strength assessment to improve decision making in injury prevention processes.[1]

Muscle Contraction

In the context of muscle contraction, isokinetic force has emerged as the predominant assessment method over the past decade and has been extensively used in both clinical practice and research. It facilitates the evaluation of muscle torques and imbalances, yielding valid and reliable data on muscle function that enhances decision-making in prevention, sports rehabilitation, and training.[4] Gonosova et al[13] identified isokinetic dynamometry as the benchmark for assessing ankle joint muscles, noting that reciprocal muscle actions exhibit good to excellent test reliability when preceded by proper warm-up and strict adherence to the assessment protocol.

Conversely, Webber and Porter,[43] in their investigation of the intrarater reliability of isometric, isotonic, and isokinetic ankle measurements in older women, confirmed the reliability of isokinetic and isotonic tests for assessing strength and power, except for isometric peak torque variables. Schaeffer et al[37] determined that isometric dynamometry using handheld devices is a reliable method for preprofessional dancers. Jackson et al[17] corroborated these findings regarding isometric dynamometry, emphasizing the crucial role of limb stabilization during the protocol, which renders it a more feasible option for professionals because of its affordability, portability, and minimal space requirements, in contrast to isokinetic dynamometry.

With regard to the type of muscle contraction, few articles specify concentric or eccentric results. It is important to remember that in the frontal plane, the relationship between chronic ankle instability and eccentric weakness of the evertor and invertor muscles has been established, suggesting the importance of developing eccentric strength in ankle rehabilitation processes in athletes.[9] In addition, Nozu et al[32] suggested the need for eccentric action of the dorsiflexor and plantarflexor muscles during dynamic postural control actions. In turn, it should be noted that eccentric and concentric isokinetic evaluations of both the muscles involved in movements in the sagittal and frontal planes can contribute to the measurement of bilateral and ipsilateral muscle imbalances that may be related to an increased risk of injury in ballet dancers. This may suggest the need to assess ankle strength, discriminating the type of muscle contraction, to better visualize muscle function in both eccentric and concentric actions and use this information to help decision making in clinical practice.[31]

Velocity

The velocity of movement found for the evaluation of strength ranged from 30 to 180 degrees/second, with 60 to 90 degrees/second being the velocities that showed the best ICCs, with values of 0.85 to 0.96 indicating good to excellent reliability. Gonosova et al[13] reported ICC values between 0.77 and 0.98 for all ankle movements at speeds between 30 and 120 degrees/second, although they found the lowest ICC values (0.71) in the dorsiflexion movement at 120 degrees/second. On the other hand, Tuominen et al[41] found good to excellent reliability at speeds of 30 degrees/second, although with less consistency in inversion and dorsiflexion movements in the nondominant lower extremity. Significant differences in peak torque between healthy and injured ankles have been reported, as demonstrated by Park et al[34] finding low values in the maximum ankle torque for eversion at speeds of 30 and 180 degrees/second in individuals with chronic ankle instability. The evaluation of isokinetic ankle strength allows the determination of muscle weakness between healthy and injured subjects of this joint, although it is also important to mention the importance of complementing the evaluation of ankle strength with functional tests, which present a significant correlation.

Reliability

Dorsiflexion and plantarflexion movements have demonstrated good to excellent reliability, with ICC limits between 0.78 and 0.99.[13,14,23,27,36,43] Fraser et al[12] noted the excellent reliability of ankle joint complex strength measurements (0.76-0.88). Additionally, in healthy subjects, plantar flexion measurements have been reported to range from 0.77 to 0.93, whereas for dorsiflexion values have been between 0.78 and 0.95.[30] For ankle strength measurements, considering the results found and the reported scientific evidence, it is necessary for evaluators to develop protocols, strategies, and measurements of both dorsiflexion and plantarflexion, movements widely related to activities of daily living and sports actions.[7,13]

Inversion and eversion movements showed greater variability in the ICC results found (0.47 and 0.96). In their study, Yildiz et al[45] reported that isokinetic measurements of ankle joint inversion and eversion strength presented good reliability (ICC between 0.86 and 0.89). The measurement of these 2 movements has been established as a risk factor for sports injury because strength asymmetry parameters in these movements have been found in athletes with ankle sprains and chronic ankle instability; in addition, strength assessments allow researchers and health and sports professionals to have more complete evaluation profiles.[10] However, further research is needed to establish specific parameters and consensus for evaluating both inversion and eversion.

Regarding the type of measurement, isokinetic strength showed values in reliability coefficients from poor to excellent, whereas isometric measurements reported reliability ranging from good to excellent. Although the isokinetic method of force assessment has been cataloged as the "gold standard," isometric assessment also showed good results in terms of reliability, becoming an alternative because of its low cost and the availability of studies that support it.[28] Nevertheless, the use of stabilizing devices in this type of test is necessary to limit the resistance of the evaluator and increase the reliability of the results.[17]

Regarding the speed, the findings allow establishing that between 40 and 90 degrees/second there is a good to excellent reliability. Although the reports show speeds up to 180 degrees/second, there are few studies that have developed force assessments at high speeds. In this case, a parameter that may influence is the position, because the studies that showed good to excellent reliability between 40 and 90 degrees/second were performed in a seated position, whereas only 1 study that evaluated at 30 degrees/second did so in a standing position, reporting results of 0.26 for the eccentric action of plantarflexion and 0.33 for dorsiflexion in eccentric phase, results with poor reliability at this speed. This may suggest that the velocity may be related to the position of the subject to be evaluated.

Considering the above, the methodological quality of each study, and the results of the systematic review, the following recommendations can be made for the evaluation of ankle strength:

The seated position is the most recommended to evaluate ankle strength because of its good reliability and that it allows stabilizing the knee and hip joints, isolating the action of the muscles of these joints, generating that the development of the evaluation is focused on the periarticular muscles of the ankle, avoiding compensations in the movement.

It is advisable to evaluate both the sagittal and frontal planes because, given the complexity in the mechanics of the ankle joint and its notable participation in daily life actions such as in the different sports actions, such as running, jumping, and changing direction, makes researchers as well as health and sports professionals consider evaluating the 4 movements. Although the dorsiflexion and plantarflexion movements present good to excellent reliability, there are few studies that evaluate the set of movements and there are few that demonstrate the reliability of the protocols used in the assessment of eversion and inversion, although these 2 movements in their interaction have been related to the risk of injury.[9,10,31,36]

It is recommended to use speeds between 40 and 90 degrees/second for the evaluation of isokinetic strength in the ankle. In addition, it is suggested to extend the studies in eccentric and concentric phases in the movements of dorsiflexion, plantarflexion, eversion, and inversion, because there are few studies that report the results considering the type of muscle contraction.

The present study has several limitations that preclude generalizing our findings or extending these recommendations for ankle strength assessment. Notably, the high heterogeneity of study samples, varying measurement speeds, multiple protocols, and diverse devices reported make it challenging to account for all factors in a single systematic review. Although our analysis focused on healthy individuals and athletes, the recommended methods—seated positioning, moderate testing velocities, and consistent warm-ups—are potentially adaptable to clinical contexts. However, pain, restricted range of motion, and patient apprehension may alter reliability in individuals with ankle pathology, underscoring the need for additional investigations. Future research should validate these protocols in clinical populations—such as those with chronic ankle instability or postoperative conditions—to determine whether similar reliability outcomes can be achieved.

Practical Applications. This systematic review showed that dynamometric strength measurements for ankle muscles generally achieve good to excellent reliability, especially when performed in a seated position, where ICC values range from 0.78 to 0.99 for dorsiflexion and plantarflexion. In contrast, inversion and eversion movements displayed wider variability (ICC 0.47-0.96). Testing velocities between 40 and 90 degrees/second yielded the most consistent results, and both eccentric and concentric measurements also demonstrated good to excellent reliability.

Based on these findings, the recommended testing protocol comprises 4 key steps:

1. Positioning the participant in a seated posture with secure stabilization of the knee, ankle, and foot.
2. Using moderate isokinetic velocities (around 60-90 degrees/second) or well-standardized isometric conditions.
3. Incorporating familiarization and warm-up repetitions to reduce learning effects.
4. Obtaining multiple measurements with consistent rest intervals.

These measures directly target the primary sources of variability—such as postural compensation, fatigue, and technique inconsistencies—underscoring the importance of detailed protocol documentation (joint angles, rest periods, and number of trials) to ensure reliable and comparable outcomes across studies and clinical settings.

Acknowledgments

The authors wish to express their gratitude to the Universidad del Cauca, Universidad San Sebastián, Andrés Bello University, and the University of Granada for their support and contributions to this work. This publication is part of the project MUSCLE QUALITY-LIFE (A.SEJ.227.UGR23), co-financed by the Consejería de Universidad, Investigación e Innovación and the European Union under the FEDER Andalucía 2021-2027 Program.

Ethical Approval Statement

Ethical approval was not sought for the present study because it is a systematic review.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. Disclosure forms for all authors are available online.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Andrés Felipe Villaquiran-Hurtado, PT https://orcid.org/0000-0002-6156-6425
Daniel Jerez-Mayorga, PhD, https://orcid.org/0000-0002-6878-8004

Supplemental Material

Supplementary material is available online with this article.

References

1. Abdel-aziem AA, Draz AH. Chronic ankle instability alters eccentric eversion/inversion and dorsiflexion/plantarflexion ratio. *J Back Musculoskelet Rehabil*. 2014;27:47-53. doi:10.3233/BMR-130418
2. Aydoğ E, Aydoğ ST, Çakci A, Doral MN. Reliability of isokinetic ankle inversion- and eversion-strength measurement

in neutral foot position, using the Biodex dynamometer. *Knee Surg Sports Traumatol Arthrosc*. 2004;12(5):478-481. doi:10.1007/s00167-004-0530-8
3. Beato M, Maroto-Izquierdo S, Turner AN, Bishop C. Implementing strength training strategies for injury prevention in soccer: scientific rationale and methodological recommendations. *Int J Sports Physiol Perform*. 2021;16:456-461. doi:10.1123/IJSPP.2020-0862
4. Bergamin M, Gobbo S, Bullo V, et al. Reliability of a device for the knee and ankle isometric and isokinetic strength testing in older adults. *Muscles Ligaments Tendons J*. 2017;7(2):323-330. doi:10.11138/mltj/2017.7.2.323
5. Brink Y, Louw QA. Clinical instruments: Reliability and validity critical appraisal. *J Eval Clin Pract*. 2012;18(6):1126-1132. doi:10.1111/j.1365-2753.2011.01707.x
6. Chamorro C, Armijo-Olivo S, De La Fuente C, Fuentes J, Javier Chirosa L. Absolute reliability and concurrent validity of hand held dynamometry and isokinetic dynamometry in the hip, knee and ankle joint: systematic review and meta-analysis. *Open Med (Wars)*. 2017;12(1):359-375. doi:10.1515/med-2017-0052
7. Chester R, Costa ML, Shepstone L, Donell ST. Reliability of isokinetic dynamometry in assessing plantarflexion torque following Achilles tendon rupture. *Foot Ankle Int*. 2003;24(12):909-915. doi:10.1177/107110070302401207
8. Cho SY, Myong Y, Park S, Cho M, Kim S. A portable articulated dynamometer for ankle dorsiflexion and plantar flexion strength measurement: a design, validation, and user experience study. *Sci Rep*. 2023;13(1):22221. doi:10.1038/s41598-023-49263-2
9. David P, Halimi M, Mora I, Doutrellot PL, Petitjean M. Isokinetic testing of evertor and invertor muscles in patients with chronic ankle instability. *J Appl Biomech*. 2013;29(6):696-704. doi:10.1123/jab.29.6.696
10. Eler N, Eler S, Cobanoglu Demirkan G, Karatay GM, Güzel NA. Profile of ankle isokinetic strength and proprioception in elite female handball players. Perfil de Fuerza Isokinética Del Tobillo y Propiocepción En Jugadoras de Balonmano de Élite. *Int J Morphol*. 2023;41(4):1118-1122.
11. Fragala MS, Cadore EL, Dorgo S, et al. Resistance training for older adults: position statement from the national strength and conditioning association. *J Strength Cond Res*. 2019;33(8):2019-2052.
12. Fraser JJ, Koldenhoven RM, Saliba SA, Hertel J. Reliability of ankle-foot morphology, mobility, strength, and motor performance measures. *Int J Sports Phys Ther*. 2017;12:1134-1149. doi:10.26603/ijspt20171134
13. Gonosova Z, Linduska P, Bizovska L, Svoboda Z. Reliability of ankle–foot complex isokinetic strength assessment using the Isomed 2000 dynamometer. *Medicina (Kaunas)*. 2018;54(3):43. doi:10.3390/medicina54030043
14. Halabchi F, Hassabi M. Acute ankle sprain in athletes: clinical aspects and algorithmic approach. *World J Orthop*. 2020;11(12):534-558. doi:10.5312/wjo.v11.i12.534
15. Holmbäck AM, Porter MM, Downham D, Lexell J. Ankle dorsiflexor muscle performance in healthy young men and women: reliability of eccentric peak torque and work measurements. *J Rehabil Med*. 2001;33(2):90-96.
16. Holmbäck AM, Porter MM, Downham D, Lexell J. Reliability of isokinetic ankle dorsiflexor strength measurements in healthy young men and women. *Scand J Rehabil Med*. 1999;31(4):229-239.
17. Jackson SM, Cheng MS, Smith AR, Kolber MJ. Intrarater reliability of hand held dynamometry in measuring lower extremity isometric strength using a portable stabilization device. *Musculoskelet Sci Pract*. 2017;27:137-141. doi:10.1016/j.math.2016.07.010
18. Kaminski TW, Dover GC. Reliability of inversion and eversion peak-and average-torque measurements from the Biodex system 3 dynamometer. *J Sport Rehabil*. 2001;10(3):205-220.
19. Kimura M, Ogata Y, Akebi T, Ochi M, Hachisuka K, Saeki S. Development and reliability of a hand-held dynamometer device to measure the ankle dorsiflexor muscle strength. *J Rehabil Assist Technol Eng*. 2018;5:2055668318802558. doi:10.1177/2055668318802558
20. Kobayashi T, Tanaka M, Shida M. Intrinsic risk factors of lateral ankle sprain: a systematic review and meta-analysis. *Sports Health*. 2016;8(2):190-193. doi:10.1177/1941738115623775
21. Lauersen JB, Andersen TE, Andersen LB. Strength training as superior, dose-dependent and safe prevention of acute and overuse sports injuries: a systematic review, qualitative analysis and meta-analysis. *Br J Sports Med*. 2018;52(24):1557-1563. doi:10.1136/bjsports-2018-099078
22. Lucas NP, Macaskill P, Irwig L, Bogduk N. The development of a quality appraisal tool for studies of diagnostic reliability (QAREL). *J Clin Epidemiol*. 2010;63(8):854-861. doi:10.1016/j.jclinepi.2009.10.002
23. Maestroni L, Read P, Bishop C, et al. The benefits of strength training on musculoskeletal system health: practical applications for interdisciplinary care. *Sports Med*. 2020;50(8):1431-1450. doi:10.1007/s40279-020-01309-5
24. Man HS, Leung AKL, Cheung JTM, Sterzing T. Reliability of metatarsophalangeal and ankle joint torque measurements by an innovative device. *Gait Posture*. 2016;48:189-193. doi:10.1016/j.gaitpost.2016.05.016
25. Marinho HVR, Amaral GM, Moreira BS, et al. Myofascial force transmission in the lower limb: an in vivo experiment. *J Biomech*. 2017;63:55-60. doi:10.1016/j.jbiomech.2017.07.026
26. Martins J, Da Silva JR, Da Silva MRB, Bevilaqua-Grossi D. Reliability and validity of the belt-stabilized handheld dynamometer in hip-and knee-strength tests. *J Athl Train*. 2017;52(9):809-819. doi:10.4085/1062-6050-52.6.04
27. Mendez-Rebolledo G, Guzmán-Venegas R, Valencia O, Watanabe K. Contribution of the peroneus longus neuromuscular compartments to eversion and plantarflexion of the ankle. *PLoS One*. 2021;16(4):e0250159. doi:10.1371/journal.pone.0250159
28. Mentiplay BF, Perraton LG, Bower KJ, et al. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study. *PLoS One*. 2015;10(10):e0140822. doi:10.1371/journal.pone.0140822
29. Morris-Chatta R, Buchner DM, de Lateur BJ, Cress ME, Wagner EH. Isokinetic testing of ankle strength in older adults: assessment of inter-rater reliability and stability of strength over six months. *Arch Phys Med Rehabil*. 1994;75(11):1213–1216.

30. Morrison KE, Kaminski TW. The reproducibility of an isokinetic testing technique at the ankle joint. *Isokinet Exerc Sci*. 2007;15(4):245-251.
31. Nagy P, Brogden C, Greig M. Isokinetic ankle eversion and inversion strength profiling of female ballet dancers. *J Sports Sci*. 2021;39(1):1-9. doi:10.1080/02640414.2020.1803185
32. Nozu S, Johnson KA, Tanaka T, Inoue M, Nishio H, Takazawa Y. The accuracy of ankle eccentric torque control explains dynamic postural control during the Y-Balance Test. *Int J Sports Phys Ther*. 2023;18(5):1113-1122. doi:10.26603/001C.87760
33. O'Neill S, Weeks A, Nørgaard JE, Jorgensen MG. Validity and intrarater reliability of a novel device for assessing plantar flexor strength. *PLoS One*. 2023;18(3):e0282395. doi:10.1371/journal.pone.0282395
34. Park YH, Park SH, Kim SH, Choi GW, Kim HJ. Relationship between isokinetic muscle strength and functional tests in chronic ankle instability. *J Foot Ankle Surg*. 2019;58(6):1187-1191. doi:10.1053/j.jfas.2019.04.005
35. Porter MM, Vandervoort AA, Kramer JF. A method of measuring standing isokinetic plantar and dorsiflexion peak torques. *Med Sci Sports Exerc*. 1996;28(4):516-522.
36. Sarcon AK, Heyrani N, Giza E, Kreulen C. Lateral ankle sprain and chronic ankle instability. *Foot Ankle Orthop*. 2019;4(2):2473011419846938.doi:10.1177/2473011419846938
37. Schaeffer M, Daniels Abbruzzese L, Tawa Z, et al. Inter- and intra-rater reliability of handheld dynamometry for lower extremity strength testing in pre-professional dancers. *J Dance Med Sci*. 2021;25(2):86-95. doi:10.12678/1089-313X.061521c
38. Shamseer L, Moher D, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ*. 2015;350:g7647. doi:10.1136/bmj.g7647
39. Spink M, Fotoohabadi MR, Menz HB. Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. *Gerontology*. 2009;56:525-532.
40. Tavakkoli Oskouei S, Malliaras P, D Hill K, Garofolini A, Clark R, Perraton L. Assessment of ankle plantar flexor neuromuscular properties: a reliability study. *J Electromyogr Kinesiol*. 2021;61:102603. doi:10.1016/j.jelekin.2021.102603
41. Tuominen J, Leppänen M, Jarske H, Pasanen K, Vasankari T, Parkkari J. Test-retest reliability of isokinetic ankle, knee and hip strength in physically active adults using Biodex System 4 Pro. *Methods Protoc*. 2023;6(2):26. doi:10.3390/mps6020026
42. van Cingel R, van Melick N, van Doren L, Aufdemkampe G. Intra-examiner reproducibility of ankle inversion-eversion isokinetic strength in healthy subjects. *Isokinet Exerc Sci*. 2009;17(3):181-188. doi:10.3233/IES-2009-0351
43. Webber SC, Porter MM. Reliability of ankle isometric, isotonic, and isokinetic strength and power testing in older women. *Phys Ther*. 2010;90(8):1165-1175.
44. Witchalls J, Blanch P, Waddington G, Adams R. Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. *Br J Sports Med*. 2012;46(7):515-523. doi:10.1136/bjsports-2011-090137
45. Yildiz Y, Şekir U, Hazneci B, Örs F, Saka T, Aydin T. Reliability of a functional test battery evaluating functionality, proprioception and strength of the ankle joint. *Turk J Med Sci*. 2009;39(1):115-123. doi:10.3906/sag-0709-4