Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

ANKLE STRENGTH ASSESSED BY ONE REPETITION MAXIMUM A NEW APPROACH TO DETECT WEAKNESSES IN CHRONIC ANKLE LATERAL INSTABILITY

Aude Aguilaniu [a,b], Cédric Schwartz [a,b], Guillaume Abran [a,b], Laura Baudoux [c], Prof Jean-Louis Croisier [a,b,c]

[a] *LAM – Motion Lab, University of Liège, Liège, Belgium*
[b] *Department of Physical Activity and Rehabilitation Sciences, University of Liège, Belgium*
[c] *Central University Hospital of Liège, Belgium*

ABSTRACT

Background : Ankle muscle strength should be assessed after a lateral ankle sprain (LAS) because a strength deficit can lead to chronic ankle instability (CAI). No field method is available to obtain quantitative ankle dynamic strength values. This study aimed to assess the reliability of the one-repetition maximal (1-RM) method and to compare ankle muscle strength between healthy volunteers and those with CAI using 1-RM strength assessment approach.

Methods : We recruited 31 healthy volunteers and 32 with CAI. Dorsiflexor, evertor, and invertor 1-RM were performed twice at a one-week interval. The intraclass correlation coefficient (ICC) and minimal detectable change (MDC) were calculated. Strength values were compared between healthy volunteers and CAI.

Results : The 1-RM method is reliable for assessing ankle dorsiflexor, evertor, and invertor strength, with an ICC ranging from 0.76 to 0.88, and MDC ranging from 19 to 31%. Volunteers with CAI obtained evertor (3.0 vs. 3.5 N/kg), invertor (2.9 vs. 3.7 N/kg), and dorsiflexor (5.9 vs. 6.5 N/kg) strength values that were lower than healthy volunteers ($p < 0.05$).

Conclusion : The 1-RM test can be used in practice to assess evertor, invertor, and dorsiflexor strength during the rehabilitation of LAS. This field method could help practitioners to detect a strength deficit and individualize a strengthening programme if necessary.

KEYWORDS: Ankle injury ; Muscle strength ; Measurement errors ; Reliability ; Sports medicine

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

1. Introduction

Lateral ankle sprain (LAS) is one of the most common ankle injuries in sports [10], [33], [38]. Among patients who sustain a LAS, up to 40% develop long-term disabilities, defined as chronic ankle instability (CAI) [7]. This chronicity could negatively impact physical activity levels and quality of life, and contribute to the high rate of LAS re-injury [15]. The ankle muscles (evertor, invertor, dorsiflexor, and plantarflexor) contribute to active stabilization of the ankle [27]. Consequently, global ankle muscle strength is of great importance in rehabilitation after LAS [5], [27], [32]. In daily practice, the assessment of ankle muscle strength after LAS could also help clinicians to prioritize the parameters of rehabilitation they should focus on within an evidence-based practice approach [1], [4], [9].

Dynamic strength assessment is required to detect weaknesses, then to individualize a strengthening programme if necessary, and finally to quantify improvement [1]. First, dynamic ankle weaknesses are detected in individuals with CAI [22]. In order to prevent weaknesses in CAI individuals, after LAS an assessment of dynamic ankle strength using an isokinetic dynamometer is recommended [4]. Moreover, exercise intervention programmes frequently include dynamic ankle strength repetitions [18]. Currently, the hand-held dynamometer (HHD) is the only field device used to quantify ankle muscle strength [4]. However, the HHD only measures isometric strength and does not measure dynamic strength as an isokinetic dynamometer can. Thus, to our knowledge, no field alternative is available to quantify dynamic ankle muscle (e.g., evertor, invertor, and dorsiflexor) strength in daily practice.

An isokinetic dynamometer and the 1-RM method are the main approaches used to assess dynamic strength. However, no studies have reported reliability and validity values for ankle strength assessment with the 1-RM method, except for plantarflexor strength [34]. In contrast to the isokinetic dynamometer, which is well-adapted to laboratory conditions, the one repetition maximal (1-RM) method is better adapted to non-laboratory conditions [14], [26], [35]. One-RM measures the maximum load that an individual can move through the full range of motion while maintaining the correct lifting technique [31]. First, the reliability of the 1-RM method has been demonstrated to assess leg strength with an intraclass correlation coefficient (ICC) ranging from 0.64 to 0.99 [14]. Second, the 1-RM method is valid because it is strongly correlated with the dynamometer method used to assess knee extension strength [37].

Consequently, the purpose of our study was to establish a newly adapted 1-RM method to assess ankle muscle strength (i.e., evertor, invertor, and dorsiflexor). First, we explored the reliability of the adapted 1-RM for the ankle. We then compared the results between the volunteers with CAI and healthy volunteers to determine the sensitivity of the method.

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

2. Methods

The physical characteristics of the 32 volunteers with CAI and the 31 healthy volunteers are presented in Table 1. There were no significant differences between the groups in terms of age, sex, height, weight, and body mass index (BMI) ($p > 0.05$).

Table 1. Physical characteristics of the volunteers with chronic ankle instability (CAI) and healthy volunteers.

	Healthy (n = 31)	**CAI (n = 32)**	**Significance**
Age (years)	23 ± 2.2	24 ± 2.2	t = −1.288, p = 0.203
Sex (F/M)	18/13	18/14	χ2 = 0.021, p = 0.884
Height (cm)	173 ± 8.91	175 ± 11.0	t = −0.462, p = 0.646
Weigth (kg)	67.5 ± 10.9	71.7 ± 13.6	t = −1.331, p = 0.188
Body mass index (kg/m²)	22.3 (21.4-23.1)	22.3 (21.3-25.2)	W = 433, p = 0.390

All parametric physical characteristics are expressed as mean ± standard deviation. All nonparametric physical characteristics are expressed as median (IQR 25%−75%). t = result of Student t-test. χ2 = result of Chi-square statistical test. W = result of Wilcoxon bivariate test

In total, 32 affected ankles from volunteers with CAI were compared with 31 unaffected ankles from healthy volunteers between January 2021 and April 2022. Voluntary participants were recruited via social media and posters on the university campus. The study protocol and data collection were approved by the University Hospital Institutional Review Board. Volunteers were informed of the risks and benefits of the study prior to any data collection and then signed an institutionally approved informed consent document.

All volunteers (CAI and healthy) were young adults older than 18 years old and below 30 years old who reported undertaking at least 2h30 of physical activity per week. All volunteers also had no history of lower-extremity surgery or pathology that would influence neuromuscular control, and no injuries in the three months prior to the study. The inclusion criteria of volunteers with CAI defined by Gribble et al. [16] were as follows: [1] volunteers with at least one ankle injury that occurred at least 12 months prior to the study, [2] volunteers with two or more "giving way" episodes in the six months prior to the study or patients with recurrent sprains, [3] volunteers with a value ≤ 23 points based on the Cumberland Ankle Instability Tool (CAIT) [12], [19] or volunteers with a value ≥5 points based on the Ankle Instability Instrument (AII) [6], [28], [4] volunteers with a percentage score on the foot and ankle ability measure in sports activity (FAAM-sport) <80% [3], [29]. The healthy volunteers had no history of lower extremity injury, including ankle sprains, within the previous five years.

Prior strength assessments and anthropometric parameters of the volunteers were collected by the assessors. Age, sex, height, weight, and body mass index (BMI) were recorded.

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

2.1. 1-RM ASSESSMENT PROTOCOL

2.1.1. INSTRUMENTS

To realize the 1-RM method, a load is applied from a classical vertical cable-pull machine to the foot through a rigid strap that is fixed to the shoes of the volunteers. This rigid strap has three metal rings: one under the second metatarsal head for dorsiflexor (Fig. 1), one beside the first metatarsal head for evertor (Fig. 2), and one beside the fifth metatarsal head for invertor (Fig. 3). This measure allows the foot to have freedom of movement because the subtalar joint axes and other foot axes vary within the population and between dynamic movements [23].

Fig. 1. A. Plantarflexion foot position, B. dorsiflexion foot position, C. dorsiflexor assessment position.

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

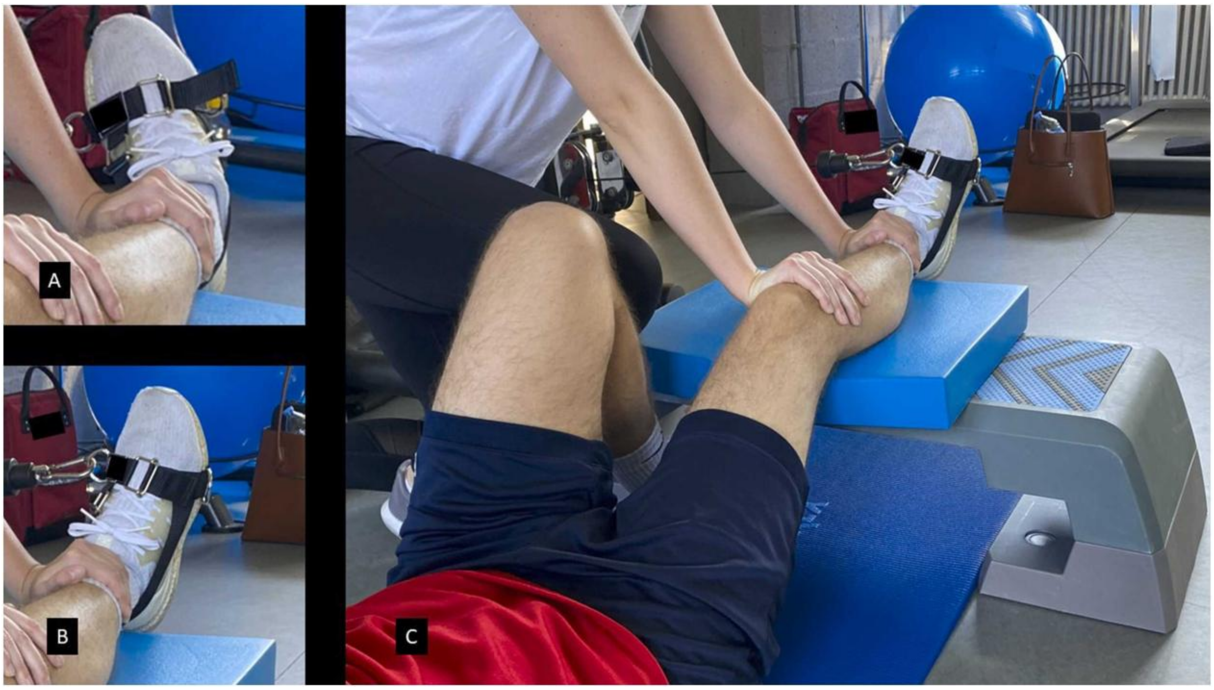

Fig. 2. A. Inversion foot position, B. eversion foot position, C. evertor assessment position.

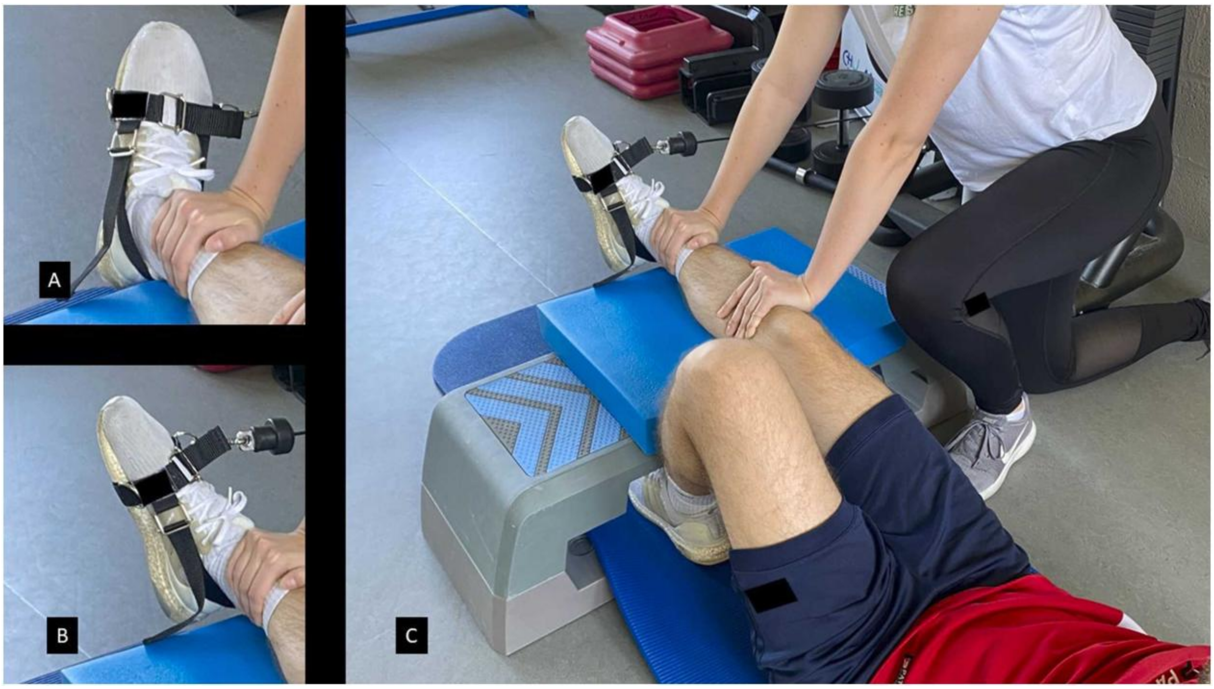

Fig. 3. A. Eversion foot position, B. inversion foot position, C. invertor assessment position.

2.1.2. WARM-UP AND FAMILIARIZATION

A warm-up was first performed with the volunteers. They started with active ankle mobilization in all directions; then, they practised jumping rope for three repetitions of 20 s each. After this general warm-up, the volunteers began a familiarization of two sets of ten repetitions performed with a light load. The volunteers continued with two sets of four to six repetitions at a medium load. A final set of approximately three repetitions of high load was performed. During this specific familiarization,

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

feedback was provided by the assessor to help the participants to perform the correct movements (Fig. 1, Fig. 2, Fig. 3). A rest period of one and a half minutes was imposed between each set for the familiarization. A numerical scale of difficulty ranging from zero to ten was used with the volunteers to better estimate the load.

2.2. 1-RM ASSESSMENT

For the 1-RM assessment, the volunteers performed each movement with verbal encouragement from an assessor. Weight was increased or decreased by 5–20% after each attempt [24]. A maximum of five attempts were performed with three minutes of rest. The same protocol was performed for the dorsiflexor, evertor, and invertor with five minutes' rest between movements. The instruction to perform dorsiflexion was "The back of the foot should come closer to you" (Fig. 1), to perform eversion was "The sole of the foot should face outward" (Fig. 2), and to perform the inversion was "The sole of the foot should face inward" (Fig. 3). The order of the movements was randomized.

The maximal load was moved over the entire range of movement by the volunteers and was expressed in Newtons for each movement. The values were divided by the body mass of the volunteers in order to obtain normalized values (N/kg).

2.3. STATISTICAL ANALYSIS

Reliability analysis was performed using RStudio software (RStudio Team 2021) with the psych 1.0.12 package. Test-retest reliability was determined by the intraclass correlation coefficient (ICC) [20] and the model of the ICC was "$ICC_{2,1}$" [25]. ICC values less than 0.5 indicate poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.9 indicate excellent reliability [25]. To determine the measurement error between-trial variability in scores, the standard error of measurement (SEM_{95}) [2] and the minimal detectable change (MDC_{95}) were calculated. MDC_{95} values ≤ 20% indicate good absolute reliability [8], values between 20% and 30% indicate acceptable absolute reliability, values between 30% and 40% indicate poor absolute reliability, and values greater than 40% indicate unacceptable absolute reliability [17].

Normality of data distribution was assessed using the Shapiro-Wilk test. The distribution was normal for evertor and dorsiflexor but not for invertor. Descriptive statistics were reported, including the mean (± SD) or median (IQR 25–75%). Analysis, including Student's t-test, Chi-square χ^2 test, and Wilcoxon test, as appropriate, were used to evaluate differences between independent study groups.

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

3. Results

3.1. RELIABILITY

Table 2 presents the reliability and measurement errors for 1-RM testing. The $ICC_{2,1}$ reliability of the 1-RM testing was good (range 0.76–0.88). The measurement error was good for dorsiflexor strength (MDC_{95} 19%). The measurement error was poor for evertor and invertor strength (MDC_{95} 31% for both).

Table 2. Test-retest reliability and measurement error of ankle strength measurement, using one-repetition maximal (1-RM), in 63 volunteers (31 healthy and 32 with chronic ankle instability (CAI)).

Muscles	$ICC_{2,1}$ (CI 95%)	SEM (N/kg)	MDC_{95} (N/kg)
Dorsiflexors	0.88 (0.82-0.92)	0.43 (7%)	1.19 (19%)
Evertors	0.76 (0.66-0.84)	0.37 (11%)	1.02 (31%)
Invertors	0.83 (0.73-0.89)	0.37 (10%)	1.09 (31%)

ICC: intraclass correlation coefficient. CI: confidence interval. SEM: standard error of measurement. MDC: minimal detectable change

3.2. MUSCLE STRENGTH IN VOLUNTEERS WITH AND WITHOUT CAI

The volunteers with CAI produced evertor and invertor strength values that were significantly lower than healthy volunteers ($p < 0.01$ and $p < 0.03$, respectively). The volunteers with CAI also produced dorsiflexor strength values that were lower than those of the healthy volunteers ($p < 0.05$). However, the volunteers with CAI had an evertor/invertor strength ratio that was similar to that of the healthy volunteers ($p > 0.05$). The comparison of strength values between volunteers with and without CAI is presented in Table 3.

Table 3. Comparison of ankle muscle strength values, using one-repetition maximal (1-RM), in 32 volunteers with chronic ankle instability (CAI) and 31 healthy volunteers.

	Healthy (n = 31)	CAI (n = 32)	significance
Dorsiflexor (N/kg)	6.5 ± 1.3	5.9 ± 1.0	t = 2.05, p = 0.045*
Evertor (N/kg)	3.5 ± 0.7	3.0 ± 0.7	t = 2.99, p = 0.004**
Invertor (N/kg)	3.7 (3.1-4.4)	2.9 (2.6-3.8)	W = 659, p = 0.026*
Ratio evertors/invertors	1.1 ± 0.2	1.1 ± 0.2	t = −0.34, p = 0.736

All parametric strength values are expressed as mean ± standard deviation. All nonparametric strength values are expressed as median (IQR 25%–75%). t = result of Student t-test. W = result of Wilcoxon bivariate test.

*: $p < 0.05$; **: $p < 0.01$

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

4. Discussion

Our study is the first to accurately describe an adaptation of the 1-RM method to assess dynamic dorsiflexor, evertor, and invertor strength. A new field method to assess the strength of the ankle-stabilizing muscles is of great importance in the care of patients with a history of LAS. The 1-RM method could help to quantify a weakness, individualize a strengthening programme, and quantify improvement during rehabilitation [1]. First, we determined the reliability of the 1-RM method to quantify the strength of three ankle muscle groups (evertor, invertor, and dorsiflexor). We then compared ankle muscle strength values between healthy volunteers and volunteers with CAI to assess the ability of the method to detect ankle strength deficits (sensitivity analysis).

The reliability (relative reliability) of dynamic evertor, invertor, and dorsiflexor strength assessed by the 1-RM method was good (ICC range 0.76–0.88), and the measurement error (absolute reliability) ranged from poor to good (MDC range 19–31%). These results are not as good as the reliability and measurement error found for isometric ankle strength when assessed using an isokinetic dynamometer (ICC range 0.87–0.96; MDC range 11–22%) [36]. However, our results are similar to those of a previous study assessing isometric ankle strength with a hand-held dynamometer (HHD) (ICC range 0.74–0.88; MDC range 21–34%) [11]. Although the 1-RM method assesses dynamic contraction, which is more challenging to measure than isometric contraction, the measurement errors (absolute reliability) of the 1-RM method are similar to those of the HHD method. Consequently, the HHD and the 1-RM method are fair field alternatives for assessing isometric and dynamic ankle muscle strength, respectively.

The reliability and measurement errors of dorsiflexor 1-RM strength evaluations (ICC 0.88; SEM 7%) were better than those of the evertor and invertor evaluations (ICC range 0.76–0.83; SEM range 10–11%). Similarly, Gonosova et al. [13] found better reliability and measurement errors for the isokinetic evaluation of dorsiflexor strength (ICC range 0.95–0.97, SEM 3.5–4%) than for evertor and invertor strength (ICC range, 0.64–0.94; SEM range, 7–11%) at 30°/sec. During familiarization in our study, volunteers frequently reported that eversion or inversion was less commonly performed than dorsiflexion or plantarflexion. Similarly, other studies considered that inversion and eversion movement patterns were more challenging to perform than dorsiflexion or plantarflexion [13], [21]. Thus, the larger variability of reliability and measurement error for dynamic evertor and invertor strength assessment compared to dorsiflexor strength could be explained by a feeling of discomfort when medio-lateral movement of the ankle was performed.

Dynamic evertor, invertor, and dorsiflexor strength values assessed by the 1-RM method were significantly lower in volunteers with CAI than in healthy volunteers. Our results are partially similar to those of a recent systematic review and meta-analysis that found evertor and invertor weaknesses but no dorsiflexor weaknesses in populations with CAI [22]. However, the small number of studies on dorsiflexor strength included in the meta-analysis could explain the lack of a link between CAI and dorsiflexor weaknesses [22]. Moreover, it has been suggested that lower dorsiflexor strength could be a risk factor for LAS [39], and one article has reported dorsiflexor weaknesses in volunteers with CAI [30] as was found in our study. The variability of the methods used to assess

Published in : Foot and Ankle Surgery (2024), vol. 30, no.4, pp. 349-353
DOI: 10.1016/j.fas.2024.02.005
Status : Postprint (Author's version)

ankle strength could probably explain conflicting results concerning dorsiflexor strength. Nevertheless, the 1-RM method used in our study is sensitive enough to detect evertor, invertor, and dorsiflexor weaknesses in volunteers with CAI.

The present study had some limitations. First, the speed of movement was not controlled. However, speed is rarely controlled to determine 1-RM, and a self-selected speed seems to be more practical, ecologically valid, and comfortable for participants [26]. Second, while this study focused on ankle muscle strength, in daily practice it is necessary not only to assess ankle muscle strength but also other potential deficits because CAI is a complex condition in which patho-mechanical, sensory-perceptual, and motor-behavioural impairments could be involved [20]. Ankle muscle strength is part of a necessary holistic approach to rehabilitation [4]. Finally, further research is required to define normative strength values, with prospective study on larger population with different age, gender, BMI, and sports characteristics.

5. Conclusion

The 1-RM method demonstrated acceptable reliability for assessing dynamic evertor, invertor, and dorsiflexor strength in young and active participants. The measurement error of the 1-RM method is currently similar to that of the HHD method, which is recommended for daily practice. However, the HHD only measures isometric strength whereas the 1-RM method measures dynamic strength. Moreover, the 1-RM method could detect ankle weaknesses in a population with CAI. The 1-RM method is a new field alternative to the isokinetic dynamometer in order to measure dynamic ankle muscle strength. The 1-RM method will help clinicians to quantify an ankle strength deficit and to individualize a strengthening plan if necessary.

Ethics approval

Ethical approval for this study was obtained from University Hospital Ethics Committee of Liege, Belgium (Ref: 2021/227).

Funding

None.

Declaration of Competing Interest

None.

Acknowledgments

The authors would like to thank C. Letondal, L. Jansen, J. Donval and A. Dezavelle for their contribution to the data collection. They also thank A. Vaillant for her writing assistance. The authors also wish to thank the Wallonia Brussels Federation and Sports Performance Assistance Centre (CAPS) for their support.

References

[1] American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009;41:687–708.

[2] Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med 1998;26:217–38.

[3] Borloz S, Crevoisier X, Deriaz O, et al. Evidence for validity and reliability of a french version of the FAAM. BMC Musculoskelet Disord 2011;12:40.

[4] Delahunt E, Bleakley CM, Bossard DS, et al. Clinical assessment of acute lateral ankle sprain injuries (ROAST): 2019 consensus statement and recommendations of the International Ankle Consortium. Br J Sports Med 2018;52:1304–10.

[5] DiGiovanni CW, Brodsky A. Current concepts: lateral ankle instability. Foot Ankle Int 2006;27:854–66.

[6] Docherty CL, Gansneder BM, Arnold BL. Development and reliability of the ankle instability instrument. J Athl Train 2006;41:154–8.

[7] Doherty C, Bleakley C, Hertel J, et al. Recovery from a first-time lateral ankle sprain and the predictors of chronic ankle instability: a prospective cohort analysis. Am J Sports Med 2016;44:995–1003.

[8] Dvir Z. How much is necessary to indicate a real improvement in muscle function? A review of modern methods of reproducibility analysis. Isokinet Exerc Sci 2003;11:49–52.

[9] Flaherty H. Bridging the gap between research and practice: a discussion about how to integrate evidence-based interventions in clinical practice through education. J Pr Teach 2020;17:25–41.

[10] Fong DT-P, Hong Y, Chan L-K, Yung PS-H, Chan K-M. A systematic review on ankle injury and ankle sprain in sports. Sports Med 2007;37:73–94.

[11] Fraser JJ, Koldenhoven RM, Saliba SA, Hertel J. Reliability of ankle-foot morphology, mobility, strength, and motor perfomance measures. Int J Sports Phys Ther 2017;12:1134–49.

[12] Geerinck A, Beaudart C, Salvan Q, et al. French translation and validation of the cumberland ankle instability tool, an instrument for measuring functional ankle instability. Foot Ankle Surg 2020;26:391–7.

[13] Gonosova Z, Linduska P, Bizovska L, Svoboda Z. Reliability of ankle–foot complex isokinetic strength assessment using the Isomed 2000 dynamometer. Medicina 2018;54:43.

[14] Grgic J, Lazinica B, Schoenfeld BJ, Pedisic Z. Test–retest reliability of the one- repetition maximum (1RM) strength assessment: a systematic review. Sports Med - Open 2020;6:31.

[15] Gribble PA, Bleakley CM, Caulfield BM, et al. Evidence review for the 2016 International Ankle Consortium consensus statement on the prevalence, impact and long-term consequences of lateral ankle sprains. Br J Sports Med 2016;50:1496–505.

[16] Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. Br J Sports Med 2014;48:1014–8.

[17] Hagen M, Lahner M, Winhuysen M, Maiwald C. Reliability of isometric subtalar pronator and supinator strength testing. J Foot Ankle Res 2015;8:15.

[18] Hall EA, Docherty CL, Simon J, Kingma JJ, Klossner JC. Strength-training protocols to improve deficits in participants with chronic ankle instability: a randomized controlled trial. J Athl Train 2015;50:36–44.

[19] Hiller CE, Refshauge KM, Bundy AC, Herbert RD, Kilbreath SL. The cumberland ankle instability tool: a report of validity and reliability testing. Arch Phys Med Rehabil 2006;87:1235–41.

[20] Hopkins WG. Measures of reliability in sports medicine and science. Sports Med 2000;30:1–15.

[21] Karnofel H, Wilkinson K, Lentell G. Reliability of isokinetic muscle testing at the ankle. J Orthop Sports Phys Ther 1989;11:150–4.

[22] Khalaj N, Vicenzino B, Heales LJ, Smith MD. Is chronic ankle instability associated with impaired muscle strength? Ankle, knee and hip muscle strength in individuals with chronic ankle instability: a systematic review with meta-analysis. Br J Sports Med 2020;54:839–47.

[23] Kirby KA. Subtalar joint axis location and rotational equilibrium theory of foot function. J Am Podiatr Med Assoc 2001;91:465–87.

[24] Kirk H, Geertsen SS, Lorentzen J, et al. Explosive resistance training increases rate of force development in ankle dorsiflexors and gait function in adults with cerebral palsy. J Strength Cond Res 2016;30:2749–60.

[25] Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15:155–63.

[26] Levinger I, Goodman C, Hare DL, et al. The reliability of the 1RM strength test for untrained middle-aged individuals. J Sci Med Sport 2009;12:310–6.

[27] Liu K, Delaney AN, Kaminski TW. A review of the role of lower-leg strength measurements in ankle sprain and chronic ankle instability populations. Sports Biomech 2022;21:562–75.

[28] Locquet M, Benhotman B, Bornheim S, et al. The "Ankle Instability Instrument": cross-cultural adaptation and validation in French. Foot Ankle Surg 2021;27: 70–76.

[29] Martin RL, Irrgang JJ, Burdett RG, Conti SF, Swearingen JMV. Evidence of validity for the foot and ankle ability measure (FAAM). Foot Ankle Int 2005;26:968–83.

[30] Negahban H, Moradi-Bousari A, Naghibi S, et al. The eccentric torque production capacity of the ankle, knee, and hip muscle groups in patients with unilateral chronic ankle instability. Asian J Sports Med 2013;4:144–52.

[31] Niewiadomski W, Laskowska D, Gąsiorowska A, et al. Determination and prediction of one repetition maximum (1RM): safety considerations. J Hum Kinet 2008;19:109–20.

[32] Pearce CJ, Tourné Y, Zellers J, et al. Rehabilitation after anatomical ankle ligament repair or reconstruction. Knee Surg Sports Trauma Arthrosc 2016;24: 1130–1139.

[33] Roos KG, Kerr ZY, Mauntel TC, et al. The epidemiology of lateral ligament complex ankle sprains in national collegiate athletic association sports. Am J Sports Med 2017;45:201–9.

[34] Salem GJ, Wang M-Y, Sigward S. Measuring lower extremity strength in older adults: the stability of isokinetic versus 1RM measures. J Aging Phys Act 2002;10:489–503.

[35] Seo D, Kim E, Fahs CA, et al. Reliability of the one-repetition maximum test based on muscle group and gender. J Sports Sci Med 2012;11:221–5.

[36] Tankevicius G, Lankaite D, Krisciunas A. Test-retest reliability of biodex system 4 pro for isometric ankle-eversion and -inversion measurement. J Sport Rehabil 2013;22:212–5.

[37] Verdijk LB, van Loon L, Meijer K, Savelberg HHCM. One-repetition maximum strength test represents a valid means to assess leg strength **in vivo** in humans. J Sports Sci 2009;27:59–68.

[38] Waterman BR, Owens BD, Davey S, Zacchilli MA, Belmont PJ. The epidemiology of ankle sprains in the United States. J Bone Jt Surg 2010;92:2279–84.

[39] Willems TM, Witvrouw E, Delbaere K, et al. Intrinsic risk factors for inversion ankle sprains in male subjects: a prospective study. Am J Sports Med 2005;33:415–23.