Reference Values for Isometric Ankle Strength: A Scoping Literature Review and Comparison with Novel Data from 683 Athletes

Article *in* Critical Reviews in Physical and Rehabilitation Medicine · January 2023

DOI: 10.1615/CritRevPhysRehabilMed.2022045289

4 authors:

Luka Kejzar
University of Primorska

Žiga Kozinc
University of Primorska

Darjan Smajla
University of Primorska

Nejc Sarabon
University of Primorska

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Authors: Luka Kejžar[1], Žiga Kozinc[1,2], Darjan Smajla[1,3], Nejc Šarabon[1,3,4]

1 University of Primorska, Faculty of Health Sciences, Polje 42, SI-6310 Izola, Slovenia

2 University of Primorska, Andrej Marušič Institute, Muzejski trg 2, SI-6000 Koper, Slovenia

3 InnoRenew CoE, Human Health Department, Livade 6, SI-6310 Izola, Slovenia

4 S2P, Science to Practice, Ltd., Laboratory for Motor Control and Motor Behavior, Tehnološki park 19, SI-1000 Ljubljana, Slovenia

Corresponding author:

Prof. Dr. Nejc Šarabon

University of Primorska

Faculty of Health Sciences

Polje 42, SI-6310 Izola,

Slovenia

E-mail: nejc.sarabon@fvz.upr.si

ABSTRACT

The aim of the study was to obtain body-mass normalised reference values of isometric ankle strength through a thorough literature review and consequent meta-analysis of the acquired data. A total of 133 studies with a total of 3755 participants were included in the final analysis. The results were sorted by the angle in the knee joint (extended, partially flexed, flexed) while the ankle joint was always in a neutral position. For easier comparison, the results were normalised to body mass (Nm/kg). The adult population (18-65 years) reached higher values than the older adult (65+ years) population. In the adult and athlete populations, the plantarflexion strength was highest when the knee was extended. Conversely, the strength values of plantarflexion were highest when the knee was flexed in the elderly population. Dorsiflexion strength was the highest when the knee was partially flexed in all populations. Our results appear to be similar to the results of previous studies conducting similar measurements on smaller sample sizes. We only managed to obtain a limited range of values for athletes. Consequently, we included an additional analysis of our existing database for ankle strength (683 athletes from 10 different sports). The athletes reached higher values than the general adult population and there were noticeable differences in strength between individual sports. With the obtained normalized reference values, kinesiologists, trainers, physiotherapists and other experts in the field will be able to better interpret the values they will obtain from their own measurements.

Key words: ankle strength, lower limb, muscle capacity, normative, reference values.

1 INTRODUCTION

Assessment of maximal muscular strength is commonly performed in sport science[1] as well as physical therapy and rehabilitation practice.[2] While the knee joint appears to be assessed most often,[3–5] the strength of the ankle joint plays a pivotal role in balance[6,7] and gait speed,[8] and is protective against ankle sprains.[9] Measurements should be performed using standardized procedures that provide reliable and useful data that can be compared and easily put into practice.[10] Such data allow professionals to monitor changes in strength during intervention or the course of certain pathologies and other conditions that affect strength.[11] In clinical practice, there is a need for reference values specific to different age and sex groups, sports, or levels of physical activity.

Reference values pertaining to muscle strength, including the ankle joint, have been focusing on muscle imbalances instead of the raw values. Indeed, asymmetries in muscle strength of inverters and evertors have been linked with functional instability of the ankle and the occurrence of ankle sprain.[12,13] Santos and Liu[14] also showed a significant difference in the maximum strength of evertors between the injured (11.6 ± 3.9 Nm) and uninjured side (13.7 ± 4.6 Nm) in individuals with functional ankle instability. Likewise, some studies report a lower ankle extension (plantar flexion) strength of in the injured joint when compared to a control group that was not injured.[15,16] Negahban et al.[17] showed a deficit in ankle plantarflexion in both injured and intact ankle (0.51 ± 0.08 Nm/kg and 0.53 ± 0.15 Nm/kg) in patients with ankle sprain when compared to results of healthy individuals (0.59 ± 0.1 Nm/kg and 0.61 ± 0.10 Nm/kg). While the knowledge on the ankle strength deficits and links to injuries is important, raw reference values are urgently needed for a comprehensive interpretation.

In addition, muscle mass and strength decline with age. Simoneauet et al.[18] showed a 38% difference in the strength of ankle plantarflexion between young and older adults. This difference increased to 44% when the ankle was moved to a 20° of plantarflexion. Ankle strength is a good predictor of functional performance in older adults[8] and is possibly related to balance and risk of falling. For instance, Skelton et al.[19] pointed out that increased asymmetry in ankle muscle strength is a major predictor of falls in older women. Again, while the knowledge of the differences between young and older adults (or fallers vs. non-fallers within the older adult groups) are valuable to know, absolute reference values would enhance the interpretation of the results and by extension, the clinical decision-making.

An important aspect when considering the reference values for strength is the normalization of the results to body mass. The influence of body mass should not be neglected when comparing different groups or individuals. With increasing body size and thus body mass, greater muscle capacity is expected in the absolute sense.[20] The proportion of body mass used for normalization depends on the type of measurement. Jaric et al.[21] suggested normalization of muscle torques (obtained with an isokinetic device) to total body mass and measures of muscle forces and rate of force development to 2/3 of body weight. As an example, an extensive study obtained data on the isometric strength of five muscle groups in a sample of over 1,000 participants,[10] but without normalization, these data are less relevant than they could be. The need to normalize research results in the field of sports science and medicine is obvious, as this is the only way to enable comparability of data between different research and populations.[20,21]

Recently, we performed a large systematic literature review to provide the reference values for knee exntension and flexion strength, pooled from more than 400 existing studies [5]. However, a similar review on ankle strength is currently lacking. Therefore, the aim of this paper was to review all available studies that reported isometric ankle strength as assessed during maximal voluntary contraction. In this paper, we focus specifically on reference values for isometric plantarflexion and dorsiflexion ankle strength. To facilitate the comparison of the studies and study subgroups, we aimed to obtain body-mass normalized torque values. For this purpose, we calculated body-mass normalized strength values scores by using appropriate estimates. Since our review resulted in only a limited amount of useful pooled data for athletes, we also report the mean ankle strength data for 683 athletes from 10 different sports, based on our recently acquired database.

2 METHODS

2.1 Search strategy

The search was performed in two scientific databases (PubMed and PEDro). Peer-reviewed English language papers, published from the inception of the field to the April 2020 were considered. The PubMed database was searched with the following key word combination*: (ankle OR lower limb OR leg) AND (dynamometer OR dynamometry OR hand-held dynamometer OR hand-held OR isometric) AND (maximal voluntary contraction OR maximal strength OR maximal force OR maximal torque OR peak torque OR peak force OR Fmax).* In the PEDro database, we used a single key word ''ankle strength''. We also scrutinized the reference lists of several relevant systematic reviews that which we identified during the search process.

2.2 Inclusion criteria

The a priori determined inclusion criteria are outlined below in the form of PICOS search tool, as follows:[22]

- **Population (P):** The only inclusion criterion was that the participants were healthy and aged over 18 years. We included studies that involved participants of both sexes, independent of age. Participants from the general population, as well as professional and recreational athletes were considered. If a study investigated patient populations, we considered the data from the healthy control group when available. Regarding age, adult (18-65 years) and older adult (65+ years) groups were analyzed separately.
- **Intervention (I):** No interventions were considered in this study. In case of interventional studies, baseline control group values were considered.
- **Comparisons (C):** Not applicable.
- **Outcomes (O):** Isometric ankle plantaflexion and dorsiflexion strength, measured as force (N or N/kg) or torque (Nm or N/kg) during maximal voluntary contraction. For the analyses, all results were converted into body mass normalized torque (see section 2.4 for details). The data was accepted if it was obtained by isometric dynamometers, or isokinetic dynamometers that enabled measurements in isometric mode, as well as if it was obtained by hand-held dynamometry. If multiple methods were used in a study, we considered the results obtained by the method that we judged to be more

valid (e.g. isometric or isokinetic dynamometers were chosen over hand-held dynamometry).

- **Study design (S):** All study designs were accepted, with the exception of case studies. For reliability and validity studies, we used the averaged data from multiple trials when available, and median value when the results were reported for each trial separately.

2.3 Data extraction

Following the inclusion criteria, the extracted data included: (a) means and standard deviations for all eligible data on knee plantar- and dorsiflexion strength; (b) participant data (gender, age, body height, body mass, body mass index, health status, athletic discipline); (c) measurement characteristics (ankle and hip angle, number repetitions, duration of breaks, duration of sustained contraction, type of dynamometer and task (unilateral or bilateral)). The data were carefully entered into Microsoft Excel 2016 (Microsoft, Redmond, WA, USA). The data was generally taken from the tables. For determining the data from the figures, we used the Adobe Illustrator Software (version CS5, Adobe Inc., San Jose, CA, USA). In of case of missing data, the corresponding author of the target article was contacted by e-mail and through ResearchGate platoform. If the author did not reply to the second inquiry, the data was considered unobtainable.

2.4 Estimating body mass normalized torque from absolute values

The force data was converted to torque using the presumed moment arms, estimated from body height data according to available anthropometric models.[23,24] To facilitate comparisons across populations, we also analyzed torque values, normalized to body mass. The mean normalized values were estimated with the following equation:[5]

$$\bar{Z} \approx \frac{\bar{y}}{\bar{x}} + \frac{2\bar{y}}{\bar{X}^3} s_x^2 - \frac{2}{\bar{X}^2} \rho \, s_x s_y$$

where Z, Y and X represent the mean normalized value, mean absolute value and body mass, respectively, while s_y and s_x are standard deviations of the raw values and body mass. Finally, ρ represents a correlation coefficient between strength in absolute values and body mass. This value was determined at 0.5, as both our own analyses and reports from the literature[25] show correlation coefficinent aroind 0.5 between maximal voluntary joint torque and body mass. Standard deviations of the normalized values were further estimated with the following equation [5]:

$$s_z^2 = \frac{\overline{\mathrm{y}}^2}{\overline{\mathrm{x}}^4}\, s_x^2 + \frac{1}{\overline{\mathrm{x}}^2}\, s_y^2 - \frac{2\overline{\mathrm{y}}}{\overline{\mathrm{x}}^3}\, \rho\, s_x$$

2.5 Data grouping, elimination and analysis

After the data was extracted and converted to body-mass normalized units (Nm/kg), further decisions were made on how to group the data. A large majority of studies assessed the ankle strength in a neutral position or very close to the neutral position. Thus, we decided to include only studies where the ankle angle was set between -10° and 10° from the neutral. As the knee position is known to affect ankle strength [26], we further categorized the studies based on the knee angle as follows: a) extended (0-10°), partially flexed (30-60°) and flexed (80-90°). Regarding age, adult (18-65 years) and older adult (65+ years) groups were analyzed separately. The mean data for ankle strength was pooled in Comprehensive Meta Analysis software (V3.0, Biostat Inc., Englewood, USA). A random-effects model was applied to calculate the pooled mean values for normalized torque data, with respective 95 % confidence intervals from means, standard deviations and sample sizes of individual studies. The data was analyzed for each age group, gender and muscle group within each knee angle range.

2.6 Ankle strength measurements

In addition to pooling the mean values of ankle strength from the literature, we also report the results on isometric ankle strength measurements in 683 athletes. These measurements were conducted within a larger project. This project was intended to assess inter-limb asymmetries at different levels (joint strength, joint flexibility, leg power, trunk function, etc.) and potential associations with injury risk. Within the project, athletes also performed bilateral ankle strength measurement on an isometric dynamometer. The athletes were included if they were free of injuries in the past 6 months. The basic data (age, body height and body mass), stratified by sex and sports discipline, are available in Table 1.

****Table 1 about here****

The measurements were conducted within a single session that also encompassed assessment of isometric knee, hip and trunk strength, as well as postural sway assessment and vertical jump tests (descriptions available in previous studies, e.g.[27,28]). In total, the session lasted for approximately 3 hours, with long breaks between the measurement sections.

****Figure 1 about here****

Isometric ankle strength tasks were done using isometric dynamometers (S2P, Science to Practice, Ljubljana, Slovenia) with embedded force sensors (model 1-Z6FC3/200 kg HBM, Darmstadt, Germany). The participant's shins were tightly secured within the dynamometer rigid metal frame (Figure 1), and the feet were placed on a rigid plate mounted above the torque sensor. The axis of the dynamometer was carefully aligned with the medial malleolus, and the ankle was in the neutral position (90°). The foot was tightly fixated against the plate with a strap to prevent the ankle from moving into flexion. Ankle plantar- and dorsi-flexion measurements were performed in random order. The participants were instructed to "push as hard and as fast as possible". The maximal voluntary contraction was maintained for 3-4 seconds and loud verbal encouragement was provided. Torque data was sampled at 1000 Hz and analyzed in the manufacturer's software (Analysis and Reporting Software, S2P, Ljubljana, Slovenia). The software smooths the data with 5-ms moving average filter and provides the peak torque data as the largest 1-s mean value within the contraction duration. Three repetitions were performed for each task for each participant, and the best values were used for calculating means and standard deviations for the participant subgroups.

3 RESULTS

3.1 Summary of search results and study characteristics

In total, 5736 articles were reviewed (5490 from the PubMed database, 129 from the PEDro database and an additional 117 addresses from the reference lists). 175 articles were selected to review the text. A further 55 studies were obtained from the sources of the reviewed articles, which were subsequently reviewed. Due to insufficient reported data, inadequate measurement procedures or overlapping databases with other studies, a total of 97 studies were excluded. The total number of included studies covered was 133. The sum of participants was 3755 (1924 adults from the general population in 75 studies, 512 older adults people in 26 studies, 813 recreational and athletes in 38 studies and 506 adolescents in 5 studies). Of the 133 studies, 59 studies conducted measurements in the male population exclusively, 7 studies performed exclusively in the female population, 8 studies had a separate male and female group, and 56 studies had mixed groups without reporting sex-specific data. Regarding the movements analayzed, 96 studies took measurements of the ankle plantarflexion (i.e., plantar flexion), 52 studies conducted dorsiflexion measurements and only 6 studies included inversion and only 8 eversion measurements. Because the studies including inversion/eversion were very heterogenous, the analyses were carried out only on the ankle exntension and flexion data.

The strength measurements were most often performed in three repetitions (66 studies) or two repetitions (36 studies). Some studies used other repetition numbers (1 repetition in 4 studies, 4 repetitions in 8 studies, 5 repetitions in seven studies, 6 repetitions in 6 studies, 10 repetitions in 3 studies, 11 repetitions in 2 studies and 20 repetitions in 1 study). Most commonly, the maximal voluntary contraction was held for 5 seconds (64 studies), and slightly fewer studies used 3 seconds (32 studies). Other contraction times were rarer (2 seconds in 4 studies, 4 seconds of 13 studies, 6 seconds of 9 studies, 7 seconds of 5 studies, 8 seconds in 2 studies and 10 seconds in 4 studies). Breaks between repetitions also varied. Most often, breaks were 60 seconds long (39 studies), 120 seconds (25 studies), 30 seconds (24 studies), 180 seconds (21 studies) or 90 seconds (11 studies). Other break times were 5 seconds in 1 study, 10 seconds in 3 studies, 15 seconds in 2 studies, 20 seconds in 2 studies, 40 seconds in 1 study and 45 seconds in 4 studies. Table 2 shows all pooled means that were possibly calculated based on the number of the studies and their homogeneity.

3.2 Ankle strength in the general population

We were unable to obtain data exclusively for female, as the number of studies testing and reporting separate data for the female population was too small. The results are consequently divided into studies in which the subjects were exclusively male or a combination of males and females Within the general population, the total number of subjects was 2873. Most studies performed measurements of the strength of the ankle with the knee extented (87 studies), and slightly fewer studies performed the measurement swith knee flexed (54 studies) and even fewer in partially flexed position (27 studies). In some categories of data, such as data for the older adults with a flexed knee, the number of studies was quite small.

****Table 2 about here****

In the general adult population (Figure 2, left), the mean ankle plantar dorsiflexion strength was 2.03 Nm/kg (1.80-2.25) and ankle dorsiflexion stength 0.56 Nm/kg (0.43-0.69) measured when with knee extended. For the measurements with a partially flexed knee, the mean ankle plantar dorsiflexion strength was 1.98 Nm/kg (1.62-2.34) and the mean ankle dorsiflexion strength was 1,09 Nm/kg (0.83-1.35). Furthermore, ankle plantar dorsiflexion strength of 1.50 Nm/kg (1.34-1.67) and ankle dorsiflexion strength of 0.46 Nm/kg (0.41-0.50) were calculated for the measurements with the knee flexed. For men only, the ankle plantar dorsiflexion strength with the knee extended was 2.46 Nm/kg (1.92-3.00), the ankle plantar dorsiflexion strength with the flexed knee was 1.51 Nm/kg (1.29-1.74) and ankle dorsiflexion strength with knee flexed was 0.51 Nm/kg (0.46-0.56).

****Figure 2 about here****

In older adults (Figure 2, right), the pooled means for measurements with knee extended were 0.58 Nm/kg (0.44-0.73) for ankle plantar dorsiflexion and 0.25 Nm/kg (0.19-0.31) for ankle dorsiflexion. When measurements with a partially flexed knee were considered, the ankle plantar dorsiflexion strength was 0.87 Nm/kg (0.66-1.08), and the ankle dorsiflexion strength was 0.70 Nm/kg (0.48-0.93). With the knee flexed, the ankle plantar dorsiflexion strength was 1.19 Nm/kg (0.94-1.44) and the ankle dorsiflexion strength was 0.35 Nm/kg (0.30-0.41).

3.2 Ankle strength in athletic populations

There were far fewer studies that involved athletic populations. The total number of participants was 375 (27 studies). The heterogeneity of the participant characteristics, data acquisition and reporting was were high, and only two pooled means could be calculated with reasonable confidence. With the knee extended, the mean ankle plantar dorsiflexion strength was 1.89 Nm/kg (1.61-2.16). With the knee flexed, the ankle plantar dorsiflexion strength was 1.96 Nm/kg (1.55-2.37).

3.3 Ankle strength in our sample of athletes

Table 3 displays the mean values for the bilateral ankle strength, obtained in our study. Ankle plantar dorsiflexion strength means ranged from 3.14 Nm/kg (females long distance runners) to 4.68 Nm/kg (male track&field athletes). Across sports disciplines, males had consistently larger ankle plantar dorsiflexion strength than females, except in martial arts (males: 3.97 ± 0.57 Nm/kg, females: 4.38 ± 0.99 Nm/kg). Note that the martial art group had only 34 participants, which limits the generalization of these results. The means for ankle dorsiflexion strength ranged from 0.85 ± 0.22 Nm/kg (female martial arts) to 1.35 ± 0.14 Nm/kg (male track&field athletes). The males had consistently larger values across sports disciplines. The ratios between plantar dorsiflexion and dorsiflexion are also displayed and indicate that ankle extensors are ~3 to 4 times stronger than ankle flexors in neutral joint position, with substantial variability within groups (many standard deviations exceeded 1) and among sport disciplines.

DISCUSSION

The purpose of this paper was to obtain body-mass-normalized isometric ankle strength reference values for different populations, strartified by sex and age. We were able to obtain several reference values for the general population, however, due to the heterogeneity of the samples and reporting, separation was by sex was largely impossible. While strength ratios are commonly used in sport and rehabilitation practice, this study is one of the first to provide reference values for absolute ankle strength values. Practitioners may use these values to assess the strength of their athletes or clients.

We are not aware of any studies that would obtain reference values of strength normalized to body weight in the general population. McKay et al.[29] conducted an extensive study that provided reference strength values for the general population, but the values were not normalized to body mass. Cattagini et al.[30] obtained data for normalized strength of ankle flexors and extensors in young adults (18-34 years), middle-age adults (44-59 years), and older adults, which were further divided into fallers and non-fallers. The mean maximum strength in young adults was 4.4 Nm/kg for plantarflexion and 1.2 Nm/kg for flexion, which is higher than our pooled means (2.03 Nm/kg for plantarflexion and 0.58 Nm/kg for flexion) anat1d closer (but still lower) than the values found by Cattagini et al.[30] for middle-aged adults (3.2 Nm/kg for plantarflexion and 1.0 Nm/kg for flexion). In the older adults, plantarflexion mean values were 2.5 Nm/kg for non-fallers and 1.7 Nm/kg (fallers) for plantarflexion 0.9 Nm/kg (non-fallers) to 0.7 Nm/kg (fallers) for flexion, which is again higher than the values we obtained (0.58 Nm/kg and 0.25 Nm/kg, respectively). Higher results could potentially be attributed to the use of a purpose-built dynamometer for which no data were found to verify the reliability and comparability of the results with isokinetic dynamometers. Moreover, the authors did not specify the sex distribution of the sample, which could affect the end result, as men typically develop substantially higher strength values than females.[31] Another relatively extensive study was performed by Moraux et al.[32] who obtained ankle strength values were similar to our pooled means. For instance, in the older adults, our values were 0.35 Nm/kg for ankle flexion and 1.19 Nm/kg for ankle plantarflexion (60-69 years old men: 0.39 Nm/kg and 1.29 Nm/kg, 60-69 year old women: 0.29 Nm/kg and 1.49 Nm/kg). Similar values of flexion strength of 21.6 Nm and 0.28 Nm/kg were achieved by a group of 30 older women (n = 30, age = 73.3 years) in their study.

Looking at the values in older adults, it seems that dorsiflexion strength seems to decline similarly in all measurement positions. However, in comparison to general adult population, older adults tend to show particularly impaired plantarflexion strength when the knee is extended, while plantarflexion strength with knee flexed seems to be almost completely preserved. Given that gastrocnemius has a greater contribution to plantarflexion moment when the knee is extended[26,33] and that has a substantially greater percentage of fast muscle fibres relative to soleus,[34] our finding could be related to preferential atrophy of the fast over slow muscle fibres with ageing. Moreover, performing isometric plantar strength tasks in extended knee position might require higher truk stabilization, which is also likely to be somewhat impaired in older adults.[35] In contrast, when flexed knee position is used (as in our study, see Figure 1) the shins are typically fixated and no trunk activation is needed.

In our review, we excluded the studies conducted with patient populations. Neverthlees, putting previous works with patients in the context of our results is possible. Chung et al.[36] reported 0.31 Nm/kg for isometric ankle flexion strength in woman (n = 12) with multiple sclerosis, which was slightly lower compared to their control groups (0.35 Nm/kg). Similar results were obtained by Wagner et al.[37] who performed measurements in adults with multiple sclerosis (n = 42). The mean value for ankle flexion strength was 0.30 Nm/kg and 0.91 Nm/kg the for ankle plantarflexion. The control group (n = 14) averaged 0.35 Nm/kg for flexion and 1.15 Nm/kg for ankle plantarflexion. Dallmeijer et al.[38] assessed 25 young patients with cerebral palsy and reported ankle plantarflexion and flexion values at 0.15 Nm/kg and 0.19 Nm/kg, respectively. Ferreira et al.[39] reported 0.72 Nm/kg for plantarflexion and 0.34 Nm/kg for flexion in adult men with diabetic peripheral neuropathy group (n = 28), which was lower compared in neuropathy-free groups of diabetics (0.95 Nm/kg at plantarflexion and 0.40 Nm/kg at flexion) and the healthy control group for plantarflexion (1.21 Nm/kg and 0.38 Nm/kg, respectively). Lin et al.[40] measured the maximum strength of ankle extensors and flexors in 68 patients after a stroke with hemiparesis or weakness of one of the lower extremities. The strength of the ankle extensors on the affected side was 0.55 Nm/kg, which was lower than the unaffected side (0.76 Nm/kg). Similar was found for ankle flexion strength (0.33 Nm/kg vs. 0.53 Nm/kg). Muscle strength decreases more sharply when hemiplegia or paralysis occurs after a stroke.[41]

Since we could only pool a limited number of studies for athletes, we subsequently included and processed data for 683 athletes (Table 3) obtained in a larger project.[27,28] We did not find any existing studies that would attempt to obtain normalized strength reference values for the ankle joint in athletes. Buchanan and Vardaxis[42] reported 1.48 Nm/kg (plantarflexion) and 0.46 Nm/kg (flexion) for slow isokinetic (30°/s) ankle strength with the knee extended in basketball players, which is fairly close to our values for basketball players (dividing the bilateral data yields the values of 1.59 Nm / kg and 0.47 Nm/kg, respectively). A study on young martial arts athletes[43] reported unilateral ankle plantarflexion of the dominant leg at 2.79 Nm/kg in the first category of taekwondo, 2.71 Nm/kg in the second category of taekwondo and 2.93 Nm/kg in boxers. Our results yielded lower values, which could be attributed to different martial arts (our study included karate and jiu-jitsu). Felser et al.[44] performed measurements on young speed skaters. The average values were 2.2 Nm/kg for plantarflexion and 0.37 Nm/kg for flexion. Slightly lower values were achieved by speed skaters in our study for plantarflexion (1.93 Nm / kg in men and 1.73 Nm / kg in women) while the flexion values were higher (0.54 Nm / kg in men and 0.51 Nm / kg in women). We did not include the injured athletes in our analyses, but it is worthwhile to mention that several previous studies have highlighted the role of ankle strength in injury risk in athletes. For instance, Naicker et al.[45] performed isokinetic measurements (60°/s) in a group of hockey players with (n = 47) and without (n = 18) ankle sprains. The groups had similar ankle plantarflexion strength (values not reported), but the flexion strength of the injured ankle (0.46 Nm/kg) was lower compared to the uninjured ankle (0.53 Nm/kg).

One of the limitations of our review is that many studies have performed measurements with hand-held dynamometers, which may be less reliable than gold standard dynamometers. Their reliability in measuring the more powerful muscle groups of the lower extremities (ankle and knee extensors) depends on the measurement technique and the ability and physical characteristics of the rater.[46] In certain studies, we had to contact the authors, as they did not provide means and standard deviations. In case of unresponsiveness of the authors, we had to exclude such studies from the paper. Some other studies reported measured values that were not normalized to body mass. In this case, we used the appropriate equations to obtain normalized values. Such equations allow for the probability of error, which must be taken into account when interpreting the results. Despite the large number of studies covered, we are aware that the field of ankle strength measurements is extensive and that it is likely that had missed a certain proportion of studies.

CONCLUSION

The study was conducted to obtain normalized reference values of ankle strength for different populations, separately by age, sex and level or type of sports activity. The final analysis included 133 studies and were were able to obtain results mainly for the general population

Ankle plantarflexion strength was the highest in the adult general population with the knee extended and lowest with the knee flexed. The elderly achieved lower values of plantarflexion and flexion compared to the adult general population. However, they had the highest values of the plantarflexion when the knee was extended. Ankle flexion values were highest in both age groups with a partially flexed knee. We did not find enough studies in the review to be able to obtain reference values for children and youth. In the case of athletes, we initially managed to obtain reference values only for the ankle plantarflexion. As a result, we added to the analysis the results of our research project study, which provided reference values for ten different sports. With the obtained normalized reference values, kinesiologists, trainers, physiotherapists and other experts in the field will be able to better interpret the values they will obtain from their own measurements.

Conflict of interest: The paper was prepared in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The article has not been published elsewhere and that it has not been simultaneously submitted for publication elsewhere

Funding: The authors were supported by the Slovenian Research Agency through the project TELASIPREVENT [L5-1845] (Body asymmetries as a risk factor in musculoskeletal injury development: studying aetiological mechanisms and designing corrective interventions for primary and tertiary preventive care) and by the University of Primorska through internal research program KINSPO (2990–1-2/2021).

Acknowledgements: None

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FIGURE LEGENDS

Figure 1. The set-up for measurements of ankle strength in our study.

Figure 2. The pooled mean values with confidence intervals for ankle strength in the general population.

TABLES

Table 1. Basic data for the participants enrolled in our study.

Sport	Sex	Sample size	Age (years)		Body height (cm)		Body mass (kg)	
			Mean	SD	Mean	SD	Mean	SD
Basketball	Male	104	16.8	1.2	188.7	8.3	80.4	12.5
	Female	57	16.7	1.6	175.1	5.6	69.9	11.0
Dancing	Male	23	24.3	6.0	179.1	4.9	71.7	6.6
	Female	52	21.8	6.8	166.7	5.1	55.1	5.9
Soccer	Male	162	17.4	3.4	179.3	7.0	70.3	10.1
Track&Field	Male	20	18.0	2.7	180.7	5.9	73.9	8.2
	Female	8	17.8	3.1	167.3	3.8	60.4	5.9
Volleyball	Male	42	17.0	3.8	183.3	9.3	73.4	12.7
Alpine skiing	Male	8	23.1	3.4	181.1	7.3	82.5	6.0
Tennis	Male	65	16.3	3.7	176.5	10.7	66.7	13.3
	Female	42	16.1	2.9	169.1	6.6	61.1	8.2
Martial arts	Male	17	18.6	5.9	179.0	8.9	78.2	17.7
	Female	17	18.6	4.0	166.0	5.0	59.7	6.8
Speed skating	Male	12	16.8	5.1	169.5	15.6	61.3	16.6
	Female	6	16.7	3.3	159.3	7.9	53.5	10.1
Long distance running	Male	29	30.6	9.5	182.1	6.0	78.0	7.1
	Female	19	36.3	10.8	166.5	7.9	61.1	7.5

Table 2. Overview of the pooled means for ankle strength by knee angle, age group, sex and population.

Knee angle	Age group	Sex	Athletes / General pop.	Task	Raw torque data (Nm)					Normalized torque data (Nm/kg)				
					Pooled mean	95 % CI		Total N	Studies	Pooled mean	95 % CI		Total N	Studies
0	Adults	Both	Athletes	Plantarflexion	126.45	114.51	138.39	167	11	1.89	1.61	2.16	249	18
0	Adults	Both	General	Plantarflexion	160.06	138.53	181.60	503	26	2.03	1.80	2.25	600	31
0	Adults	Males	General	Plantarflexion	189.03	140.30	237.76	159	13	2.46	1.92	3.00	187	15
0	Adults	Both	General	Dorsiflexion	38.09	28.49	47.70	126	7	0.56	0.43	0.69	174	8
0	Older adults	Both	General	Plantarflexion	46.91	37.92	55.90	195	11	0.58	0.44	0.73	170	9
0	Older adults	Both	General	Dorsiflexion	19.09	14.09	24.08	138	6	0.25	0.19	0.31	138	6
30–60	Adults	Both	General	Plantarflexion	138.75	108.76	168.74	130	7	1.98	1.62	2.34	191	7
30–60	Adults	Both	General	Dorsiflexion	81.05	62.38	99.73	152	10	1.09	0.83	1.35	119	9
30–60	Older adults	Both	General	Plantarflexion	69.73	53.89	85.57	302	5	0.87	0.66	1.08	302	5
30–60	Older adults	Both	General	Dorsiflexion	56.25	38.29	74.21	63	6	0.70	0.48	0.93	63	6
90	Adults	Both	Athletes	Plantarflexion	152.64	116.50	188.78	117	8	1.96	1.55	2.37	126	9
90	Adults	Both	General	Plantarflexion	108.19	95.45	120.94	305	15	1.50	1.34	1.67	305	15
90	Adults	Males	General	Plantarflexion	114.86	95.31	134.41	142	9	1.51	1.29	1.74	142	10
90	Adults	Both	General	Dorsiflexion	39.82	33.56	46.08	256	11	0.46	0.41	0.50	248	9
90	Adults	Males	General	Dorsiflexion	39.87	36.57	43.18	106	5	0.51	0.46	0.56	96	4
90	Older adults	Both	General	Plantarflexion	100.75	85.55	115.96	54	3	1.19	0.94	1.44	84	4
90	Older adults	Both	General	Dorsiflexion	26.35	19.81	32.89	54	3	0.35	0.30	0.41	54	3

CI – confidence interval; Total N – the sum of participants across the studies.

Table 3. Mean ankle strength in our sample of athletes

Sport	Sex	Plantarflexion (Nm/kg)		Dorsiflexion (Nm/kg)		P:D ratio	
		Mean	SD	Mean	SD	Mean	SD
Basketball	Male	3.90	0.76	1.11	0.18	3.60	0.95
	Female	3.17	0.89	0.94	0.16	3.40	0.91
Dancing	Male	4.60	1.06	1.08	0.19	4.39	1.22
	Female	4.52	1.03	0.95	0.17	4.90	1.47
Soccer	Male	4.26	0.92	1.30	0.24	3.33	0.78
Track&Field	Male	4.68	1.16	1.35	0.14	3.48	0.79
	Female	4.17	0.79	1.21	0.21	3.51	0.67
Volleyball	Male	4.25	0.77	1.18	0.21	3.76	1.13
Alpine skiing	Male	3.83	0.49	1.17	0.12	3.30	0.61
Tennis	Male	3.77	0.75	1.04	0.14	3.69	0.86
	Female	3.57	0.90	0.90	0.19	4.04	0.96
Martial arts	Male	3.97	0.57	0.98	0.18	4.16	0.90
	Female	4.38	0.99	0.85	0.22	5.51	1.92
Speed skating	Male	3.86	1.12	1.08	0.14	3.60	1.08
	Female	3.45	0.56	1.01	0.08	3.46	0.70
Long distance running	Male	3.67	0.87	1.07	0.15	3.56	1.41
	Female	3.14	0.70	1.00	0.13	3.15	0.75

SD – standard deviation.