Sports Medicine and Health Science 8 (2026) 273–290

Contents lists available at ScienceDirect

Sports Medicine and Health Science

journal homepage: www.keaipublishing.com/smhs

Review Article

Lower body muscular strength as a predictor of health indicators in youth population: A systematic review and meta-analysis

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ARTICLE INFO

Keywords:
Physical fitness
Children and adolescents
Muscular power
Jump tests

ABSTRACT

Muscular strength in the lower body during childhood and adolescence is crucial for determining various health indicators. While previous reviews have examined the benefits of health-related muscular fitness (MF) in youth, this study aims to analyse a specific indicator of muscular fitness, focusing on current evidence regarding lower-limb muscular strength and power tests as predictors of health parameters in children and adolescents. A systematic search was conducted in Web of Science, MEDLINE (PubMed), and Scopus databases up to December 2023. Observational studies were considered if they quantitatively assessed the association between lower body muscular strength and health outcome variables. Meta-analyses were performed to determine the pooled standardized coefficients. Age was evaluated as a potential moderating factor. Twenty-four studies (n = 121 306) were included, covering outcomes like adiposity, cardiometabolic risk, bone health, and inflammatory biomarkers. Meta-analyses of 11 studies revealed pooled standardized coefficients; statistical significance was determined for $p < 0.001$. Lower body strength/power was negatively associated with multiple adiposity indicators: waist circumference ($r = -0.27$), body fat percentage ($r = -0.31$), sum of skinfolds ($r = -0.31$). Additionally, significant negative correlations were observed with insulin resistance ($r = -0.20$), and cardiometabolic risk index ($r = -0.27$). Associations with systolic ($r = 0.14$) and diastolic ($r = 0.07$) blood pressure, and bone mineral density of the femoral neck ($r = 0.12$) were weaker. Lower body muscular strength predicts health outcomes like obesity and cardiometabolic diseases. Although no direct link to bone mass was found, lean mass influenced by muscle is essential for bone health. Further research is needed to clarify these relationships and guide interventions, supporting guidelines promoting muscle-strengthening activities in youth.

1. Introduction

Physical fitness is considered one of the strongest predictors of health status in the youth population.[1] It has as main components cardiorespiratory fitness (CRF) and musculoskeletal fitness (MSF).[2] These health-related fitness components have been characterized by the set of attributes required to perform physical activities, without excessive fatigue and by qualities and abilities associated with a reduced risk of chronic diseases.[3,4] Traditionally, research on physical fitness and health outcomes focused on CRF,[1,5] consistently revealing strong associations.

MSF is a multidimensional construct that comprises the ability of muscles to produce force (muscular strength), to perform repetitive contractions or to maintain a prolonged contraction under submaximal loads (muscular endurance), and to achieve a high rate of maximal dynamic muscle contraction (muscular power).[2,4] The motivation to encourage adequate levels of muscular fitness (MF) is based on the increasing body of evidence linking MF with positive effects on health status in youth.[1,2,4,6] It is associated with bone health,[7,8] healthier cardiovascular profiles[2] and insulin sensitivity,[9,10] and inversely associated with markers of inflammation and metabolic syndrome.[5,11] The role of

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Peer review under the responsibility of Editorial Board of Sports Medicine and Health Science

https://doi.org/10.1016/j.smhs.2025.06.004
Received 19 September 2024; Received in revised form 24 April 2025; Accepted 5 June 2025

Abbreviations

%BF	Body fat percentage
aBMD	Areal bone mineral density
BMD	Bone mineral density
BMI	Body mass index
CCS	Cross-country skiing
CI	Confidence interval
CMJ	Countermovement jump
Cont	Control group
CRF	Cardiorespiratory fitness
CRP	C-reactive protein
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
F	Female
FFM	Fat free mass
FM	Fat mass
GYMN	Rhythmic gymnastics
HDL-c	High-density lipoprotein cholesterol
HOMA-IR	Homeostasis model assessment for insulin resistance
I^2	Heterogeneity
M	Male
MAP	Mean arterial pressure
MF	Muscular fitness
MSF	Musculoskeletal fitness
n	Sample
p	P-value
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
Q	Heterogeneity (Cochran's Q)
r	Pooled correlation coefficient
RBM	Relative body mass
RJ15	Rebound jumps for 15 s
RJ30	Rebound jumps for 30 s
SBP	Systolic blood pressure
SD	Standard deviation
SG	Sport games
SPR	Track sprint
SW	Swimming
TC	Total cholesterol
TG	Triglycerides
WBLH	Whole body less head
WC	Waist circumference
WHtR	Waist to height ratio
β	Regression coefficient
ΣSF	Sum of skinfolds

MF in preventing chronic diseases has also been increasingly acknowledged.[6,12] In addition, various studies have demonstrated that lower body muscular power is rightly associated with levels of blood pressure,[13] bone strength and bone mineral content.[8] The Institute of Medicine highlighted that muscular strength and muscular power are essential elements in an integral assessment of children fitness.[14] In this regard, the World Health Organization acknowledges the significance of MF and, in it is physical activity guidelines for children and adolescents, recommends the promotion of muscle strengthening at least three times a week, in addition to aerobic activity.[15]

These findings emphasize the importance of evaluating MF from an early age.[4] Muscular strength in youth is not only an indicator of their current health but also a predictor of future health outcomes.[7] There are different tests to assess several dimensions of muscular strength, and more specifically, to assess lower body muscular strength and muscular power.[16,17] These tests include the most important fitness test batteries for children and adolescents,[18,19] and the information provided by each test pertains specifically to different regions of the body. However, these tests have certain limitations for use in extensive population studies, such as school settings. In such cases, it is imperative that the methodologies utilized are both uncomplicated and efficient, thus minimizing the need for strict laboratory settings.[18,20] As a practical alternative, field-based fitness tests are used.[16,17]

Field-based fitness tests are a practical substitute commonly employed because they are easy to administer, require minimal equipment, and are cost-effective.[16] Previous research indicates that field tests to measure lower body muscular strength are reliable and valid in a youth population.[16,17] Some authors have even proposed them as a general index of upper and lower body MF in children.[17] This emerging evidence has led to reviews examining the benefits of health-related MF in youth from a broad perspective.[7,21] However, the aim of this review and meta-analysis is to analyse a specific aspect of muscular fitness, focusing on the current evidence regarding lower-limb muscular strength and power as predictors of health parameters in children and adolescents.

2. Methods

2.1. Protocol and registration

The protocol for the review and meta-analysis was registered on the International Prospective Register of Systematic Reviews (PROSPERO) database (registration number: CRD42023473379). This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[22]

2.2. Search strategy

A systematic electronic search for articles was conducted in Web of Science, MEDLINE (PubMed), and SCOPUS databases from the earliest record available up to November 2023, to identify relevant studies.

Relevant keywords for each search term were identified through preliminary searches (reviewing titles/abstracts, keywords, full texts, and related reviews previously published). The following Boolean search strategy was applied using the terms defined a priori using the "OR" operator, and the final search phrase was constructed using the "AND": ["physical fitness" OR "fitness" OR "motor skill" OR "motor competence" OR "motor performance" OR "lower body" OR "lower limb"] AND ["muscular" OR "muscle"] AND ["strength" OR "power"] AND ["jump"] AND ["health"] AND ["youth" OR "children" OR "adolescents"].

No limits on the publication date were imposed; however, only original, published full texts written in English were considered for review. Grey literature was excluded due to its lack of peer review, which may compromise the quality and reliability of the data. Also, reference lists of relevant studies and previous reviews on the topic were checked to find any articles that may have been missed by the search criteria, to identify further studies for inclusion in the database.

2.3. Eligibility criteria

Studies that examined the relationship between muscular strength/power and health indicators in a general population of healthy children and adolescents were considered. Before screening the remaining studies, we identified and eliminated duplicate records. To be eligible for inclusion, studies had to meet the following criteria: (1) participants were aged 6–18 years, without any diagnosed medical conditions; (2) study design: data were obtained from observational studies (cross-sectional or baseline measurements of longitudinal studies); (3) the studies used quantitative assessment of lower body muscular strength/power measured by field tests with demonstrated validity and reliability in children and adolescents; (4) studies that report at least one health indicator associated with measures of lower body muscular strength/power (e.g. cardiometabolic risk/metabolic syndrome, bone health, anthropometric and adiposity status) was provided. We did not restrict the inclusion criteria to a specific primary or secondary outcome in the studies. Based on the predefined inclusion, studies were identified by two authors through two stages of screening performed independently. In the first stage, the relevance of the search results was examined by reviewing titles and abstracts for eligibility. In the second stage, the full texts were screened and evaluated against the inclusion criteria. When necessary, discrepancies were resolved by discussion, or a third author was involved in the decision-making. In all cases, the reasons for the exclusion of identified articles were recorded. The included health outcome measures were classified into the following four categories: (1) anthropometric and adiposity status; (2) cardiometabolic parameters; (3) bone health indicators; and (4) inflammatory biomarkers.

2.4. Data extraction

One researcher extracted descriptive data into a specifically designed and standardized Microsoft Excel spreadsheet, and this was verified by a second researcher verified for accuracy. If any additional data were required, the publication's corresponding author was requested via email or via ResearchGate. The following data of the selected studies were extracted and summarized in an ad hoc table including author identification, country of study, year of publication, study design (cross-sectional, longitudinal, participant characteristics (sample size, sex, age, mean age), methods for assessing lower body muscular strength/power muscular, health indicator outcomes, and the association between body muscular strength/power and health indicators.

2.5. Data synthesis and analysis

Random-effects meta-analyses for each variable were performed using the metafor package in R (version 4.2.2, 2022-10-31, ucrt; The R Foundation for Statistical Computing). Two meta-analyses were conducted for each physical fitness variable to assess the magnitude and significance of the relationship with vertical jump performance. The first meta-analysis included the sample size and correlation coefficient from each study. To avoid incorrect variance calculations and non-normal distributions, all correlation coefficients were converted to Fisher's z-scores and standard errors. Fisher's z-scores were then back-transformed to obtain the pooled correlation coefficient (95% confidence interval) for the forest plots.

The pooled correlation coefficients were categorized as follows: 0.00–0.10 (trivial); 0.10–0.30 (small); 0.30–0.50 (moderate); 0.50–0.70 (high); 0.70–0.90 (very high); and > 0.90 (nearly perfect).[23,24] Statistical significance was determined for $p < 0.001$. The Cochran's Q-statistic[25] was employed to gauge the proportion of total variation attributable to heterogeneity across the studies. This information was then utilized to compute the I^2 statistics. I^2 values falling below 25%, between 25% and 75%, and exceeding 75% were respectively categorized as indicating small, moderate and high levels of heterogeneity.[25,26] Leave-one-out sensitivity analyses was performed to assess whether removing a single study had a significant influence on the final pooled correlation coefficient.[27]

In the second analysis, mean age was included as a moderator variable to examine its impact on the magnitude of the relationship, and a meta-regression was performed. To assess the risk of bias due to small sample sizes and missing studies, funnel plots with an Egger test were included, using the trim and fill method.[28]

2.6. Risk of bias assessment

Consistent with previous research,[7,29] the assessment to evaluate bias within included studies was the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[30] This tool evaluates six criteria to assess the risk of bias within included studies. For each criterion, studies were scored with a tick ("✓"), low risk of bias; a cross ("×"), high risk of bias; or an exclamation mark ("!"), unclear/inadequate description. The criteria were: (i) Did the study adequately describe participant sampling procedures and inclusion criteria? (ii) Did the study clearly outline the health indicator assessment(s) used, including specific measures, procedures and their validity? (iii) Did the study provide acceptable reliability information for the health indicator assessment(s) used? (iv) Did the study clearly outline the physical fitness assessment(s) used (specific measures/procedures/valid)? (v) Did the study provide acceptable reliability information for the physical fitness assessment(s) used? (vi) Of those who consented to the study, did an adequate proportion have complete data for the health indicator and the physical fitness assessments? A score for each article ranged from zero to six points. Studies with scores ≤ 2 were considered high risk of bias, studies that achieved 3–4 points were classified as medium risk, and those that had scores of 5–6 were classified as low risk of bias. To establish clear criteria and ensure high agreement between reviewers, two independent researchers performed this step, and a third researcher resolved any disagreements.

2.7. Risk of bias across studies

Small study effects and potential publication bias were visually interpreted from funnel plots and calculation of Egger's linear regression intercepts for each comparison.[31] Publication bias was considered present if there was significant asymmetry in the funnel plot; moreover, in the case of asymmetry, the figure shows hypothetical studies (black dots) when there is a risk of publication bias, and we are overestimating the effect. An Egger statistic p-value < 0.05 indicated the presence of a small study effect.

3. Results

3.1. Overview studies/study selection

The search identified 730 screened records after eliminating 491 duplicate records through database searching. From the title and abstract screening, 142 records were identified to assess for eligibility. Finally, 24 studies met the inclusion criteria and were included in the systematic review. Of the studies identified for the systematic review, 13 were excluded from the meta-analysis due to insufficient data (e.g. unreported correlations, lack of sample size information for a reported correlation) required for conducting the meta-analyses. The PRISMA flow chart of the systematic review and meta-analyses is presented in Fig. 1.

3.2. Study characteristics

All studies included were published in English between 2008 and 2023. Twenty-two studies consisted of cross-sectional evaluations,[10,11,13,32–50] while two studies collected cohort observational evaluations.[51,52] Sixteen studies were conducted in European countries,[10,11,32–39,41,42,45,47,51,52] four in Asia,[43,48–50] two in Africa,[13,46] one in Australia[40] and one in South America.[44] The included studies represented a total sample of 121 306 healthy children and adolescents, age ranged from 6 to 18 years. All the selected studies assessed lower body muscular strength using field tests, specifically

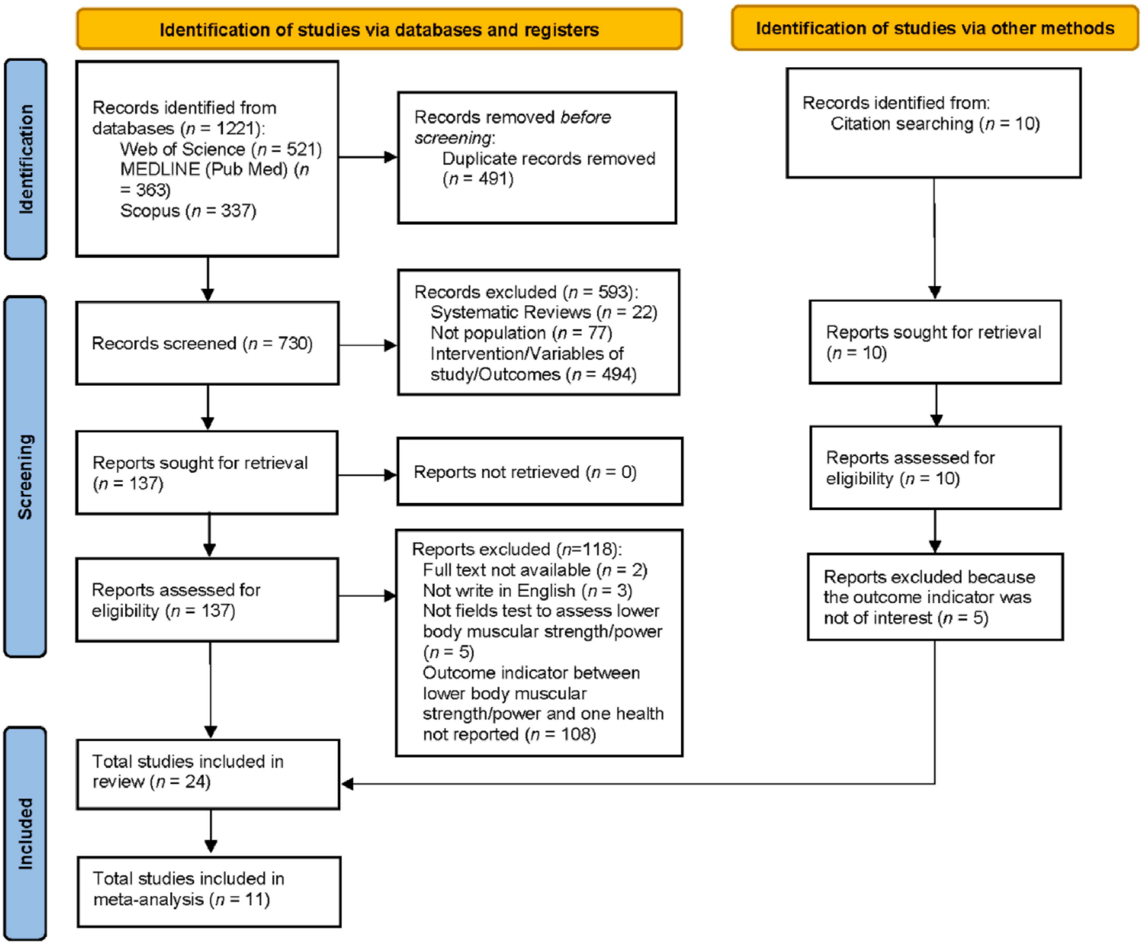

Fig. 1. PRISMA flow diagram for study selection process.

various validated jumping tests: eighteen studies used the standing long jump[11,17,32–34,36,37,39,40,42,43,46–52]; three used the standing broad jump[10,41,45]; two used the countermovement jump[13,38]; and one used the countermovement vertical jump.[35] All studies quantitatively analysed the association between lower body muscular strength or power and at least one quantitative measure of health indicators, including twelve anthropometric and adiposity status,[32,37,40–43,45,46,48–51] nine cardiometabolic risk/metabolic syndrome,[13,32–34,36,40,46,51,52] four bone health,[35,38,44,47] and two inflammatory biomarkers.[11,39] Table 1 summarizes the characteristics of the studies.

3.3. Risk of bias within studies

The risk of bias overview of included studies is presented in Fig. 2. One study met all six criteria,[39] while five studies met five criteria,[32,41,45,46,52] three studies met four criteria,[42,49,51] seven studies met three criteria,[10,11,13,33,34,40,47] and four studies met two criterion.[36,44,48,50] Additionally, four studies met only one criterion.[35,37,38,43] Criteria four and one were the most frequently met ($n = 21/24$ and $20/24$, respectively), followed by criterion five ($n = 14/24$) and criterion two ($n = 12/24$). Criteria three and six were the least frequently met criteria ($n = 7/24$ and $n = 6/24$, respectively). Consequently, 25% of the studies were considered to have a low risk of bias, 42% were considered to have a moderate risk of bias, and 33% were considered to have a high risk of bias.

3.4. Meta-analysis

Meta-analyses were conducted to determine the associations between lower body muscular strength/power and health indicators. They were performed if at least three studies provided standardized coefficients for the reported variables. The forest plots in Figs. 3–5 estimate the pooled correlation coefficients, their corresponding 95% confidence intervals, the I^2 heterogeneity statistic, and the statistical significance (p-value < 0.001) reported for each health indicator. The moderating role of each participant's age was assessed for the analysis conducted between the lower body muscle strength variable and each health parameter (Supplementary Figs. 1–3).

Leave-one-out sensitivity analysis was conducted to diagnose the influence of individual studies on the results of our meta-analysis (Supplementary Fig. 4–6). By systematically excluding each study and observing changes in the results, we can identify particularly influential studies that could distort the overall findings. In our figures, the study whose exclusion may cause a substantial change is shown in red.

3.4.1. Pooled correlation coefficients for lower body muscular strength/power and anthropometric and adiposity status

The association between lower body muscular strength/power and waist circumference (WC) was analysed from eight studies (Fig. 3A). The pooled correlation coefficient was negative and small ($r = -0.27$, 95% *CI:* -0.35 to 0.18), with high heterogeneity and significance ($I^2 = 91.2\%$, $p < 0.001$). Five studies examined the association between lower body muscular strength/power and body fat percentage (%BF) (Fig. 3B). The pooled correlation coefficient was negative and moderate ($r = -0.31$, 95% *CI:* -0.44 to -0.17), with high heterogeneity and significance ($I^2 = 89.1\%$, $p < 0.001$). A total of four studies were evaluated for the association between lower body muscular strength/power and sum of skinfolds (ΣSF) (Fig. 3C), with the pooled correlation coefficient

Table 1
Summary of the studies included.

Study	Country or Region	Design	*n*; sex(M/F)	Age (years) range, mean (± *SD*), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
Abdelkarim et al., 2017[49]	China	Cross-sectional study	676; (341/ 335)	6–11; 8.59 (± 1.6)	Standing Long Jump	Anthropometric and adiposity status (height, weight, BMI)	Height: $r = 0.388$ $p < 0.01$ Weight: $r = 0.263$, $p < 0.01$ BMI: $r = 0.101$, $p > 0.05$
Agostinis-Sobrinho et al., 2016[32]	Portugal	Cross-sectional study	529; (262/ 267)	12–18; 14.33 (± 1.73); M:14.39 (± 1.74) /F:4.27 (± 1.71)	Standing Long Jump	Anthropometric and adiposity status (BMI, %BF, WC, sum of skinfold) Cardiometabolic risk/metabolic syndrome (adiponectin, CRP, HOMA-IR, HDL-c)	BMI: $r = -0.314$, $p < 0.001$ %BF: $r = -0.39$, $p < 0.001$ WC: $r = -0.36$, $p < 0.001$ Sum of skinfolds: $r = -0.419$, $p < 0.001$ Adiponectin: $r = -0.145$, $p < 0.001$ CRP: $r = -0.077$, $p > 0.03$ HOMA-IR: $r = -0.251$, $p < 0.001$ HDL-C: $r = 0.097$, $p < 0.03$
Agostinis-Sobrinho et al., 2017[11]	Portugal	Cross-sectional study	529; (262/ 267)	12–18; 14.3 (± 1.7); M:14.39 (± 1.74) /F:14.27 (± 1.71)	Standing Long Jump	Inflammatory biomarker (score)	Inflammatory score: Model 1: $\beta = -0.869$, $p < 0.001$, $r^2 = 0.68$ Model 2: $\beta = -0.863$, $p < 0.001$, $r^2 = 0.6$ Model 3: $\beta = -0.335$, $p = 0.02$, $r^2 = 0.274$ Model 4: $\beta = -0.170$, $p = 0.251$, $r^2 = 0.315$
Agostinis-Sobrinho et al., 2018[33]	Portugal	Cross-sectional study	734; (385/ 349)	12–18; M:14.52 (± 1.8) /F:14.17 (± 1.7)	Standing Long Jump	Cardiometabolic risk/metabolic syndrome (SBP, DBP, PP, rate pressure product)	SBP: Model 1: $\beta = -0.035$, $p = 0.267$, $r^2 = 0.017$ Model 2: $\beta = -0.005$, $p = 0.9$, $r^2 = 0.115$ DBP: Model 1: $\beta = -0.027$, $p = 0.395$, $r^2 = 0.013$ Model 2: $\beta = 0.006$, $p = 0.114$, $r^2 = 0.046$ PP: Model 1: $\beta = -0.026$, $p = 0.413$, $r^2 = 0.003$ Model 2: $\beta = 0.09$, $p = 0.107$, $r^2 = 0.073$ Rate pressure product: Model 1: $\beta = -0.047$, $p = 0.137$, $r^2 = 0.009$ Model 2: $\beta = 0.052$, $p = 0.120$, $r^2 = 0.052$
Artero et al., 2011[34]	European countries	Cross-sectional study	709; (346/ 363)	12.5–17.5; 14.9 (± 1.3); M: 14.9 (± 1.3) /F: 14.9(± 1.2)	Standing Long Jump	Cardiometabolic risk/metabolic syndrome (WC, HOMA-IR, TG, TC/HDL-c, metabolic risk score, SBP)	WC: $r = -0.317$, $p < 0.001$ HOMA-IR: $r = -0.174$, $p < 0.001$ TG: $r = -0.075$, $p < 0.05$ TC/HDL-c: $r = -0.100$, $p < 0.01$ Metabolic risk score: $r = -0.236$, $p < 0.001$ SBP: $r = -0.031$, $p > 0.05$
Baptista et al., 2016[35]	Portugal	Cross-sectional study	114; (63/51)	7.9–9.7; 8.5(± 0.4); M: 8.6(± 0.4) /F: 8.5(± 0.4)	Countermovement Vertical Jump	Bone health (WBLH BMD, femoral neck BMD, 1/3 radius BMD)	WBLH BMD: Model 1: $\beta = 0.743$, $p < 0.001$ Model 2: $\beta = 0.653$, $p < 0.001$ Femoral neck BMD: Model 1: $\beta = 0.741$, $p < 0.001$ Model 2: $\beta = 0.654$, $p < 0.001$ 1/3 radius BMD: Model 1: $\beta = 0.753$, $p < 0.001$ Model 2: $\beta = 0.658$, $p < 0.001$
Castro-Piñero et al., 2019[51]	Spain	Longitudinal study	511; (270/ 241)	6–10 (237 children) and 12–16 (274 adolescents)	Standing Long Jump	Anthropometric and adiposity status (sum of skinfold) Cardiometabolic risk/metabolic syndrome (HOMA-IR, TG, TC/HDL-c, CVD risk score, SBP)	Sum of skinfold: Children: *Male:* $\beta = -0.437$, $p < 0.001$ Female: $\beta = -0.461$, $p < 0.001$ Adolescents: *Male:* $\beta = -0.698$, $p < 0.001$ Female: $\beta = -0.363$, $p < 0.001$ HOMA-IR: Children: *Male:* $\beta = -0.279$, $p = 0.048$ Female: $\beta = -0.045$, $p = 0.773$

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Table 1 (*continued*)

Study	Country or Region	Design	n; sex(M/F)	Age (years) range, mean (± SD), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
							Adolescents: *Male:* $\beta = -0.094$, $p = 0.513$ Female: $\beta = -0.138$, $p = 0.159$ TG: Children: *Male:* $\beta = -0.6$, $p = 0.101$ Female: $\beta = -0.167$, $p = 0.133$ Adolescents: *Male:* $\beta = -0.008$, $p = 0.950$ Female: $\beta = -0.124$, $p = 0.171$ TC/HDL-c: Children: *Male:* $\beta = -0.235$, $p = 0.037$ Female: $\beta = -0.239$, $p = 0.032$ Adolescents: *Male:* $\beta = -0.221$, $p = 0.046$ Female: $\beta = -0.230$, $p = 0.039$ CVD risk score: Children: *Male:* $\beta = -0.380$, $p < 0.001$ Female: $\beta = -0.268$, $p = 0.017$ Adolescents: *Male:* $\beta = -0.397$, $p = 0.002$ Female: $\beta = -0.216$, $p = 0.017$ SBP: Children: *Male:* $\beta = -0.118$, $p = 0.007$ Female: $\beta = -0.230$, $p = 0.02$ Adolescents: *Male:* $\beta = -0.018$, $p = 0.724$ Female: $\beta = -0.027$, $p = 0.561$
Diez-Fernandez et al., 2015[36]	Spain	Cross-sectional study	1 158; (587/ 571)	8–11; 9.5(± 0.71); M:9.5(± 0.73) /F:9.5(± 0.69)	Standing Long Jump	Cardiometabolic risk/metabolic syndrome (WC, HOMA-IR, TG/HDL-c, cardiometabolic risk index, MAP)	WC: Total: $r = -0.32$, $p < 0.001$ Male: $r = -0.4$, $p < 0.001$ Female: $r = -0.3$, $p < 0.001$ HOMA-IR: Total: $r = -0.24$, $p < 0.001$ Male: $r = -0.27$, $p < 0.001$ Female: $r = -0.14$, $p < 0.05$ TG/HDL-c: Total: $r = -0.23$, $p < 0.001$ Male: $r = -0.25$, $p < 0.001$ Female: $r = -0.14$, $p < 0.05$ Cardiometabolic risk index: Total: $r = -0.29$, $p < 0.001$ Male: $r = -0.37$, $p < 0.001$ Female: $r = -0.22$, $p < 0.001$ MAP: Total: $r = -0.10$, $p < 0.05$ Male: $r = -0.14$, $p < 0.001$ Female: $r = -0.09$, $p < 0.05$
Gjonbalaj et al., 2022[37]	Macedonia	Cross-sectional study	2 197; (1 086/1 101)	6–10; 8.63(± 2.34); M:8.59(± 1.32) /F:8.66(± 3.03)	Standing Long Jump	Anthropometric and adiposity status (BMI, %BF, WC)	BMI: Male: $\beta = -0.043$, $p < 0.001$, $r^2 = 0.171$ Female: $\beta = -0.022$, $p < 0.001$, $r^2 = 0.038$ %BF:

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Table 1 (*continued*)

Study	Country or Region	Design	n; sex(M/F)	Age (years) range, mean (± SD), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
							Male: $\beta = -0.121$, $p = 0.000$, $r^2 = 0.132$ Female: $\beta = -0.102$, $p < 0.001$, $r^2 = 0.079$ WC: Male: $\beta = -0.096$, $p < 0.001$, $r^2 = 0.452$ Female: $\beta = -0.078$, $p = 0.000$, $r^2 = 0.357$
Gruodyte et al., 2009[38]	Estonia	Cross-sectional study	F: 202	13–15; Cont:14.2(± 1.2) /SG:14.2(± 1.0)/SPR:14.2(± 1.1) /GYMN:14.4(± 0.9) /SW:13.8(± 1.3) /CCS:13.9(± 0.9)	Countermovement Jump; RJ15s and RJ30s	Bone health (femoral neck BMD, lumbar spine BMD)	BMD femoral neck: Cont CMJ: Unadjusted: $r = 0.144$, $p > 0.05$; adjusted: $r = 0.206$, $p > 0.05$ RJ15: Unadjusted: $r = 0.087$, $p > 0.05$; adjusted: $r = 0.166$, $p > 0.05$ RJ30: Unadjusted: $r = 0.2$, $p > 0.05$; adjusted: $r = 0.162$, $p > 0.05$ SG CMJ: Unadjusted: $r = 0.141$, $p > 0.05$; adjusted: $r = 0.274$, $p < 0.05$ RJ15: Unadjusted: $r = 0.170$, $p > 0.05$; adjusted: $r = 0.282$, $p < 0.05$ RJ30: Unadjusted: $r = 0.087$, $p > 0.05$; adjusted: $r = 0.204$, $p > 0.05$ SPR: CMJ: Unadjusted: $r = 0.21$, $p > 0.05$; adjusted: $r = -0.033$, $p > 0.05$ RJ15: Unadjusted: $r = 0.473$, $p < 0.05$; adjusted: $r = 0.3$, $p > 0.05$ RJ30: Unadjusted: $r = 0.375$, $p > 0.05$; adjusted: $r = 0.198$, $p > 0.05$ GYMN: CMJ: Unadjusted: $r = -0.173$, $p > 0.05$; adjusted: $r = 0.08$, $p > 0.05$ RJ15: Unadjusted: $r = 0.214$, $p > 0.05$; adjusted: $r = 0.510$, $p < 0.01$ RJ30: Unadjusted: $r = 0.217$, $p > 0.05$; adjusted: $r = 0.489$, $p < 0.05$ SW: CMJ: Unadjusted: $r = -0.211$, $p > 0.05$; adjusted: $r = -0.074$, $p > 0.05$ RJ15: Unadjusted: $r = -0.009$, $p > 0.05$; adjusted: $r = 0.040$, $p > 0.05$ RJ30: Unadjusted: $r = -0.018$, $p > 0.05$; adjusted: $r = -0.036$, $p > 0.05$ CCS: CMJ: Unadjusted: $r = 0.164$, $p > 0.05$; adjusted: $r = 0.261$, $p > 0.05$ RJ15: Unadjusted: $r = 0.216$, $p > 0.05$; adjusted: $r = 0.359$, $p > 0.05$ RJ30: Unadjusted: $r = 0.320$, $p > 0.05$; adjusted: $r = 0.344$, $p > 0.05$ BMD lumbar spine: CMJ: Unadjusted: $r = 0.179$, $p > 0.05$; adjusted: $r = 0.164$, $p > 0.05$ RJ15: Unadjusted: $r = 0.168$, $p > 0.05$; adjusted: $r = 0.189$, $p > 0.05$ RJ30: Unadjusted: $r = 0.3$, $p > 0.05$; adjusted: $r = 0.220$, $p > 0.05$

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Table 1 (*continued*)

Study	Country or Region	Design	*n*; sex(M/F)	Age (years) range, mean (± *SD*), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
							SG: CMJ: Unadjusted: $r = 0.228$, $p > 0.05$; adjusted: $r = 0.401$, $p < 0.01$ RJ15: Unadjusted: $r = 0.269$, $p < 0.05$; adjusted: $r = 0.369$, $p < 0.01$ RJ30: Unadjusted: $r = 0.265$, $p < 0.05$; adjusted: $r = 0.386$, $p < 0.01$ SPR: CMJ: Unadjusted: $r = 0.02$, $p > 0.05$; adjusted: $r = -0.402$, $p > 0.05$ RJ15: Unadjusted: $r = 0.140$, $p > 0.05$; adjusted: $r = -0.358$, $p > 0.05$ RJ30: Unadjusted: $r = 0.17$, $p > 0.05$; adjusted: $r = -0.188$, $p > 0.05$ GYMN: CMJ: Unadjusted: $r = -0.508$, $p < 0.01$; adjusted: $r = 0.106$, $p > 0.05$ RJ15: Unadjusted: $r = -0.218$, $p > 0.05$; adjusted: $r = 0.386$, $p > 0.05$ RJ30: Unadjusted: $r = -0.142$, $p > 0.05$; adjusted: $r = 0.437$, $p < 0.05$ SW: CMJ: Unadjusted: $r = -0.251$, $p > 0.05$; adjusted: $r = -0.087$, $p > 0.05$ RJ15: Unadjusted: $r = -0.121$, $p > 0.05$; adjusted: $r = -0.093$, $p > 0.05$ RJ30: Unadjusted: $r = 0.1$, $p > 0.05$; adjusted: $r = -0.038$ $p > 0.05$ CCS: CMJ: Unadjusted: $r = 0.173$, $p > 0.05$; adjusted: $r = 0188$, $p > 0.05$ RJ15: Unadjusted: $r = 0.285$ $p > 0.05$; adjusted: $r = 0.333$, $p > 0.05$ RJ30: Unadjusted: $r = 0.372$, $p > 0.05$; adjusted: $r = 0.309$, $p > 0.05$
Haapala et al., 2023[39]	Finland	Cross-sectional study	391; (202/ 189)	6–9; 7.6(±0.4); M:7.7(± 0.4) /F: 0.6 (± 0.4)	Standing Long Jump	Inflammatory biomarker (score)	Inflammatory score: Model 1: $\beta = -0.270$, $p < 0.001$ Model 2: $\beta = 0.026$, $p > 0.001$ Model 3: $\beta = -0.120$, $p < 0.001$ Model 4: $\beta = -0.091$, $p < 0.001$
Huang & Malina. 2010[50]	Taiwan, China	Cross-sectional study	102 765; (51 825/ 50 940)	9–18	Standing Long Jump	Anthropometric and adiposity status (BMI)	BMI: 9-10: Female: $r = 0.06$, $p < 0.0001$ Male: $r = 0.04$, $p < 0.0001$ 11-12: Female: $r = 0.11$, $p < 0.0001$ Male: $r = 0.06$, $p < 0.0001$ 13-15: Female: $r = 0.12$, $p < 0.0001$ Male: $r = 0.11$, $p < 0.0001$ 16-18: Female: $r = 0.11$, $p < 0.0001$ Male: $r = 0.09$, $p < 0.0001$
Magnussen et al., 2012[40]	Australia	Cross-sectional study	1 642; (870/ 771)	9, 12 and 15	Standing Long Jump	Cardiometabolic risk/metabolic syndrome (CVD risk score)	CVD risk score: $r = 0.35$, $p < 0.01$

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Table 1 (*continued*)

Study	Country or Region	Design	*n*; sex(M/F)	Age (years) range, mean (± *SD*), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
Mancini et al., 2022[41]	Italy	Cross-sectional study	565; (353/ 212)	10–13; 11.7(± 1.0); M:11.7(± 1.0) /F:11.6(± 1.0)	Standing Broad Jump	Anthropometric and adiposity status (BMI)	BMI: $\beta = -0.123$, $p = 0.227$, $r^2 = 0.07$
Martinez-Tellez et al., 2016[42]	Spain	Cross-sectional study	403; (233/ 170)	71, 133 and 199 for 3-, 4- and 5-year-olds	Standing Long Jump	Anthropometric and adiposity status (BMI, WC)	BMI: $\beta = -0.20$, $p = 0.001$, $r^2 = 0.04$ WC: $\beta = -0.072$, $p < 0.001$, $r^2 = 0.07$
Megawati et al., 2019[43]	Indonesia	Cross-sectional study	50; (23/27)	7–11; 9.94(± 1.0); M:10.13(± 1.1) /F:9.78(± 0.89)	Standing Long Jump	Anthropometric and adiposity status (height, weight, BMI, %BF, WC, WHtR, biceps skinfold, triceps skinfold, subscapular skinfold)	Height: $r = -0.145$, $p = 0.314$ Weight: $r = -0.307$, $p = 0.03$ BMI: $r = -0.321$, $p = 0.023$ %BF: $r = -0.333$, $p = 0.018$ WC: $r = -0.242$, $p = 0.09$ WHtR: $r = -0.218$, $p = 0.128$ Biceps skinfold: $r = -0.228$, $p = 0.111$ Triceps skinfold: $r = -0.356$, $p = 0.011$ Subscapular skinfold: $r = -0.321$, $p = 0.023$
Mello et al., 2023[44]	Brazil	Cross-sectional study	160; (85/75)	6–11; 8.90(± 1.50); M:8.20(± 1.60) /F: 8.30(± 1.50)	Standing Long Jump	Bone health (total aBMD, WBLH aBMD, arms aBMD, trunk aBMD, spine aBMD, hip aBMD, legs aBMD)	Total aBMD: $r = 0.36$, $p < 0.001$; crude analysis: $\beta = 0.001$, $p < 0.001$; adjusted analysis: $\beta < 0.001$, $p = 0.032$, $r^2 = 0.64$ WBLH aBMD: $r = 0.3$, $p < 0.001$; crude analysis: $\beta = 0.001$, $p < 0.001$; adjusted analysis: $\beta < 0.001$, $p = 0.178$, $r^2 = 0.77$ Arms aBMD: $r = 0.25$, $p = 0.001$; crude analysis: $\beta = 0.001$, $p < 0.001$; adjusted analysis: $\beta < 0.001$, $p = 0.407$, $r^2 = 0.51$ Trunk aBMD: $r = 0.3$, $p = 0.007$; crude analysis: $\beta = 0.001$, $p = 0.007$; adjusted analysis: $\beta < 0.001$, $p = 0.554$, $r^2 = 0.69$ Spine aBMD: $r = 0.1$, $p = 0.2$; crude analysis: $\beta = 0.001$, $p = 0.217$; adjusted analysis: β $r = 0.001$, $p = 0.0318$ $r^2 = 0.62$ Hip aBMD: $r = 0.3$, $p < 0.001$; crude analysis: $\beta = 0.001$, $p < 0.001$; adjusted analysis: $\beta < 0.001$, $p = 0.114$, $r^2 = 0.65$ Legs aBMD: $r = 0.37$, $p < 0.001$; crude analysis: $\beta = 0.002$, $p < 0.001$; adjusted analysis: $\beta = 0.001$, $p = 0.006$, $r^2 = 0.72$
Moliner-Urdiales et al., 2010[45]	Spain	Cross-sectional study	363; (177/ 186)	12.5–17.5; 14.8(± 1.2); M:14.8(± 1.3) /F: 14.8(± 1.1)	Standing Broad Jump	Anthropometric and adiposity status (%BF, WC, sum of skinfold, abdominal adiposity)	%BF: Female: $r = -0.29$, $p < 0.001$; $\beta = 0.300$ $p < 001$, $r^2 = 0.208$, r^2 change $= 0.084$ Male: $r = -0.42$, $p < 0.001$; $\beta = -0.52$, $p < 0.001$, $r^2 = 0.208$, r^2 change $= 0.173$ WC: Female: $r = -0.144$, $p = 0.055$; $\beta = -0.149$, $p = 0.055$, $r^2 = 0.1$, r^2 change $= 0.021$ Male: $r = -0.38$, $p < 0.001$; $\beta = -0.421$ $p < 0.001$, $r^2 = 0.133$, r^2 change $= 0.114$ Sum of skinfolds: Female: $r = -0.239$, $p = 0.002$; $\beta = -0.246$, $p = 0.002$, $r^2 = 0.105$, r^2 change $= 0.057$ Male: $r = -0.447$, $p < 0.001$; $\beta = -0.561$, $p < 0.001$, $r^2 = 0.293$, r^2 change $= 0.2$ Abdominal adiposity: R1: *Female:* $r = -0.298$, $p < 0.001$; $\beta = -0.309$, $p < 0.001$, $r^2 = 0.154$, r^2 change $= 0.089$

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Table 1 (*continued*)

Study	Country or Region	Design	n; sex(M/F)	Age (years) range, mean (± SD), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
							Male: $r = -0.411$, $p < 0.001$; $\beta = -0.514$, $p < 0.001$, $r^2 = 0.182$, r^2 change $= 0.169$ R2: *Female:* $r = -0.315$, $p < 0.001$; $\beta = -0.326$, $p < 0.001$, $r^2 = 0.165$, r^2 change $= 0.099$ Male: $r = -0.393$, $p < 0.001$; $\beta = -0.492$, $p < 0.001$, $r^2 = 0.165$, r^2 change $= 0.154$ R3: *Female:* $r = -0.306$, $p < 0.001$; $\beta = -0.246$, $p < 0.001$, $r^2 = 0.153$, r^2 change $= 0.094$ Male: $r = -0.399$, $p < 0.001$; $\beta = -0.499$, $p < 0.001$, $r^2 = 0.157$, r^2 change $= 0.159$
Monyeki et al., 2008[46]	South Africa	Cross-sectional study	1 817; (938/ 879)	7–13	Standing Long Jump	Anthropometric and adiposity status (BMI, %BF, WC, WHtR, FM, FFM, RBM, sum of skinfold, triceps skinfold, subscapular skinfold) Cardiometabolic risk/metabolic syndrome (SBD, DBP)	BMI: $r = -0.021$, $p > 0.05$ %BF: $r = -0.13$, $p < 0.001$ WC: $r = -0.04$, $p > 0.01$ WHtR: $r = 0.038$, $p > 0.05$ FM: $r = -0.106$, $p < 0.001$ FFM: $r = -0.021$, $p > 0.05$ RBM: $r = -0.018$, $p > 0.05$ Sum of skinfolds: $r = -0.117$, $p < 0.001$ Triceps skinfold: $r = 0.126$, $p < 0.001$ Subscapular skinfold: $r = 0.09$, $p > 0.05$ SBP: $r = 0.017$, $p > 0.05$; unadjusted: $\beta = 0.083$, $p = 0.000$; adjusted: $\beta = 0.001$, $p = 0.978$ DBP: $r = 0.001$, $p > 0.05$; unadjusted: $\beta = 0.030$, $p = 0.017$; adjusted: $\beta = -0.003$, $p = 0.816$
Musa et al., 2022[13]	Nigeria	Cross-sectional study	2 047; (960/ 1 087)	12–15; 13.6(± 1.3); M:13.6(± 1.3) /F:13.6(± 1.3)	Countermovement Jump	Cardiometabolic risk/metabolic syndrome (SBP, DBP)	SBP: Male: $r = 0.334$, $p < 0.01$; $\beta = 0.165$, $p < 0.001$ Female: $r = 0.314$, $p < 0.01$; $\beta = 0.263$, $p < 0.001$ DBP: Male: $r = 0.094$, $p < 0.05$; $\beta = 0.026$, $p = 0.592$ Female: $r = 0.118$, $p < 0.01$; $\beta = -0.003$, $p = 0.949$
Steene-Johannessen et al., 2009[10]	Norway	Cross-sectional study	1 592; (854/ 738)	9 and 15	Standing Broad Jump	Cardiometabolic risk/metabolic syndrome (WC, HOMA-IR, HDL-c, TG, metabolic risk score, SBP)	WC: $r = -0.3$, $p < 0.001$ HOMA-IR: $r = -0.16$, $p < 0.001$ HDL-c: $r = 0.06$, $p < 0.001$ TG: $r = -0.09$, $p < 0.001$ Metabolic risk score: $r = -0.2$, $p < 0.001$ SBP: $r = 0.02$, $p > 0.05$
Ubago Guisado 2017[47]	England	Cross-sectional study	121	12–14; 13.1(± 0.1); Swimmers:13.4(± 1.0) /Footballers: 12.8(± 0.9) /Cyclists:13.2(± 1.0) /Non-athletes:12.3(± 0.5)	Standing Long Jump; Vertical Jump	Bone health (WBLH aBMD, femoral neck aBMD, lumbar spine aBMD, hip aBMD)	Vertical Jump WBLH aBMD: $r = 0.471$, $p < 0.01$; model 1: $\beta = 0.273$, $p < 0.001$; model 2: $\beta = 0.277$, $p < 0.001$; model 3: $\beta = 0.105$, $p = 0.163$ Hip aBMD: $r = 0.411$, $p < 0.01$; model 1: $\beta = 0.308$, $p = 0.001$; model 2: $\beta = 0.314$, $p = 0.001$; model 3: $\beta = 0.227$, $p = 0.022$ Lumbar spine aBMD: $r = 0.526$, $p < 0.01$; model 1: $\beta = 0.362$, $p < 0.001$; model 2: $\beta = 0.363$, $p < 0.001$; model 3: $\beta = 0.209$, $p = 0.012$

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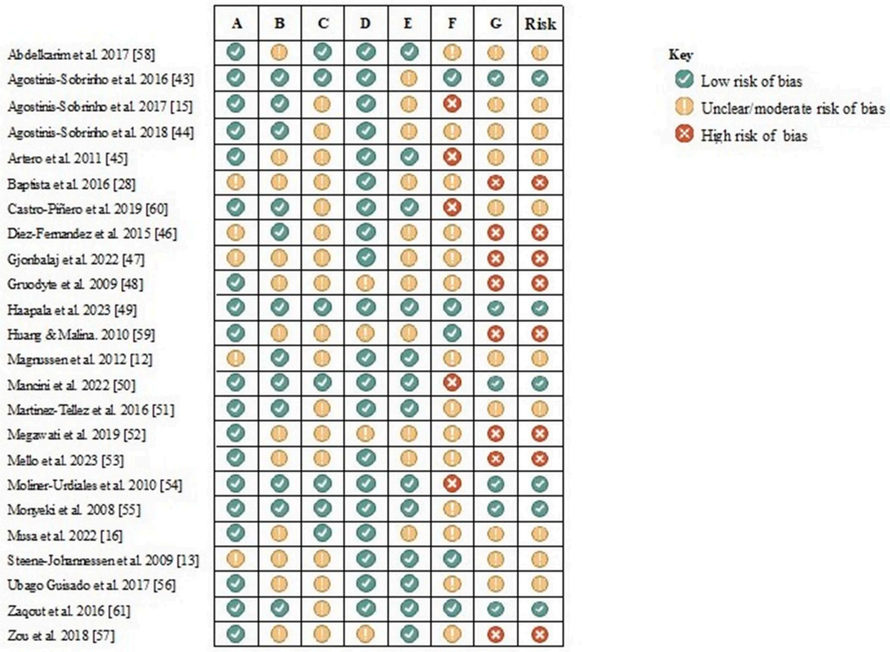
Table 1 (*continued*)

Study	Country or Region	Design	n; sex(M/F)	Age (years) range, mean (± SD), by sex (M/F)	Lower limb strength/ power measure	Health outcome of interest	Associations
							Femoral neck aBMD: $r = 0.349$, $p < 0.01$; model 1: $\beta = 0.244$, $p = 0.011$; model 2: $\beta = 0.249$, $p = 0.008$; model 3: $\beta = 0.169$, $p = 0.102$ Trochanter aBMD: $r = 0.399$, $p < 0.01$; model 1: $\beta = 0.312$, $p = 0.001$; model 2: $\beta = 0.318$, $p = 0.001$; model 3: $\beta = 0.194$, $p = 0.050$ Standing Long Jump WBLH aBMD: $r = 0.553$, $p < 0.01$; model 1: $\beta = 0.262$, $p = 0.001$; model 2: $\beta = 0.255$, $p = 0.001$; model 3: $\beta = 0.113$, $p = 0.134$ Hip aBMD: $r = 0.514$, $p < 0.01$; model 1: $\beta = 0.391$, $p < 0.001$; model 2: $\beta = 0.358$, $p < 0.001$; model 3: $\beta = 0.284$, $p = 0.004$ Lumbar spine aBMD: $r = 0.567$, $p < 0.01$; model 1: $\beta = 0.291$, $p = 0.001$; model 2: $\beta = 0.289$, $p = 0.001$; model 3: $\beta = 0.148$, $p = 0.078$ Femoral neck aBMD: $r = 0.433$, $p < 0.01$; model 1: $\beta = 0.309$, $p = 0.002$; model 2: $\beta = 0.276$, $p = 0.005$; model 3: $\beta = 0.208$, $p = 0.045$ Trochanter aBMD: $r = 0.516$, $p < 0.01$; model 1: $\beta = 0.429$, $p < 0.001$; model 2: $\beta = 0.387$, $p < 0.001$; model 3: $\beta = 0.289$, $p = 0.003$
Zaqout et al., 2016[52]	European countries	Longitudinal study	1 635	6–11; 8.4(±1.6)	Standing Long Jump	Cardiometabolic risk/metabolic syndrome (metabolic risk)	Metabolic risk: Model 1: $\beta = -0.308$, $p < 0.001$ Model 2: $\beta = -0.111$, $p < 0.001$ Model 3: $\beta = -0.111$, $p < 0.001$
Zou et al., 2018[48]	China	Cross-sectional study	449; (246/ 203)	12–17; 12.98(± 1.72)	Standing Long Jump	Anthropometric and adiposity status (Weight, %BF, scapular skinfold, calf skinfold)	Weight: $\beta = 0.423$, $p < 0.001$, $r^2 = 0.514$ %BF: $\beta = -0.096$, $p = 0.013$, $r^2 = 0.514$ Scapular skinfold: $\beta = -0.389$, $p = 0.000$, $r^2 = 0.514$ Calf skinfold: $\beta = -0.165$, $p = 0.016$, $r^2 = 0.514$

n sample, *M* male, *F* female, ± *SD* standard deviation, *r* pooled correlation coefficient, *p* p-value, *β* regression coefficient, *BMI* body mass index, *%BF* body fat percentage, *WC* waist circumference, *CRP* C-reactive protein, *HOMA-IR* homeostasis model assessment for insulin resistance, *HDL-c* high-density lipoprotein cholesterol, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *TG* triglycerides, *TC/HDL-c* total cholesterol/high-density lipoprotein cholesterol, *BMD* bone mineral density, *WBLH* whole body less head;, *CVD* cardiovascular disease, *TG/HDL-c* triglycerides/high-density lipoprotein cholesterol, *MAP* mean arterial pressure, *aBMD* areal bone mineral density, *WHtR* waist to height ratio, *FM* fat mass, *FFM* fat free mass, *RBM* relative body mass, *Cont control group, SG sport games, SPR track sprint, GYMN rhythmic gymnastics, SW swimming, CCS cross-country skiing, CMJ* countermovement jump, *RJ15* rebound jumps for 15 seconds, *RJ30* rebound jumps for 30 seconds.



	A	B	C	D	E	F	G	Risk
Abdelkarim et al. 2017 [58]	✓	!	✓	✓	✓	!	!	!
Agostinis-Sobrinho et al. 2016 [43]	✓	✓	✓	✓	!	✓	✓	✓
Agostinis-Sobrinho et al. 2017 [15]	✓	✓	!	✓	!	✗	!	!
Agostinis-Sobrinho et al. 2018 [44]	✓	✓	!	✓	!	!	!	!
Artero et al. 2011 [45]	✓	!	!	✓	✓	✗	!	!
Baptista et al. 2016 [28]	!	!	!	✓	!	!	✗	✗
Castro-Piñero et al. 2019 [60]	✓	✓	!	✓	✓	✗	!	!
Diez-Fernandez et al. 2015 [46]	!	✓	!	✓	!	!	✗	✗
Gjonbalaj et al. 2022 [47]	!	!	!	✓	!	!	✗	✗
Gruodyte et al. 2009 [48]	✓	!	!	!	!	!	✗	✗
Haapala et al. 2023 [49]	✓	✓	✓	✓	✓	✓	✓	✓
Huang & Malina. 2010 [59]	✓	!	!	!	!	✓	✗	✗
Magnussen et al. 2012 [12]	!	✓	!	✓	✓	!	!	!
Mancini et al. 2022 [50]	✓	✓	✓	✓	✓	✗	✓	✓
Martinez-Tellez et al. 2016 [51]	✓	✓	!	✓	✓	!	!	!
Megawati et al. 2019 [52]	✓	!	!	!	!	!	✗	✗
Mello et al. 2023 [53]	✓	!	!	✓	!	!	✗	✗
Moliner-Urdiales et al. 2010 [54]	✓	✓	✓	✓	✓	✗	✓	✓
Monyeki et al. 2008 [55]	✓	✓	✓	✓	✓	!	✓	✓
Musa et al. 2022 [16]	✓	!	✓	✓	!	!	!	!
Steene-Johannessen et al. 2009 [13]	!	!	!	✓	✓	✓	!	!
Ubago Guisado et al. 2017 [56]	✓	!	!	✓	✓	!	!	!
Zaqout et al. 2016 [61]	✓	✓	!	✓	✓	✓	✓	✓
Zou et al. 2018 [57]	✓	!	!	!	✓	!	✗	✗

Key
✓ Low risk of bias
! Unclear/moderate risk of bias
✗ High risk of bias

Fig. 2. Risk of bias overview of studies included
A = Does the study adequately describe participant sampling procedures and inclusion criteria?
B = Does the study clearly outline the motor competence assessment(s) used (specific measures/procedures/valid)?
C = Does the study provide acceptable reliability information for the motor competence assessment(s) used?
D = Does the study clearly outline the physical activity/physical fitness/psychosocial assessment(s) used (specific measures/procedures/valid)?
E = Does the study provide acceptable reliability information for the physical activity/physical fitness/psychosocial assessment(s) used?
F = Of those who consented to the study, did an adequate proportion have complete data for the motor competence and the physical activity/physical fitness/psychosocial assessments?
G = Overall summary.

negative and moderate ($r = -0.31$, 95% *CI:* -0.45 to -0.14), with high heterogeneity and significance ($I^2 = 92.7\%$, $p < 0.001$). The age moderator potential did not find consistent effects on anthropometric variables. (Supplementary Fig. 1).

3.4.2. Pooled correlation coefficients for lower body muscular strength/power and cardiometabolic risk/metabolic syndrome

Fig. 4A shows that the pooled correlation coefficient of five studies for the association between lower body muscular strength/power and homeostasis model assessment for homeostasis model assessment for insulin resistance (HOMA-IR) was negative and small ($r = -0.20$, 95% *CI:* -0.24 to -0.15), with moderate heterogeneity and significance ($I^2 = 59\%$, $p < 0.001$). Five studies analysed the association between lower body muscular strength/power and cardiometabolic risk index (Fig. 4B). The pooled correlation coefficient was negative and small ($r = -0.27$, 95%*CI:* -0.33 to -0.30), with high heterogeneity and significance ($I^2 = 81.2\%$, $p < 0.001$). The association between lower body muscular strength/power and systolic blood pressure (SBP) of five studies is shown in Fig. 4C. The pooled correlation coefficient was positive and small ($r = 0.14$, 95%*CI:* -0.03 to 0.29), with high heterogeneity and non-significance ($I^2 = 97.9\%$, $p = 0.098$). Three studies examined the association between lower body muscular strength/power and diastolic blood pressure (DBP) (Fig. 4D), with the pooled correlation coefficient being positive and trivial ($r = 0.07$, 95%*CI*: -0.00 to 0.14), high heterogeneity and non-significance ($I^2 = 80.2\%$, $p = 0.063$). The age moderator potential found consistent effects HOMA-IR and DBP variables ($p < 0.001$) (Supplementary Fig. 2A–2D, respectively).

3.4.3. Pooled correlation coefficients for lower body muscular strength/power and bone health

A total of seven studies were evaluated for the association between lower body muscular strength/power and of the femoral neck (Fig. 5). The pooled correlation coefficient was positive and trivial ($r = 0.12$, 95%*CI*: -0.05 to 0.28), with high heterogeneity and non-significance ($I^2 = 49.3\%$, $p = 0.176$). The age moderator potential did not show a consistent effect on bone mineral density (BMD) of the femoral neck. (Supplementary Fig. 3).

3.5. Publication bias

Inspection of the funnel plots and Egger's regression intercepts only revealed statistically significant Egger's regression statistics for the association of lower body muscular strength with DBP ($z = 2.664$; $p = 0.0077$), and with BMD femoral neck ($z = -2.1586$; $p = 0.0309$) (Supplementary Table 1), indicating the presence of a small study effect.[30] The funnel plots for the meta-analyses are shown in Supplementary Data (Figs. 7–9). Some asymmetries can be seen in the relationship between lower body muscular strength with WC and HOMA-IR, where the figures show that the analysis added a hypothetical study on the right in both cases (Supplementary Fig. 7A and Fig. 8A, respectively).

4. Discussion

This meta-analysis provides a comprehensive and systematic review of the association between lower body muscular strength and health indicators in children and adolescents. Overall, a total of 24 studies encompassing eight health parameters (WC, %BF, ΣSF, HOMA-IR, cardiometabolic risk index, blood pressure (SBP and DBP) and bone health) were reviewed. The importance of this analysis lies in the establishment of an inverse association between lower body muscular strength/power and anthropometric parameters, along with the cardiometabolic risk variables.

4.1. Anthropometric and adiposity status

The findings of this meta-analysis evidence a negative association between excess body fat and poor performance in MF tests, particularly explosive and dynamic movements, which was consistent with what was previously demonstrated in children and adolescents.[7] These results are in accordance with previous studies,[53,54] indicating an inverse relationship between lower body muscular strength and body fat levels in the youth population. This could be attributed to the necessity for greater propulsion or lifting of body mass among this population with higher body fat levels compared to their normal-weight peers,[7,55] taking on additional load during weight-bearing tasks[21,45] or difficulty in fitness assessments involving rapid positional changes.[53,56]

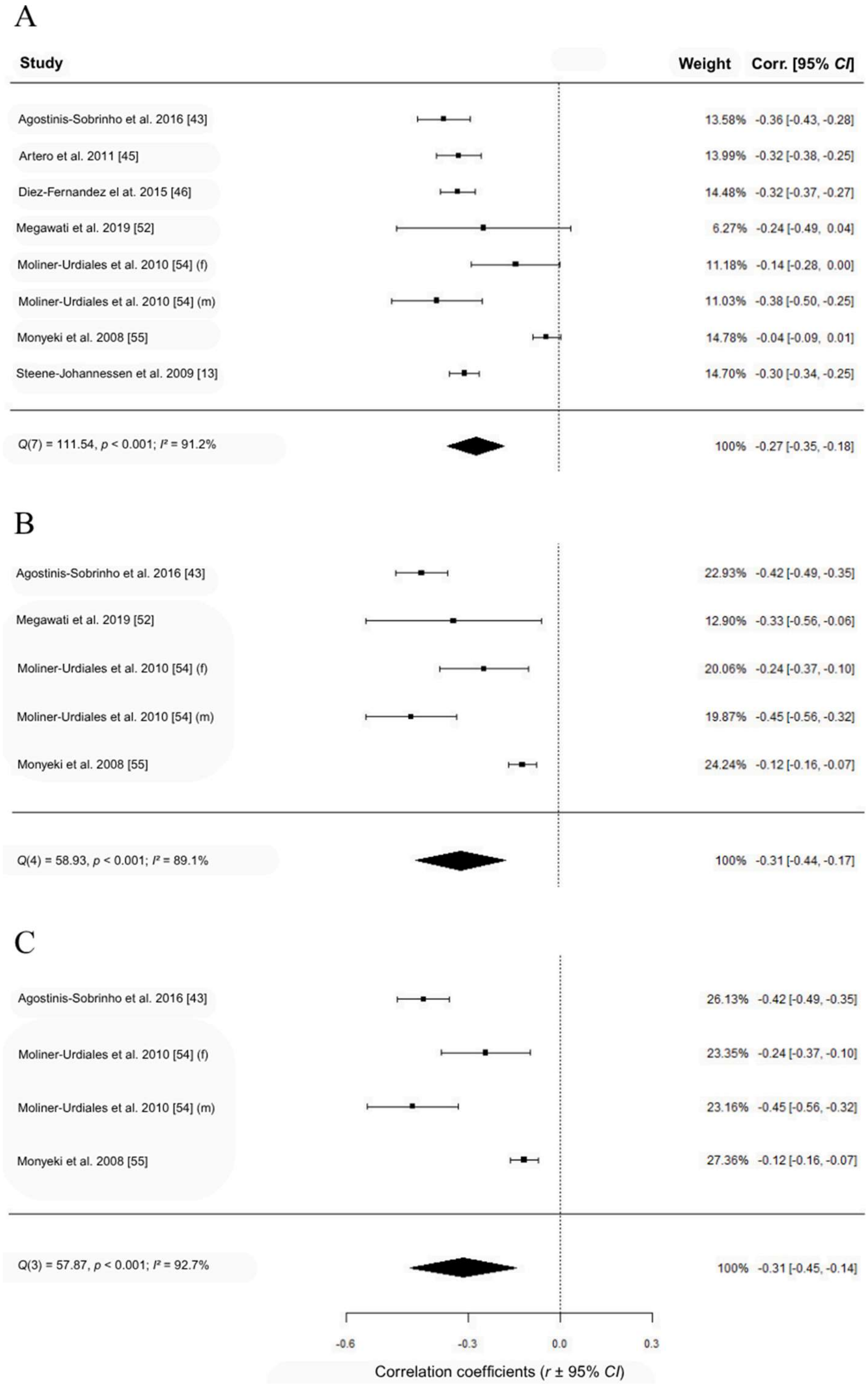


Fig. 3. Forest plot showing the pooled correlation coefficients between lower body muscular strength/power and WC (A), %BF (B) and ΣSF (C). *WC* waist circumference, *%BF* percentage body fat, *ΣSF* sum of skinfolds, *CI* confidence interval, *Q* heterogeneity (Cochran's Q), I^2 heterogeneity, *f* female, *m* male.

There is a clear evidence demonstrating the significance of MF in relation to adiposity among children, potentially mediated by physiological, morphological and psycho-behavioural mechanisms.[7,21] Longitudinal studies have shown that increases in muscular strength correspond to reductions in adiposity,[57,58] suggesting a cause-and-effect relationship.[7] Given the association of fat tissue with energy imbalance, wherein excess energy is stored as adipose tissue,[7] it is reasonable to hypothesize that the protective attributes of MF are linked to its impact on energy expenditure.[45] In this regard, it is known that the skeletal muscle is a highly metabolically active tissue that significantly influences the basal metabolic rate.[59] In addition, elevated levels of MF may indicate increased skeletal muscle mass, enhanced metabolic efficiency of the muscle (such as lipid oxidation and glucose transport capacity), or both, leading to a higher overall daily energy expenditure.[45] Thus, it is necessary to focus on MF training, as it has been shown that a progressive reduction in muscular strength is due to the accumulation of excess body fat in the youth population.

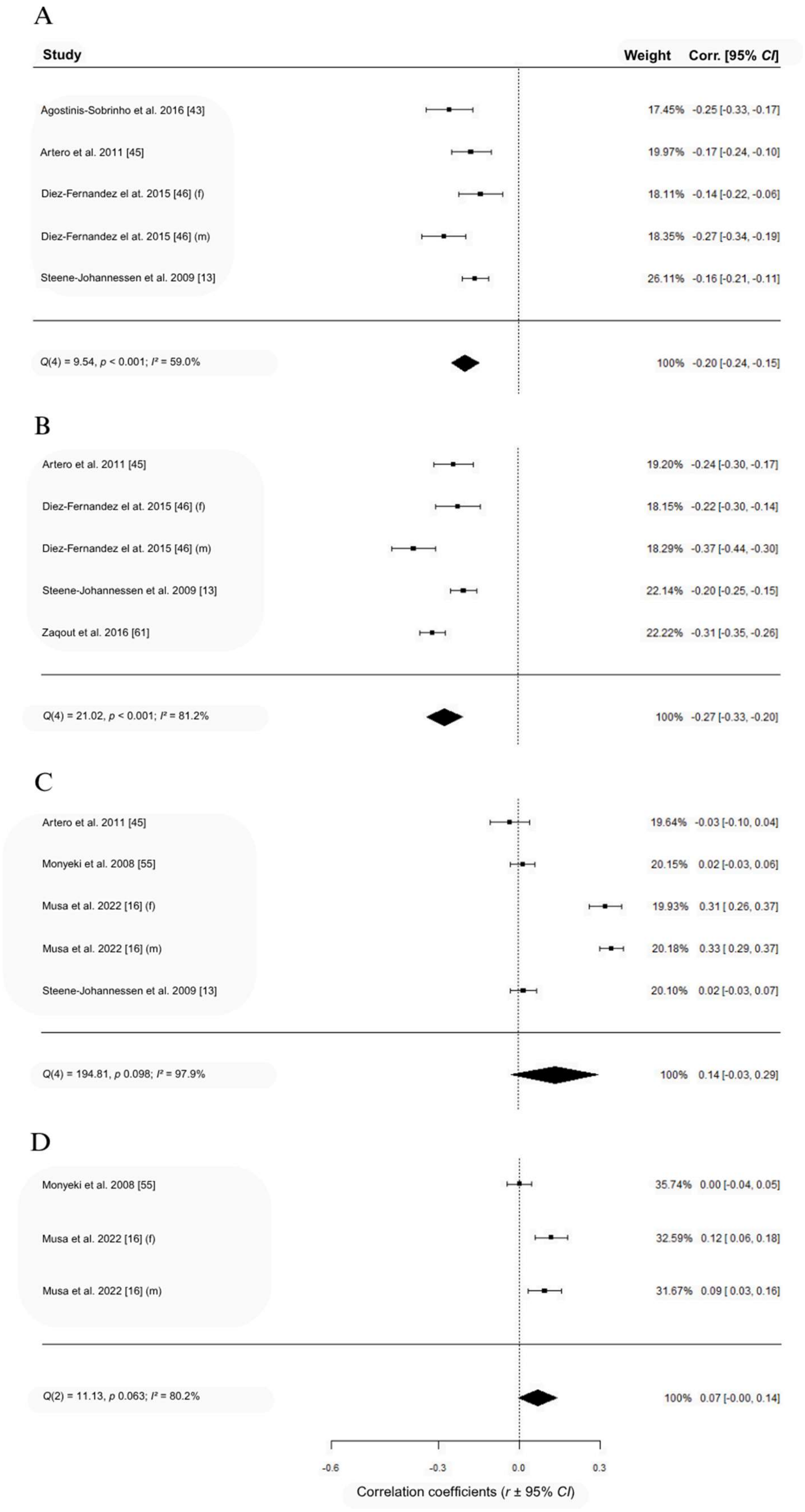


Fig. 4. Forest plot showing the pooled correlation coefficients between lower body muscular strength/power and HOMA-IR (A), cardiometabolic risk index (B), SBP (C), DBP (D). *HOMA-IR* homeostasis model assessment for insulin resistance, *SBP* systolic blood pressure, *CI* confidence interval, *DBP* diastolic blood pressure, *Q* heterogeneity (Cochran's Q), I^2 heterogeneity, *f* female, *m* male.

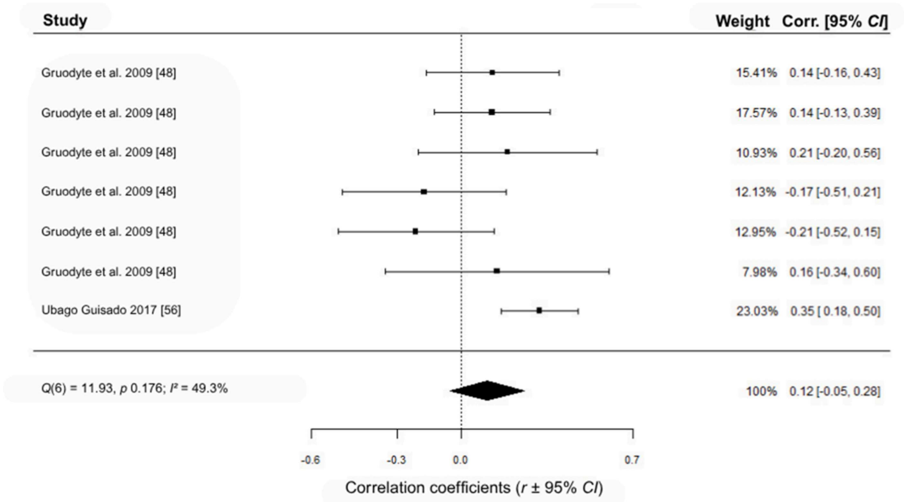


Fig. 5. Forest plot showing the pooled correlation coefficients between lower body muscular strength/power and BMD of the femoral neck. *BMD* bone mineral density, *CI* confidence interval; *Q* heterogeneity (Cochran's Q), I^2 heterogeneity.

4.2. Cardiometabolic risk

Clinical symptoms of cardiovascular disease (CVD) typically emerge in adulthood, but evidence suggests that the origins of CVD begin during youth, as indicated by elevated levels and clustering of recognized risk factors already apparent in childhood.[60,61] Our results support the notion that an optimal level of muscular fitness (MF), independent of cardiorespiratory fitness (CRF) and other confounders,[10,34] may have a positive effect on cardiometabolic risk and the development of metabolic syndrome from an early age, as demonstrated in previous studies.[1,52] In this context, emerging evidence highlights the importance of recognizing the early onset of CVD in children and adolescents.

Although the effect size for the association between lower body muscular strength and insulin sensitivity is small, as observed in the meta-analysis, it is important to recognize that even small effects can have clinical significance, particularly when considering their long-term impact on metabolic health.[61] This is especially relevant given that skeletal muscle, the largest insulin-sensitive tissue in the body, plays a crucial role in insulin-stimulated glucose utilization.[62] Moreover, high MF levels correlate with reduced body fat, improved insulin sensitivity, enhanced β-cell function and increased basal metabolic rate.[63,64] However, a negative correlation between MSF and certain anthropometric measures, such as WC, may be associated with decreased levels of insulin resistance.[21] This evidence supports the previous idea that skeletal muscle is considered the main tissue for glucose and triglyceride metabolism.[6] A study demonstrated that WC decreases the relationship between childhood lower limb strength and insulin resistance outcomes,[21] and this aspect potentially explains our findings. Despite the well-established benefits of muscular strength for reducing cardiometabolic risk factors, further research is needed to better understand the mechanisms driving this relationship.[65]

When examining the association between lower body muscular strength and parameters of blood pressure, our analysis did not observe significant differences. Consistent with our findings, previous scientific literature[52,66] that included blood pressure as an outcome of physical activity in children also did not observe significant effects. It is important to note that these studies were conducted in non-clinical children with normal levels of blood pressure, where a reduction in blood pressure is not expected.[67] Therefore, this evaluation to predict health outcomes would be more effective in youth with increased metabolic risk factors, such as being overweight or at risk of high blood pressure,[68] rather than in healthy children.

4.3. Bone health

Throughout puberty, bone tissue exhibits remarkable responsiveness to osteogenic stimuli.[69] Consequently, researchers have explored the possibility of maximizing peak bone mass during adolescence as a primary preventive measure against osteoporosis in adulthood.[70,71] A positive association between lower body strength and bone outcomes in youth population,[72,73] including total and site-specific bone mineral status[74] has been previously demonstrated. However, despite this evidence, this meta-analysis found no association between lower body strength and femoral neck BMD area. The lack of a positive effect between lower body strength and bone mass may be influenced by several confounding determinants, such as genetics, nutrition, hormones, skeletal age and physical activity.[73,75] Consistent with these results, other studies have shown that lower body strength does not appear to be a significant predictor of bone mineral status.[21,69] Evidence suggests that the relationship between these variables attenuates after adjustment for adulthood,[21,76] indicating that muscular power is only an important predictor of adult bone mass if sustained into adulthood.

Another strong predictor of bone mass during growth and throughout life is lean mass,[77] which, in certain instances, accounts for over 60% of the observed variance independently.[78,79] Longitudinal and intervention studies in prepubertal and peripubertal children have shown that increased weight-bearing activity, particularly that involving the lower limbs, stimulates bone mineral accrual.[80] This relationship may be explained through the mechanostat theory,[81] which posits that bone strength is regulated by processes of modelling and remodelling, dependent on mechanical forces exerted on the skeleton. Given that skeletal muscle constitutes the primary component of lean mass,[1] enhancement in MF associated with muscular development is likely to amplify the forces exerted on bone attachments, thereby promoting bone growth.[79,81] Hence, these findings suggest that lean mass can serve as a mediator of the association between MF and bone outcomes.[82] Improvements in muscular performance often correlate with increases in lean mass, measuring muscular strength could serve as a valuable, simple and reproducible tool for identifying children or adolescents at risk of poor skeletal health.[79]

4.4. Strength and limitations

Although other previous reviews focused on muscular fitness in general are available,[4,7,21] the main strength of this meta-analysis is that it is novel and highly focused. To the best of our knowledge, it is the first review to provide a quantitative and comprehensive evaluation of lower body muscular strength as a predictor of health parameters in children and adolescents. These findings enable the utilization of simple and affordable tests for monitoring health parameters in large populations, particularly among children and adolescents. Additionally, this review adhered to the updated PRISMA guidelines, conducting extensive database searches throughout the review process, and implemented clear and robust inclusion/exclusion criteria (title/abstract/full-text screening, study bias assessment). Strengths of the review included the fact that the evidence was evaluated from more than 20 countries, which represents a broad overview of the objective of the study. Furthermore, our discussion facilitated a detailed examination of potential moderators of the observed association by focusing on a specific component of muscular strength. However, this research is not devoid of limitations. Several challenges are inherent to meta-analyses, such as study bias, limited access to comprehensive data from the included studies, and variations in methodological quality.[25] The findings of this meta-analysis also reveal substantial heterogeneity across several variables, including the anthropometric measures analysed, the cardiometabolic risk index and blood pressure. This variability is likely attributable to differences in the assessment methods employed, as well as variations in population characteristics such as sex, age, health status, and physical fitness levels. These methodological discrepancies and diverse study populations may have contributed to the observed heterogeneity, underscoring the importance of addressing these issues and standardizing assessment procedures in future research to improve comparability and strengthen the robustness of the conclusions. Further, our review only included studies published in English, which could lead to missing information from publications in other languages. It should be noted that the observational design of the included studies, while useful for identifying associations and generating hypotheses, has intrinsic limitations. One major limitation is its inability to establish causal relationships between observed variables. Future research should prioritize experimental and longitudinal designs to better understand causal relationships and mitigate the influence of confounding variables.

5. Conclusion

This systematic review and meta-analyses underscore the importance of evaluating lower body muscle strength as a predictor of overall health in youth. The inverse association between muscular strength and adiposity status, coupled with a positive effect on the cardiometabolic profile, suggests that enhancing lower body muscular strength may be crucial in predicting, from an early age, diseases like obesity and metabolic syndrome. While a direct association between lower body muscular strength and bone mass was not found, lean mass, directly influenced by skeletal muscle, remains a significant predictor of bone health. These findings support the importance of conducting future longitudinal and experimental studies to deepen our understanding of how lower body muscular strength impacts the health of children and adolescents over time. These additional studies will allow us to address specific aspects and establish stronger cause-and-effect relationships. Thereby, our results reaffirm the assessment of lower body muscular strength/power through easy and accurate field tests, such as jump tests, as well as lending support to current guidelines recommending regular engagement in muscle-strengthening physical activities for youth.

CRediT authorship contribution statement

Laura Moreno-Gonzalez: Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Conceptualization. **Antonio Alonso-Callejo:** Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Jose Luis Felipe:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Investigation. **Samuel Manzano-Carrasco:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Leonor Gallardo:** Visualization, Validation, Supervision, Resources, Methodology, Conceptualization. **Jorge Garcia-Unanue:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Investigation, Data curation, Conceptualization.

Manuscript registration statement

The protocol for the review and meta-analysis was registered on the International Prospective Register of Systematic Reviews (PROSPERO) database (registration number: CRD42023473379). This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

L.M.G. acknowledges the Spanish Ministry of Science, Innovation, and Universities for funding the development of their doctoral thesis (Grant Number: FPU22/01538). A.A.-C. expresses gratitude to the Spanish Ministry of Science, Innovation, and Universities for funding the development of their doctoral thesis (Grant Number: FPU21/01758). This research has been developed with the help of Grant EQC2021-006804-P funded by MCIN/AEI/10.13039/501100011033 and by the “European Union NextGenerationEU/PRTR”, Grant EQC2019-005843-P funded by MCIN/AEI/10.13039/501100011033 and ERDF ‘A way of making Europe’ and Grant 2021-GRIN- 31185 cofounded by University of Castilla-La Mancha and ERDF.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smhs.2025.06.004.

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