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Do physical fitness and motor skill performances in underweight children differ from normal weight peers? A meta-analysis

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Abstract

Background Undernourished children are at risk of mortality and infection and tend to present with impaired cognitive and physical development with potentially lower physical fitness and motor skill competence. This meta-analysis aimed to compare the physical fitness and motor skill competence of underweight (UW) 3–12-year-old children to that of normal-weight (NW) peers of the same age.

Methods PubMed, Web of Science, and Scopus were systematically searched (last update: April 4th, 2024). The methodological quality of the studies was assessed with the Scottish Intercollegiate Guideline Network checklist. Pooled standardized mean differences (SMD; Hedges' g) were calculated using random-effects meta-analyses. Heterogeneity was considered too high if the I-squared value exceeded 50%. Then, subgroup analysis was considered. The level of evidence was estimated using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) method.

Results Seventeen studies were included in the meta-analysis on physical fitness, while six focused on motor skills, with one study contributing to both. Overall, children with UW have slightly lower physical fitness (SMD = -0.10) and motor skill competence (SMD = -0.12) compared to their NW peers, but the evidence to support this is very low. In North America and Europe, there was no significant difference in physical fitness between the groups. Asian and African children with UW have slightly but significantly weaker strength than NW peers (Asia: SMD = -0.21 Africa: SMD = -0.27). Asian UW children present with weaker anaerobic capacity (SMD = -0.25), whereas African UW children have less flexibility (SMD = -0.16) than NW peers.

Conclusion UW children are less fit and have weaker motor skills than NW peers. Specifically in developing regions, UW children exhibited slightly but significantly poorer performance in specific fitness domains. Therefore, not all UW children will experience these problems. The heterogeneity across the studies may have masked the true differences. Future research on these children is needed to help us understand their profiles better.

PROSPERO registration number CRD42023446239.

Keywords Children, Fitness, Health-related fitness, School-age children, Undernourished children, Wasting

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Introduction

Undernutrition in children is a serious public health issue, particularly in many low- and middle-income countries (LMIC) [1]. It serves as an umbrella term for a group of disorders that includes stunting (low height-for-age), wasting (low weight-for-height), underweight (low weight-for-age), and thinness (low sex-specific BMI-for-age) [2]. In this study, we use the term"underweight"to refer to various forms of undernourishment. While"undernourished"generally means inadequate nutrition, we specifically use"underweight"to consistently describe children with low anthropometric measurements. Globally, it was estimated that 149 million children under 5 were stunted, 45 million were wasted, and 37 million had overweight and obesity in 2022. Despite the global trend towards overweight and obesity, undernutrition remains an important (public) health issue [2], accounting for approximately 45% of the deaths among children under 5 years of age, mostly occurring in LMIC [3]. According to the World Health Organization (WHO), 190 million of the children and adolescents aged 5–19 years were living with thinness, and 390 million with overweight, including 160 million with obesity [2]. A recent systematic review among children aged 5–19 years showed that the prevalence of moderate to severe underweight (thinness and wasting) decreased globally in girls from 9.2% to 8.4% and in boys from 14.8% to 12.4% between 1975 and 2016. However, this reduction varied significantly by region. The rates of underweight and thinness among school-age children (6–12 years) who live on LMIC still varies between 21 to 36% [4].

Child undernutrition, often reflected in altered physical growth (e.g., stunting), has been associated with developmental challenges, including neurological, cognitive, and behavioral complications [5]. Early-life malnutrition may trigger inflammation, hormonal imbalances, and epigenetic changes, leading to neurodevelopmental disorders, impaired neurogenesis, and developmental delays [6]. While the relationship between early childhood undernutrition and developmental impairments is complex and influenced by multiple socioeconomic,environmental factors, lack of movement opportunities [7–9]. However, studies suggest that child undernutrition can contribute to deficits in gross and fine motor skills, increased fatigability, reduced flexibility, impaired coordination, behavioral difficulties, and cognitive challenges such as lower attention spans, language delays, and learning difficulties [10, 11]. Yet, diverging results have been published on physical fitness and motor skill competence in undernourished children [12, 13].

Physical fitness serves as a significant health indicator during childhood and has been shown to predict health outcomes in later life [5, 14–16] and, is therefore considered a public health priority [17]. Monitoring children's physical fitness should align with encouraging an active lifestyle [18], as it gives them direction and helps them make the necessary adjustments to their daily activities. Physical fitness encompasses the body's overall ability to perform physical activities and includes various components, including cardiorespiratory fitness, muscle strength, muscle endurance, and flexibility [19], all of which are important indicators of overall child health. Physical fitness is also closely related to children's nutritional status [20] Undernourished children often exhibit lower muscle mass, reduced strength, and compromised endurance, which may affect their physical fitness levels compared to their normal-weight peers [21]. Physical fitness is essential for children's growth and overall well-being. It supports both physical health and skill development, playing a crucial role in their overall developmental journey [22]. When evaluating physical fitness, it is essential to assess the functional status of all relevant systems namely, the musculoskeletal, cardiorespiratory, psychoneurological, and endocrine-metabolic systems associated with daily physical activity and exercise. This comprehensive approach is why physical fitness is now considered a vital health indicator and a predictor of morbidity and mortality associated with cardiovascular disease and other health conditions [23–26].

Several studies have found links between physical fitness and nutritional status in children [5, 12, 13, 27, 28]. Results from previous studies indicate that UW children exhibit poorer physical fitness performance than their normal-weight (NW) peers, although the relationship is not always straightforward [29]. Compared to the NW group, UW children, i.e. a combination of stunted and underweight children, perform worse than NW children in most physical fitness tests that require power and strength [5, 16, 21, 30]. However, they seem to excel in endurance tasks [12, 28]. Sometimes, no significant differences are reported on several different (types of) outcomes (including the standing long jump, 50-m sprint, the shuttle run [31], sit-and-reach, sit-ups, and ball throw test [5]). Nutritional deprivation during the growth of children may cause structural, metabolic, and functional changes in skeletal muscle, which manifest as a decrease in the size and number of fast-twitch muscle fibers, yet slow-twitch fibers are spared [32]. Different muscle fiber types affect different aspects of physical performance; these changes would result in a reduced capacity to perform exercise tasks with a high load but of relatively short duration, as shown among groups of stunted, wasted, and underweight children [12, 33]. As such, not only the physical fitness may be limited in these children due to muscle loss, but they may also experience difficulties in developing their motor skills. A good nutritional status is known to have a positive and significant effect on the development of both gross and fine motor skills in early childhood [34]. Good nutritional status of the child leads to healthy and strong bodies in children, enabling them to perform activities that support the development of motor skills [34].Motor competence refers to an individual's ability to perform various motor tasks, encompassing the coordination of both fine and gross motor skills essential for carrying out daily activities [35]. Gross motor competence plays a vital role in a child's growth, development, and ability to engage in an active lifestyle [35]. It is characterized by proficiency in fundamental movement skills such as throwing, catching, and running, which are ideally acquired during the preschool and early school years. Developing these skills early on supports overall motor development and enhances participation in physical activities [36, 37]. It is, therefore, reasonable to assume that UW children may experience lowered motor skill competence compared to their NW peers [30, 38]. Yet, diverging results have been reported in the literature [13].

Given these conflicting results available in the literature on physical fitness and motor skills, a meta-analysis would help disentangle the performances of UW children compared to their NW peers and establish a physical fitness and motor skill profile in these children. This study, therefore, aims to investigate whether there are differences in physical fitness and motor skills measures between UW and NW children in the age group 3 to 12 years old. This age range was chosen because it encompasses early to late childhood, a crucial stage for the development of motor and physical skills. Children below the age of 3 generally struggle to complete standardized assessments reliably, whereas those over 12 may experience pubertal changes and shifts in lifestyle that can introduce variability in their performance. We hypothesize that UW children will present with poorer physical fitness and motor skill performances compared to their NW peers in this age range.

Methods

Protocol registration

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (updated PRISMA guidelines 2020). The study protocol was registered in PROSPERO (registration number CRD42023446239).

Eligibility criteria

The PICOS criteria (Population, Intervention, Comparison, Outcome, and study design) were used for study selection. The studies discussing the physical fitness and motor skill performance among UW children aged 3–12 years old, as reported in the literature, were included for data extraction.

Population

To fulfill the criterion, children between 3 and 12 years of age had to be diagnosed with undernutrition using the WHO growth standard and reference without bilateral pitting edema. Literature on children with overweight/obesity and adolescents (age > 12 years) or children under 3 years, children with medical complications, chronic diseases such as cardiovascular, metabolic (e.g. diabetes mellitus), neurological (e.g. cerebral palsy), musculoskeletal (e.g. torticollis), or neurodevelopmental disorders (e.g. autism spectrum disorder) were excluded.

Comparator

Includes NW children.

Outcome

Any domain of physical fitness or motor skill competence was included if it was assessed using a field-based assessment tool. Raw values for performances, including a mean/median with a standard deviation (SD), an interquartile range (IQR), or a 95% confidence interval (95% CI), had to be reported for both groups.

Design and Language

Case–control or comparative cross-sectional studies were included in this review. Any other design was excluded, such as randomized controlled trials, conference proceedings/reports, abstract only, case reports, case series, newspaper, qualitative formative assessment, discussion papers, thesis dissertation papers, unpublished papers, and any language other than English. ***Search Methods.***

The electronic database Medline (PubMed interface), Scopus, and Web of Science were searched using the PICOs method (UW children between age 3 and 12 (P), NW children (C), numeric values for field-based physical fitness and/or motor skill performance measures (O), case–control design (S)). The initial search string was developed in PubMed and then adjusted for the other databases (Appendix.4). A systematic approach for finding relevant articles was employed by combining Medical Subject Headings (MeSH) and free-text keywords with Boolean operators ("AND" and "OR"), truncation, and field tags. The final search was updated on the 4th of April 2024. Finally, backward citation tracking was applied to all included studies.

Screening and Study Selection

Relevant studies were identified in two screening phases (title/abstract and full text) using predefined selection criteria (order: population, intervention, outcome, study design, and language). Two independent reviewers (YD, ES) selected the studies. Studies were screened on full text during the first screening phase in case of ambiguity. Discrepancies regarding the screening were discussed until a consensus was reached. If consensus could not be reached, a third reviewer's opinion (EV) was decisive. Records were maintained for the reasons of exclusion during title/abstract and full-text screening.

Risk of Bias Assessment

The risk of bias was addressed with the Scottish Intercollegiate Guideline Network (SIGN) checklist, which has been designed specifically to rate case–control methodology. Two independent researchers (YD and ES/LV or BH) assessed the risk of bias in each study. Discrepancies were deliberated until a consensus was reached. If consensus could not be reached, a third reviewer's opinion (EV) was decisive.

The SIGN checklist considers the following questions: 1) The study addresses an appropriate and focused question, 2) The cases and controls are taken from comparable populations, 3) The same exclusion criteria are used for both cases and controls, 4) What percentage of each group (cases and controls) participated in the study, 5) Comparison is made between participants and non-participants to establish their similarities or differences, 6) Cases are clearly defined and differentiated, 7) It is established that controls are non-cases, 8) Measures were taken to prevent knowledge of primary exposure influencing case ascertainment from controls, 9) Exposure status is measured in a standard, valid and reliable way, 10) The main potential confounders are identified and taken into account in the design and analysis, 11) Confidence intervals were provided. The reviewers rated each question with the options 'yes,' 'no,' or 'can't say'. After a consensus meeting with both reviewers, all articles received an overall score classified as low, acceptable, or high quality [39]. High quality indicates that further research is unlikely to substantially alter our confidence in the effect estimate. Acceptable quality suggests that future research is likely to significantly influence our confidence in the estimate and may lead to changes. Low quality signifies that future research is highly likely to impact our confidence in the estimate and is likely to result in changes.

Data Extraction and Synthesis of Results

Information regarding the population (number of UW participants, mean age (SD) and age range, sex distribution, height, weight, and number of stunted children), comparator (NW children: number of participants, their mean age (SD), age range, sex distribution, height and weight), outcomes (physical fitness and motor skill test results of performance (mean and SD/95% CI or median and IQR) for both the UW and NW group) were extracted from each study by one reviewer (YD), and its accuracy was checked by a second reviewer (EV).

Data-analysis

Random-effects meta-analyses were calculated using SPSS 29.0 to estimate the pooled standardized mean differences (SMD) in physical fitness and motor skill competence. The SMDs (at the individual study level) were calculated using Hedges' g. The SMDs can be interpreted as small (0.2), medium (0.5), or large (0.8). The prediction interval was calculated alongside the SMDs, which represents the interval within which the effect size of a new study would fall if this study was selected at random from the same population of the studies already included in the analyses. The prediction interval is a measure of the dispersion of the true effects across studies [40]. Additionally, heterogeneity was determined by calculating the I^2, representing the percentage of variation across studies. Higher I^2 values (> 50%) indicate more heterogeneity among individual studies. If the heterogeneity was too large (> 50%), we planned a subgroup analysis. Both the 'physical fitness' and 'motor skills' were subclassified according to the type of construct of the outcome measures. Physical fitness was divided into strength/power, anaerobic capacity, aerobic capacity, and flexibility, and the motor skills into balance, locomotor skills, ball skills, coordination, and manual dexterity. For 'physical fitness,' we also considered the continent, i.e., the origin of the sample, as a grouping variable. Continent was considered to account for potential regional differences in children's physical fitness [41]. Countries within the same continent often share similar environmental, cultural, socioeconomic, and policy-related factors that may influence these outcomes. Grouping studies by continent helps reduce heterogeneity and allows for more meaningful comparisons.

Level of evidence

The quality of evidence was appraised using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) method (25). Study limitations, inconsistency of results, indirectness of evidence, imprecision, and publication bias were used to assess the quality of the evidence. Each test underwent a thorough assessment of the certainty of the evidence, considering these factors. The precision of the results was evaluated based on the magnitude of the 95% confidence intervals (CIs). Smaller confidence intervals indicated higher precision, providing the sample size was adequate. The consistency of the results was determined by analyzing the variability in the point estimates across studies, the overlap of the 95% CIs, and the degree of heterogeneity (as measured by the I^2 statistic). The directness of the evidence was assessed by examining differences in the characteristics of the study populations and variations in the outcome measures used across the studies. Publication bias was assessed using a funnel plot. The level of evidence was downgraded by one level when asymmetry was present, or the pattern of distribution did not resemble an inverted funnel. One reviewer (YD) assigned the level of evidence, which was checked by a second reviewer (EV).

Results

Information source and search strategy

The literature search generated in the three different electronic databases resulted in 4476 studies. After removing 1713 duplicates, a total of 2763 papers were screened, and 2682 papers were excluded based on title and abstract. Finally, 81 studies were selected for full-text review, 22 of which were eligible and included for risk of bias assessment, data extraction, and analysis. Backward citation tracking did not reveal any additional relevant papers. Figure 1 depicts the selection process.

Risk bias assessments

The SIGN checklist (Table 1) indicates that the methodological quality was acceptable in 18 studies (81.8%) and

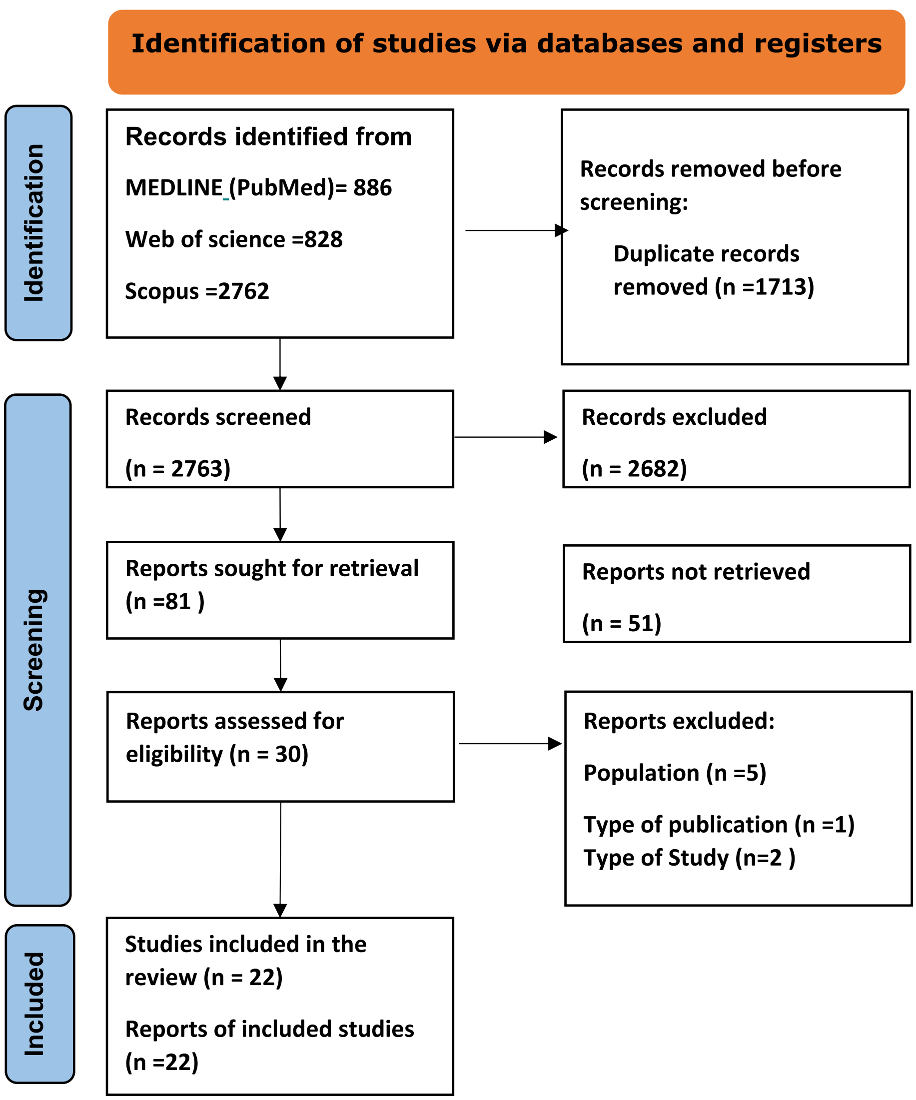

Fig. 1 Prisma flow diagram of the study selection

Table 1 Critical appraisal (Scottish Intercollegiate Guidelines Network (SIGN)

Authors	SIGN-checklist items											Overall rating
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	1.11	
Armstrong 2017	+ +	+ +	+ +	/	-	+ +	/	+ +	+ +	+ +	+ +	Acceptable
Arsenault 2011	+ +	+ +	+ +	/	-	+ +	/	+ +	+ +	+ +	+ +	Acceptable
Battaglia 2021	+ +	+ +	+ +	/	-	+ +	/	+ +	+ +	+	+ +	Acceptable
Bénéfice 1998	+ +	+ +	+ +	/	-	+ +	+	+	+ +	+	+ +	Acceptable
Chen 2022	+ +	+ +	+ +	/	-	+ +	+	+	+ +	+	+ +	Acceptable
Chowdhury 2010	+ +	+ +	+ +	/	-	+ +	+	+	+ +	+	+ +	Acceptable
Goldstein 2020	+ +	+	+	/	-	+	+ +	+ +	+ +	+ +	+	Acceptable
Gontarev 2018	+ +	+ +	+ +	/	-	+ +	+	+	+ +	+	+ +	Acceptable
Kryst 2016	+ +	+	+ +	/	-	-	+	+	-	+	+ +	Low
Lopes 2018	+ +	+	+ +	/	-	+ +	+	+	+ +	+	+ +	Acceptable
Malina 2011	+ +	+	+ +	/	-	+ +	+	+	+ +	+	+ +	Acceptable
Monyeki 2005	+ +	+ +	+	/	-	+	+	+ +	+ +	+ +	+ +	Acceptable
Roberts 2012	+ +	+	+ +	/	-	+ +	+	+	+ +	+	+	Acceptable
Santos 2020	+ +	+ +	+ +	/	-	+ +	+	+	+ +	+ +	+	Acceptable
Serrano-Gallén 2020	+ +	+	+	/	-	+	+	+ +	+ +	+ +	+	Acceptable
Šekeljić 2019	+ +	+ +	-	/	-	-	+	+ +	-	+	+	Low
Shang 2010	+ +	+ +	+	/	-	+ +	+	+ +	+ +	+ +	+	Acceptable
Smith 2020	+ +	+ +	+ +	/	-	+ +	+ +	+ +	+ +	+ +	+	Acceptabe
Verbecque 2022	+	+ +	+	/	-	+ +	+	+ +	+ +	+ +	+	Acceptable
Yip 2022	+ +	+	+	/	-	+	+	-	+	+ +	+	Low
Yip 2024	+	+	+	/	-	+	+	-	+	+	+	Acceptable
Zhang 2019	+	+ +	+	/	-	+	+	+ +	+ +	+ +	+	Acceptable

Legend: 1.1: The study addresses an appropriate and clearly focused question, 1.2: The cases and controls are taken from comparable populations, 1.3: The same exclusion criteria are used for both cases and controls; 1.4: What percentage (%) of each group (cases and controls) participated in the study, 1.5: Comparison is made between participants and non-participants to establish their similarities or differences, 1.6: Cases are clearly defined and differentiated from controls, 1.7: It is clearly established that controls are non-cases, 1.8: Measures will have been taken to prevent knowledge of primary exposure influencing case ascertainment, 1.9: Exposure status is measured in a standard, valid and reliable way, 1.10: The main potential confounders are identified and taken into account in the design and analysis, 1.11: Confidence intervals are provided, 2.1 How well was the study done to minimize the risk of bias or confounding?.

" + + " All or most of the criteria have been fulfilled. Where they have not been fulfilled the conclusions

of the study or review are thought very unlikely to alter. " + " Some of the criteria have been fulfilled. Those criteria that have not been fulfilled or not adequately described are thought unlikely to alter the conclusions."- " Few or no criteria fulfilled. The conclusions of the study are thought likely or very likely to alter; H: High Quality, A: Acceptable quality; R: Reject

low in four studies (18.2%). All studies tackled a pertinent and well-defined research question, clearly distinguished between cases and controls, identified the primary confounding variables during the design and/or analysis and clearly establish whether controls were non-cases. The majority of the studies drew the cases and controls from a comparable population (95.5%), but most studies did not address whether measures were taken to prevent knowledge of primary exposure (90.9%), nor did they make a comparison between participants and non-participants (95.4%). None of the studies were clear about the percentage of cases and controls that participated in the study relative to the number of invited participants.

Study characteristics

The twenty-two included studies have investigated a total number of 273 134 children. Five studies were conducted in African countries: one in Senegal [42], three studies in South Africa, and one in both Ghana and South Africa [5, 21, 28, 43]. Five studies were conducted in Asian countries: four in China [16, 31, 44, 45] and one in India [30]. Six studies were done in Europe: one in Serbia [38], one in Macedonia [46], one in Spain [47], one in Portugal [48], one in Italy [49], and one in Poland [50]. One study was done in North America [51], and two in South America [51, 52]. One study was done all across the United States of America [53]. Three studies were done in rural areas [28, 30, 42], whereas ten studies in urban areas [31, 38, 44, 47–51, 54, 55] and nine studies in both rural and urban settings [5, 16, 21, 33, 43, 45, 46, 52, 53]. Sample sizes ranged from 120 to 96,828 per individual study with a total of 21,321 UW children with a mean age of 10.3 (SD: 1.7) and 251 813 NW children with a mean age of 10.8 (SD: 2.2). Among the twenty-two studies analyzed, nineteen were identified as cross-sectional studies, while three were classified as longitudinal studies (Table 2). In the studies reviewed, the classification of nutritional status in the included studies primarily relied on anthropometric indicators, with BMI-for-age being the most common measure. However, there was significant variation in the reference standards and cut-off points utilized. Specifically, nine studies applied the WHO growth standards [5, 30, 31, 38, 42, 46, 48, 51, 52], three used the IOTF criteria [21, 44, 55], one relied on the CDC reference population [53], and four followed Cole et al.'s cut-off points [33, 47, 49, 50]. One study combined WHO and CDC references [16], while another employed country-specific standards [28]. Additionally, three studies did not clearly report the reference standards used [43, 45, 54]. Table 2 contains the population characteristics of the included studies.

Outcome measures

Physical fitness was assessed using various test batteries across studies: The European Test of Physical Fitness test battery (Eurofit) [5, 28, 44, 50–52], the FITness testing in Preschool children (PREFIT) battery [47], the PERFormance and FITness (PERF-FIT) test battery [21] and the Chinese National Survey on Student's Constitution and Health (CNSSCH) guidelines [45]. Additionally, five studies [31, 33, 42, 45, 46] utilized a combination of individual fitness tests, including standing long jump, shuttle run, sit and reach, grip strength, endurance running, sprint tests, and others. Motor skill performance was assessed using different test batteries, including Körperkoordinationstest für Kinder (KTK) [48, 49, 54], a selection of test items of the Bruininks–Oseretsky Test (BOT) series, the BOT short form [30, 53], and the Movement Assessment Battery for Children (MABC) [53]. One study evaluated nine motor abilities by eighteen test battery developed by Kurelic et al. (1975) [56]. The outcome measures are listed in Table 2, which outlines the characteristics of the included studies and are described in detail in Appendix Table A.1, which provides a description of the applied outcome measures.

Physical fitness and motor skill performances

The main results regarding physical fitness performance in UW children compared to their NW peers are summarized in Table 3 and Fig. 2, including the mean effects size and its 95% confidence interval and prediction interval.

The overall random-effects meta-analysis [5, 16, 21, 28, 31, 33, 42–47, 50–52, 54, 55] revealed that UW children exhibit slightly but significantly poorer physical fitness compared to their NW peers (SMD = −0.10, 95% CI = [−0.14, −0.07], $p < 0.001$. However, the heterogeneity between the included studies was very large ($I^2 = 95\%$), as can be seen graphically *(*Appendix 1*)* and the prediction interval (−0.51 to 0.31) indicates a high degree of dispersion for the true effect size.

Because of diverse samples concerning their origin (African, Asian, North American, European) and the different constructs being measured with the tests classified as physical fitness, subgroup analyses were performed using two grouping variables: continent (including Asia, North America and Europe, and Africa) and subcategories of physical fitness (strength/power, anaerobic capacity, aerobic capacity and flexibility).

For Asia, when combining all measures, there was a significantly lower performance for the UW children but again rather small-sized (SMD = −0.14, 95% CI = [−0.18; −0.10], $p < 0.001$, $I^2 = 96\%$) *(*Appendix 1.*1).* The estimate of the true effect size shows high dispersion (prediction interval [−0.45; 0.16]).The subgroup analysis revealed that *Asian UW children* performed significantly poorer on measures of strength and power (SMD = −0.21, 95% CI = [−0.28, −0.14], $p < 0.001$, $I^2 = 97.3\%$). They particularly tend to have difficulties with tasks requiring (sub)maximal strength/power (SMD = −0.24, 95% CI = [−0.32;−0.15], $I^2 = 96.2\%$) *(*Appendix 1.*2).* Additionally, UW children showed slightly, but significantly, lower anaerobic capacity compared to their NW peers (SMD = −0.15, 95% CI = [−0.18, −0.12], $p < 0.001$, $I^2 = 12\%$). However, no significant difference was found between UW and NW children on measures of aerobic capacity (SMD = 0.01, 95% CI = [−0.01, 0.03], $p = 0.28$, $I^2 = 45.5\%$).

In *Europe and North America,* the subgroup analysis results indicated no significant difference between UW and NW children of strength/power measurements (SMD = −0.05, 95% CI = [−0.12, 0.02], $p = 0.17$, $I^2 = 80.8\%$), aerobic capacity (SMD = 0.01, 95% CI = [−0.23, 0.25], p = 0.25, $I^2 = 87.9\%$) or flexibility (SMD = −0.05, 95% CI = [0.10, 0.01], $p = 0.09$, $I^2 = 0\%$). As shown in Table 3, the prediction interval indicates a high degree of dispersion [−0.49; 0.40].

The subgroup analysis for the data retrieved from *African UW* children showed that they had small-sized, significantly poorer physical fitness performance compared to NW children (SMD = −0.14, 95% CI = [−0.24, −0.03], $p = 0.01$, $I^2 = 86\%$) *(*Appendix 2*).* The subgroup analysis result revealed that African UW children experienced significantly more difficulties in producing lower limb strength (SMD = −0.34, 95% CI = [−0.56, −0.12], $p < 0.001$, $I^2 = 76.6\%$) or (sub) maximal strength power (SMD = −0.34, 95% CI = [−0.46, −0.21], $p < 0.001$, $I^2 = 64.7\%$) *(*Appendix 2*.**1 and 2.2).*** They also presented with lower body flexibility (SMD = −0.16, 95% CI = [−0.27, −0.04], $p < 0.01$, $I^2 = 20.8\%$) compared to NW peers. As shown in Table 3, the prediction interval indicates a high degree of dispersion [−0.70; 0.43]).

Table 2 Characteristics of the Included Studies

Study/Reference	Study design	Study duration	Country	Rural versus urban	Number of children		Age range (years)	The instrument/battery for assessing physical fitness/motor skill	PF/MS
					Total	Boys			
Armstrong 2016	CS	2001–2004	South African children	Both	10 285	5 604	6–13	**EUROFIT**: standing long jump, shuttle run, sit and reach, sit-ups and cricket ball throw	PF
Arsenault 2011	CS	2006	Bogota, Colombia	Urban	1945	916	5–12	**EUROFIT**: shuttle run, standing long jump	PF
Battaglia 2021	CS	2019- 2020	Italy	Urban	1 961	1 026	6–13	**KTK**: jumping laterally, shifting platforms, hopping on one leg	MS
Bénéfice, 1998	CS	/	Senegal	Rural	140	66	8.5–13.5	50-m dash, standing long jump, throw, grip strength, step-test	PF
Chen 2022	L	/	Xinjiang China	urban and rural	17 356	8671	7–18	Chinese National Survey Students Constitution and Health guidelines: grip strength, standing long jump, sit and reach, 50-m dash, endurance run	PF
Chowdhury 2010	CS	/	Santal, India	Rural	841	427	5–12	**BOT-2-SF**: full push-ups, sit-ups	PF
								BOT-2-SF: drawing lines through crooked path, folding paper, copying a square, copying a star, transferring pennies, jumping in place, tapping feet and finger, walking forward on a line, standing on one leg, one-legged stationary hop, dropping and catching ball, dribbling a ball,	MS
Goldstein 2020	CS	/	Israel	Urban	286	144	7–9 years	Standing long-jump, vertical jump test, bent arm hang test, modified pull-up test	PF
								KTK	MS
Gontarev 2018	CS	2013	Macedonia	Both	9 081	4 608	6–14 years	**EUROFIT**: sit-ups, bent arm hang, handgrip test, sit and reach, 4× 10 shuttle run, standing broad jump	PF
Kryst 2016	L	2007–2011	Poland: Kraków and Tarnów	Urban	469	252	4–6 years	**EUROFIT**: sit and reach, standing broad jump, handgrip test	PF
Lopes 2018	CS	/	Azores islands, Portugal	Urban	3 738	1 912	6–10	**KTK**	MS
Malina 2011	CS	/	Mexico	Both	152	73	6–12	Sit and reach, sit-ups, distance run, hand grip strength, standing long jump, 50-m dash	PF
Monyeki 2005	CS	2000	South Africa	Rural	855	462	7–14	**EUROFIT**: bent arm hang, standing long jump, sit-ups, sit and reach, 10 × 5 m shuttle run, plate tapping and flamingo balance	PF
Roberts 2012	CS	2001–2008	all across the United States	Both	4 650	2 150	4.6–6.2	**BOT-MP**: standing long jump, balance on one foot, skipping 8 steps	PF
								MABC: Catching beanbag, walking backwards	MS

Table 2 (continued)

Study/Reference	Study design	Study duration	Country	Rural versus urban	Number of children		Age range (years)	The instrument/battery for assessing physical fitness/motor skill	PF/MS
					Total	Boys			
Santos 2020	L	2009- 2010	Peru, South America	Both	483	246	6–12 year	**EUROFIT**: grip strength, standing long jump, shuttle-run **AAHPERD**: 12 min run	PF
Serrano-Gallén 2022	CS	2019	Cuenca, Spain	urban	150	70	3–6 years	**PREFIT**: grip strength, standing long jump, sit and reach, 4 × 10 m shuttle run, 20-m shuttle run	PF
Šekeljić 2019	CS	/	Serbia	Urban	180	180	10	Standing long jump, throwing a medicine ball, lifting the trunk, stretching the trunk, Hanging pull-ups (sec), grip strength, 20-m run, 30-m run, hand plate tapping, leg plate tapping, deep bent(cm), spagat(cm)	PF
								Standing on one leg across the balance bench, standing on one leg with eyes closed, twenty steps with moving through the sticks, bouncing of a ball, shooting a horizontal target, darts	MS
Shang 2010	CS	/	Eastern China	Urban	226	70	6–12	Standing long jump, 50-m dash, 8 × 50 m shuttle run	PF
Smith 2020	CS	2015	South Africa	Both	965	498	8–12	**EUROFIT**: 20-m shuttle run test, grip strength, standing long jump	PF
Verbecque 2022	CS	2019	Ghana and South Africa	Both	853	459	5.8–12.9	**PERF-FIT**: running, stepping, side jump, standing long jump (peak power), overhead throw	PF
Yip 2022	CS	2017–2018	Hong Kong, China	Urban	5 909	2 688	6–17	**EUROFIT**: grip strength, Push-ups, mini-sit-ups, sit and reach, 6 min run/walk, 9 min run/walk	PF
Yip 2024	CS	2018- 2019	Hong Kong China	Urban	90 684	46 707	6–12	**EUROFIT**: grip strength, sit-ups, sit and reach, endurance run	PF
Zhang 2019	CS	2015	China	Both	5 254	2 526	8.6–12.5	15-m PACER, standing long jump, 50-m sprint	PF

Abbreviations: CS: cross-sectional; L: longitudinal; PF: Physical fitness; MS: motor skills; KTK: Körperkoordinationstest für Kinder; BOT-2-SF: Bruininks–Oseretsky Test of Motor Proficiency-Second Edition, short form; MABC: Movement Assessment Battery for Children; PERF-FIT: Performance and fitness battery; AAHPERD: The American Alliance for Health, Physical Education and Recreation Distance run; EUROFIT: European Fitness test battery

Table 3 Standardized mean differences in physical fitness and motor skills between underweight and NW children

	Number of studies	% of insignificant results	Standardized Mean Difference	95% confidence interval		Prediction interval		Heterogeneity (I^2)
				Lower	Upper	Upper	Lower	
Physial Fitness (overall)	17	64.5%	−0.10	−0.14	−0.07	−0.51	0.31	94.7%
Asia (all absolute measures)	6	63.9%	−0.14	−0.18	−0.10	−0.60	0.18	96%
- Strength/Power	5	41%	−0.21	−0.28	−0.14	−0.60	0.18	97.3%
o *Upper limb*	2	16.7%	−0.34	−0.45	−0.22	−0.77	0.09	95.9%
o *Lower limb*	3	66.7%	−0.09	−0.18	−0.001	−0.40	0.22	87.3%
o *Trunk*	1	0%	−0.15	−0.24	−0.05	−1.38	1.08	94.9%
o *(Sub)maximal*	5	44%	−0.24	−0.32	−0.15	−0.66	0.19	96.2%
o *Endurance*	2	33.3%	−0.11	−0.18	−0.04	−0.36	0.14	94.3%
- Anaerobic capacity	3	41.6%	−0.15	−0.18	−0.12	−0.20	−0.09	12%
- Aerobic capacity	5	83.3%	0.01	−0.01	0.03	−0.05	0.08	45.5%
- Flexibility	2	54.5%	−0.21	−0.27	−0.14	−0.40	−0.01	83.9%
North America and Europe	5	68.2%	−0.05	−0.10	0.01	−0.49	0.40	77.7%
- Strength/Power	5	67.2%	−0.05	−0.12	0.02	−0.53	0.44	80.8%
- Anaerobic capacity	1	100%	0.01	−0.17	0.19	−0.39	0.41	0%
- Aerobic capacity	4	70%	0.01	−0.23	0.25	−0.83	0.86	87.9%
- Flexibility	4	100%	−0.05	0.10	0.01	−0.14	0.01	0%
Africa	5	62.2%	−0.14	−0.24	−0.03	−0.70	0.43	85.8%
- Strength/Power	5	55%	−0.27	−0.41	−0.12	−0.85	0.31	83.3%
o *Upper limb*	4	18.2%	−0.19	−0.42	0.05	−0.91	0.54	79.5%
o *Lower limb*	4	66.7%	−0.34	−0.56	−0.12	−1.00	0.32	76.6%
o *Trunk*	2	0%	−0.22	−0.75	0.30	-	-	96%
o *(Sub)maximal*	5	58.8%	−0.34	−0.46	−0.21	−0.76	0.08	64.7%
o *Endurance*	2	33.3%	−0.04	−0.51	0.43	−6.01	5.98	96.5%
o *Absolute measures*	5	53.3%	−0.25	−0.42	−0.09	−0.88	0.38	86.7%
o *Relative measures*	2	60.0%	−0.32	−0.58	−0.50	1.09	0.46	47.2%
- Anaerobic capacity	3	80%	−0.03	−0.20	0.14	−0.54	0.49	70.3%
- Aerobic capacity	3	50%	0.18	−0.05	0.40	−0.85	1.20	84.7%
- Flexibility	3	66.7%	−0.16	−0.27	−0.04	−1.12	0.81	20.8%
Motor skills (overall)	5	82.5%	−0.12	−0.16	−0.08	−0.40	0.16	48.6

Legend: Italics indicate that the minimum of 3 studies was not met. The trends are reported, but should not be interpreted

When combining all measures [30, 38, 48, 49, 53, 54], UW children had slightly but significantly poorer motor skill performance compared to NW children (SMD = −0.12, 95% CI = [−0.16, −0.08], $p < 0.001$, $I^2 = 49\%$; prediction interval: [−0.40;0.16]) *(Appendix 3).*

The main results regarding physical fitness and motor skill performance in UW children compared to their NW peers are summarized in Table 3 and Fig. 2.

Level of evidence

According to the GRADE summary of the evidence we performed, we have limited confidence in the effect estimate for both physical fitness and motor skill outcomes in all different continents, such as Asia, Africa, North America, and Europe. The true effect may be substantially different from the effect estimate. Despite the acceptable methodological quality of the individual studies, the substantial inconsistency and indirectness of the results alongside the publication bias resulted from low overall evidence (Table 4).

Discussion

This systematic review and meta-analysis aimed to gain a better understanding of the physical fitness and motor skill competence of UW children aged 3 to 12 years. We aimed to explore the physical fitness and motor skill profiles in these children compared to their NW peers. This study revealed (very) low evidence for differences in UW and NW children with respect to physical fitness performance and motor skill competence based on

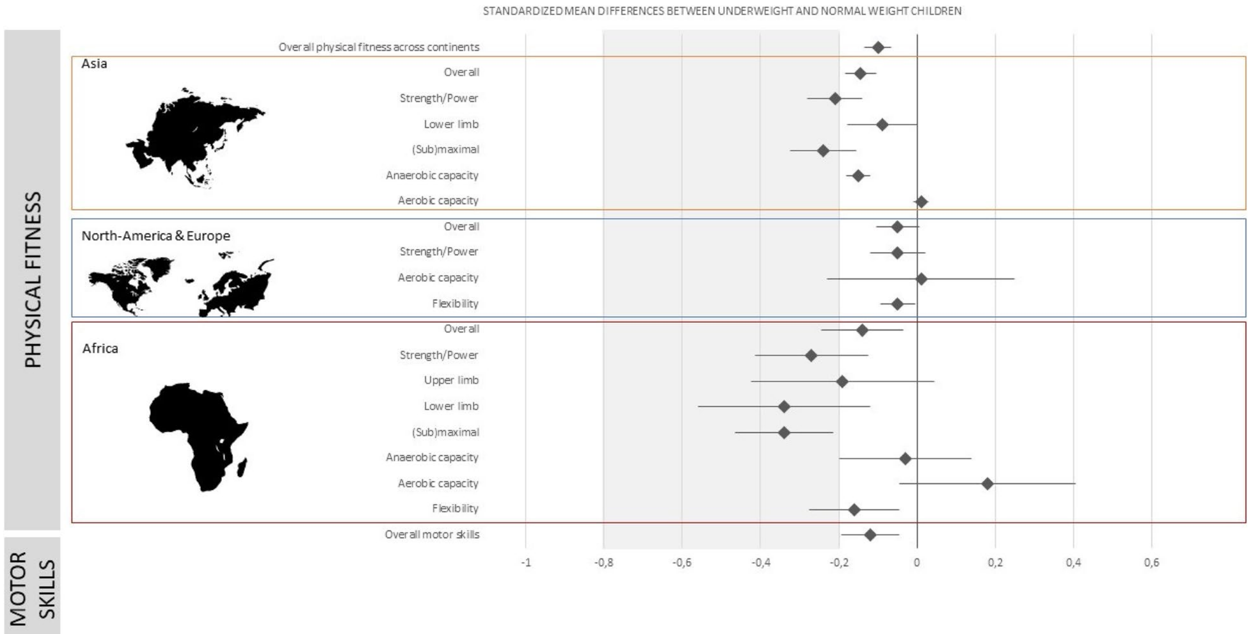

Fig. 2 Summary of result on underweight children's Physical fitness and motor skill profile compared to normal-weight peers

Table 4 Quality of evidence appraised using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE)-method

	Study limitation	Inconsistency	Indirectness	Imprecision	Publication bias	Quality of the evidence (Grade)
Physical fitness						
Asia	=	↓↓	↓	↑	↓	⊕⊖⊖⊖
North America and Europe	↑	↓↓	↓	=	↓	⊕⊖⊖⊖
Africa	↑	↓↓	↓↓	=	↓	⊖⊖⊖⊖
Motor skill						
All together	=	=	↓↓	=	↓	⊕⊖⊖⊖

Explanation: ↓GRADE score downgraded by one point; = No impact on GRADE score

⊕ Point on final GRADE score awarded; ⊖ Point on final GRADE score not awarded and suggested representations of the quality of evidence; Symbol ⊕⊕⊕⊕ = high; ⊕⊕⊕⊖ = moderate; ⊕⊕⊖⊖ = low, and ⊕⊖⊖⊖ or ⊖⊖⊖⊖ = very low

22 studies, including 21 321 UW children and 251 813 NW children. While these differences were statistically significant, the small SMDs may have limited practical implications in real-world settings. As confirmed by the large prediction intervals that also include zero the difference is very dependent upon the sample of under investigation. Despite these minor differences, the implications for child development should not be underestimated, particularly in those children that would present with significantly lower physical fitness. The World Health Organization (WHO) emphasizes that undernutrition, including being underweight, adversely affects children's health and development. Even slight deficits in physical fitness can impede motor skill acquisition, academic success, and psychosocial well-being. Therefore, it is crucial to address these seemingly minor variations, as they can have significant long-term consequences for a child's overall growth, functional development, and quality of life.

Physical fitness

To estimate the difference in physical fitness between UW and NW children, we conducted subgroup analyses considering the continent where the study was conducted and the type of fitness test used. Our findings indicated variability depending on the context. In developed countries, we observed no significant differences between (UW) and (NW) peers. This suggests that the UW group in these studies may not represent malnourished children but rather those with a naturally lean body stature.

However, in low- and middle-income countries (LMICs), particularly in Asian and African contexts, UW children demonstrated poorer strength and power, more likely reflecting the effects of undernutrition. These disparities may be further exacerbated by socioeconomic factors such as low parental education, inadequate cognitive stimulation, limited access to quality healthcare and education, and cultural influences [9]. These factors often have a more significant impact on children's developmental outcomes than nutrition alone, highlighting the complex interplay between environmental and biological determinants of physical fitness and motor skill competence.

Previous studies in Asian and African countries have also emphasized the significant impact of socioeconomic and environmental factors on children, preventing them from reaching their developmental potential [57].

The UW children in both Asian and African contexts have more difficulties with the (sub)maximal strength, which will more likely reflect undernutrition. The connection between undernutrition and decreased muscle strength can be attributed to several important factors, including relative strength, delayed biological maturation, and other variables that affect muscular performance. Undernourished children often fail to consume sufficient protein, calories, and essential micronutrients needed to sustain muscle mass. The common loss of muscle mass in these children can be explained by reductive adaptation [58], a process that the body undergoes to reduce its energy expenditure and modifies its growth and development patterns in response to a lack of energy or sufficient nutrients. This leads to various physiological adaptations, including growth restriction, loss of fat, muscle, and visceral mass, a reduced basal metabolic rate, and reduced total energy expenditure, all of which help the child survive on minimal resources [59–61]. Additionally, undernutrition is associated with increased inflammation, which can speed up muscle wasting [62]. Another critical factor is failure to consider the relative strength, as many studies in this Systematic review and meta-analysis assess absolute strength measure (e.g., handgrip force in kg/cm^2, jump power in watts) without adjusting for body weight (strength-to-body-weight ratio), which provides a more accurate measure of functional performance. Overlooking this factor may lead to underestimating the actual strength capacity of UW children. Furthermore, delayed biological maturation plays a crucial role, as growth delays result in postponed muscle mass accumulation and later peak strength development, which further increases the performance gap in muscular strength between (UW) and (NW) children, as growth is delayed, muscle mass accrual occurs later, resulting in a delay in reaching peak strength [63, 64]. Lastly, reduced muscle mass and strength contributes to weakness, fatigue, and poor coordination and seem to be characterized by a decrease in size and number of fast-twitch fibers, whereas the slow-twitch-fibers are spared. As a result, activities that demand muscle power might pose challenges for UW children [5] and can ultimately lead to reduced overall fitness levels and physical activity but also a more sedentary lifestyle in these children [65, 66].

A child's physical activity is influenced by cultural and socioeconomic factors. Access to outdoor environments, involvement in structured programs, and past physical activity experiences significantly impact fitness performance [67, 68]. Interestingly, parental education affects children's physical activity in different regions. In Europe, higher maternal education is often linked to increased physical activity in children. Conversely, it has the opposite effect in Latin America, possibly due to time constraints or cultural priorities [68]. In Africa, lower parental education or limited involvement may contribute to children being less active [69]. This underscores the importance of further research in African and Asian contexts to understand how educational levels, cultural factors, and time availability impact children's physical activity [68]. Furthermore, physical activity levels are influenced by socioeconomic backgrounds. Specifically, children and adolescents with a higher socioeconomic status (SES) tend to be more physically active [70]. This relationship is closely tied to the built environment in which they live, as certain environments may limit opportunities for physical activity [71]. Children and adolescents from higher socioeconomic backgrounds may experience an environment encouraging physical activity. In contrast, those with lower SES might encounter an environment that hinders physical activity. Consequently, variations in the built environment, alongside the socioeconomic differences in Asia and Africa in relation to physical activity behavior, could partially explain this difference [68, 71]. Another reason is also related to the socio-economic factors which can be expressed by the ability to buy foods. Again, low SES may lead to the deterioration of their nutritional status because of the lack of variety in the types of foods or the composition of the meals [34]. Evidence from previous studies showed that nutritional status is closely associated with family income. In turn, several studies have shown a link between nutrition and family income [34] and its relation with physical and environmental characteristics [72].

Moreover, a strong relationship exists between education and nutritional status; among illiterates, more than half have been reported to be undernourished [72], and households with uneducated parents tend to have low income and thus spend less on proper nutrition [73]. As a result, in these families, children are more susceptible to growth failure due to lack of access to sufficient food of adequate quality, poor living conditions, lack of access to basic health care services, and greater exposure to diseases. This is the case in Sub-Saharan Africa, including Senegal,Ghana,and South Africa, where the overall education level is low and the poverty level is high, which leads to children's undernutrition [73].

According to our systematic review and meta-analyses that focused specifically on Africa and Asia, UW children exhibit lower limb strength compared to their NW peers. This finding suggests that UW children engage in limited daily physical activity which may also explained by school abstinence. Children often avoid going to school due to nutritional problems, which in turn cause underweight children to experience chronic fatigue and low energy. These issues limit their ability to participate in daily activities and physical play, further restricting their physical activity and overall development [34, 74]. Additionally, a study highlighted the link between undernutrition and school absenteeism, emphasizing the impact of health and nutrition problems on attendance. Notably, household food insecurity significantly contributes to school absenteeism in LMICs [75].

Motor skill profile

Physical fitness, activity, and motor skills are closely related and reciprocally influence each other in school-aged and older children [76]. In younger children, on the other hand, the amount of physical activity will influence both physical fitness and motor skills [76]. As such, it is reasonable to assume that if wasting causes a vicious cycle of limited activity, a further reduction of physical fitness and even motor skill competence may be induced at any age during childhood. However, the slightly, but significant differences found for the motor skills [30, 38, 48, 49, 53], indicate that only a small portion of these children seem to present with actual impaired motor skill competence. Either the UW children included in this meta-analysis have skinny body statures and do not actually reflect a group of undernourished children, which may mask the true difference between UW and NW, or impaired motor skill competence only occurs in severe cases. Literature reports on motor skills in UW children are scarce, and the ones included in our meta-analysis (n = 6) mainly comprise UW children from North American and European origin, which may distort the results similarly as seen for the physical fitness profile. However, due to the very small number of available papers on this topic and the included studies used different motor skill assessment tools, that direct comparisons across these assessments may introduce some variability in our findings. However, to minimize this issue, we used SMDs, which allow for comparability across different measurement tools. we could not explore differences based on continent in this data subset. Literature reports on children living in low socio-economic circumstances indeed suggest that nutritional status and SES are significant predictors of fine and gross motor development [77]. For instance, children living in India who have poor nutritional status and have lower SES tend to have lower motor proficiency compared to children who have a higher SES and nutritional status [34]. This emphasizes the need to further explore the impact of malnutrition on physical development beyond merely fitness measures.

Previous studies have also reported that malnutrition can adversely affect the rapid development of the brain by compromising both its structure and function, leading to deficits across various developmental domains [57, 78]. However, unfavorable environmental conditions can impede children's ability to acquire essential social and developmental skills [79]. As a result, a combination of social, biological, and psychological factors contributes to developmental delays in children. These findings highlight the necessity of comprehensive and locally targeted research and interventions that address both nutritional deficiencies and the environmental factors impacting child development as evidenced by previous studies. Catch-up growth in undernourished children has been linked to improved cognitive and academic outcomes, including better receptive vocabulary, reading comprehension, and mathematical achievement [80, 81].

Strengths and limitations of this study

This systematic review and meta-analysis employed an extensive search strategy across three reputable databases, applying no restrictions on publication dates, thereby ensuring a broad and inclusive array of studies was considered. We did, however, limit ourselves to the English language and the age range is also limited to 3–12 years old. Overall, the included studies comprised a low risk of bias. Only a few studies investigated motor skill competence in UW children, indicating the need for more research in this area. Nevertheless, this meta-analysis indicates that UW children tend to have lower physical fitness and motor skill performance than their NW peers. However, this will only be present in a portion of the children and does not seem to be a feature present in all UW children (indicated by the small-sized mean SMDs). The lack of differences may also be caused by the use of an anthropometric proxy to identify UW children. The reliance on anthropometric proxies for the identification of undernourished children may result in misclassification. Specifically, children who exhibit low BMI relative to their age may be inaccurately categorized as undernourished despite having adequate nutritional status due to differing body compositions. This highlights the need for a more nuanced approach in assessing nutritional health among study populations, e.g. body composition. Additionally, using various cut-off points and reference standards to classify nutritional status can introduce potential heterogeneity in findings, as these methods define undernutrition in different ways and may lead to different classifications across studies.

UW children tend to be less fit and have weaker motor skills than NW peers. Differences in scoring and sensitivity among motor skill assessment tools may have influenced reported effect sizes. While SMDs were used for comparability, some variability remains. Additionally limited number of studies assessing motor skills also weakens our findings. Future research should focus on more consistent assessments and a larger body of studies for stronger comparisons. Regarding physical fitness, the pooled estimates exhibit substantial heterogeneity. The significant variability observed, especially in strength/power measurements, can be attributed to differences in sample characteristics and measurement protocols used in various studies. This variability complicates efforts to draw clear conclusions and underscores the need for more standardized methods in future research. For example, some studies reported absolute values for strength (standing long jump distance), whereas others reported relative values (standing long jump peak power). Despite absolute and relative values representing different approaches to map performance, our subgroup analyses did not reveal substantial differences. All this variability leads to inconsistent effect sizes (individual studies included in the meta-analysis have varying effect sizes or results), making the interpretation of the overall pooled effect size more complex and less straightforward, eventually resulting in a very low level of evidence. Despite the fact that sufficient studies were included in the overall meta-analyses on physical fitness, still too few papers on this topic are available for adequate subgroup analysis. By combining all studies, the true differences apparent for the LMIC remain masked. As such, the current paper provides a rationale for future research in this specific group of children, but it is rather fragmented and lacks strong evidence to draw firm conclusions.

Clinical implications and recommendations for future research

Differentiating between NW and UW children is crucial for understanding the effects of nutrition on physical fitness and motor skill development. Comparing these two groups allows for the identification of specific deficits in physical fitness and motor skills that may arise from undernutrition, which in turn facilitates the creation of targeted interventions. This distinction also underscores the long-term health consequences of malnutrition, as inadequate physical fitness and motor skills in childhood can have lasting effects on future health, cognitive abilities, and social participation. Additionally, it provides valuable insights into body composition, informing policies and support strategies aimed at addressing the nutritional and physical activity needs of vulnerable children. Although UW children tend to be less physically fit and have weaker motor skills than NW peers, the differences are very small, and the prediction interval clearly indicated that depending on the study group (e.g., severity of the undernourishment), there may or may not be significant differences indicating we need more research on this topic. Since the participants may have differed significantly between the studies, in future research skinny, but well-nourished children should be distinguished from undernourished children by not only focusing on an anthropometric proxy for UW but by combining this with a body composition measure. Additionally, consistently reporting both absolute and relative strength measures will enhance comparability and validity in this field. Conducting simultaneous assessments of physical fitness, motor skills, and activity levels in future research will enhance our understanding of their interconnections. This approach will clarify whether lower physical fitness or diminished motor skills contribute to reduced activity levels, yielding valuable insights for promoting healthier lifestyles. This holistic approach is crucial for designing effective interventions. By identifying specific areas of physical fitness or motor skills that require focus, tailored interventions can be developed. Future studies should investigate whether the severity of undernutrition and the age of children are significant factors in developing physical fitness or motor skill deficits. Targeted, combined interventions that improve both physical fitness and nutritional intake could provide a dual approach to meeting the needs of undernourished children. Conducting more homogeneous studies on various physical fitness tests will further clarify the differences between UW and NW children, providing deeper insights and informing targeted support strategies.

Conclusion

This systematic review and meta-analysis found that UW children tend to be less physically fit and have weaker motor skills than their NW peers, although the differences were relatively small. The high degree of heterogeneity across the included studies may have masked the true extent of these differences, with factors such as the type and severity of malnutrition contributing to this variability. More homogeneous studies are needed to better understand the physical fitness and motor skills of undernourished children.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12887-025-05738-x.

Supplementary Material 1. Appendix 1. A random effects meta-analysis comparing physical fitness between underweight and normal-weight children

Supplementary Material 2. Appendix 1.1. A Subgroup meta-analysis comparing physical fitness between underweight and normal-weight children for the Asian continent

Supplementary Material 3. Appendix 1.2. A subgroup meta-analysis of studies comparing strength/power between underweight and normal-weight children using the Energy system as a grouping variable for the Asian continent

Supplementary Material 4. Appendix 2. A Subgroup meta-analysis comparing physical fitness tests between underweight and normal-weight children for the African continent

Supplementary Material 5. Appendix 2.1 A subgroup meta-analysis of studies comparing strength/power between underweight and normal-weight children using body limbs as a grouping variable for the African continent

Supplementary Material 6. Appendix 2.2 A subgroup meta-analysis of studies comparing strength/power between underweight and normal-weight children using the energy system as a grouping variable for the African continent

Supplementary Material 7. Appendix 3. A random effects meta-analysis comparing motor skills between underweight and normal-weight children

Supplementary Material 8. Appendix 4. Search strategy and search string

Supplementary Material 9. Table A.1: Description of the applied outcome measures

Authors' contributions

YD and EV conceptualized the study, designed the search strategy, conducted the search and meta-analysis, and wrote the initial manuscript. Two independent reviewers (YD, ES) selected the studies and conducted the entire search, study selection, and data extraction. Two independent researchers (YD and ES/LV or BH) assessed the risk of bias in each study. ER, TB, and BA contributed their invaluable guidance and support by providing crucial insights throughout this research, aiding in acquiring funding, giving feedback, and assisting with editing. All authors reviewed the manuscript approved the submitted version.

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Data availability

All relevant data are available in this manuscript, and its Supporting Information files are available in the Appendix.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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