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Sex Differences in Upper- and Lower-Limb Muscle Strength in Children and Adolescents: A Meta-Analysis

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ABSTRACT

On average, adult men are physically stronger than adult women. The magnitude of this difference depends on the muscle tested, with larger sex differences observed in upper- than lower-limb muscles. Whether body region-specific sex differences in strength exist in children is unclear. The purpose of the current meta-analysis was to determine whether sex differences in muscle strength in children and adolescents differ between upper- and lower-limb muscles. Data were extracted from studies of participants aged ≤ 17 years who completed tests of maximal isometric or isokinetic strength of upper-limb muscles (e.g., elbow flexors and elbow extensors) or lower-limb muscles (e.g., knee extensors and ankle dorsiflexors). Participants were partitioned into three age groups: 5–10 years old, 11–13 years old, and 14–17 years old. The analysis included 299 effects from 34 studies. The total sample was 6634 (3497 boys and 3137 girls). Effect sizes of sex differences in upper- and lower-limb strength were $g = 0.65$ (95% confidence intervals (CI) [0.46, 0.84]) and 0.34 (95% CI [0.19, 0.50]) in 5–10-year-olds; $g = 0.73$ (95% CI [0.56, 0.91]) and 0.43 (95% CI [0.27, 0.59]) in 11–13-year olds; and $g = 1.84$ (95% CI [1.64, 2.03]) and 1.18 (95% CI [1.00, 1.37]) in 14–17-year-olds. Upper- and lower-limb strength were 17% and 8% greater in boys than girls when 5–10 years old, 18% and 10% greater when 11–13 years old, and 50% and 30% greater when 14–17 years old. Thus, boys are stronger than girls on average. This sex difference exists before puberty, increases markedly with male puberty, and is more pronounced in upper- than lower-limb muscles throughout development.

1 | Introduction

On average, adult men are physically stronger than adult women (Nuzzo 2023). The magnitude of this difference depends on the muscle tested. In upper-limb muscles, adult female strength is 50%–60% of adult male strength (Nuzzo 2023). In lower-limb muscles, adult female strength is 60%–70% of adult male strength (Nuzzo 2023). However, less is known about whether these sex differences in strength also exist in children.

A recent meta-analysis revealed that boys have greater grip strength than girls from birth onward (Nuzzo 2025). Between 3 and 10 years old, the sex difference in grip strength is small-to-moderate in size (g = 0.33–0.45), it decreases for a year at age 11 presumably due earlier female than male maturation (g = 0.28), and it increases thereafter such that by the age of 16 the difference is substantial (g = 2.07) (Nuzzo 2025). At the age of 16, girls' grip strength relative to boys' grip strength is 65% compared to 90% between the ages of 3–10 years (Nuzzo 2025). Nevertheless, the meta-analysis

Summary

- Before, during, and after puberty, boys are stronger than girls on average.
- The sex difference in muscle strength increases markedly with male puberty, averaging ~10% in 5–10-year-olds and then ~40% in 14–17-year-olds.
- Throughout development, sex differences in strength are more pronounced in upper- than lower-limb muscles.

was limited to grip strength (Nuzzo 2025). The analysis did not summarize results from muscles of the lower limbs or muscles of the upper limbs that are not explicitly involved in gripping. Thus, whether children and adolescents exhibit the same body region-specific sex differences in strength as adults is unclear.

Childhood sex differences in physical fitness and athletic performance are topics of contemporary interest (Atkinson et al. 2024; Brown et al. 2024b, 2025a, 2025b; Handelsman 2017). This interest stems, in part, from debates about whether males who identify as females should be allowed to participate in the female category of sport. To determine if boys have physical performance advantages over girls prior to puberty, Brown and colleagues examined results from youth championship track and field events in the United States of America (USA) (Brown et al. 2024b, 2025a, 2025b). The authors found that 8–10-year-old boys often exhibited greater athletic performances than 8–10-year-old girls. The sex differences were more pronounced in events that relied on upper-limb strength and power (e.g., shot put and javelin throw; 7%–33% sex difference) than in events that relied more on lower-limb strength and power (e.g., 100 and 200 m sprints; 4%–6% sex difference) (Brown et al. 2024b, 2025a). This latter ~5% sex difference in sprint performance was also reported by Atkinson et al. (2024). Results from these studies imply that sex differences in muscle strength and power exist throughout development but that the difference is greater in the upper than lower limbs. Yet, body region-specific sex differences in strength have not been confirmed in children and adolescents. A formal examination of this question with meta-analysis might help to inform ongoing debates about sex differences in physical fitness, with implications for sport policies relating to males who identify as females wanting to compete in the female category of sport (Atkinson et al. 2024; Bekker et al. 2023; Brown et al. 2024a; Brown et al. 2024b, 2025a, 2025b; B. Hamilton et al. 2024; B. R. Hamilton et al. 2024a, 2024b; Handelsman 2017; Hilton and Lundberg 2021; Hunter et al. 2023; Hunter and Senefeld 2024; B. A. Jones et al. 2017; Lundberg, O'Connor, et al. 2024; Lundberg, O'Connor, et al. 2024; Nokoff et al. 2023; Nuzzo 2023; Senefeld and Hunter 2024; Sin et al. 2023; Tucker et al. 2024a, 2024b; Williams et al. 2024).

Therefore, the purposes of the current meta-analysis were to determine if a sex difference in muscle strength exists during childhood and adolescence and if the magnitude of any sex difference differs between the upper and lower limbs. We hypothesized, based on recent work (Brown et al. 2024b, 2025a; Nuzzo 2023; Nuzzo 2025), that sex differences in upper- and lower-limb muscle strength would exist at all ages but that the difference would be more pronounced in the upper limbs. Grip strength was not included in the current study because it was the focus of a recent meta-analysis (Nuzzo 2025). Sudies that measured strength using the back-and-leg dynamometer were also excluded from the current study because the back-and-leg dynamometer test involves combined use of lower-limb, trunk, and upper-limb muscles and thus cannot be categorized as a test of either lower- or upper-limb strength.

2 | Methods

2.1 | Literature Search

The literature search for this study was performed between May and October of 2024. Papers on sex differences in muscle strength in children and adolescents were known to the authors, as previous searches had been conducted for reviews on related topics (Nuzzo 2023; Nuzzo 2025). The search strategy was similar to that described by Greenhalgh and Peacock (2005). The approach relied on (a) personal knowledge and checking of personal digital files from previous research (Nuzzo 2023; Nuzzo 2025; Nuzzo et al. 2023; Nuzzo, Pinto, Nosaka, et al., 2023; Nuzzo et al. 2024); (b) relevant keyword searches performed in PubMed and Google Scholar; and (c) "snowballing" strategies (i.e., reference and citation tracking). Example keyword searches included combinations of words such as "boys," "girls," "youth," "children," "adolescents," "strength," "muscle strength," "isokinetic," and "isometric." We have used this type of search strategy successfully in previous reviews and meta-analyses (Nuzzo 2023, 2024, 2025; Nuzzo et al. 2023; Nuzzo, Pinto, Nosaka, et al., 2023; Nuzzo et al. 2024).

2.2 | Eligibility

For a study to be included in the current meta-analysis, it needed to meet the following criteria: (a) published in an academic journal in 2023 or earlier; (b) published in English; (c) included healthy male and female participants who were 17 years old or younger and not explicitly part of competitive athlete cohorts; (d) included sex- and age-segregated sample sizes; (e) included sex- and age-segregated means and standard deviations (SDs) or standard errors for maximal isometric or isokinetic muscle strength for any of the following muscle groups: elbow flexors, elbow extensors, knee flexors, knee extensors, ankle dorsiflexors, ankle plantarflexors, or multijoint tests of upper- or lower-limb strength; and (f) included strength scores that were neither statistically adjusted for covariates nor normalized to participant body anthropometrics (e.g., body mass and lean mass). Common reasons for exclusion from the current analysis included: (a) participants were competitive athletes; (b) strength was measured via hand-held dynamometry; (c) no sex- or age-specific sample sizes were reported; (d) no group means or SDs or standard errors for muscle strength were reported; and (e) the age range of participants was beyond the criteria for the analysis (described below).

2.3 | Data Extraction and Organization

Information extracted from eligible studies included the year of publication, year of data collection (if provided), sample size, sample age, type of strength test completed, muscle group assessed, and means and SDs or standard errors of muscle strength. Researchers reported their data in various ways. Consequently, we established criteria for data eligibility, extraction, and organization.

Age and body region. Age was treated as a categorical variable in the current meta-analysis, partly because researchers often reported age in a categorical form (e.g., "10-year-olds" or "13-year-olds") (Miyashita and Kanehisa 1979; Montoye and Lamphiear 1977). Unlike the previous meta-analysis of grip strength that quantified the size of the sex difference in strength at each year of development (Nuzzo 2025), less data were available here to allow for accurate and meaningful portrayals of muscle-specific sex differences in strength at each year of development. Consequently, the data were aggregated in two ways to allow for informative comparisons.

First, data were categorized into two broad body areas: "upper-limb muscles" and "lower-limb muscles." The group "upper-limb muscles" included results from isometric and isokinetic strength tests of the elbow flexors, elbow extensors, and multijoint upper-limb tests. The group "lower-limb muscles" included results from isometric and isokinetic strength tests of the knee flexors, knee extensors, ankle dorsiflexors, ankle plantarflexors, and multijoint lower-limb tests.

Second, data were categorized into three age groups: 5–10 years old, 11–13 years old, and 14–17 years old. These three age ranges were utilized because 5–10 years old represents prepuberty for most boys and girls (Tanner 1971), and grip strength is mostly stable between 5 and 10 years old, whereas grip strength becomes less stable between 11 and 13 years old and has a clearer trajectory starting at the age of 14 (Nuzzo 2025). Thus, studies were included in the current analysis if the span of years of the cohorts did not exceed any of the following age ranges: 5–10 years old, 11–13 years old, and 14–17 years. Exceptions were made for one study group of 10–12 years old whose group data were categorized as 11–13 years old (Kanehisa, Yata, et al., 1995), one study group of 13–15years old whose group data were categorized as 14–17 yearsold (Kanehisa, Yata, et al., 1995), and and one study group of 12–14 years old whose group data were categorized as 11–13 years old (Streckis et al. 2007). A study was ineligible for inclusion in the current analysis if any participant in the cohort was older than 17 years of age or was suspected of being older than 17 years of age based on the cohort's SD for age.

Study design. Muscle strength data were reported in various types of studies. For longitudinal studies on child development, muscle strength scores from each age of development were included in the current analysis. For reliability studies on consistency of muscle strength across trials, only strength scores from the first trial or day of testing were included in the current analysis. For cross-sectional studies that compared muscle strength in healthy children versus children with health conditions, only data from healthy children were included in the current analysis. For intervention studies that involved testing of muscle strength before and after an intervention, only data from the baseline strength assessments were included in the current analysis.

Sidedness. Some researchers presented muscle strength scores from only one limb, whereas other researchers presented strength scores from both limbs (e.g., Bäckman and Oberg 1989 and Sunnegårdh et al. 1988). If a researcher reported strength scores from only one limb, that value was included in the current analysis. If a researcher reported data from both limbs, data from the right limb or dominant limb were included in the current analysis. If the researcher reported data by both sidedness and dominance, priority was given to data from the right limb.

Data extraction from graphs. When muscle strength means and SDs were presented in graphs, the values were estimated using a graph digitzer (WebPlotDigitizer, https://apps.automeris.io/wpd/). With the digitizer, we first calibrated the *y*-axis. This involved identifying and inputting the strength values associated with the bottom and top of the *y*-axis. We then identified and clicked each symbol on the graph that represented a mean and SD of interest. The software then generated a spreadsheet of the calibrated means and SDs. When researchers published standard errors rather than SDs, the standard errors were converted to SDs by multiplying the standard error by the square root of the sample size. All studies reported measures of central tendency and dispersion, so no imputation was necessary.

2.4 | Statistical Analysis

The data spreadsheet and statistical results associated with this study are available at the Open Science Framework (https://osf.io/bpm5a/). Effect sizes and the meta-analyses were conducted using R (v 4.3.3 (2024-02-29 ucrt) (R Core Team. 2024) Viena, Austria), RStudio (v 2024.04.1 + 748, RStudio Team (Posit 2024)), and the 'metafor' package (v 4.8-0 (Viechtbauer 2010)). Frequency counts for certain variables (e.g., country and decade of data collection) were computed using Version 29 of the Statistical Software Package for the Social Sciences (SPSS, Armonk, New York, USA).

The primary objective of the meta-analysis was to examine sex differences in muscle strength in children and adolescents and determine whether these differences are moderated by age category (5–10 years old, 11–13 years old, and 14–17 years old) and body region (upper limb and lower limb). Given that some studies contributed multiple effects due to repeated measurements within the same participant, a multilevel random-effects meta-analytic approach was used to account for statistical dependency. Within-study dependencies arose from two sources: (1) cross-sectional designs, in which the same group of boys and girls completed multiple strength tests within the same study and (2) longitudinal designs, in which the same group of boys and girls was reassessed at multiple times during development.

To account for these dependencies, a multilevel random-effects model was fitted using restricted maximum likelihood. The model included random effects at both the study and effect size levels, with the following random effect structure: (~1|StudyID/Pairs, ~1|Effect), where 'StudyID/Pairs' accounts for within-studies dependencies arising from for repeated measures from the same pair of boys and girls within the same study, capturing both cross-sectional (multiple strength tests) and longitudinal (repeated time points) dependencies, whereas 'Effect' accounts for residual heterogeneity at the effect size level.

Effect sizes were computed as standardized mean differences (Hedges' g) and ratio of means (response ratios) using the 'escalc' function in 'metafor' package (Jané et al. 2024). A main model was conducted to examine overall sex differences including all age categories and body limb regions. To assess whether sex differences varied using the age category and body region, meta-regression analyses were performed including these variables as fixed effects (moderators) in the model.

Interaction effects between the age category and body region were tested to determine whether the magnitude of sex differences differed across limbs and developmental stages. These interaction effects were tested using a Wald-type chi-squared test and a likelihood ratio test, which indicated that including the interaction term contributed to the model and slightly improved the model fit compared to a model without interaction ($p = 0.018$), supporting its retention in the final model. Predicted pooled effect sizes and exponentiated response ratios, which were used to quantify the relative strength differences as percentages (e.g., 1.2 ratio equals a 20% sex difference in strength), were estimated using the 'predict' function in 'metafor', with 95% confidence intervals (CIs) and prediction intervals (PIs) (Borg et al. 2024) computed for interpretation.

Effect sizes equal to 0.2, 0.5, and 0.8 are often interpreted as being small, moderate, and large, respectively; however, such benchmarks are arbitrary and should be interpreted cautiously (Lakens, 2013). Confidence intervals that do not cross zero indicate effects that are statistically significant (i.e., $p \leq 0.05$) (Cumming, 2009).

3 | Results

3.1 | Study Characteristics

A total of 34 studies met the eligibility criteria and provided data for the meta-analysis (Andersen and Henckel 1987; Bäckman and Oberg 1989; Davies et al. 1983; B A De Ste Croix et al. 2002; De Ste Croix et al. 2003; Detter et al. 2014; Falkel 1978; Fritz et al. 2016; Fukunaga et al. 1992; Godhe et al. 2019; Holm et al. 2008; Ikai and Fukunaga 1968; G. Jones and Dwyer 1998; Kanehisa, Ikegawa, & Fukunaga, 1994; Kanehisa, Yata, et al., 1995; Katzmarzyk et al. 1997; Linderholm et al. 1971; Lundgren et al. 2011; Miyashita and Kanehisa 1979; Montoye and Lamphiear 1977; Muehlbauer et al. 2012; O'Brien et al. 2010; Pääsuke et al. 2003; Parker et al. 1990; Perry et al. 1997; Ramos et al. 1998; Raudsepp and Pääsuke 1995; Seger and Thorstensson 1994, 2000; Siegel et al. 1989; Streckis et al. 2007; Sunnegårdh et al. 1988; Wood et al. 2004, Wood et al. 2008).

The studies included 299 effects from 6634 children and adolescents (3497 boys and 3137 girls). The number of effects listed by decade, country, study type, age group, strength test type, body part tested, joint tested, and muscle group or exercise tested are provided in Table 1. A total of 189 effects (63.2%) came from cross-sectional studies, 84 (28.1%) came from longitudinal studies, and 26 (8.7%) came from baseline measurement in intervention studies. Results from tests of publication bias and sensitivity analysis are presented in the Supporting Information.

3.2 | Overall Pooled Estimate

Boys were stronger than girls at all ages and in the upper and lower limbs. All 299 effect sizes of the sex differences in muscle strength are displayed in Figure 1. The overall pooled effect size across all 299 effects was $g = 0.72$ (95% CI [0.50, 0.94] and 95% PI [−0.71, 2.15]). Prediction intervals were wide, suggesting substantial between-effect heterogeneity ($I^2 = 86.9\%$) with most variance accounted for at the study level (38.4%) and within-study level (45.5%). A high level of heterogeneity was expected because effect sizes were not expected to be the same across ages (Supporting Information).

3.3 | Effect of Age and Muscle Group

Muscle strength was significantly greater (all $p < 0.001$) in boys than girls at 5–10 years old ($g = 0.45$ (95% CI [0.28, 0.62] and 95% PI [−0.52, 1.43])), 11–13 years old ($g = 0.52$ (95% CI [0.34, 0.69] and 95% PI [−0.46, 1.49])), and 14–17 years old ($g = 1.43$ (95% CI [1.24, 1.62] and 95% PI [0.46, 2.41])). The limb-specific effect sizes of the sex differences in strength by age group are displayed in Figure 2. The upper-limb sex difference in strength was significantly greater than the lower-limb sex difference in strength in all age groups but was more pronounced in 14–17 years old. Finally, for descriptive purposes, boys' muscle strength as a ratio of girls' muscle strength is presented in Table 2. Across all participant ages (5–17 years old) and all tests of upper- and lower-limb strength, boys had 17% (95% CI [13%, 22%] and 95% PI [−12%, 57%]) greater muscle strength than girls. However, the ratio differed by age and the limb tested; it was greatest in 14–17-year-olds and in the muscles of the upper limb.

4 | Discussion

Results from the current meta-analysis show that boys are physically stronger than girls on average. The magnitude of this sex difference depends on age and muscle group. Specifically, this sex difference increases markedly after male puberty and is greater in upper- than lower-limb muscles at all stages of development. Multiple biological factors likely contribute to the observed results (discussed below).

TABLE 1 | Number of effects in the meta-analysis using the decade, country, study type, age group, strength test type, body part tested, joint tested, and muscle group or exercise tested.

Category	No. effects (of 299)	Percent (in category)
Decade		
1960s	13	4.3
1970s	8	2.7
1980s	88	29.4
1990s	89	29.8
2000s	90	30.1
2010s	11	3.7
Country		
Australia	1	0.3
Denmark	4	1.3
England	69	23.1
Estonia	4	1.3
Japan	31	10.4
Lithuania	1	0.3
Norway	12	4.0
Puerto Rico	7	2.3
Sweden	141	47.2
United States	27	9.0
Study type		
Cross-sectional	189	63.2
Intervention	26	8.7
Longitudinal	84	28.1
Age group		
5–10 years old	128	42.8
Upper limb	35	11.7
Lower limb	93	31.3
11–13 years old	109	36.5
Upper limb	33	11.0
Lower limb	73	24.4
14–17 years old	62	20.7
Upper limb	32	10.7
Lower limb	33	11.0
Limb tested		
Upper limb	100	33.4
Lower limb	199	66.6
Joint tested		
Ankle	41	13.7
Elbow	81	27.1
Knee	155	51.8
Multijoint upper-body	19	6.4
Multijoint lower-body	3	1.0
Muscle group or exercise tested		
Ankle dorsiflexors	31	10.4
Ankle plantarflexors	10	3.3
Elbow extensors	28	9.4
Elbow flexors	53	17.7
Knee extensors	104	34.8
Knee flexors	51	17.1
Lat pulldown	13	4.3
Leg press	3	1.0
Shoulder press	6	2.0
Strength test type		
Isokinetic concentric	181	60.5
Isokinetic eccentric	15	5.0
Isometric	103	34.3

4.1 | Age and Muscle Group

Male puberty is known as a key deflection point for causing substantial differences in muscle strength between males and females (Nuzzo 2025). This difference is maintained throughout adulthood, with women exhibiting 50%–60% and 60%–70% of men's upper- and lower-limb strength, respectively (Nuzzo 2023). Nevertheless, sex differences in muscle strength are also present prior to puberty. A recent meta-analysis revealed small-to-moderate sex differences in grip strength from birth to age 10, with girls' grip strength 90% of boys' grip strength (Nuzzo 2025). Similarly, the current meta-analysis found small-to-moderate sex differences in strength of the elbow flexor and extensor muscles between 5- and 10-year-old boys and girls, with boys producing approximately 17% greater strength from these muscles than girls, with CIs ranging from 12% to 21% and PIs ranging from 0% to 36%. The current analysis also identified prepubertal sex differences in strength of lower-limb muscles. Specifically, 5–10-year-old boys produced approximately 8% greater strength from the flexors and extensors of the knee and ankle than girls, with CIs ranging from 4% to 11% and PIs ranging from −8%–26%. Thus, prior to puberty, sex differences in muscle strength are present on average, but they are small and more likely to exist in upper- than lower-limb muscles.

In 11–13-years-olds, sex differences in upper- and lower-limb strength are nearly identical in magnitude to those observed prior to age 11. However, at the age of 14, a substantial increase in the sex difference in muscle strength is observed. The lower bound of the PI is above zero at this age, suggesting that future studies in similar populations are likely to observe a sex difference in strength during this age. The results indicate that between 14 and 17 years old, upper- and lower-limb strength are 50% and 30% greater in boys than girls, respectively. Thus, body region-specific sex differences in strength are present before, during, and after puberty. These differences persist throughout

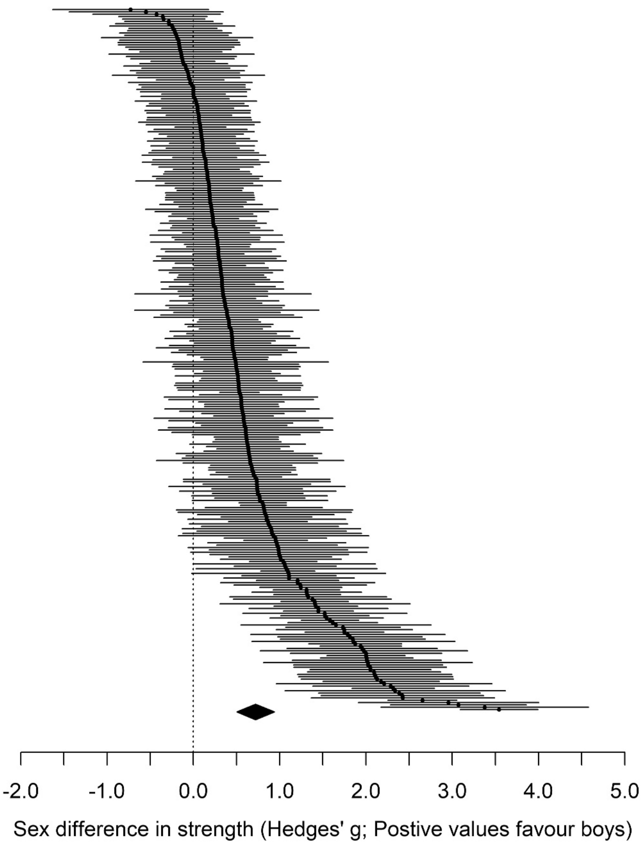

FIGURE 1 | Caterpillar plot displaying 299 effect sizes of sex differences in muscle strength (black circles, Hedges *g*) included in the meta-analysis. Horizontal lines around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CIs). Positive effect sizes to the right of the dashed vertical zero line represent when boys were stronger than girls. Negative effect sizes to the left of the dashed vertical zero line represent when girls were stronger than boys. The pooled effect size (large black diamond) was $g = 0.72$ (95% CIs [0.50, 0.94] and 95% PIs [−0.71, 2.15]).

adulthood, as adult female upper-limb strength is 50%–60% of adult male upper-limb strength, whereas adult female lower-limb strength is 60%–70% of adult male lower-limb strength (Nuzzo 2023).

4.2 | Causes of Sex Differences in Muscle Strength

Multiple factors likely contribute to sex differences in muscle strength in children and adolescents. As discussed elsewhere, the roles of muscle fiber type and voluntary activation are unclear due to a relative lack of data in children and adolescents (Nuzzo 2025), whereas differences in body height, body mass, and body composition likely contribute significantly to differences in strength and power between boys and girls (Brown et al. 2024b, 2025a; Nuzzo 2025).

Boys tend to be slightly taller and weigh more than girls at most ages (Kuczmarski et al. 2002). Body height and body mass correlate positively with muscle strength in children and adolescents (Hogrel et al. 2012; Jürimäe et al. 2009; Kocher et al. 2019, 2017; Parker et al. 1990). Thus, greater body heights and body masses of boys than girls throughout most of development can partly explain greater strength among boys than girls.

Body composition also likely contributes to the sex difference in muscle strength before and after puberty. In 5–15-year-olds, fat-free mass correlates positively and strongly with muscle strength ($r = 0.81$–0.85) (Sartorio et al. 2002). Prepubertal boys often have more fat-free or lean mass, less fat mass, and lower body fat percentages than prepubertal girls (Arfai et al. 2002; Garnett et al. 2004; He et al. 2002; Kirchengast 2010; Leppänen et al. 2017; McCarthy et al. 2014; Nelson and Barondess 1997; Soininen et al. 2018; Taylor et al. 1997). During and after puberty, sex differences in absolute and relative amounts of fat and fat-free mass become more pronounced (Hage et al. 2009; Henche et al. 2008; McCarthy et al. 2014; Ogle et al. 1995; Ripka et al. 2020). Given that fat infiltration into muscle reduces its force-generating capacity (Biltz et al. 2020), sex differences in fat and fat-free mass throughout development might partly explain the greater muscle strength in boys than girls.

Regional differences in body composition have also been noted in boys and girls and may help to explain how the sex difference in strength is greater in upper- than lower-limb muscles throughout childhood and adolescence. Compared to boys of the same age, 8–12-year-old girls carry a greater proportion of their total body mass in their legs and have greater total fat mass and greater fat percent in their arms and legs (Fuller et al. 2002). Boys, on the other hand, carry a greater percent of their fat-free mass in their arms, though no sex difference in absolute fat-free mass in the arms was observed (Fuller et al. 2002). In one study of 7–10-year-old, cross-sectional areas (CSAs) of the forearm and lower-leg muscles were found to be larger in boys than girls, whereas CSAs of fat and fat percentage in the forearm and lower leg were greater in girls than boys (Ducher et al. 2009).

Nevertheless, not all studies have observed sex differences in muscle mass or size in children. Regarding the lower limbs, some studies have not found statistically significant differences in muscle mass, volume, or CSA in cohorts who are 12 years of age or younger (Kanehisa, Ikegawa, Tsunoda, et al., 1994; Kanehisa, Yata, et al., 1995; Lundgren et al. 2011; O'Brien et al. 2010; Peeters et al. 2023; Welsman et al. 1997). In one study, sex differences in CSAs of the ankle dorsiflexors and plantarflexors emerged only after participants reached 13 years of age (Kanehisa, Ikegawa, et al. 1995). Regarding the upper limbs, Lundgren et al. (2011) observed no difference in arm muscle mass between boys and girls aged 6–12 years, and Wood et al. (2006) and Gillen et al. (Gillen et al. 2024) observed no sex difference in CSA of the elbow flexors in prepubertal boys and girls. Interestingly, some studies that have not found sex differences in upper- (Gillen et al. 2024; Wood et al. 2006) or lower-limb (O'Brien et al. 2010) strength have also reported no sex difference in muscle size. Such findings suggest that a sex difference in muscle size in a study cohort could be key to also observing a sex difference in muscle strength. In one longitudinal study, Wood et al. (2004) assessed boys' and girls' elbow flexion and extension strength every year from age 13 to 15. The researchers found that sex differences in muscle strength were eliminated when CSA of the elbow flexor and extensor muscles were added into explanatory models, whereas body stature and

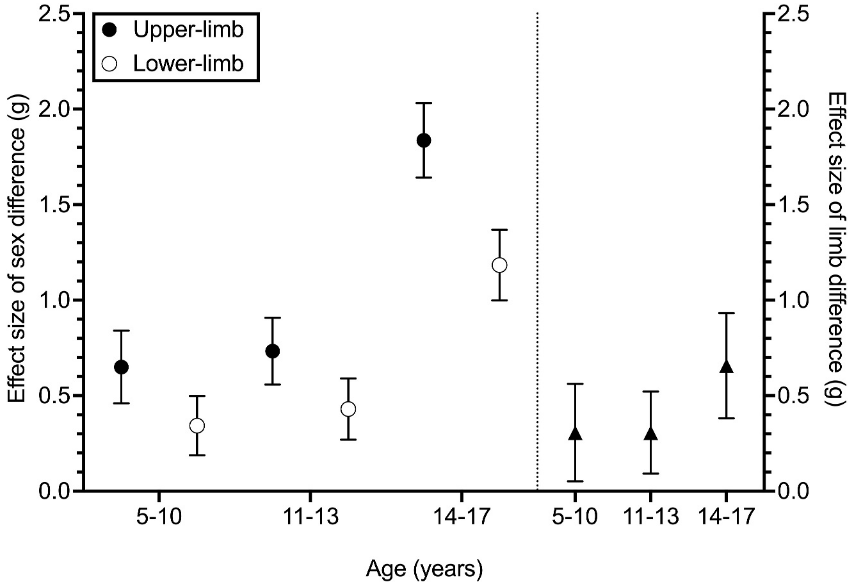

FIGURE 2 | Effect sizes of sex differences in upper- and lower-limb muscle strength in 5–10-year-olds, 11–13-year-olds, and 14–17-year-olds are plotted on the left *y*-axis. Circles represent pooled effect sizes (Hedges *g*) for each age cohort and for all upper-limb muscles combined (black circles) or all lower-limb muscles combined (white circles). Error bars around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CIs). Positive effect sizes represent boys having greater muscle strength than girls. Upper-limb strength was significantly greater (all $p < 0.001$) in boys than girls at 5–10 years old ($g = 0.65$ (95% CIs [0.46, 0.84] and 95% PIs [−0.15, 1.44])), 11–13 years old ($g = 0.73$ (95% CIs [0.56, 0.91] and 95% PIs [−0.06, 1.53])), and 14–17 years old ($g = 1.84$ (95% CIs [1.64, 2.03] and 95% PIs [1.04, 2.63])). Lower-limb strength was also significantly greater in boys than girls at 5–10 years old ($g = 0.34$ (95% CIs [0.19, 0.50] and 95% PIs [−0.45, 1.13])), 11–13 years old ($g = 0.43$ (95% CIs [0.27, 0.59] and 95% PIs [−0.36, 1.22])), and 14–17 years old ($g = 1.18$ (95% CIs [1.00, 1.37] and 95% PIs [0.39, 1.98])). Plotted on the right *y*-axis are effect sizes (black triangles) that compare the mean upper-limb sex difference in strength to the lower-limb sex difference in strength. The upper-limb sex difference in strength was significantly greater (all $p \leq 0.007$) than the lower-limb sex difference in strength in participants who were 5–10 years old ($g = 0.31$ (95% CIs [0.05, 0.56] and 95% PIs [−0.49, 1.11])), 11–13 years old ($g = 0.31$ (95% CIs [0.09, 0.52] and 95% PIs [−0.49, 1.10])), and 14–17 years old ($g = 0.66$ (95% CIs [0.38, 0.93] and 95% PIs [−0.15, 1.46])).

TABLE 2 | Predicted means of boys' strength expressed as a ratio[a] of girls' strength by age and limb.

		95% CI		95% PI	
Age group, limb	**Response ratio**	**Lower**	**Upper**	**Lower**	**Upper**
5–10 years old	1.11	1.06	1.14	0.91	1.34
Upper limb	1.17	1.12	1.21	1.00	1.36
Lower limb	1.08	1.04	1.11	0.92	1.26
11–13 years old	1.12	1.08	1.16	0.93	1.35
Upper limb	1.18	1.14	1.22	1.01	1.38
Lower limb	1.10	1.06	1.13	0.94	1.28
14–17 years old	1.39	1.33	1.44	1.15	1.67
Upper limb	1.50	1.45	1.56	1.29	1.76
Lower limb	1.30	1.25	1.34	1.11	1.51
Overall (5–17 years old)	1.17	1.13	1.22	0.88	1.57
Upper limb	1.25	1.20	1.30	0.96	1.63
Lower limb	1.14	1.09	1.18	0.87	1.48

[a]For example, a ratio of 1.10 means that boys have 10% or 1.1 times greater muscle strength than girls and a ratio of 1.50 means that boys have 50% or 1.5 times greater muscle strength than girls.

arm length did not explain the sex differences in strength (Wood et al. 2004). Similarly, in boys and girls ≥ 12 years old, sex differences in elbow flexion strength are largely eliminated when strength is expressed relative to muscle CSA (Gillen et al. 2024; Ikai and Fukunaga 1968). Yet, prior to puberty, a complicating issue is that muscle strength does not appear to develop in proportion to muscle CSA (Kanehisa, Ikegawa, et al. 1995), leaving the cause of the sex difference in muscle strength prior to puberty somewhat less certain than after puberty.

Sex differences in body composition throughout development and aging are caused by sex differences in hormones and genetic factors (Garnett et al. 2004; Link and Reue 2017; Wells 2007). Higher absolute and relative body fat levels in prepubertal girls than boys appear linked to higher estradiol levels in girls (Garnett et al. 2004). In boys, greater muscle mass is caused by higher testosterone levels (Round et al. 1999). Higher testosterone levels correlate with greater growth velocity during infancy (Kiviranta et al. 2016), and boys have higher testosterone levels than girls *in utero* (Abramovich 1974) and during infancy (Garagorri et al. 2008; Kiviranta et al. 2016; Kuijper et al. 2013; Tomlinson et al. 2004). Testosterone levels are similar in boys and girls during childhood, but male puberty eventually causes boys to experience a 20–30-fold increase in testosterone (Courant et al. 2010; Elmlinger et al. 2005; Handelsman et al. 2018; Khairullah et al. 2014).

An alternative theory about sex differences in muscle strength prior to puberty is that they are "mostly environmentally induced" and could "easily be eliminated if girls and boys were treated similarly" (Thomas and French 1985). Evidence for this theory is lacking, and a recent meta-analysis revealed that the size of the sex difference in grip strength in children and adolescents has remained stable over the past 60 years and is the same size in most countries (Nuzzo 2025). Also, when prepubertal boys and girls are matched in time spent practicing a sport (Manzano-Carrasco et al. 2022), or compete in the same sport (Peek et al. 2022), boys are still physically stronger than girls. Also, a strong case exists that greater male than female upper-limb strength is one of many innate sex differences that have evolved in humans from selection pressures associated with throwing in males (Lombardo and Deaner 2018). Thus, overall, the findings from studies cited above suggest that biology rather than environment is the primary driver of sex differences in muscle strength before, during, and after puberty.

4.3 | Implications

Muscle strength is fundamental to athletic performance. In children and adolescents, lower-body muscle strength correlates positively with vertical jump height and sprint times (Castro-Piñero et al. 2010; Miyashita and Kanehisa 1979; Peñailillo et al. 2016; Sommerfield et al. 2022) and shoulder rotator strength correlates with 100 m freestyle swim time (Miyashita and Kanehisa 1979). Results from the current meta-analysis and a meta-analysis on grip strength (Nuzzo 2025) illustrate that maximal strength is greater in boys than girls before, during, and after puberty. Thus, greater muscle strength in prepubertal boys than girls helps to explain how prepubertal and post-pubertal boys outperform girls in various athletic events, particularly events that rely more heavily on upper-limb strength (i.e., shot put and javelin throw) (Atkinson et al. 2024; Brown et al. 2024b, 2025a, 2025b; Handelsman 2017). Other meta-analyses have also revealed that prepubertal boys outperform prepubertal girls in pull-ups, broad jump distance, throw velocity, throw distance, shuttle run time, and 800 m time (Thomas and French 1985; Thomas et al. 1991).

In recent years, the topic of sex differences in physical performance has received heightened attention due to some males who identify as female wanting to participate in the female category of sport. Many of the reasons why this policy is unfair and potentially unsafe for females have been presented elsewhere (Brown et al. 2024a; Hilton and Lundberg 2021;Lundberg, Tucker, et al., 2024; Senefeld et al. 2023; Tucker et al., 2024a). This policy also does not have strong public support, as three large surveys—two from the USA and one from the United Kingdom—have shown that the majority of survey respondents do not support the idea of males who identify as females participating in the female category of sport (Blazina and Baronavski 2022; J. M. Jones 2023; Smith 2025).

The current meta-analysis informs the debate surrounding the claim that puberty-blocking hormones would prevent males from obtaining their puberty-inducing physical advantages over females, because "prior to puberty there are no measurable athletic differences between boys and girls" (Safer 2022). One study was cited to support that claim (Tønnessen et al. 2015). Putting aside the serious ethical and medical implications of administering puberty blocking hormones to children, the basis of the argument—that is, there are no prepubertal performance advantages of boys over girls—is not supported by the results of the current meta-analysis nor is it supported by several other studies and meta-analyses on prepubertal sex differences in physical performance (Atkinson et al. 2024; Brown et al. 2024b; Brown et al. 2025a, 2025b; Handelsman 2017; Thomas and French 1985; Thomas et al. 1991). Exploration of sex-segregated fitness data will help to establish accurate estimates of prepubertal sex differences in performance and thus continue to clarify one aspect of a much larger debate about human physiology and sports philosophy.

4.4 | Limitations

The current study has limitations. First, the literature search did not follow a formal flow diagram. Consequently, replication of the search is probably not possible. Nevertheless, the aim of the research was to meta-analyze existing data on sex differences in lower-limb muscles and in upper-limb muscles not explicitly involved in gripping (Nuzzo 2025; Thomas and French 1985; Thomas et al. 1991). That aim was accomplished. The results suggest that sex differences in both upper- and lower-limb muscles exist prior to puberty, are markedly increased with puberty, and are greater in upper- than lower-limb muscles irrespective of age.

A second potential limitation of the current research is that, compared to the recent meta-analysis on grip strength (Nuzzo 2025), much fewer effects were available. Thus, confidence in the effect sizes is lower than in the recent meta-analysis on grip strength (Nuzzo 2025). The small number of effects at some ages and for some muscle groups were the reason for data aggregation. Nonetheless, the results still show that sex differences in strength exist throughout development and that these differences are greater in upper- than lower-limb muscles. Moving forward, researchers can use both longitudinal and cross-sectional designs to study strength of various muscles in large numbers of boys and girls at all years of development to increase confidence in estimates of effect sizes.

A third limitation of the current study is that the cause of the body region-specific sex difference in muscle strength was not studied directly. Based on the literature cited earlier, biological factors, such as sex differences in body composition, are the most plausible explanations for the observed differences in upper- and lower-limb strength between boys and girls before, during, and after puberty.

5 | Conclusion

Muscle strength is greater in boys than girls before, during, and after puberty, though the presence of this sex difference is more certain after puberty. At all stages of development, the difference is greater in upper- than lower-limb muscles. Between 5 and 13 years old, boys have, on average, 17%–18% greater upper-limb strength than girls and 8%–10% greater lower-limb strength. Male puberty causes the sex difference in muscle strength to increase dramatically, such that, between the ages of 14–17 years, boys have, on average, 50% greater upper-limb strength than girls and 30% greater lower-limb strength. Sex differences in body height, body mass, and body composition are the likely causes of greater muscle strength in boys than girls throughout development.

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Ethics Statement

Ethical approval is not required for a meta-analysis of published data.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data spreadsheet and statistical results associated with this study are available at the Open Science Framework. A preprint of this paper was made at available at SportRxiv.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.