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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 muscle tested, with larger sex differences observed in upper- than lower-limb muscles. Whether muscle-group-specific sex differences in strength are present 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 that included participants aged ≤ 17 years who completed maximal isometric or isokinetic tests of upper-limb (elbow flexors or extensors; multi-joint tests) or lower-limb strength (knee flexors or extensors; ankle dorsiflexors or plantarflexors; multi-joint tests). Participants were partitioned into three age groups (5-10, 11-13, 14-17 years old). The analysis included 299 effects from 33 studies. The total sample was 17,263 (9,269 boys, 7,994 girls). For upper-limb tests aggregated, effect sizes were g = 0.58 (95% confidence intervals (CIs) [0.45, 0.71]) and 2.02 (95% CIs [1.81, 2.23]) for 5-10- and 14-17-year-olds, respectively. For lower-limb tests, effect sizes were g = 0.21 (95% CIs [0.15, 0.27]) and 1.25 (95% CIs [0.99, 1.45]) for 5-10- and 14-17-year-olds, respectively. In 5-10-year-olds, weighted means of girls' upper- and lower-limb strength relative to boys' strength were 84.5 ± 8.2% and 94.1 ± 7.2%, respectively. In 14-17-year-olds, they were 64.7 ± 6.1% and 76.0 ± 8.6%, respectively. Thus, boys are stronger than girls on average. The sex difference in strength increases markedly with male puberty and is more pronounced in upper- than lower-limb muscles throughout development.

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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). Whether muscle-group-specific sex differences in strength are present in children and adolescents is less clear.

A recent meta-analysis revealed that boys have greater grip strength than girls from birth onward (Nuzzo, 2024b). Between 3-10 years old, the difference in grip strength between boys and girls is small-to-moderate (g = 0.33 – 0.45), it decreases for a year at age 11 presumably due earlier female than male maturation (g = 0.28), it increases each year thereafter such that by age 16 the difference is substantial (g = 2.07) (Nuzzo, 2024b). At age 16, girls' grip strength relative to boys' grip strength is 65% compared to 90% between the ages of 3-10 years (Nuzzo, 2024b). Nevertheless, this new meta-analysis was limited to grip strength. Strength of lower-limb muscles was not summarized nor was strength of upper-limbs not explicitly involved in gripping. Thus, it is also unclear if muscle-specific sex differences in muscle strength observed in adults (Nuzzo, 2023) are also present in children and adolescents.

Therefore, 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. I hypothesized, based on two recent analyses (Nuzzo, 2023; Nuzzo, 2024b), that sex differences in muscle strength would exist at all ages and in both the upper and lower limbs but that the difference would be more pronounced in the upper than lower limbs. The results are projected to have implications for ongoing debates about sex and gender, development, and sports performance and policy (Brown et al., 2024; Hamilton et al., 2024; Hilton & Lundberg, 2021; Lundberg et al., 2024; Nokoff et al., 2023; Nuzzo, 2023; Tucker et al., 2024).

METHOD

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 me based on searches conducted for reviews on related topics (Nuzzo, 2023; Nuzzo, 2024b). 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, 2024b; Nuzzo, Pinto, & Nosaka, 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." I have used this type of search strategy successfully in previous reviews and meta-analyses (Nuzzo, 2023; Nuzzo, 2024a, 2024b; Nuzzo, Pinto, & Nosaka, 2023; Nuzzo, Pinto, Nosaka, et al., 2023; Nuzzo et al., 2024).

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 (SD) 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 multi-joint tests of upper- or lower limb strength, (f) included strength scores that were neither statistically adjusted for covariates nor normalized to participant body anthropometrics (e.g., body mass, 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 were reported; and (e) the age range of participants was beyond the criteria for the analysis (described below).

Grip strength was not included in the current study because it was the focus of a recent meta-analysis (Nuzzo, 2024b). Also, studies that measured strength using the back-and-leg dynamometer were excluded because this test involves combined use of lower-limb, trunk, and upper-limb muscles and thus cannot be categorized as a test of either lower-limb or upper-limb strength

Data extraction and organization

Information extracted from eligible studies included 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 of muscle strength. Researchers reported their data in various ways. Consequently, I established criteria for data eligibility, extraction, and organization.

Age. For the current study, age was treated as a categorical variable (e.g., "5-year-olds"). This was done because most researchers presented their data this way and because it allows for examination of how the sex difference in muscle strength changes year-by-year. Unlike my previous analysis of grip strength (Nuzzo, 2024b), it became apparent early in the literature search process that there were less data available for each joint and muscle group for the current study to allow for accurate and meaningful portrayals of joint- and muscle-specific sex differences of *for each year of development*. To accommodate for this limitation in number of effects available when data were segregated by joint or muscle and each year of development, the data were aggregated in two ways to allow for informative comparisons.

First, data for each year of development were presented as two broad body area categories: “upper-limb muscles” and “lower-limb muscles” (Fig. 1). The group “upper-limb muscles” included results from isometric and isokinetic strength tests of the elbow flexors, elbow extensors, and multi-joint 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 multi-joint lower-limb tests.

Second, to allow for a more formal statistical comparison between the effect sizes of sex differences in upper- and lower-limb strength, the data were also aggregated into three age groups: 5-10 years old, 11-13 years old, 14-17 years old (Fig. 2). These three age ranges were utilized because 5-10 years old represents pre-puberty for most boys and girls (Tanner, 1971), and grip strength is mostly stable between 5-10 years old, whereas grip strength becomes less stable between 11-13 years old, and then has a clearer trajectory starting at age 14 (Nuzzo, 2024b). With these age group comparisons in mind, studies in which the cohort’s age spanned multiple years were also eligible for inclusion in the current analysis under certain conditions. The first criterion was that a study was ineligible for inclusion in the meta-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. The second criterion was that a study, although most studies in the current analysis presented data for single age cohorts (e.g., “8-year-olds”), cohorts in some studies spanned multiple years, and thus, studies were included in the current analysis if the span of years of the cohorts in their study did not exceed any of the following three age ranges: 5-10 years old, 11-13 years old, and 14-17 years. Overall, the purpose of this approach was to allow for as much data as possible to be included in the analysis without negatively impacting scientific validity

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 muscle strength before and after an intervention, only data from the baseline strength assessments were included in the current analysis

Sidedness means. Some researchers presented muscle strength scores from only one limb, whereas other researchers presented strength scores from both limbs. 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 – sometimes "right" and "left" or "dominant" and "non-dominant" – 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, I first calibrated the y-axis. This involved identifying and inputting the strength values associated with the bottom and top of the y-axis. I then 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.

Statistical analysis

The data spreadsheet and statistical results associated with this study are available at the Open Science Framework (https://osf.io/bpm5a/). Version 29 of the Statistical Software Package for the Social Sciences (SPSS, Armonk, USA) was used to generate frequency counts (e.g., number of effects by age, country, decade of data collection) and effect sizes (Hedges *g* for random effects) with 95% confidence intervals (CI), prediction interval, and associated forest plots. The effect sizes were generated for each age cohort (5-10, 11-13, and 14-17 years old) by body area (upper-limb, lower-limb) and joint (elbow, knee, ankle, multi-joint upper limb, multi-joint lower limb). Effect sizes equal to 0.2, 0.5, and 0.8 are often considered small, moderate, and large, respectively, but 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). For descriptive purposes, girls' strength relative to boys' strength was computed. Girls' mean strength scores were divided by boys' mean grip strength and weighted means (by sample size) were computed

Results

Study characteristics

A total of 33 studies studies met the eligibility criteria and provided data for the meta-analysis (Andersen & Henckel, 1987; Bäckman & Oberg, 1989; Davies et al., 1983; 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 & Fukunaga, 1968; Jones & Dwyer, 1998; Kanehisa, Ikegawa, & Fukunaga, 1994; Kanehisa, Yata, et al., 1995; Katzmarzyk et al., 1997; Linderholm et al., 1971; Lundgren et al., 2011; Miyashita & Kanehisa, 1979; Montoye & 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 & Paasuke, 1995; Seger & Thorstensson, 1994, 2000; Siegel et al., 1989; Streckis et al., 2007; Wood et al., 2004, 2008).

The studies included 299 effects from 17,263 children and adolescents (9,269 boys, 7,994 girls). The number of effects by age and muscle group are provided in Table 1. The number of effects by country are provided in Table 2. The number of effects by decade of data collection were as follows: 13 effects from the 1960s, 8 effects from the 1970s, 88 effects from the 1980s, 89 effects from the 1990s, 90 effects from the 2000s, and 11 effects from the 2010s (i.e., 2010-2023)

Age and muscle group

Boys were stronger than girls at most ages and for both upper- and lower-limb muscles (Table 1, Fig. 1, Fig. 2). However, the size of the sex difference differed by age and muscle group. Sex differences in muscle strength for all muscle groups were more pronounced in the 14-17-year-olds than the younger cohorts. Moreover, at all ages, the sex difference in strength was more pronounced in upper- than lower-limb muscles.

In 5-10-year-olds, girls' upper- and lower-limb strength relative to boys' upper- and lower-limb strength were 84.5 ± 8.2% and 94.1 ± 7.2%, respectively (Table 3). In 11-13-year-olds, girls' upper- and lower-limb strength relative to boys' upper- and lower-limb strength were 83.9 ± 7.1% and 92.8 ± 6.4%, respectively. In 14-16-year-olds, girls' upper- and lower-limb strength relative to boys' upper- and lower-limb strength were 64.7 ± 6.1% and 76.0 ± 8.6%, respectively

Discussion

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

Age and muscle group

Male puberty is known as a key deflection point for causing substantial differences in muscle strength between males and females. 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, 2024b). Similarly, the current found found small-to-moderate sex differences in strength of the elbow flexor and extensor muscles between 5-10-year-old boys and girls, with girls exhibiting 85% of boys' strength. The current analysis also identified pre-pubertal sex differences in strength of *lower*-limb muscles. Specifically, girls exhibit 94% of boys' strength for the flexors and extensors of the knee and ankle. Thus, sex differences in muscle strength are systemic in humans prior to puberty but the difference is greater in upper- than lower-limb muscles.

Sex differences in upper- and lower-limb strength present prior to age 11 are similar to those observed between 11-13 years old. At age 14, a marked increase in the sex differences in muscle strength occurs. Between 14-17 years of age, girls' upper- and lower-limb strength is 65% and 76% of boys' upper- and lower-limb strength, respectively. Thus, muscle-specific sex differences in strength are present before, during, and after puberty. They also persist throughout 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).

Causes of sex differences in muscle strength

Multiple factors likely contribute to sex differences in muscle strength in children and adolescents. As detailed elsewhere, key factors include sex differences in body height, body mass, and body composition (e.g., muscle mass) (Nuzzo, 2024b). Sex differences in factors such as muscle fiber type and voluntary activation are less clear due to a relative lack of data in children and adolescents (Nuzzo, 2024b).

Both 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; Kocher et al., 2017; Parker et al., 1990), and boys tend to be slightly taller and weigh more than girls up until age 11 (USA data) (Kuczmarski et al., 2002). At age 11, which is when girls first exhibit greater body heights and body masses than boys (Kuczmarski et al., 2002), the sex difference in grip strength narrows (Nuzzo, 2024b). In the current analysis, a narrowing of the sex difference in muscle strength at age 11 was not apparent. In fact, in lower-limb muscles, the sex difference in strength was *higher* than in the preceding and subsequent years of development (i.e., ages 10 and 12). The cause of this unexpected result is uncertain. However, in the current analysis, the number effects available for the knee extensors at age 11 (27 effects) was considerably greater than at all other ages (e.g., 15 effects at age 7 was the next highest number of effects for the knee extensors). Thus, this unexpected result might be due to the relative lack of data in the current analysis compared to the more statically powerful analysis of sex differences in grip strength (Nuzzo, 2024b). Moving forward, more effects from all muscle groups will lead to greater confidence in sizes of sex differences in strength at each age of development and for each muscle group.

Body composition is likely the most significant contributor to the sex difference in muscle strength before and after puberty. In both boys and girls, fat-free mass correlates positively and strongly with muscle strength (r = 0.81 – 0.85) (Sartorio et al., 2002). Pre-pubertal boys often have more fat-free or lean mass, less fat mass, and lower body fat percentages than pre-pubertal girls (Arfai et al., 2002; Garnett et al., 2004; He et al., 2002; Kirchengast, 2010; Leppänen et al., 2017; McCarthy et al., 2014; Nelson & Barondess, 1997; Soininen et al., 2018; Taylor et al., 1997). Then, during and after puberty, sex differences in absolute and relative amounts of fat and fat-free mass become more pronounced (El Hage et al., 2009; Henche et al., 2008; McCarthy et al., 2014; Ogle et al., 1995; Ripka et al., 2020).

Regional differences in body composition have also been noted in boys and girls and may help explain how the sex difference in strength is greater in upper- than lower-limb muscles throughout childhood and adolescents. 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 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-olds, cross-sectional areas (CSA) 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 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; Welsman et al., 1997). For example, in one study, sex differences in CSAs of the ankle dorsiflexors and plantarflexors emerged only after participants reached 13 years of age (Kanehisa, Yata, 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) observed no sex difference in CSA of the elbow flexors in pre-pubertal boys and girls who had a mean age of 9.5 years. Interestingly, some studies that have reported no sex difference in upper- (Wood et al., 2006) or lower-limb (O'Brien et al., 2010) muscle strength have also reported no sex difference in muscle size. Such findings suggest that the presence of 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. They 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 arm length did not explain the sex differences in strength (Wood et al., 2004). Similarly, in boys and girls ≥ 12 years old, Ikai and Fukunaga (1968) found that sex differences in elbow flexion strength were eliminated when strength was expressed relative to muscle CSA. Yet, a complicating issue is that, prior to puberty, 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 are caused by sex differences in hormones. Higher absolute and relative body fat levels in 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 consequently, could "easily be eliminated if girls and boys were treated similarly" (Thomas & French, 1985). However, 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, 2024b). Also, when pre-pubertal boys and girls are matched in time spent practicing sports (Manzano-Carrasco et al., 2022), or compete in the same sport (Peek et al., 2022), boys are still physically stronger than girls. Thus, biology, not environment, appears to be the primary drivers of sex differences in muscle strength prior, during, and after puberty

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 upper-limb muscles not explicitly involved in gripping (Nuzzo, 2024b; Thomas & French, 1985; Thomas et al., 1991). This aim was accomplished. The results reveal, with a sufficient level of confidence 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, 2024b), much fewer effects were available. Thus, confidence in the effect sizes is lower than in the recent meta-analysis on grip strength (Nuzzo, 2024b). The small number of effects at some ages and for some joints and muscle groups were why the data were aggregated for certain comparisons. Nonetheless, the results still clearly show that sex differences in strength exist throughout development and that they 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 muscle- specific sex difference in muscle strength was not studied directly. Nevertheless, based on the literature cited earlier, biological factors, such as sex differences in body composition, are the most plausible explanations for the observed sex differences in upper- and lower-limb strength before, during, and after puberty.

Conclusion

Muscle strength is greater in boys than girls before and after puberty. At all stages of development, the difference is greater in upper- than lower-limb muscles. Between 5-10 years old, girls' strength relative to boys' strength is 85% and 94% for upper- and lower-limb muscles, respectively. Male puberty causes the sex difference in muscle strength to increase dramatically, such that, between the ages of 14-17 years, girls have 65% and 76% of boy's upper- and lower-limb strength, respectively. Sex differences in body height, body mass, and body composition (e.g., muscle mass) are the likely causes of greater muscle strength in boys than girls throughout childhood and adolescence

Data availability statement

The data spreadsheet and statistical results associated with this study are available at the Open Science Framework (https://osf.io/bpm5a/).

Discloser and funding statement

I have no conflicts of interest to report.

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Ethics approval

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

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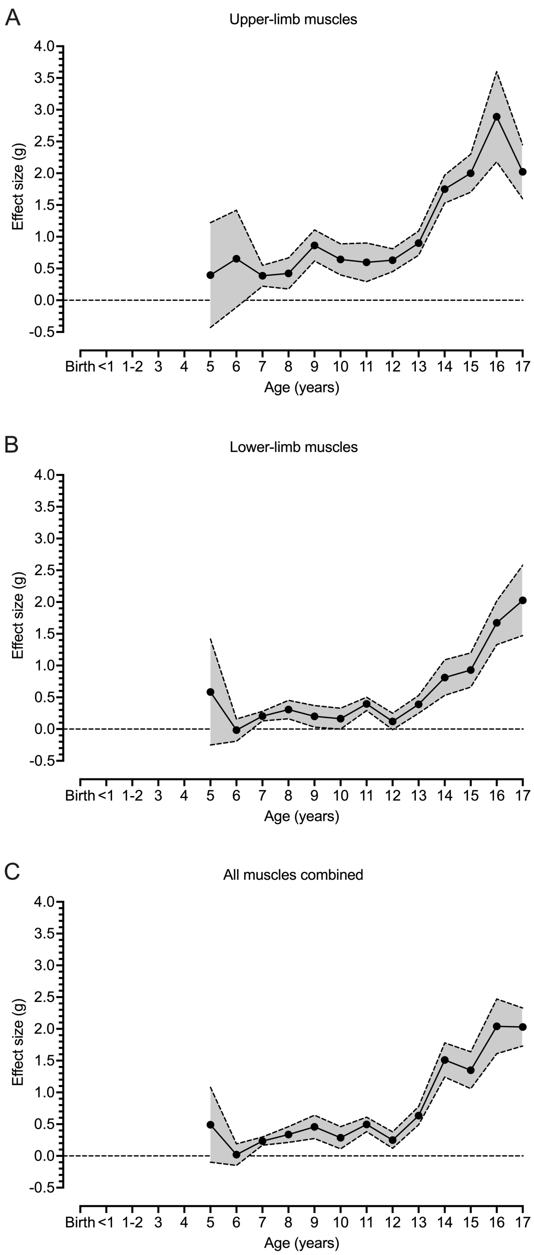

Figure 1. Effect sizes of differences in strength of upper-limb muscles (A), lower-limb muscles (B), and all muscles combined (C) between boys and girls from age 5 to 16. Black circles represent cumulative effect sizes (Hedges *g*) for each age. Dashed lines around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CIs). Positive effect sizes (above the dashed zero line) represent when boys' strength is greater than girls' strength. Negative effect sizes (below the dashed zero line) represent when girls' strength is greater than boys' strength.

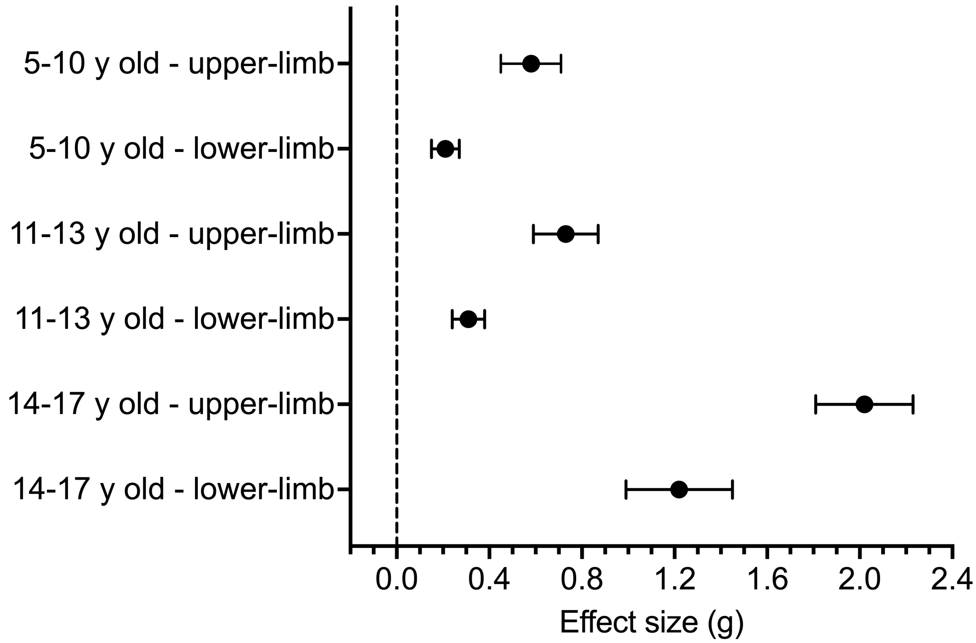

Figure 2. Effect sizes of sex differences in upper- and lower-limb muscle strength in 5-10-, 11-13-, and 14-17-year-old boys and girls. Black circles represent cumulative effect sizes (Hedges *g*) for each age cohort and for all upper- or lower-limb muscles combined. Error bars around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CIs). Positive effect sizes (above the dashed zero line) represent when boys' strength is greater than girls' strength

Table 1. Effect sizes of the difference in sit-and-reach flexibility between boys and girls by age group.

Age group	No. effects	Hedges *g*	*p*	95% CI Lower	95% CI Upper	95% PI Lower	95% PI Upper
5-10 years old	128	0.29	<.001	0.23	0.36	-0.15	0.74
Upper-limb	35	0.58	<.001	0.45	0.71	0.09	1.07
Elbow	26	0.51	<.001	0.37	0.66	0.25	0.77
Multi-joint	9	0.65	<.001	0.42	0.87	-0.12	1.41
Lower-limb	93	0.21	<.001	0.15	0.27	-0.06	0.48
Knee	73	0.20	<.001	0.13	0.26	-0.08	0.47
Ankle	19	0.25	<.001	0.10	0.39	-0.03	0.53
Multi-joint	1	0.74	0.005	0.22	1.26	NA	NA
11-13 years old	109	0.47	<.001	0.39	0.54	-0.06	0.99
Upper-limb	33	0.73	<.001	0.59	0.87	0.11	1.35
Elbow	26	0.64	<.001	0.49	0.80	0.13	1.16
Multi-joint	7	0.90	<.001	0.66	1.14	0.11	1.69
Lower-limb	76	0.31	<.001	0.24	0.38	0.24	0.39
Knee	63	0.33	<.001	0.25	0.40	0.25	0.41
Ankle	11	0.19	<.001	0.00	0.39	-0.03	0.42
Multi-joint	2	0.70	0.056	-0.02	1.42	NA	NA
14-17 years old	62	1.64	<.001	1.45	1.82	0.33	2.94
Upper-limb	32	2.02	<.001	1.81	2.23	0.99	3.05
Elbow	29	1.91	<.001	1.73	2.09	1.25	2.57
Multi-joint	3	2.58	<.001	1.47	3.69	-11.59	16.75
Lower-limb	30	1.22	<.001	0.99	1.45	0.10	2.34
Knee	19	1.52	<.001	1.26	1.79	0.45	2.60
Ankle	11	0.63	<.001	0.44	0.83	0.41	0.86
Multi-joint	0	NA	NA	NA	NA	NA	NA
Overall (5-17 years old)	299	0.62	<.001	0.55	0.70	-0.55	1.80
Upper-limb	100	1.08	<.001	0.93	1.24	-0.34	2.51
Elbow	91	1.09	<.001	0.92	1.27	-0.29	2.48
Multi-joint	19	1.04	<.001	0.68	1.41	-0.68	2.77
Lower-limb	199	0.39	<.001	0.32	0.46	-0.36	1.15
Knee	155	0.40	<.001	0.32	0.48	-0.44	1.24
Ankle	41	0.33	<.001	0.23	0.43	0.14	0.52
Multi-joint	3	0.73	<.001	0.30	1.15	-2.00	3.45

CI = confidence interval; NA = not applicable; PI = prediction interval.

Table 2. Number of effects in the meta-analysis by country or region of data collection.

Country or region	No. effects	Percent
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 of America	27	9.0
Wales	1	0.3
Total	299	100.0

Table 3. Weighted means of girls' strength expressed as a percent of boys' strength by age group and body area.

Age group	*n*	Mean (%)	SD (%)
5-10 years old	8,348	91.8	8.5
Upper-limb	2,006	84.5	8.2
Elbow	837	89.1	6.6
Multi-joint	1,169	81.2	7.6
Lower-limb	6,342	94.1	7.2
Knee	5,477	94.5	6.6
Ankle	805	91.7	9.7
Multi-joint	60	88.2	0.0
11-13 years old	5,420	89.0	8.0
Upper-limb	2,313	83.9	7.1
Elbow	1,193	86.4	6.8
Multi-joint	1,120	81.3	6.5
Lower-limb	3,107	92.8	6.4
Knee	2,692	92.7	6.4
Ankle	387	94.2	6.1
Multi-joint	28	85.3	5.6
14-17 years old	3,505	70.0	9.3
Upper-limb	1,855	64.7	6.1
Elbow	1,297	66.4	5.3
Multi-joint	558	60.9	6.3
Lower-limb	1,650	76.0	8.6
Knee	1,243	73.7	7.6
Ankle	407	83.0	7.6
Multi-joint	NA	NA	NA
Overall	17,273	86.5	11.9

NA = not applicable; SD = standard deviation.