Sex differences in grip strength from birth to age 16: a meta-analysis

Supplementary materials:
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ABSTRACT

In 1985, Thomas and French published results of a meta-analysis that examined sex differences in grip strength in children 5 years of age and older. Their analysis included results from only four studies, and no update of it has been published. The purpose of the current study was to use meta-analysis to examine sex differences in grip strength from birth to age 16. The analysis included 808 effects from 169 studies conducted in 45 countries between 1961–2023. The total sample was 353,676 (178,588 boys, 175,088 girls). From birth to 16 years of age, grip strength was consistently greater in boys than girls. Between 3-10 years old, the effect size was small-to-moderate, with female grip strength equaling 90% of male grip strength (Hedges g = 0.33-0.46). At age 11, the effect size decreased, likely due to girls reaching puberty before boys (g = 0.29, 95% confidence intervals (CI) [0.22, 0.35]). At age 13, the effect size increased markedly likely due to male puberty (g = 0.63, 95% CIs [0.55, 0.70]). By age 16, the sex difference in grip strength was substantial, with female grip strength equaling 65% of male grip strength (g = 2.07, 95% CIs [1.86, 2.27]). Secondary analyses revealed that the sex difference in grip strength is broadly similar between countries and has been mostly stable since the 1960s, except for a narrowing of the difference among 5-10-year-olds after 2010. Various biological factors explain why, on average, boys are stronger than girls from birth onward.

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INTRODUCTION

Puberty causes the average adult human male to develop the capacity to generate significantly more muscle force than the average adult human female (Nuzzo, 2023a). For upper-body muscles, adult female strength is approximately 55-60% of adult male strength (Nuzzo, 2023a). Emphasis on male puberty as the major inflection point for the sex difference in muscle strength gives the impression that little or no sex difference in muscle strength exists before puberty. But is that the case? Studies have generated conflicting results, perhaps due to differing age cohorts and muscle groups examined (De Smet & Vercammen, 2001; De Ste Croix et al., 2003; Ervin et al., 2013; Krammel et al., 2018).

Meta-analysis can be used to clarify sex differences in muscle strength in children and adolescents. However, only one published meta-analysis has addressed this topic (Thomas & French, 1985). Forty years ago, Thomas and French (1985) used meta-analysis to examine sex differences in physical fitness in boys and girls aged 5-17 years. At all ages assessed, boys had greater grip strength than girls. In 5-10-year-olds, the effect size was small-to-moderate (approximately $d = 0.5$). At age 11, the effect size decreased ($d = 0.2$) but then trended upward culminating in substantially greater grip strength in boys than girls at age 16 ($d = 1.6$). Thomas and French (1985) speculated that the small-to-moderate differences in grip strength between boys and girls prior to puberty were "mostly environmentally induced" and that these differences could "easily be eliminated if girls and boys were treated similarly."

For many years, the meta-analysis by Thomas and French (1985) has served as a useful source for understanding sex differences in physical fitness during childhood and adolescence. However, the analysis was not without limitations. First, it included data from only four studies (Thomas & French, 1985). Two of these studies were unpublished reports, as later revealed by the researchers in a follow-up article (Thomas & French, 1987). In total, the four studies provided 42 effects from 1,446 boys and 1,338 girls (Thomas & French, 1985). Today, grip strength data are available from hundreds of papers and tens of thousands of boys and girls. For this reason alone, an updated meta-analysis is warranted. Second, Thomas and French (1985) analysis included grip strength data only from children in the United States of America (USA). Grip strength data are now available from children who reside in other countries. Thus, comparisons of sex differences in grip strength between countries are now possible. Third, Thomas and French (1985) analysis did not include grip strength data from children younger than 5 years old. Such data are now available, and they can reveal if sex differences in grip strength exist in newborns and infants.

Therefore, the primary aim of the current study was to use meta-analysis to provide an updated examination of sex differences in grip strength from birth to age 16. The current study also had two secondary, exploratory aims. The first exploratory aim was to examine if sex differences in grip strength in children and adolescents have changed over time (i.e., secular analysis). The second exploratory aim was to examine if sex differences in grip strength in children and adolescents differ between countries. Findings generated from these various aims are likely to inform ongoing debates regarding sex and gender, development, and sports performance (Brown et al., 2024; Hamilton et al., 2024; Hilton & Lundberg, 2021; Hunter et al., 2023; Hunter & Senefeld, 2024; Lundberg et al., 2024; Nokoff et al., 2023; Nuzzo, 2023a; Senefeld & Hunter, 2024).

METHOD

Literature search

Papers on sex differences in grip strength in children and adolescents were known to me based on searches conducted for a previous narrative review (Nuzzo, 2023a). In May-Aug 2024, I updated this search, performing it more exhaustively. 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, 2023a; 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. Example keyword searches included combinations of words such as "children," "boys," "girls," "youth," "adolescents," "grip," "strength," "muscle strength," and "physical fitness." Snowballing strategies included reference and citation tracking. I have used this strategy successfully in previous reviews and meta-analyses (Nuzzo, 2023b; 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 male and female participants who were healthy, 16 years of age or younger, and not competitive athlete cohorts; and (d) included sex-segregated samples sizes and means and SD of grip strength, which were neither normalized to anthropometric measurements nor statistically adjusted for covariates. Common reasons for exclusion included: (a) no sex- or age-specific sample sizes reported; (b) no means or SDs reported; and (c) age range of cohort was beyond established criteria (described below).

Data extraction and organization

Extracted data from eligible studies included year of publication, year of data collection (if provided), sample size, sample age, and means and SDs of grip strength. Because researchers reported their data in various ways, I established criteria for data extraction and organization.

Year of data collection. Some researchers reported the year of data collection. For the current meta-analysis, the year of data collection was considered more scientifically valid for examining secular changes in grip strength than year of publication. Some researchers reported data collection dates that spanned two or more years, but they did not segregate their data by year. Thus, when data collection spanned two years (e.g., 2004-2005), the first of the two years was included in the meta-analysis. When data collection spanned more than two years (e.g., 2004-2006), the year in the middle of the range (i.e., 2005) was included in the meta-analysis. When the researcher did not report the year(s) of data collection, the year of publication was used in the meta-analysis.

Age. Researchers presented information on sample age in various ways. Thus, I adopted eligibility and data extraction criteria that would be liberal enough to allow for as much data as possible to be included in the analysis, while not compromising scientific validity. Based on how most researchers presented their data, I organized and analyzed grip strength scores with age as a categorical variable (e.g., "5-year-olds"), with certain restrictions in place. This strategy prioritized grip strength data presented for categorical age groups that spanned only one year (e.g., "5-year-olds"). However, this strategy also permitted inclusion of grip strength scores for categorical age groups that spanned multiple years under the following conditions. First, a study was ineligible for inclusion in the meta-analysis if participants in a cohort were 17 years of age or older or if the cohort's age spanned four or more years (e.g., "5-10-year-olds"). Second, if the researcher reported grip strength scores for a cohort whose age spanned three years (e.g., "5-7-year-olds"), the middle age (e.g., 6-year-olds) was typically entered into the meta-analysis, because the middle age often corresponded with the cohort's rounded down mean age (e.g., 6.4 years in a cohort of 5-7-year-olds whose ages could have ranged from 5.0-7.9 years). Third, if the researcher reported grip strength scores for a cohort whose age spanned two years (e.g., "5-6-year-olds"), the younger of the two ages was entered into the meta-analysis, particularly as the rounded down mean often corresponded with the younger of the two ages (e.g., mean age of 5.5 years in a cohort of 5-6-year-olds whose ages could have ranged from 5.0-6.9 years).

Grip means and study type. Grip strength data were reported in studies of various designs. For longitudinal studies on child development, grip strength from each year of development was included in the meta-analysis. For reliability studies on the consistency of grip strength across time, only grip strength data from the first trial or day of testing were included in the meta-analysis. For cross-sectional studies that compared grip strength in healthy children and children with health conditions, only data from healthy children were included in the meta-analysis. For intervention studies that involved comparisons of grip strength before and after an intervention (e.g., exercise program), only data from baseline were included in the meta-analysis. A small number of studies assessed grip strength at different grip widths. Strength scores for the "middle" grip position were included in the meta-analysis.

Grip means and sidedness, handedness. Some researchers presented grip strength from only one hand, whereas other researchers presented grip strength from both hands or the average of both hands. When a researcher reported only the average of both hands, that average was included in the meta-analysis. When a researcher reported grip strength from only one hand, that value was included in the meta-analysis. When a researcher reported data from both hands – sometimes "right" and "left" or "dominant" and "non-dominant" – data from the right hand or dominant hand were included in the meta-analysis. If the researcher reported data by both sidedness and handedness, priority was given to data from the right hand.

Data extraction from graphs. When grip strength means and SDs were presented in graphs, the values were estimated using a graph digitzer (WebPlotDigitizer, https://automeris.io) (Aydin & Yassikaya, 2022). With the digitizer, I calibrated the y-axis, identifying and inputting the grip strength scores 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 means and SDs calibrated against the y-axis. 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/6m3jw/). Version 29 of the Statistical Software Package for the Social Sciences (SPSS, IBM Corporation, Armonk, NY, USA) was used to complete the statistical analyses. Frequency counts were generated for the number of effects by age, country, and decade of data collection. Random effects meta-analyses were used to generate effect sizes (Hedges g) with 95% confidence intervals (CI) and prediction intervals. Forest plots of the effect sizes and funnel plots of tests of heterogeneity were also generated. Effect sizes equal to 0.2, 0.5, and 0.8 are often considered small, moderate, and large, respectively, though such benchmarks are arbitrary and should not be interpreted rigidly (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' mean grip strength for each study effect were divided by boys' mean grip strength. Weighted means (by sample size) were then used to compute girls' strength as a percent of boys' strength for each age.

For the secular and between-countries analyses, cumulative effect sizes were generated for two large age cohorts (5-10 and 14-16 years-olds) and across each of the six decades from which data were available from these cohorts (1960s, 1970s, 1980s, 1990s, 2000s, 2010s, and 2020s [i.e., 2020-2023]). Ages 11-13 are most closely aligned with puberty onset in both sexes. Thus, removing participants in this age range from the secular and between-countries analyses allowed for examination of a mostly pre-pubescent group (5-10-year-olds) and a mostly post-pubescent group (14-16-year-olds). This segregation helped minimize any confounding impact of pubertal status on the effect of time. For example, if one decade or country included proportionally more samples of 5-10-year-olds, whereas other decades or countries included proportionally more samples of 14-16-year-olds, any observed difference over time or between countries would be confounded by pubertal status. Moreover, this segregation helped minimize a potentially confounding influence of secular changes in age at menarche (Gomula & Koziel, 2018; Lei et al., 2021; Wang et al., 2024) and differences in age at menarche between countries (Lei et al., 2021; Saczuk et al., 2018; Wang et al., 2024). Finally, one might argue that social changes over time (i.e., opportunities for physical activity) might impact pre-pubescent and post-pubescent boys and girls differently and thus warrant separate analyses for such cohorts.

Results

Study characteristics

A total of 169 studies met the eligibility criteria and were included in the current meta-analysis (Abe et al., 2023; Abe et al., 2022; Ager et al., 1984; Al-Rahamneh et al., 2020; Alqahtani et al., 2023; Amado-Pacheco et al., 2019; Amo-Setién et al., 2020; Andersen et al., 2017; Arias Téllez et al., 2018; Atiković et al., 2023; Bae et al., 2015; Bala et al., 2010; Baptista et al., 2012; Barr et al., 2010; Bear-Lehman et al., 2002; Bénéfice et al., 1999; Benzo et al., 2023; Bohannon et al., 2017; Bohannon et al., 2019; Bou-Sospedra et al., 2021; Buck & Lambert, 2022; Butterfield et al., 2009; Cadenas-Sánchez et al., 2015; Cadenas-Sanchez et al., 2016; Casajús et al., 2007; Cetin et al., 2013; Chen et al., 2022; Cohen et al., 2010; Coulter, 1978; de Chaves et al., 2016; De la Cruz-Sánchez & Pino-Ortega, 2010; De Smet & Vercammen, 2001; de Souza et al., 2014; Deforche et al., 2003; Delextrat et al., 2019; Demirel et al., 2014; Dodds et al., 2014; Dong et al., 2016; Eather et al., 2016; Ehrlich et al., 2013; Elezi et al., 2021; Ervin et al., 2014; Espenschade & Meleny, 1961; Fang et al., 2017; Finlayson & Reitan, 1976; Flanagan et al., 2015; Fullwood, 1986; Gantiraga et al., 2006; Garcia-Hermoso et al., 2021; Gisladottir et al., 2023; Godoy-Cumillaf et al., 2020; Godoy-Cumillaf et al., 2023; Gómez-Bruton et al., 2020; Gómez-Campos et al., 2018; Gontarev et al., 2018; Gulías-González et al., 2014; Haapala et al., 2016; Häger-Ross & Rösblad, 2002; Haugland et al., 2023; He et al., 2019; He et al., 2023; Henriksson et al., 2016; Hepping et al., 2015; Herráez et al., 2022; Herrmann et al., 2015; Hirao et al., 2015; Hoekstra et al., 2008; Holm et al., 2008; Ignasiak et al., 2016; Isaacs & Frederick, 1985; Isen et al., 2014; Jacklin et al., 1984; Jacklin et al., 1981; Jürimäe & Saar, 2003; Jürimäe & Volbekiene, 1998; Katzmarzyk et al., 1997; Katzmarzyk et al., 2000; Ke et al., 2022; Kenjle et al., 2005; Kidokoro & Edamoto, 2021; Kidokoro et al., 2016; Kocher et al., 2019; Kocher et al., 2017; Kozieł et al., 2019; Krammel et al., 2018; Kryst et al., 2023; Latorre Román et al., 2017; Legarra-Gorgoñon et al., 2023; Leppänen et al., 2017; Leppänen et al., 2016; Li et al., 2018; Linderholm et al., 1971; Lintu et al., 2016; Lirgg et al., 2011; Little, 2017; Luz et al., 2017; Mačak et al., 2022; Malina et al., 2010; Martinez-Tellez et al., 2016; Mathiowetz et al., 1986; Mayorgaa et al., 2012; McQuiddy et al., 2015; Merino-De Haro et al., 2019; Molenaar et al., 2010; Montalcini et al., 2016; Montoye & Lamphiear, 1977; Montpetit et al., 1967; Morita et al., 2018; Murase et al., 1996; Müürsepp et al., 2009; Naka et al., 2005; Nara et al., 2023; Neu et al., 2002; Ng et al., 2020; Niempoog et al., 2007; Nieto-López et al., 2020; O'Keeffe et al., 2020; Oja & Jürimäe, 2002; Omar et al., 2015; Örjan et al., 2005; Ortega et al., 2008; Ozaki et al., 2020; Parízková et al., 1977; Pavlović et al., 2023; Perna et al., 2016; Perry et al., 1997; Peterson et al., 2018; Peterson et al., 2016; Ploegmakers et al., 2013; Puszczałowska-Lizis et al., 2023; Ramírez-Vélez et al., 2017; Ramos-Sepúlveda et al., 2016; Richards et al., 2022; Riddoch et al., 1991; Rostamzadeh et al., 2021; Ryu et al., 2021; Sanchez-Delgado et al., 2015; Santos et al., 2023; Sasayama & Adachi, 2019; Sember et al., 2022; Siegel et al., 1989; Sokolowski & Chrzanowska, 2012; Spreen & Gaddes, 1969; Steene-Johannessen et al., 2009; Sunnegårdh et al., 1988; Tan et al., 1992; Tanaka et al., 2012; Thomas & Palma, 2018; Tishukaj et al., 2017; Torrijos-Niño et al., 2014; Trajković et al., 2021; Trudeau et al., 2003; Tsimeas et al., 2005; Tsoukos & Bogdanis, 2021; Wang et al., 2019; Weedon et al., 2022; Welk et al., 2015; Wen et al., 2020; Westerstahl et al., 2003; Weston et al., 2019; Wick et al., 2022; Wilcox & Nordstokke, 2022; Xu et al., 2020; Yapici et al., 2022; Yim et al., 2003; Yoshizawa et al., 1977; Yuki et al., 2023; Żegleń et al., 2020; Zhang et al., 2021; Zhang et al., 2022; Zverev & Gondwe, 2001).

The studies included a total of 808 effects from 353,676 children and adolescents (178,588 boys, 175,088 girls). The number of effects available by age group are listed in Table 1.

Study publication dates ranged from 1961 to 2023. The earliest year of data collection was 1935 (Espenschade & Meleny, 1961). The number of effects available by decade of data collection were as follows: 1930s (1 effect, 0.1%), 1950s (1 effect, 0.1%), 1960s (26 effects, 3.2%), 1970s (29 effects, 3.6%), 1980s (64 effects, 7.9%), 1990s (42 effects, 5.2%), 2000s (136 effects, 16.8%), 2010s (401 effects, 49.6%), and 2020s (108 effects, 13.4%). Data were collected in 45 countries. The number of effects available by country are listed in Table 2.

Grip strength

Age. From birth, grip strength was greater in boys than girls (Fig. 1, Table 1). During these ages, female grip strength equaled approximately 90% of male grip strength (Fig. 2, Table 3). From birth up to and including age 2, relatively few effects were available. Consequently, the 95% CIs for these ages were wide. From ages 4 to 10, the 95% CIs narrowed markedly, and the mean effect sizes were consistently small-to-moderate in magnitude (g = 0.33–0.46). At age 11, the effect size decreased (g = 0.29, 95% CIs [0.22, 0.35]), falling below the lower band of the 95% CIs from ages 8-10. At age 13, the effect size increased noticeably (g = 0.63, 95% CIs [0.55, 0.70]). At age 16, the sex difference in grip strength was substantial, with female grip strength equaling 65% of male grip strength (g = 2.07, 95% CIs [1.86, 2.27]).

Secular changes. In the 5-10-year-olds and 14-16-year-olds cohorts, confidence in the size of the effect improved from the 1960s to 2020s, represented by a narrowing of the CIs (Fig. 3, Table 4). For 5-10-year-olds, the effect size was relatively stable between the 1960s and 2000s. Effect sizes ranged between g = 0.50–0.70, with considerable overlap of the CIs in those decades. However, a decrease in the effect size was noted in the 2010s (g = 0.34, 95% CIs [0.31, 0.37]) and 2020s (g = 0.29, 95% CIs [0.23, 0.36]). During the 2010s and 2020s, the upper boundary of the CI fell below, or was roughly equal to, the lower boundaries from some previous decades. For the 14-16-year-olds, the effect size from the 2010s (g = 1.56, 95% CIs [1.41, 1.71]) fell within the 95% CIs from all previous decades, indicating stability in this sex difference over time. A narrowing of this sex difference was present in the 2020s (g = 1.28, 95% CIs [1.09, 1.46]), but the 95% CIs from this decade still overlapped with the 95% CIs from previous decades.

Country. Effect sizes of the difference in grip strength between boys and girls by age and country are presented in Table 5. For some countries, few effects were available, thus rendering their inclusion into the discussion about between-countries differences uninformative and unwarranted.

For 5-10-year-olds, the effect size was consistent between countries. In the USA, the effect size for 5-10-year-olds was g = 0.35 (95% CIs [0.30, 0.40]). Mean effects for most other countries listed in Table 5 fell within the 95% CIs for the USA. For the 14-16-year-olds, the USA and China contributed the greatest number of effects to the meta-analysis, and their mean effect sizes were similar (USA: g = 1.56, 95% CIs [1.40, 1.73]; China: g = 1.61, 95% CIs [1.41, 1.81]). For both the 5-10-year-old and 14-16-year-old cohorts, considerable overlap in the 95% CIs existed across most countries.

Discussion

The current meta-analysis shows that boys have greater grip strength than girls. From birth to age 10, the magnitude of this sex difference is small-to-moderate. During this period of development, female grip strength is approximately 90% of male grip strength. At age 11, the sex difference in grip strength decreases, likely due to girls reaching puberty before boys. From age 12 onward, the sex difference widens considerably. By age 16, female grip strength is 65% of male grip strength. These sex differences have been mostly stable since the 1960s and are similar in magnitude in most countries from which adequate numbers of effects are available.

Age and development

The main novel aspect of the current meta-analysis was the large aggregate sample used to update the question of sex differences in grip strength in children and adolescents. A total of 169 studies provided 808 effects from over 300,000 boys and girls. This represents a substantial enhancement in statistical power compared to the meta-analysis by Thomas and French (1985).

Three studies examined grip strength in boys and girls within the first 48 hours of birth (Jacklin et al., 1984; Jacklin et al., 1981; Tan et al., 1992). The methods used to assess grip strength in these studies included the strength of the baby's grasp reflex of a balloon that was connected to an ohmmeter and ammeter, and the force at which a baby released its grasp on a rubber ring that was attached to a chain and scale and pulled up and away from the baby by the investigator (Jacklin et al., 1984; Jacklin et al., 1981; Tan et al., 1992). Using these techniques, researchers have generally found that newborn boys exhibit greater grip strength than newborn girls (Jacklin et al., 1984; Jacklin et al., 1981; Tan et al., 1992). Nevertheless, the number of effects available in this age cohort was small, the width of the 95% CIs was wide, and the relevant data are now over 30 years old (Jacklin et al., 1984; Jacklin et al., 1981; Tan et al., 1992). Thus, this result should be interpreted cautiously. In contrast, confidence in the size of the sex difference in children 4 years of age and older is much higher because substantially more effects are available. This improved confidence is reflected in the narrow 95% CIs from age 4 onward.

From 4-10 years old, the mean effect size is $g = 0.33–0.46$, with female grip strength equal to about 90% of male grip strength. The effect size decreases from $g = 0.41–0.46$ between the ages of 8-10 to $g = 0.29$ at age 11. This decrease at age 11 is likely due to girls reaching puberty before boys (Brix et al., 2019; Tanner, 1971), illustrating the responsiveness of the sex differences in grip strength to biological factors associated with female puberty. Secular decreases in the age of onset of some pubertal stages have been observed in girls, whereas similar secular decreases in boys' pubertal stages are less certain (Euling et al., 2008). Thus, if boys and girls continue to experience different secular changes in puberty onset, the age at which the sex difference in muscle strength temporarily decreases could change across generations.

After age 11, the sex difference in grip strength widens considerably. At age 13, the effect size is g = 0.63. At age 16, the last age in the meta-analysis, the effect size is g = 2.07. Male puberty, which is characterized, in part, by disproportionate increases in testosterone levels, body height, body mass, and muscle mass, is the primary explanation for the substantial widening in the sex difference in grip strength after age 12 (Handelsman et al., 2018; Round et al., 1999).

Secular analysis

A second novel aspect of the current work was the secular analysis. One might expect sex differences in muscle strength in children and adolescents to be smaller today than in previous decades due to girls' increased participation in competitive sports in recent decades (discussed below) (Mathisen et al., 2019; Stevenson, 2007; Westerståhl et al., 2003). However, for 14-16-year-olds, the sex difference in grip strength today is roughly the same size as in previous decades. A similar result is present in 5-10-year-olds, except that the sex difference has decreased since 2010. This narrowing of the sex difference in grip strength among 5-10-year-olds could represent a true change or it could be due to more effects being available from more participants and countries since 2010 compared to previous decades. Either way, the lack of a concurrent secular change in 14-16-year-olds suggests that any secular changes in 5-10-year-olds get "wiped out" by male puberty.

Countries

A third novel aspect of the current work was the between-countries analysis. For boys and girls aged 5-10 years old, the sex difference in grip strength is broadly similar across countries, ranging between g = 0.30–0.40. For boys and girls aged 14-16 years old, between-countries comparisons are more variable. This is likely due to the limited number of effects available from many countries. The greatest number of effects were available from the USA and China, and these two countries exhibit similar differences in grip strength between 14-16-year-old boys and girls. Though mean effect sizes sometimes differed between countries, there was much overlap in the 95% CIs across countries. In the future, continued accruement of grip strength data from large numbers of boys and girls in various countries will allow for more robust international comparisons, particularly for 14-16-year-olds, and may permit correlational analyses with indices of gender equality (Stoet & Geary, 2019).

Biological and social/environmental causes

Biological and social/environmental factors are two broad potential causes of sex differences in grip strength. Thomas and French (1985) speculated that small-to-moderate differences in grip strength between pre-pubescent boys and girls were “mostly environmentally induced” and could “easily be eliminated if girls and boys were treated similarly.” Results from the current study, coupled with evidence from other studies (described below), challenge their hypothesis.

The current meta-analysis reveals little change in the difference in grip strength between boys and girls since the 1960s. For 14-16-year-olds, one might have expected the sex difference in grip strength to have decreased, given that female participation in high school sports has increased since the 1960s (Mathisen et al., 2019; Stevenson, 2007; Westerståhl et al., 2003). Yet, the effect size of the sex difference in grip strength in the 2010s for 14-16-year-olds was within the 95% CIs of all previous decades. Cohorts of competitive athlete were excluded from the current meta-analysis, but their exclusion probably does not impact the findings. One study of pre-pubertal boys and girls, whose ages, body heights, body masses, and time spent practicing sports were similar, found that boys still had significantly greater grip strength than girls (Manzano-Carrasco et al., 2022). The difference in grip strength was likely due to body composition, as the boys had significantly more muscle mass than the girls, and the girls had significantly more fat mass than the boys (Manzano-Carrasco et al., 2022). In a different study, male youth athletes had greater knee extensor and flexor strength than female youth athletes at all pubertal stages assessed (Peek et al., 2022). Such findings challenge Thomas and French (1985) conclusion that socialization is the primary cause of the sex difference in grip strength in children prior to puberty.

The current meta-analysis also revealed that the size of the sex difference in grip strength is similar between countries. Sex differences in children’s physically activity participation are not equal between all countries (Araujo et al., 2024; Cooper et al., 2015; Guthold et al., 2020). Consequently, one might have predicted that sex differences in grip strength might also differ between countries. However, this was not the case, except for Poland.

Overall, the above results suggest that biological factors rather than social factors are the primary causes of sex differences in grip strength in children and adolescents. Body height, body masses, muscle mass, muscle fiber type composition, and voluntary activation are some of the biological factors that warrant consideration.

Body height

Body height increases with age in boys and girls, but sex differences in body height are present during development (Table 6). At birth, boys' median recumbent length is longer than girls' median recumbent length (Kuczmarski et al., 2002). Boys then grow faster than girls during the first six months of life (Kiviranta et al., 2016). 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). Boys remain taller than girls up until around age 11, which is when girls become taller than boys (Kuczmarski et al., 2002). At age 14, girls' body height begins to plateau, while boys' body height continues to increase (Kuczmarski et al., 2002). Age 14 is also when a sex difference in forearm length emerges (Jürimäe et al., 2009; Neu et al., 2002). At age 16, boys' median body height is significantly greater than girls' mean body height (Kuczmarski et al., 2002).

These sex differences in body height likely contribute to sex differences in grip strength because body height correlates positively with muscle strength (r = 0.30–0.80) (Hogrel et al., 2012; Jürimäe et al., 2009; Kocher et al., 2019; Kocher et al., 2017; Parker et al., 1990). This would partly explain why the sex difference in grip strength narrows at age 11, which is when females become taller than boys.

The linearity of the relationship between body height and muscle strength depends on age, sex, and muscle group. For boys, the relationship between body height and muscle strength is linear up to about age 13 for upper- and lower-body muscles (Parker et al., 1990). However, after puberty, an exponential increase in upper-body strength occurs relative to the concurrent increase in body height (Parker et al., 1990). Such findings suggest that biological factors other than increased body height contribute to the accelerated gains in upper-body muscle strength in boys after puberty (Parker et al., 1990). For girls, the relationship between body height and upper-body strength remains more linear throughout development (Parker et al., 1990).

Body mass

Body mass increases with age in boys and girls, but sex differences in body mass are present during development (Table 6). Boys have greater body masses than girls at birth and at most ages up until about age 11 (Kuczmarski et al., 2002). At age 11, girls begin to weigh more than boys (Kuczmarski et al., 2002). However, at age 14, boys regain their body mass advantage, and by age 16, body mass is significantly greater among boys than girls (Kuczmarski et al., 2002).

These sex differences in body mass likely contribute to sex differences in grip strength because body mass correlates positively with grip strength ($r = 0.30 – 0.70$) (Kocher et al., 2019; Kocher et al., 2017). This would partly explain why the sex difference in grip strength narrows at age 11, which is when females weigh more than boys. Moreover, birth mass, which is greater in boys than girls, correlates positively with grip strength when children are 4 and 9 years old (Barr et al., 2010; Dodds et al., 2012). Nevertheless, use of ratio scaling to normalize grip strength scores to body mass does not fully eliminate the sex difference in grip strength (Köble et al., 2022; Ramírez-Vélez et al., 2017). Thus, biological factors other than body mass and body height contribute to sex differences in grip strength.

Body composition

Absolute and relative amounts of fat and muscle mass change during development and differ between boys and girls. Prior to puberty, sex differences in body composition are present. Compared to boys, pre-pubertal girls have less fat-free or lean mass, more fat mass, and higher body fat percentages (Arfai et al., 2002; Garnett et al., 2004; He et al., 2002; Leppänen et al., 2017; McCarthy et al., 2014; Nelson & Barondess, 1997; Soininen et al., 2018; Taylor et al., 1997). Importantly, such differences in body composition exist even when boys and girls are matched in body height and body mass (Garnett et al., 2004; Nelson & Barondess, 1997; Taylor et al., 1997). In one study of 3-8-year-olds, girls had ~50% more body fat than boys (Taylor et al., 1997). At age 15 and older, sex differences in absolute and relative amounts of fat and fat-free mass are even more pronounced (El Hage et al., 2009; McCarthy et al., 2014).

The cause of greater body fat in girls appears to be higher estradiol levels (Garnett et al., 2004). In boys, a marked increase in muscle mass occurs during puberty and is attributed to increased testosterone levels (Round et al., 1999). Prior to puberty, but after infancy, testosterone levels in boys and girls are similar; however, after puberty, boys experience a 20-30-fold increase in testosterone (Courant et al., 2010; Elmlinger et al., 2005; Handelsman et al., 2018; Khairullah et al., 2014).

Sex differences in body composition likely contribute to sex differences in grip strength because fat-free mass and muscle mass correlate positively with grip strength (Sartorio et al., 2002). Also, sex differences in grip strength are reduced or eliminated when muscle strength is normalized to fat-free mass (Sartorio et al., 2002). Regarding muscle mass of the forearm, Abe et al. (2023) found that forearm muscle thickness correlates positively with grip strength in 5-6-year-olds, though thicknesses did not differ between boys and girls. In an older cohort (6 – 17 years old), Neu et al. (2002) found that cross-sectional areas of forearm muscles were greater in boys than girls, except between the ages of 10-13, which corresponds with the age at which the sex difference in grip strength narrows. Neu et al. (2002) concluded that greater forearm muscle mass and grip strength in boys than girls during puberty are due to: (a) boys becoming taller than girls; (b) forearm lengths in boys becoming more pronounced than would be expected based on the sex difference in body height, thus causing an increase in the forearm length-to-body height ratio in boys but not girls; and (c) boys developing wider forearm muscles than girls even when forearm length is accounted for.

Muscle fiber type

Human skeletal muscles are often categorized as Type I, Type IIA, or Type IIB (also IIX) (Nuzzo, 2023b). Type II fibers are stronger, faster, and more powerful than Type I fibers, whereas Type I fibers are more endurant (Bottinelli et al., 1996; Bottinelli et al., 1999; Garnett et al., 1979; Krivickas et al., 2001; Meijer et al., 2015; Stienen et al., 1996; Widrick et al., 2002). Compared to women, men exhibit greater muscle fiber cross-sectional areas for all fiber types, greater distribution and area percentages for Type IIA and Type IIX muscle fibers, and greater Type II/I muscle fiber area ratios (Nuzzo, 2023b). Conversely, women exhibit greater Type I muscle fiber distribution and area percentages (Nuzzo, 2023b).

Few studies have examined muscle fiber types in boys and girls, and they all involved biopsies of vastus lateralis (Bell et al., 1980; Esbjörnsson et al., 2022; Esbjörnsson et al., 2021; Jansson & Hedberg, 1991). In 6-year-olds, there is no sex difference in Type I and Type II muscle fiber distribution percentages (Bell et al., 1980). In 9-12-year-olds, there is no sex difference in Type I, Type IIA, and Type IIB muscle fiber cross-sectional areas, distribution percentages, or area percentages (Esbjörnsson et al., 2022; Esbjörnsson et al., 2021). At age 16, boys exhibit larger Type I, Type IIA, and Type IIB muscle fiber cross sectional areas than girls, but the distribution and area percentages of Type I and Type II muscle fibers are the same between the sexes (Glenmark et al., 1992; Jansson & Hedberg, 1991).

Thus, assuming results from gripping muscles parallel those of vastus lateralis, sex differences in muscle fiber distribution and area percentages prior to puberty are probably not contributing to the sex difference in grip strength. After male puberty, larger muscle cross-sectional areas of all fiber types in boys than girls likely contribute to the large sex difference in grip strength. The exact age at which small-to-moderate sex differences in muscle fiber distribution and area percentages begin to emerge between adult males and females (Nuzzo, 2023b) remains unclear.

Voluntary activation

Voluntary activation refers to the nervous system's ability to "drive" the muscle to create its maximal force. Voluntary activation is assessed using the interpolated twitch technique (Nuzzo et al., 2019). In this test, a participant performs a maximal voluntary contraction (MVC). When the participant reaches their peak MVC force, a strong electric shock is delivered to the participant's motor nerves. If this electric shock does not produce an additional twitch force over the participant's volitional force, this means the participant's nervous system was fully driving the muscles, and the calculation for voluntary activation results in a value of 100% activation (Nuzzo et al., 2019). However, if the electrical shock produces a twitch over the MVC force, which is often the case in participants who have neurologic impairments (Nuzzo et al., 2019), then the calculation for voluntary activation reveals an activation level less than 100%. In adults, there is no sex difference in voluntary activation (Nuzzo, 2023a). Men and women who are free of neurologic impairment activate their muscles at about 90-95% (Nuzzo, 2023b).

Few studies have explored sex differences in voluntary activation in children and adolescents, and none have examined activation of gripping muscles (Gillen et al., 2021; O'Brien et al., 2009, 2010; Streckis et al., 2007). In children ~9 years old, voluntary activation of the elbow flexors and knee extensors in boys is 73-75% and in girls is 67% (Gillen et al., 2021; O'Brien et al., 2009, 2010). In children 12-14 years old, voluntary activation of the knee extensors in boys (~92%) is not statistically different than in girls (~84%) (Streckis et al., 2007). In boys and girls around 17 years old, voluntary activation of the elbow flexors is ~90% for both sexes (Gillen et al., 2021).

Thus, if voluntary activation plays a role in the sex differences observed in grip strength, its role appears small. Nevertheless, in both sexes, voluntary activation improves from childhood to adulthood (O'Brien et al., 2009, 2010; Streckis et al., 2007; Woods et al., 2022) (Dotan et al., 2012). Therefore, future research can explore if the time course of improvement in voluntary activation from childhood to adulthood differs between boys and girls.

Limitations

The current study is not without potential limitations. First, the review was not registered in PROSPERO (Page et al., 2018), and it did not explicitly follow PRISMA guidelines (Page et al., 2021). For example, the literature search was thorough, but it did not follow a formal flow diagram. Thus, replication of the search will be difficult. Moreover, the literature search, article screening, and data extraction were conducted by only one author. Nevertheless, I have used the same methods successfully in previous reviews that summarized results from more papers than previous identified on certain topics (Nuzzo, 2023b; Nuzzo, Pinto, & Nosaka, 2023; Nuzzo, Pinto, Nosaka, et al., 2023; Nuzzo et al., 2024). Here, the number of identified studies and effects were substantially greater than in the meta-analysis from 40 years ago (Thomas & French, 1985, 1987). The 95% CIs are narrow at most ages, reflecting a high level of confidence in the results and also the literature search.

Second, the current research does not reveal the cause of the sex difference in grip strength in children and adolescents. Based on literature cited earlier, and findings from the current meta-analysis, biological factors are likely primarily responsible for the sex difference in grip strength before, during, and after puberty.

Third, the current study was concerned only with grip strength. Consequently, the results do not necessarily reflect differences in muscle strength between boys and girls for other muscle groups. In adults, sex differences in muscle strength are smaller in lower- than upper-body muscles (Nuzzo, 2023a). Whether this is also true in children and adolescents, when all relevant data are submitted to meta-analysis, is unknown.

Conclusion

Boys have greater grip strength than girls from birth onward. Prior to age 11, the sex difference in grip strength is small-to-moderate in size, with female grip strength about 90% of male grip strength. At age 11, the sex difference in grip strength decreases because girls reach puberty earlier than boys. Nevertheless, boys still retain a strength advantage at age 11. After male puberty, the size of the sex difference in grip strength increases markedly. At age 16, female grip strength is 65% of male grip strength. With few exceptions, the observed effect sizes have been largely consistent across time and place. Together, with other findings from the biological and medical literature, the current results suggest a largely biological origin of the sex difference in grip strength in children and adolescents.

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Data availability statement

The data spreadsheet and statistical results associated with this study are available at the Open Science Framework (https://osf.io/6m3jw/). A pre-print of this paper was made at available at SportRxiv.

Discloser and funding statement

I have no conflicts of interest to report. I utilized crowdfunding (Go Fund Me) to generate funds for this research.

Ethics approval

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

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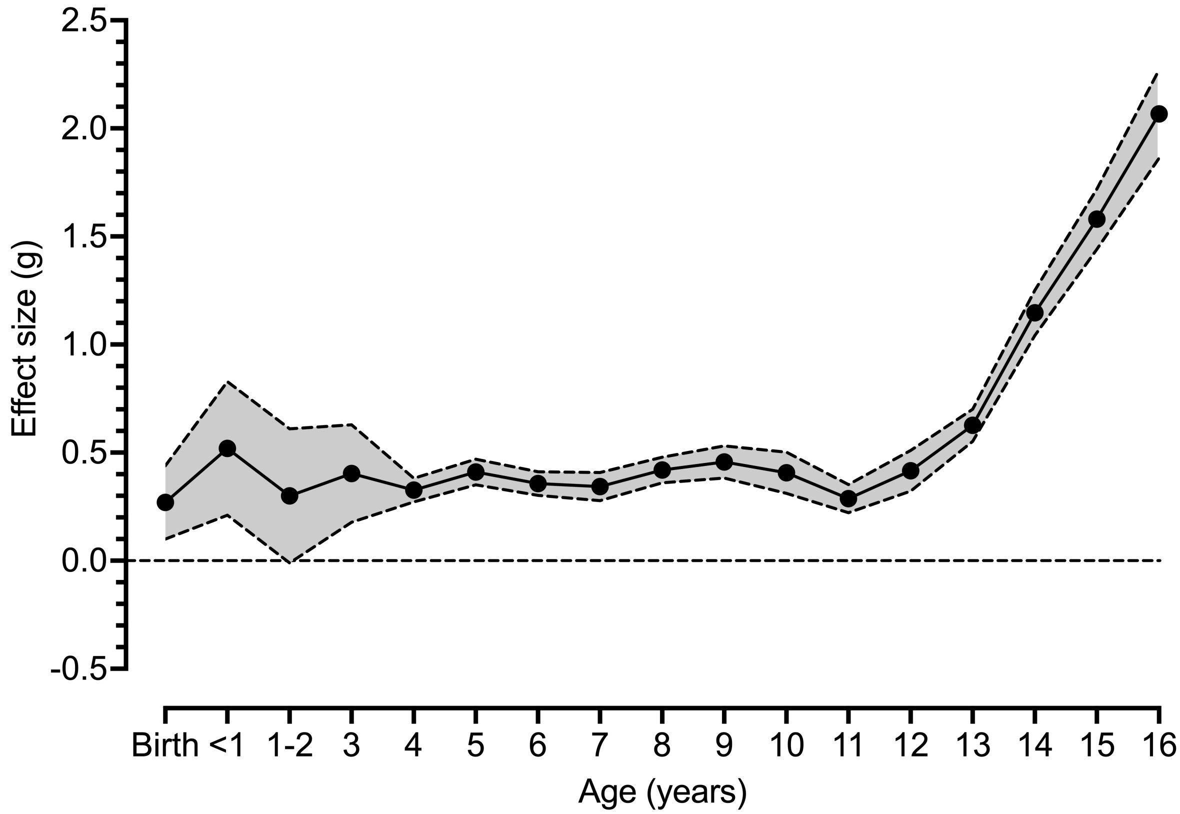

Figure 1. Effect sizes (Hedges g) of differences in grip strength between boys and girls from birth to age 16. Black circles represent cumulative effect sizes for each age. Dashed lines around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CIs). Wider CIs prior to age 4 are due to limited numbers of effects available at those ages and the variability in the available effects. Narrower CIs from age 4 onward are due to large numbers of effects available at those ages and the broad similarity in results across studies. The "dip" in the effect size at age 11 represents a decrease in the sex difference in grip strength. This dip is likely due to girls reaching puberty earlier than boys. After boys reach puberty, the sex difference in grip strength widens markedly. This is reflected in the sharp upward trend of the line after age 11. The number of effects making up each cumulative effect size presented in this figure are listed in Table 1.

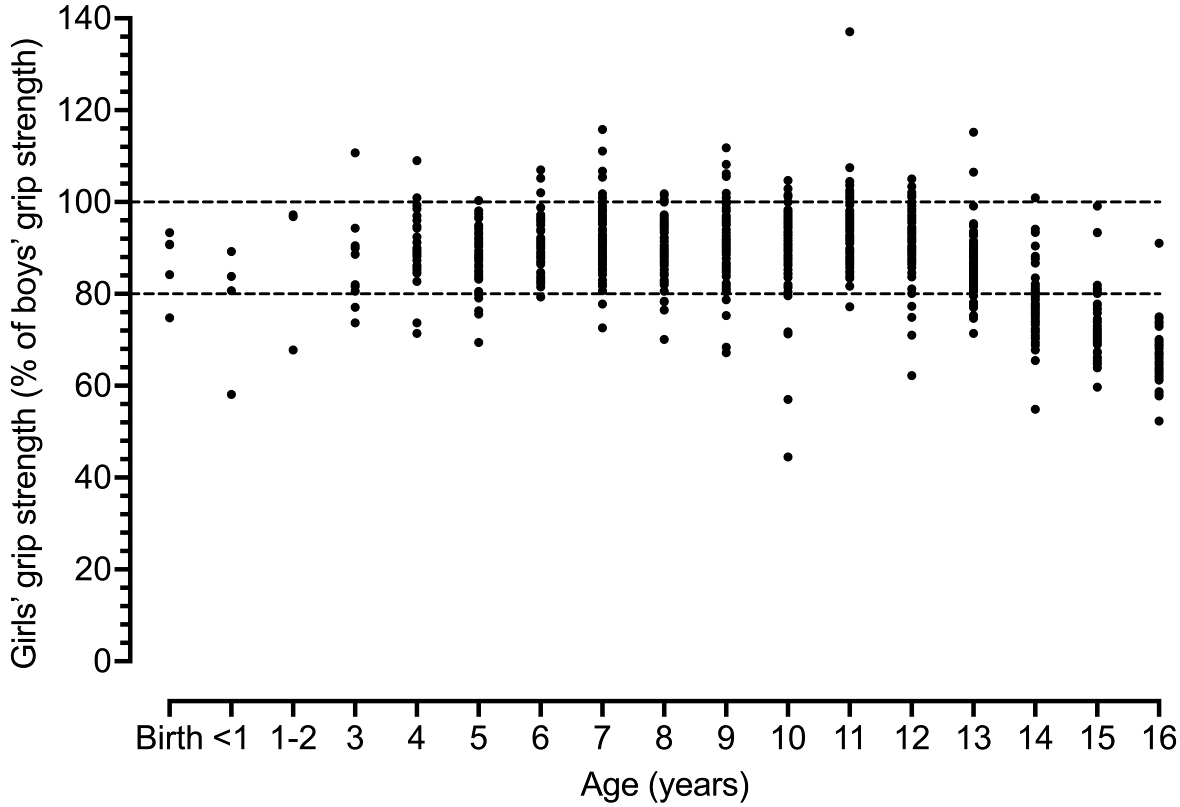

Figure 2. Grip strength in girls expressed relative (%) to grip strength in boys from birth to age 16. Each black circle represents an individual effect from a study. A total of 808 effects are depicted. The dashed horizontal lines, representing 80% and 100% of boys' grip strength, are provided for visual purposes only. For about the first 10 years of life, grip strength in girls is approximately 90% of grip strength in boys. After age 13, the sex difference in grip strength widens markedly, such that by age 16, grip strength in girls is 65% of grip strength in boys.

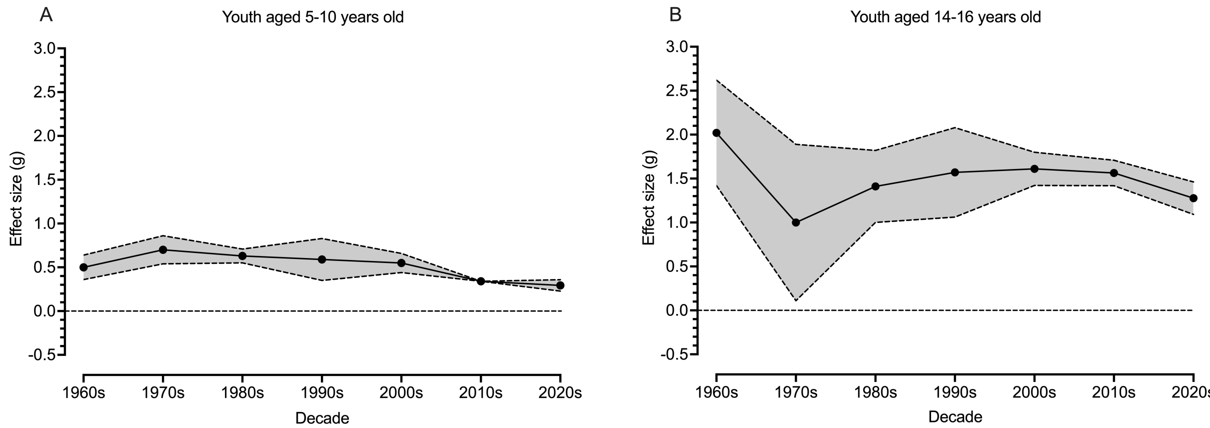

Figure 3. A: Effect sizes (Hedges g) of differences in grip strength between 5-10-year-old boys and girls from the 1960s to today. The black circles are cumulative effect sizes for all relevant study effects. The dashed lines around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CI). The sex difference in grip strength for 5-10-year-olds has remained mostly stable since the 1960s, though a decrease in the effect size is noted after 2010. The narrow, and consequently not visible, CIs in the 2010s are due, in part, to the greater amount of data available in the 2010s compared to previous decades. B: Effect size (Hedges g) of differences in grip strength between 14-16-years-ol boys and girls from the 1960s to today. The black circles are cumulative effect sizes for all relevant study effects. The dashed lines around the effect sizes represent the upper and lower limits of the 95% CIs. The sex difference in grip strength for 14-16-year-olds has remained mostly stable since the 1960s, given that there is substantial overlap in the CIs for all decades. The narrowing of the CIs after 2000 is due, in part, to the greater amount of data available.

Table 1. Effect sizes of the difference in grip strength between boys and girls by age group.

Age group	No. effects	Hedges *g*	*p*	95% CI		95% PI	
				Lower	Upper	Lower	Upper
Under 2 d	5	0.27	.002	0.10	0.44	Under 2 d	5
Under 1 yr	4	0.52	.001	0.21	0.83	Under 1 yr	4
1 2 yr	3	0.30	.059	-0.01	0.61	1 2 yr	3
3 yr	10	0.40	<.001	0.18	0.63	3 yr	10
4 yr	30	0.33	<.001	0.27	0.38	4 yr	30
5 yr	44	0.41	<.001	0.35	0.47	5 yr	44
6 yr	57	0.36	<.001	0.30	0.41	6 yr	57
7 yr	65	0.34	<.001	0.28	0.41	7 yr	65
8 yr	67	0.42	<.001	0.36	0.48	8 yr	67
9 yr	78	0.46	<.001	0.38	0.53	9 yr	78
10 yr	82	0.41	<.001	0.31	0.50	10 yr	82
11 yr	75	0.29	<.001	0.22	0.35	11 yr	75
12 yr	75	0.42	<.001	0.32	0.51	12 yr	75
13 yr	69	0.63	<.001	0.55	0.70	13 yr	69
14 yr	56	1.15	<.001	1.04	1.25	14 yr	56
15 yr	50	1.58	<.001	1.44	1.72	15 yr	50
16 yr	38	2.07	<.001	1.86	2.27	16 yr	38
Overall	808	0.63	<.001	0.58	0.67	Overall	808

CI = confidence interval; 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	16	2.0
Belgium	15	1.9
Bosnia	7	0.9
Brazil	8	1.0
Canada	30	3.7
China	60	7.4
Chile	24	3.0
Columbia	9	1.1
Czech Republic	4	0.5
England	10	1.2
Estonia	16	2.0
Finland	2	0.2
Germany	6	0.7
Greece	5	0.6
Hungary	6	0.7
Iceland	4	0.5
India	11	1.4
Iran	10	1.2
Ireland	9	1.1
Italy	6	0.7
Japan	39	4.8
Jordan	11	1.4
Kenya	6	0.7
Korea (South)	18	2.2
Kosovo	2	0.2
Lithuania	6	0.7
Macedonia	11	1.4
Malawi	12	1.5
Mexico	9	1.1
Netherlands	30	3.7
Norway	10	1.2
Oman	1	0.1
Peru	21	2.6
Poland	51	6.3
Portugal	4	0.5
Saudi Arabia	19	2.4
Senegal	2	0.2
Serbia	10	1.2
Slovenia	2	0.2
South Africa	7	0.9
Spain	56	6.9
Sweden	24	3.0
Thailand	4	0.5
Turkey	10	1.2
United States of America	184	22.8
Wales	1	0.1
Total	791	100.0

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

Age group	*n*	Mean (%)	SD (%)
Under 2 d	540	87.6	6.0
Under 1 yr	210	79.4	10.7
1 2 yr	158	83.5	14.6
3 yr	1,428	90.8	6.7
4 yr	8,454	90.0	3.7
5 yr	6,957	89.0	5.1
6 yr	9,939	91.3	4.5
7 yr	19,241	92.1	4.4
8 yr	20,703	89.2	4.9
9 yr	23,834	90.4	5.1
10 yr	33,080	92.9	4.7
11 yr	30,928	93.5	4.7
12 yr	31,004	89.0	7.1
13 yr	44,094	82.5	5.1
14 yr	51,030	73.1	5.1
15 yr	37,307	68.1	3.8
16 yr	34,685	64.6	3.0
Overall	353,676	82.4	11.4

SD = standard deviation.

Table 4. Effect sizes of the difference in grip strength between boys and girls by age and decade.

Age group, decade	No. effects	Hedges *g*	*p*	95% CI Lower	95% CI Upper
5-10 yr old					
1960s	11	0.50	<.001	0.36	0.64
1970s	17	0.70	<.001	0.54	0.86
1980s	29	0.63	<.001	0.55	0.71
1990s	12	0.59	<.001	0.35	0.83
2000	74	0.55	<.001	0.44	0.66
2010s	202	0.34	<.001	0.31	0.37
2020s (2020-23)	48	0.29	<.001	0.23	0.36
Overall	393	0.40	<.001	0.37	0.43
14-16 yr old					
1960s	6	2.02	<.001	1.42	2.62
1970s	1	1.00	.028	0.11	1.89
1980s	9	1.41	<.001	1.00	1.82
1990s	13	1.57	<.001	1.06	2.08
2000	22	1.61	<.001	1.42	1.80
2010s	71	1.56	<.001	1.42	1.71
2020s (2020-23)	22	1.28	<.001	1.09	1.46
Overall	144	1.54	<.001	1.43	1.64

CI = confidence interval.

Table 5. Effect sizes of the difference in grip strength between boys and girls by age and country.

Age group, country	No. effects	Hedges *g*	*p*	95% CI Lower	95% CI Upper
5-10 yr old					
Canada	16	0.41	<.001	0.22	0.61
China	26	0.38	<.001	0.30	0.46
Chile	14	0.31	<.001	0.16	0.46
Japan	28	0.33	<.001	0.26	0.40
Netherlands	18	0.31	<.001	0.23	0.40
Peru	15	0.29	<.001	0.23	0.36
Poland	22	0.49	<.001	0.38	0.60
Spain	24	0.34	<.001	0.26	0.43
United States of America	83	0.35	<.001	0.30	0.40
Overall*	386	0.40	<.001	0.37	0.43
14-16 yr old					
China	15	1.61	<.001	1.41	1.81
Poland	13	1.20	<.001	0.89	1.50
Spain	9	1.78	<.001	1.58	1.98
Sweden	5	2.09	<.001	1.51	2.67
United States of America	37	1.56	<.001	1.40	1.73
Overall*	144	1.54	<.001	1.43	1.64

*All countries, including those not listed in the table. Only countries with the greatest number of effects for the 5-10-year-old or 14-16-year-old age groups are presented in the table. CI = confidence interval.

Table 6. Median (50th percentile) body heights and body masses for boys and girls in the United States of America (USA) at select ages.

Outcome and age	Boys	Girls	Reference
Median body height			
Birth	51.4 cm	50.8 cm	(Kuczmarski et al., 2002)
5 years old	111.0 cm	109.9 cm	(Kuczmarski et al., 2002)
11 years old	144.5 cm	147.0 cm	(Kuczmarski et al., 2002)
14 years old	166.0 cm	161.0 cm	(Kuczmarski et al., 2002)
16 years old	173.3 cm	162.8 cm	(Kuczmarski et al., 2002)
Median body mass			
Birth	3.43 kg	3.29 kg	(Kuczmarski et al., 2002)
5 years old	19.16 kg	18.48 kg	(Kuczmarski et al., 2002)
11 years old	36.29 kg	38.1 kg	(Kuczmarski et al., 2002)
14 years old	53.32 kg	51.94 kg	(Kuczmarski et al., 2002)
16 years old	62.71 kg	54.89 kg	(Kuczmarski et al., 2002)