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| Sex differences in grip strength from birth to age 16: a meta-analysis |  | Supplementary materials: <https://osf.io/6m3jw/>  For correspondence: [j.nuzzo@ecu.edu.au](mailto:j.nuzzo@ecu.edu.au)  X: [@JamesLNuzzo](https://x.com/JamesLNuzzo) |

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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 attempt has been made to update it. 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 791 effects from 164 studies. Studies were published between 1961– 2023. The total sample was 351,559 (177,469 boys, 174,090 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 about 90% of male grip strength (Hedges *g* = 0.33-0.45). At age 11, the effect size decreased, likely due to girls reaching puberty before boys (*g* = 0.28; 95% confidence intervals (CI) = 0.21, 0.35). At age 13, the effect size increased markedly due to male puberty (*g* = 0.63; CIs = 0.55, 0.70). By age 16, the sex difference in grip strength was substantial, with female grip strength 65% of male grip strength (*g* = 2.07; 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 in the 2010s. Biological factors likely explain why, on average, boys are stronger than girls from birth onward.

# INTRODUCTION

Puberty causes the average human male to have the capacity to generate significantly more muscle force than the average human female (Nuzzo, 2023a). For upper-body muscles, adult female strength is approximately 55-60% of adult male strength (Nuzzo, 2023a). For lower-body muscles, adult female strength is approximately 65-70% of adult male strength (Nuzzo, 2023a).

The emphasis on male puberty as the major inflection point for the sex difference in muscle strength has perhaps given the impression that there is no difference in this aspect of physical fitness before puberty. But is that the case? Studies have generated conflicting results, perhaps due to different age cohorts and muscle groups under investigation (De Smet & Vercammen, 2001; De Ste Croix et al., 2003; Ervin et al., 2013; Krammel et al., 2018).

Meta-analysis – a statistical technique that aggregates and compares mean values from many studies – can clarify the extent to which there might be a sex difference in muscle strength in children and adolescents. Only one previous attempt has been made to use meta-analysis to explore differences in muscle strength between boys and girls. Forty years ago, Thomas and French (1985) used meta-analysis to examine sex differences in grip strength and other components of physical fitness in boys and girls aged 5 to 17 years old. In children aged 5 to 10 years old, Thomas and French (1985) found a small-to-moderate effect size (approximately *d* = 0.5) with boys having greater grip strength than girls. At age 11, the effect size was smaller (*d* = 0.2) before then trending upward culminating in significantly greater grip strength in boys than girls at age 16 (*d* = 1.6). Thomas and French (1985) concluded that the small-to-moderate differences in grip strength between boys and girls prior to puberty were likely “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 been a useful source for understanding sex differences in physical fitness in children and adolescents. However, the analysis was not without limitations. First, the analysis included data from only four studies, and two of those studies were unpublished reports. This was explained by the researchers in a follow-up clarification article (Thomas & French, 1987). The four studies provided a total of 42 effects, which amounted to a total participant pool of 1,446 boys and 1,338 girls (Thomas & French, 1985). Grip strength data are now available from hundreds of papers and hundreds of thousands of boys and girls. For this reason alone, an updated meta-analysis on the topic is warranted. Second, Thomas and French's (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, exploration of potential differences in the size of the sex difference in grip strength between countries is now possible. Third, Thomas and French's (1985) analysis did not include grip strength data from children below the age of 5. Such data are now available. Examining them can provide a more complete story regarding the development of grip strength in boys and girls from birth onward.

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 change). 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; Lundberg et al., 2024; Nokoff et al., 2023; Nuzzo, 2023a).

# METHOD

**Literature search**

Many papers on the topic of sex differences in grip strength in children and adolescents were already known to me based on searchers 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 associated with 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,” “fitness,” and “physical fitness.” Snowballing strategies included reference and citation tracking. I have used this strategy successfully in previous reviews and meta-analyses (Nuzzo, 2023a; Nuzzo, Pinto, & Nosaka, 2023; Nuzzo, Pinto, Nosaka, et al., 2023; Nuzzo et al., 2024). Limitations of this approach are explained in the Discussion.

**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 the year 2023 or earlier; (b) published in English; (c) included male and female participants who were healthy, 16 years of age or younger, and not select cohorts of competitive athletes; (d) included sex-segregated samples sizes and means and standard deviations of grip strength, which were neither normalized to anthropometric measurements (e.g., body mass) nor statistically adjusted for covariates; and (e) did not duplicate data from a paper already identified for inclusion into the analysis. Common reasons for exclusion included: (a) no sex- or age-group-specific sample sizes reported; (b) no means or standard deviations reported; and (c) age range of cohort beyond established criteria (described below). Notably, some historically important studies on muscle strength in children, which were published in the 1800s and early 1900s, were excluded from the current analysis because standard deviations were not reported by the researchers (Carman, 1899; Martin, 1918; Quetelet, 1842).

**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 standard deviations of grip strength. Because researchers reported their data in various ways, I established standards for data extraction and organization.

***Year of data collection.*** Some, but not all, 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 the year of publication. When the researcher did not report the year of data collection, the year of publication was used in the secular analysis instead. When the researcher listed a single year for the date of data collection, that year was extracted and used in the analysis. Some researchers reported dates of data collection that spanned two or more years, yet their grip strength data were not segregated by year. Thus, when the duration of data collection spanned two years (e.g., 2004-2005), the first of the two years was extracted and included in the current analysis. When the duration of data collection spanned *more* than two years (e.g., 2004-2006), the year in the middle of the range (i.e., 2005) was extracted and included in the current analysis.

***Age category.*** Often, researchers reported grip strength scores for categorical age groups that spanned only one year (e.g., “5-year-olds”). Other researchers reported grip strength scores for categorical age groups that spanned multiple years (e.g., “3-5-year-olds,” “5-10-year-olds”). Some researchers also presented the mean age of their study’s cohort (e.g., 5.3 years), with the paper’s text revealing that the group was composed of boys and girls of a particular categorical age range (e.g., 5 and 6-year-olds).

Given the various ways that researchers presented their data, I adopted eligibility and 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. Consequently, I organized and analyzed grip strength data with age as a categorical variable (e.g., “5-year-olds”) rather than as a continuous variable (e.g., 5.3 years), with certain restrictions in place. In brief, this strategy prioritized grip strength data that was presented for categorical age groups that spanned only one year (e.g., “5-year-olds”). However, the strategy also permitted inclusion of grip strength scores for categorical age groups that spanned multiple years under certain conditions. These conditions were as follows. First, if any participants in a cohort were 17 years of age or older, the study was ineligible for inclusion in the analysis. Second, if the researcher reported grip strength scores for a cohort whose age spanned four or more years (e.g., “5 to 10-year-olds”), the study was ineligible for inclusion in the current analysis. Third, if the researcher reported grip strength scores for a cohort whose age spanned three years (e.g., “5 to 7-year-olds”), the middle age was typically used to represent these data in the current analysis, because the middle age (e.g., 6-year-olds) tended to correspond with the rounded down mean age of the cohort (e.g., 6.4 years in a cohort of 5 to 7-year-olds whose ages could have ranged from 5.0 to 7.9 years). Fourth, if the researcher reported grip strength scores for a cohort whose age spanned two years (e.g., “5 to 6-year-olds”), the younger of the two ages was used to represent the study in the current analysis, particularly because in such datasets the rounded down mean often corresponded more closely with the younger of the two ages (e.g., mean age of 5.5 years in a cohort of 5 and 6-year-olds whose ages could have ranged from 5.0 to 6.9 years).

***Sidedness and handedness.*** Researchers used various methods for obtaining and presenting grip strength data. Some researchers presented grip strength scores from only one hand, whereas other researchers presented grip strength scores from both hands or the average of both hands. When a researcher reported only the average grip strength of both hands, that average value was included in the current analysis. When a researcher reported grip strength data from only one hand, that value was included in the current analysis. When a researcher reported data from both hands – sometimes “right” or “left” or “dominant” or “non-dominant” – data from the right hand or dominant hand were included in the current analysis. If the researcher reported data by both sidedness and handedness, priority was given to data from the right hand.

***Study type.*** Grip strength data were reported in studies of various designs. Common study designs included longitudinal studies on child development, reliability studies on the consistency of grip strength scores in children across time, cross-sectional studies comparing cohorts of children who differed on some characteristic (e.g., country of residence, health status), and intervention studies that compared grip strength scores in children before and after some intervention (e.g., physical activity programs).

For longitudinal studies, grip strength data from each year of development were included in the current analysis. For reliability studies, only grip strength data from the first day of testing were included in the current analysis. For cross-sectional studies that compared grip strength in healthy children (“controls”) and children with health conditions, only data from the healthy children were included in the current analysis. For intervention studies that involved baseline and post-intervention measurements of grip strength, only data from the baseline assessments were included in the current analysis. A small number of studies acquired measurements of grip strength at different grip widths. In such instances, the strength score reported for the “middle” grip position was included in the current analysis.

***Data extraction from graphs.*** Researchers presented grip strength data in text, tables, and graphs. When grip strength scores were presented in graphs, the scores were estimated using a graph digitzer (WebPlotDigitizer, <https://apps.automeris.io/wpd/>). 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 standard deviation of interest. The software then generated a spreadsheet of the means and standard deviations calibrated against the y-axis. Standard errors, whether presented in graphs, tables, or text, were converted to standard deviations 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, Armonk, 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 were used to graphically display the effect sizes for each study and for the cumulative effect size across all studies for a given age. 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* ≤ 0.05) (Cumming, 2009).

For the analysis of secular trends, 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 two large age cohorts (1960s, 1970s, 1980s, 1990s, 2000s, and 2010s [i.e., 2010-2023]). The data were split into these two age cohorts for the secular analysis for two reasons. First, one could argue that social changes over the decades (i.e., opportunities for physical activity) might impact boys and girls in these age groups differently. Second, splitting the data this way, and removing boys and girls aged 11-13 years, minimizes any confounding impact of age or pubertal status (pre- vs post-puberty) on the effect of time. For example, if proportionally speaking, studies in one decade include more samples of 5-10-year-olds, whereas other decades include proportionally more samples of 14-16-year-olds, then any observed secular change in the sex difference in grip strength would be confounded by the impact of age or pubertal status on the sex difference in grip strength. Ages 11-13 years are most closely aligned with the onset of puberty in both sexes. Thus, their removal for the secular analysis and between-countries analysis (described below) establishes two large age cohorts that are most closely aligned with the concepts of pre-pubescence and post-pubescence, minimizing, for example, the impact of potential differences in age at menarche over time (Gomula & Koziel, 2018; Lei et al., 2021; Wang et al., 2024) or between countries (Lei et al., 2021; Saczuk et al., 2018; Wang et al., 2024).

For the analysis that compared sex differences in grip strength between countries, cumulative effect sizes were generated for 5-10 and 14-16 years-olds for each country. For some countries, only a small number of effects were available, rendering their inclusion into the comparison uninformative. Thus, only those countries in which an informative number of effects were available were included in this exploratory analysis.

Finally, for descriptive purposes, means of girls’ grip strength for each study effect were divided by the mean of boys’ grip strength. Weighted means (by sample size) were then used to compute girls’ strength as a percent of boys’ strength for each age group.

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# Results

**Study characteristics**

A total of 164 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; 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; 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; 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; 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; 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 791 effects from 351,559 children and adolescents (177,469 boys, 174,090 girls). The number of effects available by age group are listed in Table 1.

Study publication dates ranged from 1961 to 2023, and the earliest year of data collection was 1935 (Espenschade & Meleny, 1961). The number of effects available by decade of data collection and across all age groups were as follows: 1930s (1 effect, 0.1%), 1940s (0 effects), 1950s (1 effect, 0.1%), 1960s (26 effects, 3.3%), 1970s (21 effects, 2.7%), 1980s (64 effects, 8.1%), 1990s (42 effects, 5.3%), 2000s (130, 16.4%), and 2010s (506 effects, 64.0%). The number of effects available by country and across all age groups are listed in Table 2. The largest number of effects were available from studies conducted in the USA (184 effects, 23.3%), China, (60 effects, 7.6%), Spain (56 effects, 7.1%), and Poland (51 effects, 6.4%).

**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. Nevertheless, the mean effect sizes over this period of development were broadly similar to effect sizes in subsequent ages. From age 3 to 10, effect sizes were small-to-moderate in magnitude, ranging between *g* = 0.33 – 0.45. At age 11, the effect size decreased (*g* = 0.28; 95% CIs = 0.21, 0.35), falling below the lower band of the 95% CIs from ages 8 to 10. At age 13, the effect size increased markedly (*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 about 65-70% of male grip strength (*g* = 2.07; 95% CIs = 1.86, 2.27).

***Secular changes*.** In the 5-10-year-old and 14-16-year-olds cohorts, confidence in the size of the effect improved from the 1960s to 2010s, represented by the narrowing of the CIs (Fig. 3, Table 4). For the 5-10-year-olds, the effect size was relatively stable between the 1960s and 2000s. Effect sizes ranged between *g* = 0.50 – 0.65, with considerable overlap between the CIs in those decades. However, a decrease in the effect size was noted in the 2010s (*g* = 0.33, 95% CIs = 0.30, 0.36). During the 2010s, the upper boundary of the CI was below the *lower* boundaries from some previous decades. For the 14-16-year-olds, the effect size from the 2010s (*g* = 1.49, 95% CIs = 1.37, 1.61) fell within the 95% CIs from all previous decades, indicating this sex difference has remained stable over time.

***Country.*** Effect sizes of the difference in grip strength between boys and girls by age and country are presented in Table 5. 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 all other countries listed in Table 5 fell within the 95% CIs for the USA or were just outside these boundaries (i.e., Canada, Peru). One exception was Poland, where the effect size of the sex difference in grip strength was greater than all other countries listed in Table 5 (*g* = 0.49 [95% CIs: 0.38, 0.60].

For the 14-16-year-olds, fewer effects were available for meaningful between-country comparisons. The USA and China contributed the greatest number of effects to the 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]). Again, Poland was an exception. The mean effect size for Poland (*g* = 1.20 [95% CIs: 0.89, 1.50] was below the lower boundary of the 95% CIs for the USA and China.

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# 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 in grip strength have remained mostly stable since the 1960s and are of similar magnitude in most countries from which adequate numbers of effects are available.

**Sex difference in grip strength across age**

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 164 studies provided 791 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) from 40 years ago. Thomas and French's (1985) analysis included 42 effects from four studies and a total sample of 2,784 boys and girls.

Within the first 48 hours of birth, boys exhibit greater grip strength than girls, as measured by methods that entice newborns to grasp strongly (Jacklin et al., 1984; Jacklin et al., 1981; Tan et al., 1992). However, the number of available effects is small, the width of the confidence intervals is wide, and the relevant data is now over 30 years old (Jacklin et al., 1984; Jacklin et al., 1981; Tan et al., 1992). Thus, until new data are available on grip strength in boys and girls shortly after birth, this result should be interpreted cautiously.

In contrast, confidence in the size of the sex difference in grip strength in children 4 years of age and older is greatly enhanced due to the increased number of effects available. This improved confidence is reflected in the narrow confidence intervals from age 4 onward. From ages 4 to 10, the mean effect size of the difference in grip between boys and girls ranges from *g* = 0.33 – 0.45, with female grip strength equal to about 90% of male grip strength during this period of development. The effect size then decreases from *g* = 0.40 – 0.45 between the ages of 8 to 10 to *g* = 0.28 at age 11. This reduction in the sex difference in grip strength at age 11 is likely due to girls reaching puberty before boys (Brix et al., 2019; Tanner, 1971), and this illustrates the responsiveness of the sex differences in muscle strength to biological factors. Moreover, 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 multiple 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 current analysis, the effect size is *g* = 2.07. Male puberty, which is, in part, characterized by disproportionate increases in testosterone levels, body height, body mass, and muscle mass in males (Handelsman et al., 2018; Round et al., 1999), is the primary explanation for the substantial widening in the sex difference in grip strength after age 12.

**Sex difference in grip strength across time**

A second novel aspect of the current work was the secular analysis. One might expect that sex differences in muscle strength among children and adolescents would be smaller today than in previous decades due to girls’ increased participation in competitive sports in recent decades (discussed more below) (Mathisen et al., 2019; Stevenson, 2007; Westerståhl et al., 2003). However, for 14-16-year-olds, the size of the sex difference in grip strength today is no different than in previous decades. The effect size from the 2010s lies within the CIs from all previous decades and that there is substantial overlap of the CIs from all decades.

For 5-10-year-olds, the trend is similar, with one exception. The mean effect size in the 2010s is below the lower boundary of the CIs from all previous decades. Moreover, the upper boundary of the CI from the 2010s is below or equal to the lower boundary of previous decades. This narrowing of the sex difference in grip strength among 5-10-year-olds could represent a true change between the sexes or it could be the consequence of potential confounding factors such as the small number of effects available in previous decades or the increased number of effects available from countries other than the USA in recent decades. Nevertheless, the lack of a secular change in the sex difference in grip strength among 14-16-year-olds suggests that secular changes among 5-10-year-olds get “wiped out” after male puberty.

**Sex difference in grip strength across place**

A third novel aspect of the current work was the between-countries analysis. The results show that for children aged 5-10 years old, the sex difference in grip strength is similar across countries. For most countries, the mean effect size ranged between *g* = 0.30 – 0.40.

For boys and girls aged 14-16 years old, between-countries comparisons were more variable. This is likely due to the limited number of effects available from many countries. The greatest number of effects are available from the USA and China, and these two countries show a similarly sized sex difference in grip strength between boys and girls who are 14-16 years old (*g* = 1.56 and 1.61, respectively). However, Poland, who provided a similar number of effects to the analysis as China, shows a smaller sex difference in grip strength in this age cohort (*g* = 1.20). Interestingly, whereas Poland exhibits the smallest sex difference in grip strength in 14-16-year-olds, it exhibits the *largest* sex difference in grip strength in 5-10-year-olds. The reason for this unique result is unclear. Between-country differences in puberty patterns could play a role. For example, in 2005-2006, the mean age at menarche in Poland was 12.9 years (Wang et al., 2024) compared to 11.9 years in the USA (Saczuk et al., 2018). However, the difference in age at menarche probably does not explain the current results because (a) Poland and China have similar mean ages at menarche (Lei et al., 2021) but dissimilar effect sizes of the sex difference in grip strength, and (b) data from boys and girls between the ages of 11-13 years old were purposely excluded from the between-countries analysis because of the potential confounding influence of puberty on such results. Thus, to determine why the size of the sex difference in grip strength in children and adolescents in Poland differs from other countries, additional research will be needed. Moreover, new data from countries other than the USA and China will also permit more robust between countries comparisons of the size of the sex difference in grip strength in 14-16-year-olds.

**Causes of the sex difference in grip strength**

The current study did not directly assess the causes of sex differences in grip strength in children and adolescents. Thus, the following discussion is based on evidence from other studies and from the secular and between-countries analyses in the current study.

Biological factors and social/environmental factors are the two broad potential causes of sex differences in grip strength. Thomas and French (1985) speculated that the small-to-moderate differences in grip strength between pre-pubescent boys and girls were due to social factors. They concluded that sex differences in grip strength prior to puberty were likely “mostly environmentally induced” and that these differences could “easily be eliminated if girls and boys were treated similarly.”

The rationale for Thomas and French's (1985) conclusion was unclear, and results from the current study, coupled with evidence from other studies (described below), challenge their hypothesis. The current analysis revealed that there has been little change in the sex difference in grip strength in children and adolescents 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 analysis, but their exclusion probably does not impact the findings. One study of 792 pre-pubertal boys and 348 pre-pubertal girls, whose ages, body heights, body masses, and *time spent practicing sports* were similar, found that boys had significantly higher grip strength than girls (Manzano-Carrasco et al., 2022). This sex difference in grip strength was likely due to the observed sex difference in 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 pubertal boys and girls in the same study (~14 years old), the sex differences in body composition and grip strength were even greater than in the pre-pubertal cohort (Manzano-Carrasco et al., 2022). In a different study of youth athletes, boys were found to have greater muscle strength of the knee extensor and knee flexor muscles than girls at all stages of development assessed (Peek et al., 2022). Thus, findings of greater muscle strength in male youth athletes compared to female youth athletes, particularly in pre-pubertal boys and girls who are matched in time spent practicing sports (Manzano-Carrasco et al., 2022), challenges Thomas and French's (1985) conclusion that socialization is the primary cause of the sex difference in grip strength in children prior to puberty.

The current analysis also reveals that the size of the sex difference in grip strength in children and adolescents is similar between countries. Given that sizes of sex differences in children’s *physically activity participation* differ between many countries (Araujo et al., 2024; Cooper et al., 2015; Guthold et al., 2020), one might then also expect between-country differences in the sex difference in grip strength. However, except for Poland, the size of the sex difference in grip strength does not differ between countries.

Overall, the above results suggest that *biological* factors rather than social factors are the primary causes of the sex difference 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. At birth, the median (50th percentile) recumbent length for boys is 51.40 cm compared to 50.80 cm for girls (USA data) (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 testosterone levels than girls both *in utero* (Abramovich, 1974) and during infancy (Garagorri et al., 2008; Kiviranta et al., 2016; Kuijper et al., 2013; Tomlinson et al., 2004).

By age 5, the median body height for boys is 111.0 cm compared to 109.9 cm for girls (Kuczmarski et al., 2002). Boys remain taller than girls up until about age 11 (Kuczmarski et al., 2002). At age 11, the median body height for boys is 144.5 cm compared to 147.0 cm for girls (Kuczmarski et al., 2002). At age 14, this trend reverses. For girls, body height begins to plateau around age 14, whereas body height for boys increases until about age 16 where it begins to plateau (Kuczmarski et al., 2002). At age 14, the median body height for boys is 166.0 cm compared to 161.0 cm for girls (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, the median body height for boys is 173.30 cm compared to 162.80 cm for girls (Kuczmarski et al., 2002).

These sex differences in body height likely contribute to sex differences in grip strength because muscle strength correlates positively with body height (*r* = 0.30 – 0.80 depending on age, muscle, etc.) (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, as this is the age when females become taller than boys.

The linearity of the relationship between body height and muscle strength in children and adolescents depends on age, sex, and the muscle group evaluated. 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 gain 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. Boys have greater body masses than girls at most ages up until about age 11 (Kuczmarski et al., 2002). At birth, the median body mass for boys is 3.43 kg compared to 3.29 kg for girls (USA data) (Kuczmarski et al., 2002). At age 5, the median body mass for boys is 19.16 kg compared to 18.48 kg for girls (Kuczmarski et al., 2002). However, at age 11, the median body mass for boys is 36.29 kg compared to 38.1 kg for girls (Kuczmarski et al., 2002). Then, at age 14, the trend of greater female than male body mass reverses. At age 14, the median body mass for boys is 53.32 kg compared to 51.94 kg for girls (Kuczmarski et al., 2002). At age 16, the median body mass for boys is 62.71 kg compared to 54.89 kg for girls (Kuczmarski et al., 2002).

These sex differences in body mass likely contribute to differences in grip strength between boys and girls because grip strength correlates positively with body mass (*r* = about 0.30 – 0.70 depending on age) (Kocher et al., 2019; Kocher et al., 2017). This would partly explain why the sex difference in grip strength narrows at age 11, as this is the age 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 from boys and girls to their body masses does not eliminate the sex difference in strength performance (Köble et al., 2022; Ramírez-Vélez et al., 2017). Such findings suggest that biological factors other than body mass and body height contribute to sex differences in grip strength.

**Body composition (fat and muscle mass)**

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 pre-pubertal 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 children aged 3-8 years old, girls had approximately 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, the marked increase in muscle mass experienced during period 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 – an increase that is substantially greater than what is experienced by girls (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 muscles of the forearm, Abe et al. (Abe et al., 2023) found that forearm muscle thickness correlates positively with grip strength in children aged 5 and 6, though thicknesses did not differ between boys and girls in that study. 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. Another study, which did not find a statistically significant difference in grip strength between 8-11-year-old boys (16.9 kg grip) and girls (15.6 kg grip), found that grip strength was most closely linked with body height, forearm girth, forearm length, hand lean body mass, and hand bone mineral content (Jürimäe et al., 2009).

**Muscle fiber type**

Human skeletal muscles contain fibers that differ based on their morphological and physiological characteristics. Various methods are used to classify muscle fiber types, but fibers are generally categorized as Type I (slow twitch), Type IIA (intermediate), or Type IIB or IIX (fast twitch) (Nuzzo, 2023b). Characteristics of muscle fibers that are often measured include cross-sectional areas of muscle fibers, the percentage of fibers of a given muscle that are of a specific type (distribution percentage), the area of a given muscle that is taken up by fibers of a specific fiber type (area percentage), and the ratio of Type II to Type I muscle fiber areas (Nuzzo, 2023b). 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 (Bell et al., 1980; Esbjörnsson et al., 2022; Esbjörnsson et al., 2021; Jansson & Hedberg, 1991). The vastus lateralis muscle has been examined in all of these studies, and ages of participants have been 6 (Bell et al., 1980), 9-12 (Esbjörnsson et al., 2022; Esbjörnsson et al., 2021), and 16 years old (Glenmark et al., 1992; 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, and 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 during this stage of development. 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 that emerges during this period in development. The age at which the small-to-moderate sex differences in muscle fiber distribution and area percentages between adult males and females (Nuzzo, 2023b) begin to emerge is unclear.

**Voluntary activation**

Voluntary activation refers to the nervous system’s ability to “drive” the muscle to create its maximal force. In adults, there is no sex difference in voluntary activation (Nuzzo, 2023a). Men and women are usually able to activate their muscles at about 90-95%, depending on the muscle group assessed (Nuzzo, 2023b). In children, the number of studies that have explored a potential sex difference in voluntary activation is limited (Gillen et al., 2021; O'Brien et al., 2009, 2010; Streckis et al., 2007). Moreover, none of these studies have examined muscles used in gripping (Gillen et al., 2021; O'Brien et al., 2009, 2010; Streckis et al., 2007).

In the elbow flexor muscles, Gillen et al. (2021) found that voluntary activation was statistically greater in pre-pubertal boys (73%) than girls (67%) (mean age: 9.8 years) but no difference existed between *post*-pubertal boys and girls (~90% for both) (mean age: ~17 years). In the knee extensor muscles, O'Brien et al. (2009, 2010) did not observe a statistically significant difference in voluntary activation between boys (75%) and girls (67%) (age: ~9 years old). In the same muscle group, Streckis et al. (2007) also did not observe a statistically significant difference in voluntary activation between boys (~92%) and girls (~84%) (age: 12-14 years old).

Thus, if voluntary activation plays a role in the sex differences observed in grip strength, its role appears small. However, voluntary activation does increase from childhood to adulthood in both males and females (O'Brien et al., 2009, 2010; Streckis et al., 2007; Woods et al., 2022). Therefore, an aim of future research can be to use the interpolated twitch technique to explore if the time courses of improvements in voluntary activation differ between boys and girls.

**Limitations**

The current study is not without limitations. First, the current research does not reveal the underlying cause of the sex difference in grip strength in children and adolescents. Both biological and environmental/social factors have the potential to impact muscle strength. Here, the lack of a secular change in the size of the sex difference in grip strength, the lack of a difference in the size of the sex difference in grip strength between countries, and results from other literature cited, suggest that biological factors largely underpin the difference in grip strength that exists between boys and girls before, during, and after puberty.

Second, though the literature search used in the current work was thorough, it did not follow a formal flow diagram. Thus, replication of the search will be difficult. Nevertheless, the aim of the current study was to update a meta-analysis of four studies that is now 40 years old (Thomas & French, 1985, 1987). This aim was accomplished because the search strategy resulted in identification of 164 eligible studies from which 791 effects were computed. The findings from this sample over 300,000 boys and girls are unlikely to be influenced by any small number of studies that might have been missed in the search, and the narrowness of the confidence intervals improves trust in the results.

Third, the year of data *collection* was not reported in many papers. In such cases, the date of *publication* was entered into the analysis of secular changes. This could have impacted the results regarding secular changes in the sex difference in grip strength. Moving forward, researchers are encouraged to report the date of data collection when describing their study’s methods.

Finally, the current study was only concerned with grip strength. Therefore, the current study’s results should not be interpreted to represent sex differences in muscle strength for all muscle groups in. In adults, the sex difference in muscle strength is smaller in lower- than upper-body muscles (Nuzzo, 2023a). Whether this is also true in children and adolescents, as determined by meta-analytic techniques, remains to be seen.

**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 791 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 in the 2010s. 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 (1) the effect size from the 2010s falls within the CIs from all previous decades, and (2) there is substantial overlap in the CIs for all decades. The narrowing of the CIs in the 2010s is due to the greater amount of data available in the 2010s compared to previous decades and the consistency of study results.

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 | -0.01 | 0.54 |
| Under 1 yr | 4 | 0.52 | .001 | 0.21 | 0.83 | -0.42 | 1.46 |
| 1 2 yr | 3 | 0.30 | .059 | -0.01 | 0.61 | -1.72 | 2.31 |
| 3 yr | 10 | 0.40 | <.001 | 0.18 | 0.63 | -0.25 | 1.06 |
| 4 yr | 30 | 0.33 | <.001 | 0.27 | 0.38 | 0.21 | 0.45 |
| 5 yr | 43 | 0.41 | <.001 | 0.35 | 0.47 | 0.18 | 0.64 |
| 6 yr | 56 | 0.35 | <.001 | 0.30 | 0.41 | 0.08 | 0.63 |
| 7 yr | 63 | 0.35 | <.001 | 0.28 | 0.41 | -0.06 | 0.75 |
| 8 yr | 65 | 0.43 | <.001 | 0.36 | 0.49 | 0.08 | 0.77 |
| 9 yr | 75 | 0.45 | <.001 | 0.38 | 0.52 | -0.08 | 0.98 |
| 10 yr | 79 | 0.40 | <.001 | 0.31 | 0.50 | -0.36 | 1.17 |
| 11 yr | 73 | 0.28 | <.001 | 0.21 | 0.35 | -0.19 | 0.75 |
| 12 yr | 72 | 0.42 | <.001 | 0.33 | 0.52 | -0.34 | 1.19 |
| 13 yr | 69 | 0.63 | <.001 | 0.55 | 0.70 | 0.11 | 1.15 |
| 14 yr | 56 | 1.15 | <.001 | 1.04 | 1.25 | 0.42 | 1.87 |
| 15 yr | 50 | 1.58 | <.001 | 1.44 | 1.72 | 0.64 | 2.52 |
| 16 yr | 38 | 2.07 | <.001 | 1.86 | 2.27 | 0.82 | 3.31 |
| Overall | 791 | 0.63 | <.001 | 0.58 | 0.67 | -0.49 | 1.74 |

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 | 9 | 1.1 |
| Belgium | 15 | 1.9 |
| Bosnia | 7 | 0.9 |
| Brazil | 8 | 1.0 |
| Canada | 30 | 3.8 |
| China | 60 | 7.6 |
| Chile | 24 | 3.0 |
| Columbia | 9 | 1.1 |
| Czech Republic | 4 | 0.5 |
| England | 10 | 1.3 |
| Estonia | 16 | 2.0 |
| Finland | 2 | 0.3 |
| Germany | 6 | 0.8 |
| Greece | 5 | 0.6 |
| Hungary | 6 | 0.8 |
| Iceland | 4 | 0.5 |
| India | 11 | 1.4 |
| Iran | 10 | 1.3 |
| Ireland | 9 | 1.1 |
| Italy | 6 | 0.8 |
| Japan | 39 | 4.9 |
| Jordan | 11 | 1.4 |
| Kenya | 6 | 0.8 |
| Korea (South) | 18 | 2.3 |
| Kosovo | 2 | 0.3 |
| Lithuania | 6 | 0.8 |
| Macedonia | 9 | 1.1 |
| Malawi | 12 | 1.5 |
| Mexico | 9 | 1.1 |
| Netherlands | 30 | 3.8 |
| Norway | 4 | 0.5 |
| Oman | 1 | 0.1 |
| Peru | 21 | 2.7 |
| Poland | 51 | 6.4 |
| Portugal | 4 | 0.5 |
| Saudi Arabia | 19 | 2.4 |
| Senegal | 2 | 0.3 |
| Serbia | 10 | 1.3 |
| Slovenia | 2 | 0.3 |
| South Africa | 7 | 0.9 |
| Spain | 56 | 7.1 |
| Sweden | 23 | 2.9 |
| Thailand | 4 | 0.5 |
| Turkey | 9 | 1.1 |
| United States of America | 184 | 23.3 |
| 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 | 87.6 | 6.0 |
| 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 | 6,924 | 89.0 | 5.1 |
| 6 yr | 9,917 | 91.3 | 4.5 |
| 7 yr | 19,241 | 92.1 | 4.4 |
| 8 yr | 20,614 | 89.2 | 4.9 |
| 9 yr | 23,385 | 90.4 | 5.1 |
| 10 yr | 32,558 | 92.9 | 4.7 |
| 11 yr | 30,839 | 93.5 | 4.6 |
| 12 yr | 30,175 | 88.7 | 7.0 |
| 13 yr | 44,094 | 82.5 | 5.1 |
| 14 yr | 51,030 | 73.0 | 5.0 |
| 15 yr | 37,307 | 68.1 | 3.8 |
| 16 yr | 34,685 | 64.6 | 3.0 |
| Overall | 351,559 | 82.3 | 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 | Upper |
| 5-10 yr old |  |  |  |  |  |
| 1960s | 11 | 0.50 | <.001 | 0.36 | 0.64 |
| 1970s | 11 | 0.65 | <.001 | 0.49 | 0.81 |
| 1980s | 29 | 0.63 | <.001 | 0.55 | 0.71 |
| 1990s | 12 | 0.59 | <.001 | 0.35 | 0.83 |
| 2000 | 70 | 0.56 | <.001 | 0.45 | 0.68 |
| 2010s | 248 | 0.33 | <.001 | 0.30 | 0.36 |
| Overall | 381 | 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 | 93 | 1.49 | <.001 | 1.37 | 1.61 |
| Overall | 144 | 1.54 | <.001 | 1.43 | 1.64 |

CI = confidence interval.