

## REVIEW OPEN ACCESS

# Sex Differences in Grip Strength From Birth to Age 16: A Meta-Analysis

James L. Nuzzo 

School of Medical and Health Sciences, Edith Cowan University, Joondalup, Australia

**Correspondence:** James L. Nuzzo ([j.nuzzo@ecu.edu.au](mailto:j.nuzzo@ecu.edu.au))**Received:** 24 August 2024 | **Revised:** 19 December 2024 | **Accepted:** 23 January 2025**Funding:** I utilized crowdfunding (Go Fund Me) to generate funds for this research.**Keywords:** children | fitness | gender | strength | youth

## 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 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 and 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 and 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 slightly, 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.

## 1 | 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 and Vercammen 2001; De Ste Croix, Armstrong, and Welsman 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 and 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

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## Summary

- On average, boys have greater grip strength than girls from birth onward.
- Girls' grip strength is ~90% of boys' grip strength up to about age 12 and ~65% by age 16.
- Sex differences in childhood and adolescent grip strength are broadly similar between countries and have been mostly stable since the 1960s.

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 and French 1985). Two of these studies were unpublished reports, as later revealed by the researchers in a follow-up article (Thomas and French 1987). In total, the four studies provided 42 effects from 1446 boys and 1338 girls (Thomas and 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, O'Connor, and Parker 2024; Hamilton et al. 2024; Hilton and Lundberg 2021; Hunter et al. 2023; Hunter and Senefeld 2024; Lundberg et al. 2024; Nokoff et al. 2023; Nuzzo 2023a; Senefeld and Hunter 2024).

## 2 | Methods

### 2.1 | 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–August 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, and Nosaka 2023; Nuzzo, Pinto, Nosaka, and Steele 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, and Nosaka 2023; Nuzzo, Pinto, Nosaka, and Steele 2023; Nuzzo et al. 2024).

### 2.2 | Eligibility

For a study to be included in the current meta-analysis, it needed to meet the following criteria: (a) published in an academic journal in 2023 or earlier, (b) published in English, (c) included 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 were reported, (b) no means or SDs were reported, and (c) the age range of the study's cohort was beyond the eligibility criteria for the current analysis (described below).

### 2.3 | 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.

#### 2.3.1 | 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 the 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 2 years (e.g., 2004–2005), the first of the 2 years was included in the meta-analysis. When data collection spanned more than 2 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.

#### 2.3.2 | 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 1 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 3 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 to 7.9 years). Third, if the researcher reported grip strength scores for a cohort whose age spanned 2 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 to 6.9 years).

### 2.3.3 | 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, grip strength data only 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, data only 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), data only 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.

### 2.3.4 | 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 the data from the right hand.

### 2.3.5 | Data Extraction From Graphs

When grip strength means and SDs were presented in graphs, the values were estimated using a graph digitizer (WebPlotDigitizer, <https://automeris.io>) (Aydin and 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.

## 2.4 | 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 6 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 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 1 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 and Koziel 2018; Lei et al. 2021; Z. Wang et al. 2024) and differences in age at menarche between countries (Lei et al. 2021; Saczuk, Wasiluk, and Wilczewski 2018; Z. 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.

### 3 | Results

#### 3.1 | Study Characteristics

A total of 169 studies met the eligibility criteria and were included in the current meta-analysis (Abe et al. 2022, 2023; Ager, Olivett, and Johnson 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, Soto, and Weisstaub 2018; Atiković et al. 2023; Bae et al. 2015; Bala, Krneta, and Katić 2010; Baptista et al. 2012; Barr et al. 2010; Bear-Lehman et al. 2002; Bénédicte, Foué, and Malina 1999; Benzo et al. 2023; Bohannon et al. 2017, 2019; Bou-Sospedra et al. 2021; Buck and 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 and Pino-Ortega 2010; De Smet and Vercammen 2001; de Souza et al. 2014; Deforche et al. 2003; Delextrat et al. 2019; Demirel, Kiran, and Barut 2014; R. M. Dodds et al. 2014; Dong et al. 2016; Eather, Morgan, and Lubans 2016; Ehrlich et al. 2013; Elezi et al. 2021; Ervin et al. 2014; Espenschade and Meleny 1961; Fang et al. 2017; Finlayson and Reitan 1976; Flanagan et al. 2015; Fullwood 1986; Gantiraga et al. 2006; Garcia-Hermoso et al. 2021; Gisladdottir et al. 2023; Godoy-Cumillaf et al. 2020, 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 and Rösblad 2002; Haugland et al. 2023; H. He et al. 2019; H. He et al. 2023; Henriksson et al. 2016; Hepping et al. 2015; Herráez, Marrodán, and González-Montero de Espinosa 2022; Herrmann et al. 2015; Hirao et al. 2015; Hoekstra et al. 2008; Holm et al. 2008; Ignasiak, Sławińska, and Malina 2016; Isaacs and Frederick 1985; Isen, McGue, and Iacono 2014; Jacklin et al. 1984; Jacklin, Snow, and Maccoby 1981; Jürimäe and Saar 2003; Jürimäe and Volbekiene 1998; Katzmarzyk, Malina, and Beunen 1997; Katzmarzyk et al. 2000; Ke et al. 2022; Kenjle et al. 2005; Kidokoro and Edamoto 2021; Kidokoro et al. 2016; Kocher et al. 2017, 2019; Koziel, Ignasiak, and Żadzińska 2019; Krammel et al. 2018; Kryst et al. 2023; Latorre Román et al. 2017; Legarra-Gorgoñon et al. 2023; Leppänen et al. 2016, 2017; Li et al. 2018; Linderholm et al. 1971; Lintu et al. 2016; Lirgg et al. 2011; Little 2017; Luz et al. 2017; Mačák et al. 2022; Malina et al. 2010; Martinez-Tellez et al. 2016; Mathiowetz, Wiemer, and Federman 1986; Mayorgaa et al. 2012; McQuiddy et al. 2015; Merino-De Haro et al. 2019; Molenaar et al. 2010; Montalcini et al. 2016; Montoye and Lamphiear 1977; Montpetit, Montoye, and Laeding 1967; Morita et al. 2018; Murase et al. 1996; Mürsepp et al. 2009; Naka et al. 2005; Nara et al. 2023; Neu et al. 2002; Ng et al. 2020; Niempoog, Siripakarn, and Suntharapa 2007; Nieto-López et al. 2020; O'Keeffe et al. 2020; Oja and Jürimäe 2002; Omar, Alghadir, and Al Baker 2015; Örgan, Kristjan, and Björn 2005; Ortega et al. 2008; Ozaki et al. 2020; Parízková, Cermák, and Horná 1977; Pavlović et al. 2023; Perna et al. 2016; Perry et al. 1997; Peterson et al. 2016, 2018; Ploegmakers et al. 2013; Puszczalowska-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 and

Adachi 2019; Sember et al. 2022; Siegel, Camaione, and Manfredi 1989; Sokołowski and Chrzanowska 2012; Spreen and Gaddes 1969; Steene-Johannessen et al. 2009; Sunnegårdh et al. 1988; Tan et al. 1992; Tanaka et al. 2012; E. Thomas and Palma 2018; Tishukaj et al. 2017; Torrijos-Niño et al. 2014; Trajković et al. 2021; Trudeau et al. 2003; Tsimeas et al. 2005; Tsoukos and Bogdanis 2021; Y.-C. Wang et al. 2019; Weedon et al. 2022; Welk, Saint-Maurice, and Csányi 2015; Wen et al. 2020; Westerstahl et al. 2003; Weston, Pasecinic, and Basterfield 2019; Wick, Kriemler, and Granacher 2022; Wilcox and Nordstokke 2022; Xu et al. 2020; Yapici et al. 2022; Yim, Cho, and Lee 2003; Yoshizawa, Ishizaki, and Honda 1977; Yuki, Tamase, and Nakayama 2023; Żegleń et al. 2020; Zhang et al. 2021, 2022; Zverev and 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 and 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.

#### 3.2 | Grip Strength

##### 3.2.1 | Age

From birth, grip strength was greater in boys than girls (Figure 1, Table 1). During these ages, female grip strength equaled approximately 90% of male grip strength (Figure 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 [ $1.86$ ,  $2.27$ ]).

##### 3.2.2 | 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–2020s, represented by a narrowing of the CIs (Figure 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



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

Age group	No. effects	Hedges <i>g</i>	<i>p</i>	95% CI		95% PI	
				Lower	Upper	Lower	Upper
Under 2 days	5	0.27	0.002	0.10	0.44	−0.01	0.54
Under 1 year	4	0.52	0.001	0.21	0.83	−0.42	1.46
1–2 years	3	0.30	0.059	−0.01	0.61	−1.72	2.31
3 years	10	0.40	< 0.001	0.18	0.63	−0.25	1.06
4 years	30	0.33	< 0.001	0.27	0.38	0.21	0.45
5 years	44	0.41	< 0.001	0.35	0.47	0.18	0.64
6 years	57	0.36	< 0.001	0.30	0.41	0.08	0.63
7 years	65	0.34	< 0.001	0.28	0.41	−0.05	0.74
8 years	67	0.42	< 0.001	0.36	0.48	0.08	0.76
9 years	78	0.46	< 0.001	0.38	0.53	−0.08	0.99
10 years	82	0.41	< 0.001	0.31	0.50	−0.35	1.16
11 years	75	0.29	< 0.001	0.22	0.35	−0.19	0.76
12 years	75	0.42	< 0.001	0.32	0.51	−0.34	1.17
13 years	69	0.63	< 0.001	0.55	0.70	0.11	1.15
14 years	56	1.15	< 0.001	1.04	1.25	0.42	1.87
15 years	50	1.58	< 0.001	1.44	1.72	0.64	2.52
16 years	38	2.07	< 0.001	1.86	2.27	0.82	3.31
Overall	808	0.63	< 0.001	0.58	0.67	−0.48	1.73

Abbreviations: CI, confidence interval, PI, prediction interval.

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.

### 3.2.3 | 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.

## 4 | 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.

### 4.1 | 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 h of birth (Jacklin et al. 1984; Jacklin, Snow, and Maccoby 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

**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

(Continues)

**TABLE 2** | (Continued)

Country or region	No. effects	Percent
Turkey	10	1.2
United States of America	184	22.8
Wales	1	0.1
Total	808	100.0

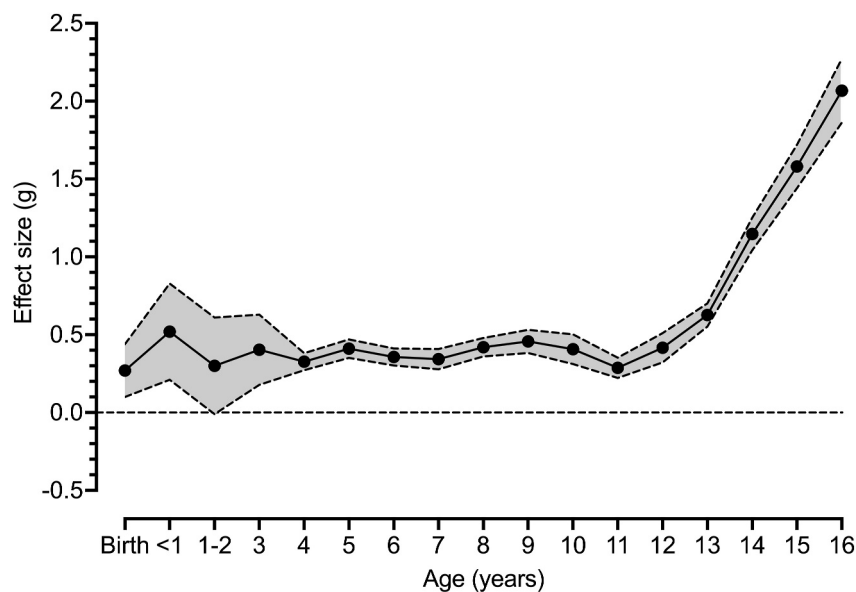
on a rubber ring that was attached to a chain and scale and pulled up and away from the baby by the investigator (Jacklin et al. 1984; Jacklin, Snow, and Maccoby 1981; Tan et al. 1992). Using these techniques, researchers have generally found that newborn boys exhibit greater grip strength than newborn girls (Jacklin et al. 1984; Jacklin, Snow, and Maccoby 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, Snow, and Maccoby 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 to 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.

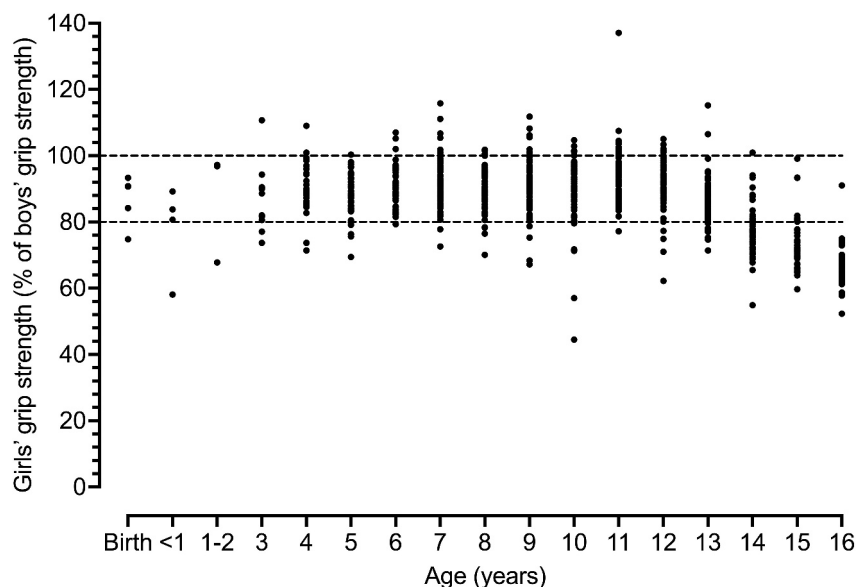
After age 11, the sex difference in grip strength widens considerably. At age 13, the effect size is  $g = 0.63$ . At age 16, the last age in the meta-analysis, the effect size is  $g = 2.07$ . Male puberty, which is characterized, in part, by disproportionate increases in testosterone levels, body height,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

## 4.2 | 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



**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 numbers 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.

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.

### 4.3 | 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 accrual 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 and Geary 2019).

#### 4.4 | Biological and Social/Environmental Causes

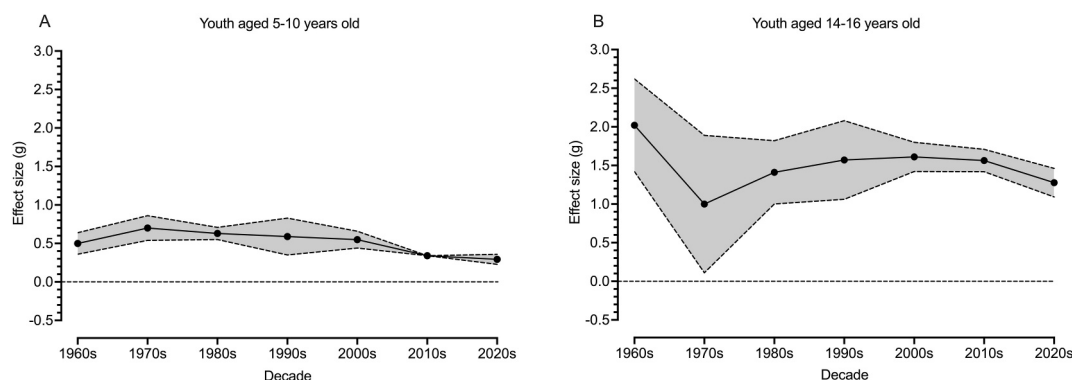
Biological and social/environmental factors are two broad potential causes of sex differences in grip strength. Thomas and French (1985) speculated that small-to-moderate differences in grip strength between pre-pubescent boys and girls were “mostly environmentally induced” and could “easily be eliminated 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). However, 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)

**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 days	540	87.6	6.0
Under 1 year	210	79.4	10.7
1–2 years	158	83.5	14.6
3 years	1428	90.8	6.7
4 years	8454	90.0	3.7
5 years	6957	89.0	5.1
6 years	9939	91.3	4.5
7 years	19,241	92.1	4.4
8 years	20,703	89.2	4.9
9 years	23,834	90.4	5.1
10 years	33,080	92.9	4.7
11 years	30,928	93.5	4.7
12 years	31,004	89.0	7.1
13 years	44,094	82.5	5.1
14 years	51,030	73.1	5.1
15 years	37,307	68.1	3.8
16 years	34,685	64.6	3.0
Overall	353,676	82.4	11.4

Abbreviation: SD, standard deviation.



**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-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% 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 4** | Effect sizes of the difference in grip strength between boys and girls by age and decade.

Age group, decade	No. effects	Hedges <i>g</i>	<i>p</i>	95% CI	
				Lower	Upper
5–10 years old					
1960s	11	0.50	< 0.001	0.36	0.64
1970s	17	0.70	< 0.001	0.54	0.86
1980s	29	0.63	< 0.001	0.55	0.71
1990s	12	0.59	< 0.001	0.35	0.83
2000	74	0.55	< 0.001	0.44	0.66
2010s	202	0.34	< 0.001	0.31	0.37
2020s (2020–2023)	48	0.29	< 0.001	0.23	0.36
Overall	393	0.40	< 0.001	0.37	0.43
14–16 years old					
1960s	6	2.02	< 0.001	1.42	2.62
1970s	1	1.00	0.028	0.11	1.89
1980s	9	1.41	< 0.001	1.00	1.82
1990s	13	1.57	< 0.001	1.06	2.08
2000	22	1.61	< 0.001	1.42	1.80
2010s	71	1.56	< 0.001	1.42	1.71
2020s (2020–2023)	22	1.28	< 0.001	1.09	1.46
Overall	144	1.54	< 0.001	1.43	1.64

Abbreviation: 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	Upper
5–10 years old					
Canada	16	0.41	< 0.001	0.22	0.61
China	26	0.38	< 0.001	0.30	0.46
Chile	14	0.31	< 0.001	0.16	0.46
Japan	28	0.33	< 0.001	0.26	0.40
Netherlands	18	0.31	< 0.001	0.23	0.40
Peru	15	0.29	< 0.001	0.23	0.36
Poland	22	0.49	< 0.001	0.38	0.60
Spain	24	0.34	< 0.001	0.26	0.43
United States of America	83	0.35	< 0.001	0.30	0.40
Overall <sup>a</sup>	386	0.40	< 0.001	0.37	0.43
14–16 years old					
China	15	1.61	< 0.001	1.41	1.81
Poland	13	1.20	< 0.001	0.89	1.50
Spain	9	1.78	< 0.001	1.58	1.98
Sweden	5	2.09	< 0.001	1.51	2.67
United States of America	37	1.56	< 0.001	1.40	1.73
Overall <sup>a</sup>	144	1.54	< 0.001	1.43	1.64

Abbreviation: CI, confidence interval.

<sup>a</sup>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.

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.

#### 4.5 | 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, Ogden, and Guo 2002). Boys then grow faster than girls during the first 6 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, Ogden, and Guo 2002). At age 14, girls' body height begins to plateau, whereas boys' body height continues to increase (Kuczmarski, Ogden, and Guo 2002). Age 14 is also when a sex difference in forearm length emerges (Jürimäe, Hurbo, and Jürimäe 2009; Neu et al. 2002). At age 16, boys' median body height is significantly greater than girls' mean body height (Kuczmarski, Ogden, and Guo 2002).

These sex differences in body height likely contribute to sex differences in grip strength because body height correlates positively with muscle strength ( $r = 0.30\text{--}0.80$ ) (Hogrel et al. 2012; Jürimäe, Hurbo, and Jürimäe 2009; Kocher et al. 2017, 2019; 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).

#### 4.6 | 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, Ogden, and Guo 2002). At age 11, girls begin to weigh more than boys (Kuczmarski, Ogden, and Guo 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, Ogden, and Guo 2002).

These sex differences in body mass likely contribute to sex differences in grip strength because body mass correlates positively with grip strength ( $r = 0.30\text{--}0.70$ ) (Kocher et al. 2017, 2019). 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,

**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, Ogden, and Guo (2002)
5 years old	111.0 cm	109.9 cm	Kuczmarski, Ogden, and Guo (2002)
11 years old	144.5 cm	147.0 cm	Kuczmarski, Ogden, and Guo (2002)
14 years old	166.0 cm	161.0 cm	Kuczmarski, Ogden, and Guo (2002)
16 years old	173.3 cm	162.8 cm	Kuczmarski, Ogden, and Guo (2002)
Median body mass			
Birth	3.43 kg	3.29 kg	Kuczmarski, Ogden, and Guo (2002)
5 years old	19.16 kg	18.48 kg	Kuczmarski, Ogden, and Guo (2002)
11 years old	36.29 kg	38.1 kg	Kuczmarski, Ogden, and Guo (2002)
14 years old	53.32 kg	51.94 kg	Kuczmarski, Ogden, and Guo (2002)
16 years old	62.71 kg	54.89 kg	Kuczmarski, Ogden, and Guo (2002)

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.

#### 4.7 | 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; Q. He et al. 2002; Leppänen et al. 2017; McCarthy et al. 2014; Nelson and 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 and 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 their 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, Hirschberg, and Bermon 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). In addition, 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.

#### 4.8 | 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 enduring (Bottinelli et al. 1996, 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 and 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, Hedberg, and Jansson 1992; Jansson and 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.

#### 4.9 | 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, Taylor, and Gandevia 2019). In this test, a participant performs a maximal voluntary contraction (MVC). When the participant reaches their peak 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, Taylor, and Gandevia 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, Taylor, and Gandevia 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, Skurvydas, and Ratkevicius 2007). In children ~9 years old, voluntary activation of the elbow flexors and knee extensors in boys is 73%–75% and 67% in girls (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, Skurvydas, and Ratkevicius 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, Skurvydas, and Ratkevicius 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.

#### 4.10 | Limitations

The current study is not without potential limitations. First, the review was not registered in PROSPERO (Page, Shamseer, and Tricco 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, and Nosaka 2023; Nuzzo, Pinto, Nosaka, and Steele 2023; Nuzzo et al. 2024). Here, the number of studies and effects identified were substantially greater than in the meta-analysis from 40 years ago (Thomas and French 1985, 1987). The 95% CIs are narrow at most ages, reflecting a high level of confidence in the results and 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.

#### 5 | 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 a 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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#### Ethics Statement

The author has nothing to report.

#### Conflicts of Interest

The author declares no conflicts of interest.

#### 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 (<https://doi.org/10.51224/SRXIV.441>).

#### References

- Abe, T., H. Ozaki, A. Abe, S. Machida, H. Naito, and J. P. Loenneke. 2023. "Longitudinal Changes of Grip Strength and Forearm Muscle Thickness in Young Children." *Physiology International* 110, no. 3: 267–276. <https://doi.org/10.1556/2060.2023.00188>.
- Abe, T., R. Sanui, A. Sasaki, et al. 2022. "Optimal Grip Span for Measuring Maximum Handgrip Strength in Preschool Children." *International Journal of Clinical Medicine* 13, no. 11: 479–488. <https://doi.org/10.4236/ijcm.2022.1311035>.
- Abramovich, D. R. 1974. "Human Sexual Differentiation--In Utero Influences." *Journal of Obstetrics and Gynaecology of the British Commonwealth* 81, no. 6: 448–453. <https://doi.org/10.1111/j.1471-0528.1974.tb00494.x>.
- Ager, C. L., B. L. Olivett, and C. L. Johnson. 1984. "Grasp and Pinch Strength in Children 5 to 12 Years Old." *American Journal of Occupational Therapy* 38, no. 2: 107–113. <https://doi.org/10.5014/ajot.38.2.107>.
- Alqahtani, B. A., A. M. Alenazi, R. K. Elnaggar, et al. 2023. "Normative Values for Hand Grip and Pinch Strength for 6 to 18 Year-Olds in Saudi Arabia." *BMC Musculoskeletal Disorders* 24, no. 1: 96. <https://doi.org/10.1186/s12891-023-06197-0>.
- Al-Rahamneh, H., H. Aloran, H. Alnader, N. A. Ghafary, W. Ismail, and S. Al Qarra. 2020. "Reference Values of Hand-Grip Strength for 6- to 18-Year-Olds in Jordan." *Journal of Exercise Physiology* 23, no. 1: 68–78.
- Amado-Pacheco, J., D. Prieto-Benavides, J. Correa-Bautista, et al. 2019. "Feasibility and Reliability of Physical Fitness Tests Among Colombian Preschool Children." *International Journal of Environmental Research and Public Health* 16, no. 17: 3069. <https://doi.org/10.3390/ijerph16173069>.
- Amo-Setién, F. J., C. Leal-Costa, R. Abajas-Bustillo, D. González-Lamuño, and C. Redondo-Figuero. 2020. "Factors Associated With Grip Strength



- Among Adolescents: An Observational Study." *Journal of Hand Therapy* 33, no. 1: 96–102. <https://doi.org/10.1016/j.jht.2018.10.005>.
- Andersen, J. R., G. K. Natvig, E. Aadland, et al. 2017. "Associations Between Health-Related Quality of Life, Cardiorespiratory Fitness, Muscle Strength, Physical Activity and Waist Circumference in 10-Year-Old Children: The ASK Study." *Quality of Life Research* 26, no. 12: 3421–3428. <https://doi.org/10.1007/s11136-017-1634-1>.
- Araujo, R. H. O., A. O. Werneck, C. L. Martins, et al. 2024. "Global Prevalence and Gender Inequalities in at Least 60 min of Self-Reported Moderate-To-Vigorous Physical Activity 1 or More Days Per Week: An Analysis With 707,616 Adolescents." *Journal of Sport and Health Science* 13, no. 5: 709–716. <https://doi.org/10.1016/j.jshs.2023.10.011>.
- Arfai, K., P. D. Pitukcheewanont, M. I. Goran, C. J. Tavaré, L. Heller, and V. Gilsanz. 2002. "Bone, Muscle, and Fat: Sex-Related Differences in Prepubertal Children." *Radiology* 224, no. 2: 338–344. <https://doi.org/10.1148/radiol.2242011369>.
- Arias Téllez, M. J., J. P. Soto, and S. G. Weisstaub. 2018. "Physical Fitness, Cardiometabolic Risk and Heart Rate Recovery in Chilean Children." *Nutrición Hospitalaria* 35, no. 1: 44–49. (Condición física, riesgo cardiometabólico y frecuencia cardíaca de recuperación en escolares chilenos.). <https://doi.org/10.20960/nh.1323>.
- Atiković, A., E. Čolakhodžić, E. Užicanin, et al. 2023. "Age and Gender Differences in Anthropometric Characteristics and Motor Performance of 3 Through 6 Young Kids Aged (Pilot Study)." *Children* 10, no. 3: 590. <https://doi.org/10.3390/children10030590>.
- Aydin, O., and M. Y. Yassikaya. 2022. "Validity and Reliability Analysis of the PlotDigitizer Software Program for Data Extraction From Single-Case Graphs." *Perspectives on Behavior Science* 45, no. 1: 239–257. <https://doi.org/10.1007/s40614-021-00284-0>.
- Bae, J. Y., K. S. Jang, S. Kang, D. H. Han, W. Yang, and K. O. Shin. 2015. "Correlation Between Basic Physical Fitness and Pulmonary Function in Korean Children and Adolescents: A Cross-Sectional Survey." *Journal of Physical Therapy Science* 27, no. 9: 2687–2692. <https://doi.org/10.1589/jpts.27.2687>.
- Bala, G., Z. Krneta, and R. Katić. 2010. "Effects of Kindergarten Period on School Readiness and Motor Abilities." Supplement, *Collegium Antropologicum* 34, no. S1: 61–67.
- Baptista, F., C. Barrigas, F. Vieira, et al. 2012. "The Role of Lean Body Mass and Physical Activity in Bone Health in Children." *Journal of Bone and Mineral Metabolism* 30, no. 1: 100–108. <https://doi.org/10.1007/s00774-011-0294-4>.
- Barr, J. G., S. R. Veena, K. N. Kiran, et al. 2010. "The Relationship of Birthweight, Muscle Size at Birth and Post-Natal Growth to Grip Strength in 9-Year-Old Indian Children: Findings From the Mysore Parthenon Study." *Journal of Developmental Origins of Health and Disease* 1, no. 5: 329–337. <https://doi.org/10.1017/s2040174410000309>.
- Bear-Lehman, J., M. Kafko, L. Mah, L. Mosquera, and B. B. Reilly. 2002. "An Exploratory Look at Hand Strength and Hand Size Among Preschoolers." *Journal of Hand Therapy* 15, no. 4: 340–346. [https://doi.org/10.1016/s0894-1130\(02\)80005-9](https://doi.org/10.1016/s0894-1130(02)80005-9).
- Bell, R. D., J. D. MacDougall, R. Billeter, and H. Howald. 1980. "Muscle Fiber Types and Morphometric Analysis of Skeletal Muscle in Six-Year-Old Children." *Medicine and Science in Sports and Exercise* 12, no. 1: 28–31. <https://doi.org/10.1249/00005768-198021000-00007>.
- Bénéfice, E., T. Fouéré, and R. M. Malina. 1999. "Early Nutritional History and Motor Performance of Senegalese Children, 4–6 Years of Age." *Annals of Human Biology* 26, no. 5: 443–455. <https://doi.org/10.1080/030144699282561>.
- Benzo, R. M., S. M. St George, S. E. Messiah, et al. 2023. "Physical Fitness Among Adolescents Who Are Hispanic With Overweight or Obesity." *Pediatric Physical Therapy* 35, no. 2: 252–258. <https://doi.org/10.1097/pep.0000000000000997>.
- Bohannon, R. W., Y.-C. Wang, D. Bubela, and R. C. Gershon. 2017. "Handgrip Strength: A Population-Based Study of Norms and Age Trajectories for 3- to 17-Year-Olds." *Pediatric Physical Therapy* 29, no. 2: 118–123. <https://doi.org/10.1097/pep.0000000000000366>.
- Bohannon, R. W., Y.-C. Wang, S.-C. Yen, and K. A. Grogan. 2019. "Handgrip Strength: A Comparison of Values Obtained From the NHANES and NIH Toolbox Studies." *American Journal of Occupational Therapy* 73, no. 2: 7302205080p1–7302205080p9. <https://doi.org/10.5014/ajot.2019.029538>.
- Bottinelli, R., M. Canepari, M. A. Pellegrino, and C. Reggiani. 1996. "Force-Velocity Properties of Human Skeletal Muscle Fibres: Myosin Heavy Chain Isoform and Temperature Dependence." *Journal of Physiology* 495, no. Pt. 2: 573–586. <https://doi.org/10.1113/jphysiol.1996.sp021617>.
- Bottinelli, R., M. A. Pellegrino, M. Canepari, R. Rossi, and C. Reggiani. 1999. "Specific Contributions of Various Muscle Fibre Types to Human Muscle Performance: An In Vitro Study." *Journal of Electromyography and Kinesiology* 9, no. 2: 87–95. [https://doi.org/10.1016/s1050-6411\(98\)00040-6](https://doi.org/10.1016/s1050-6411(98)00040-6).
- Bou-Sospedra, C., M. Adelantado-Renau, M. R. Beltran-Valls, and D. Moliner-Urdiales. 2021. "Independent and Combined Influence of Physical Fitness Components on Self-Esteem in Adolescents: DADOS Study." *Annals of Human Biology* 48, no. 7–8: 550–556. <https://doi.org/10.1080/03014460.2022.2032337>.
- Brix, N., A. Ernst, L. L. B. Lauridsen, et al. 2019. "Timing of Puberty in Boys and Girls: A Population-Based Study." *Pediatric and Perinatal Epidemiology* 33, no. 1: 70–78. <https://doi.org/10.1111/ppe.12507>.
- Brown, G. A., M. I. O'Connor, and M. G. Parker. 2024. "Comments on Sports Participation and Transgender Youths." *JAMA Pediatrics* 178, no. 3: 315. <https://doi.org/10.1001/jamapediatrics.2023.5960>.
- Buck, R., and M. I. Lambert. 2022. "Getting a Grip on Strength Measurement in Children (6–13 Y): Impact of Typical Error of Measurement." *Pediatric Exercise Science* 34, no. 3: 141–147. <https://doi.org/10.1123/pes.2021-0069>.
- Butterfield, S. A., R. A. Lehnhard, E. M. Loovis, T. Coladarci, and D. Saucier. 2009. "Grip Strength Performances by 5- to 19-Year-Olds." *Perceptual and Motor Skills* 109, no. 2: 362–370. <https://doi.org/10.2466/pms.109.2.362-370>.
- Cadenas-Sánchez, C., E. G. Artero, F. Concha, B. Leyton, and J. Kain. 2015. "Anthropometric Characteristics and Physical Fitness Level in Relation to Body Weight Status in Chilean Preschool Children." *Nutrición Hospitalaria* 32, no. 1: 346–353. <https://doi.org/10.3305/nh.2015.32.1.9092>.
- Cadenas-Sanchez, C., B. Martinez-Tellez, G. Sanchez-Delgado, et al. 2016. "Assessing Physical Fitness in Preschool Children: Feasibility, Reliability and Practical Recommendations for the PREFIT Battery." *Journal of Science and Medicine in Sport* 19, no. 11: 910–915. <https://doi.org/10.1016/j.jsams.2016.02.003>.
- Casajús, J. A., M. T. Leiva, A. Villarroya, A. Legaz, and L. A. Moreno. 2007. "Physical Performance and School Physical Education in Overweight Spanish Children." *Annals of Nutrition & Metabolism* 51, no. 3: 288–296. <https://doi.org/10.1159/000105459>.
- Cetin, A., M. Genc, S. Sevil, and Y. K. Coban. 2013. "Prevalence of the Palmaris Longus Muscle and Its Relationship With Grip and Pinch Strength: A Study in a Turkish Pediatric Population." *Hand* 8, no. 2: 215–220. <https://doi.org/10.1007/s11552-013-9509-6>.
- Chen, G., J. Chen, J. Liu, Y. Hu, and Y. Liu. 2022. "Relationship Between Body Mass Index and Physical Fitness of Children and Adolescents in Xinjiang, China: A Cross-Sectional Study." *BMC Public Health* 22, no. 1: 1680. <https://doi.org/10.1186/s12889-022-14089-6>.
- Cohen, D. D., C. Voss, M. Taylor, D. M. Stasinopoulos, A. Delextrat, and G. Sandercock. 2010. "Handgrip Strength in English Schoolchildren."



- Acta Paediatrica 99, no. 7: 1065–1072. <https://doi.org/10.1111/j.1651-2227.2010.01723.x>.
- Cooper, A. R., A. Goodman, A. S. Page, et al. 2015. “Objectively Measured Physical Activity and Sedentary Time in Youth: The International Children’s Accelerometry Database (ICAD).” *International Journal of Behavioral Nutrition and Physical Activity* 12, no. 1: 113. <https://doi.org/10.1186/s12966-015-0274-5>.
- Coulter, D. 1978. “Norms for Grip Strength on the Smedley’s Dynamometer for Dominantly Right Handed Boys and Girls Aged 5–11 Years.” *Australian Occupational Therapy Journal* 25, no. 1: 15–18. <https://doi.org/10.1111/j.1440-1630.1978.tb01112.x>.
- Courant, F., L. Aksglaede, J.-P. Antignac, et al. 2010. “Assessment of Circulating Sex Steroid Levels in Prepubertal and Pubertal Boys and Girls by a Novel Ultrasensitive Gas Chromatography-Tandem Mass Spectrometry Method.” *Journal of Clinical Endocrinology and Metabolism* 95, no. 1: 82–92. <https://doi.org/10.1210/jc.2009-1140>.
- Cumming, G. 2009. “Inference by Eye: Reading the Overlap of Independent Confidence Intervals.” *Statistics in Medicine* 28, no. 2: 205–220. <https://doi.org/10.1002/sim.3471>.
- de Chaves, R. N., A. Bustamante Valdivia, A. Nevill, et al. 2016. “Developmental and Physical-Fitness Associations With Gross Motor Coordination Problems in Peruvian Children.” *Research in Developmental Disabilities* 53–54: 107–114. <https://doi.org/10.1016/j.ridd.2016.01.003>.
- Deforche, B., J. Lefevre, I. De Bourdeaudhuij, A. P. Hills, W. Duquet, and J. Bouckaert. 2003. “Physical Fitness and Physical Activity in Obese and Nonobese Flemish Youth.” *Obesity Research* 11, no. 3: 434–441. <https://doi.org/10.1038/oby.2003.59>.
- De la Cruz-Sánchez, E., and J. Pino-Ortega. 2010. “An Active Lifestyle Explains Sex Differences in Physical Performance in Children Before Puberty.” *Collegium Antropologicum* 34, no. 2: 487–491.
- Delextrat, A., L. D. Hayes, S. S. Al Ghannami, et al. 2019. “Physical Fitness Characteristics of Omani Primary School Children According to Body Mass Index.” *Journal of Sports Medicine and Physical Fitness* 59, no. 3: 440–448. <https://doi.org/10.23736/s0022-4707.18.08136-7>.
- Demirel, P., S. Kiran, and C. Barut. 2014. “Morphological and Functional Aspects of Hand in Relation to Age, Gender and Sports Playing Condition.” *Acta Medica International* 1, no. 1: 67–73. <https://doi.org/10.5530/ami.2014.2.4>.
- De Smet, L., and A. Vercammen. 2001. “Grip Strength in Children.” *Journal of Pediatric Orthopedics. Part B* 10, no. 4: 352–354. <https://doi.org/10.1097/00009957-200110000-00017>.
- de Souza, M. A., C. R. de Jesus Alves de Baptista, M. M. Baranauskas Benedicto, T. M. Pizzato, and A. C. Mattiello-Sverzut. 2014. “Normative Data for Hand Grip Strength in Healthy Children Measured With a Bulb Dynamometer: A Cross-Sectional Study.” *Physiotherapy* 100, no. 4: 313–318. <https://doi.org/10.1016/j.physio.2013.11.004>.
- De Ste Croix, M. B. A., N. Armstrong, and J. R. Welsman. 2003. “The Reliability of an Isokinetic Knee Muscle Endurance Test in Young Children.” *Pediatric Exercise Science* 15, no. 3: 313–323. <https://doi.org/10.1123/pes.15.3.313>.
- Dodds, R., C. Macdonald-Wallis, T. Kapasi, et al. 2012. “Grip Strength at 4 Years in Relation to Birth Weight.” *Journal of Developmental Origins of Health and Disease* 3, no. 2: 111–115. <https://doi.org/10.1017/s204017441100081x>.
- Dodds, R. M., H. E. Syddall, R. Cooper, et al. 2014. “Grip Strength Across the Life Course: Normative Data From Twelve British Studies.” *PLoS One* 9, no. 12: e113637. <https://doi.org/10.1371/journal.pone.0113637>.
- Dong, B., Z. Wang, L. Arnold, Y. Song, H.-J. Wang, and J. Ma. 2016. “The Association Between Blood Pressure and Grip Strength in Adolescents: Does Body Mass Index Matter?” *Hypertension Research* 39, no. 12: 919–925. <https://doi.org/10.1038/hr.2016.84>.
- Dotan, R., C. Mitchell, R. Cohen, P. Klentrou, D. Gabriel, and B. Falk. 2012. “Child-Adult Differences in Muscle Activation—A Review.” *Pediatric Exercise Science* 24, no. 1: 2–21. <https://doi.org/10.1123/pes.24.1.2>.
- Eather, N., P. J. Morgan, and D. R. Lubans. 2016. “Improving Health-Related Fitness in Adolescents: The CrossFit Teens™ Randomised Controlled Trial.” *Journal of Sports Sciences* 34, no. 3: 209–223. <https://doi.org/10.1080/02640414.2015.1045925>.
- Ehrlich, P. F., J. G. Young, S. Ulin, et al. 2013. “Maximum Hand-Rung Coupling Forces in Children: The Effects of Handhold Diameter.” *Human Factors* 55, no. 3: 545–556. <https://doi.org/10.1177/0018720812465770>.
- Elezi, A., G. Elezi, S. Gontarev, and G. Georgiev. 2021. “Gender Differences in Absolute and Relative Values of Hand Dynamometer Test With 9 and 10-Year Old Children From the Skopje Region in R.N. Macedonia.” *Physical Education Theory and Methodology* 21, no. 2: 113–120. <https://doi.org/10.17309/tmf.2021.2.03>.
- El Hage, R. P., D. Courteix, C.-L. Benhamou, C. Jacob, and C. Jaffré. 2009. “Relative Importance of Lean and Fat Mass on Bone Mineral Density in a Group of Adolescent Girls and Boys.” *European Journal of Applied Physiology* 105, no. 5: 759–764. <https://doi.org/10.1007/s00421-008-0959-4>.
- Elmlinger, M. W., W. Kühnel, H. Wormstall, and P. C. Döller. 2005. “Reference Intervals for Testosterone, Androstenedione and SHBG Levels in Healthy Females and Males From Birth Until Old Age.” *Clinical Laboratory* 51, no. 11–12: 625–632.
- Ervin, R. B., C. D. Fryar, C.-Y. Wang, I. M. Miller, and C. L. Ogden. 2014. “Strength and Body Weight in US Children and Adolescents.” *Pediatrics* 134, no. 3: e782–e789. <https://doi.org/10.1542/peds.2014-0794>.
- Ervin, R. B., C. Y. Wang, C. D. Fryar, I. M. Miller, and C. L. Ogden. 2013. *Measures of Muscular Strength in U.S. Children and Adolescents, 2012*. NCHS data brief, no 139, 1–8. Hyattsville, MD, USA: National Center for Health Statistics.
- Esbjörnsson, M., B. Norman, M. Dahlström, J. Gierup, and E. Jansson. 2022. “Metabolic and Morphological Profile in Skeletal Muscle of Healthy Boys and Girls.” *Physiological Reports* 10, no. 16: e15414. <https://doi.org/10.14814/phy2.15414>.
- Esbjörnsson, M. E., M. S. Dahlström, J. W. Gierup, and E. C. Jansson. 2021. “Muscle Fiber Size in Healthy Children and Adults in Relation to Sex and Fiber Types.” *Muscle & Nerve* 63, no. 4: 586–592. <https://doi.org/10.1002/mus.27151>.
- Espenschade, A., and H. E. Meleny. 1961. “Motor Performances of Adolescent Boys and Girls of Today in Comparison With Those of 24 Years Ago.” *Research Quarterly* 32, no. 2: 186–189. <https://doi.org/10.1080/10671188.1961.10613132>.
- Euling, S. Y., M. E. Herman-Giddens, P. A. Lee, et al. 2008. “Examination of US Puberty-Timing Data From 1940 to 1994 for Secular Trends: Panel Findings.” Supplement, *Pediatrics* 121, no. S3: S172–S191. <https://doi.org/10.1542/peds.2007-1813D>.
- Fang, H., M. Quan, T. Zhou, et al. 2017. “Relationship Between Physical Activity and Physical Fitness in Preschool Children: A Cross-Sectional Study.” *BioMed Research International* 2017: 9314026–9314028. <https://doi.org/10.1155/2017/9314026>.
- Finlayson, M. A. J., and R. M. Reitan. 1976. “Handedness in Relation to Measures of Motor and Tactile-Perceptual Functions in Normal Children.” *Perceptual and Motor Skills* 42, no. 43: 475–481. <https://doi.org/10.2466/pms.1976.43.2.475>.
- Flanagan, S. D., C. Dunn-Lewis, D. L. Hatfield, et al. 2015. “Developmental Differences Between Boys and Girls Result in Sex-Specific Physical Fitness Changes From Fourth to Fifth Grade.” *Journal of*

- Strength and Conditioning Research* 29, no. 1: 175–180. <https://doi.org/10.1519/jsc.0000000000000623>.
- Fullwood, D. 1986. “Australian Norms for Hand and Finger Strength of Boys and Girls Aged 5–12 Years.” *Australian Occupational Therapy Journal* 33, no. 1: 26–37. <https://doi.org/10.1111/j.1440-1630.1986.tb01524.x>.
- Gantiraga, E., E. Katartzi, G. Komsis, and C. Papadopoulos. 2006. “Strength and Vertical Jumping Performance Characteristics in School-Aged Boys and Girls.” *Biology of Sport* 23, no. 4: 367–378.
- Garagorri, J. M., G. Rodríguez, Á. J. Lario-Elboj, J. L. Olivares, Á. Lario-Muñoz, and I. Orden. 2008. “Reference Levels for 17-Hydroxyprogesterone, 11-Desoxycortisol, Cortisol, Testosterone, Dehydroepiandrosterone Sulfate and Androstenedione in Infants From Birth to Six Months of Age.” *European Journal of Pediatrics* 167, no. 6: 647–653. <https://doi.org/10.1007/s00431-007-0565-1>.
- Garcia-Hermoso, A., C. Cofre-Bolados, R. Andrade-Schnettler, et al. 2021. “Normative Reference Values for Handgrip Strength in Chilean Children at 8–12 Years Old Using the Empirical Distribution and the Lambda, Mu, and Sigma Statistical Methods.” *Journal of Strength and Conditioning Research* 35, no. 1: 260–266. <https://doi.org/10.1519/jsc.0000000000002631>.
- Garnett, R. A., M. J. O'Donovan, J. A. Stephens, and A. Taylor. 1979. “Motor Unit Organization of Human Medial Gastrocnemius.” *Journal of Physiology* 287: 33–43. <https://doi.org/10.1113/jphysiol.1979.sp012643>.
- Garnett, S. P., W. Högler, B. Blades, et al. 2004. “Relation Between Hormones and Body Composition, Including Bone, in Prepubertal Children.” *American Journal of Clinical Nutrition* 80, no. 4: 966–972. <https://doi.org/10.1093/ajcn/80.4.966>.
- Gillen, Z. M., T. J. Housh, R. J. Schmidt, et al. 2021. “Comparisons of Muscle Strength, Size, and Voluntary Activation in Pre- and Post-Pubescent Males and Females.” *European Journal of Applied Physiology* 121, no. 9: 2487–2497. <https://doi.org/10.1007/s00421-021-04717-1>.
- Gisladdottir, T., P. Galan-Lopez, R. Francis, and M. Petrović. 2023. “The Relationship Between Motor Competence, Body Composition, Handgrip Strength and Sports Composition, Handgrip Strength and Sports Participation Among Icelandic Adolescents.” *Collegium Antropologicum* 47: 197–205.
- Glenmark, B., G. Hedberg, and E. Jansson. 1992. “Changes in Muscle Fibre Type From Adolescence to Adulthood in Women and Men.” *Acta Physiologica Scandinavica* 146, no. 2: 251–259. <https://doi.org/10.1111/j.1748-1716.1992.tb09414.x>.
- Godoy-Cumillaf, A., J. Bruneau-Chávez, P. Fuentes-Merino, et al. 2020. “Reference Values for Fitness Level and Gross Motor Skills of 4–6-Year-Old Chilean Children.” *International Journal of Environmental Research and Public Health* 17, no. 3: 797. <https://doi.org/10.3390/ijerph17030797>.
- Godoy-Cumillaf, A., P. Fuentes-Merino, C. Fariás-Valenzuela, et al. 2023. “The Association Between Sedentary Behavior, Physical Activity, and Physical Fitness With Body Mass Index and Sleep Time in Chilean Girls and Boys: A Cross-Sectional Study.” *Children* 10, no. 6: 981. <https://doi.org/10.3390/children10060981>.
- Gómez-Bruton, A., J. Marín-Puyalto, B. Muñoz-Pardos, et al. 2020. “Association Between Physical Fitness and Bone Strength and Structure in 3- to 5-Year-Old Children.” *Sports Health* 12, no. 5: 431–440. <https://doi.org/10.1177/1941738120913645>.
- Gómez-Campos, R., C. L. Andruske, M. de Arruda, et al. 2018. “Normative Data for Handgrip Strength in Children and Adolescents in the Maule Region, Chile: Evaluation Based on Chronological and Biological Age.” *PLoS One* 13, no. 8: e0201033. <https://doi.org/10.1371/journal.pone.0201033>.
- Gomula, A., and S. Koziel. 2018. “Secular Trend and Social Variation in Age at Menarche Among Polish Schoolgirls Before and After the Political Transformation.” *American Journal of Human Biology* 30, no. 1: e23048. <https://doi.org/10.1002/ajhb.23048>.
- Gontarev, S., R. Kalac, L. A. Velickovska, and V. Zivkovic. 2018. “Physical Fitness Reference Standards in Macedonian Children and Adolescents: The MAKFIT Study.” *Nutricion Hospitalaria* 35, no. 6: 1275–1286. (Estándares de referencia de aptitud física en niños y adolescentes de Macedonia: el estudio MAKFIT.). <https://doi.org/10.20960/nh.1881>.
- Greenhalgh, T., and R. Peacock. 2005. “Effectiveness and Efficiency of Search Methods in Systematic Reviews of Complex Evidence: Audit of Primary Sources.” *British Medical Journal* 331, no. 7524: 1064–1065. <https://doi.org/10.1136/bmj.38636.593461.68>.
- Gulías-González, R., M. Sánchez-López, Á. Olivas-Bravo, M. Solera-Martínez, and V. Martínez-Vizcaíno. 2014. “Physical Fitness in Spanish Schoolchildren Aged 6–12 Years: Reference Values of the Battery EUROFIT and Associated Cardiovascular Risk.” *Journal of School Health* 84, no. 10: 625–635. <https://doi.org/10.1111/josh.12192>.
- Guthold, R., G. A. Stevens, L. M. Riley, and F. C. Bull. 2020. “Global Trends in Insufficient Physical Activity Among Adolescents: A Pooled Analysis of 298 Population-Based Surveys With 1.6 Million Participants.” *Lancet Child & Adolescent Health* 4, no. 1: 23–35. [https://doi.org/10.1016/s2352-4642\(19\)30323-2](https://doi.org/10.1016/s2352-4642(19)30323-2).
- Haapala, E. A., J. Väistö, N. Lintu, et al. 2016. “Adiposity, Physical Activity and Neuromuscular Performance in Children.” *Journal of Sports Sciences* 34, no. 18: 1699–1706. <https://doi.org/10.1080/02640414.2015.1134805>.
- Häger-Ross, C., and B. Rösblad. 2002. “Norms for Grip Strength in Children Aged 4–16 Years.” *Acta Paediatrica* 91, no. 6: 617–625. <https://doi.org/10.1080/080352502760068990>.
- Hamilton, B., A. Brown, S. Montagner-Moraes, et al. 2024. “Strength, Power and Aerobic Capacity of Transgender Athletes: A Cross-Sectional Study.” *British Journal of Sports Medicine* 58, no. 11: 586–597. <https://doi.org/10.1136/bjsports-2023-108029>.
- Handelsman, D. J., A. L. Hirschberg, and S. Berman. 2018. “Circulating Testosterone as the Hormonal Basis of Sex Differences in Athletic Performance.” *Endocrine Reviews* 39, no. 5: 803–829. <https://doi.org/10.1210/er.2018-00020>.
- Haugland, E. S., A. K. O. Nilsen, A. D. Okely, K. N. Aadland, and E. Aadland. 2023. “Multivariate Physical Activity Association Patterns for Fundamental Motor Skills and Physical Fitness in Preschool Children Aged 3–5 Years.” *Journal of Sports Sciences* 41, no. 7: 654–667. <https://doi.org/10.1080/02640414.2023.2232219>.
- He, H., L. Pan, J. Du, et al. 2019. “Muscle Fitness and Its Association With Body Mass Index in Children and Adolescents Aged 7–18 Years in China: A Cross-Sectional Study.” *BMC Pediatrics* 19, no. 1: 101. <https://doi.org/10.1186/s12887-019-1477-8>.
- He, H., L. Pan, D. Wang, et al. 2023. “Normative Values of Hand Grip Strength in a Large Unselected Chinese Population: Evidence From the China National Health Survey.” *Journal of Cachexia, Sarcopenia and Muscle* 14, no. 3: 1312–1321. <https://doi.org/10.1002/jcsm.13223>.
- He, Q., M. Horlick, J. Thornton, et al. 2002. “Sex and Race Differences in Fat Distribution Among Asian, African-American, and Caucasian Prepubertal Children.” *Journal of Clinical Endocrinology and Metabolism* 87, no. 5: 2164–2170. <https://doi.org/10.1210/jcem.87.5.8452>.
- Henriksson, P., C. Cadenas-Sanchez, M. Leppänen, et al. 2016. “Associations of Fat Mass and Fat-Free Mass With Physical Fitness in 4-Year-Old Children: Results From the MINISTOP Trial.” *Nutrients* 8, no. 8: 473. <https://doi.org/10.3390/nu8080473>.
- Hepping, A. M., J. J. W. Ploegmakers, J. H. B. Geertzen, S. K. Bulstra, and M. Stevens. 2015. “The Influence of Hand Preference on Grip Strength in Children and Adolescents; a Cross-Sectional Study of 2284 Children and Adolescents.” *PLoS One* 10, no. 11: e0143476. <https://doi.org/10.1371/journal.pone.0143476>.
- Herráez, A., M. D. Marrodán, and M. González-Montero de Espinosa. 2022. “Hand Grip Strength in Boys and Girls From Summer School

- Camps in Spain, 1900–1925. A Comparison With 21st Century Data.” *American Journal of Human Biology* 34, no. 4: e23681. <https://doi.org/10.1002/ajhb.23681>.
- Herrmann, D., C. Buck, I. Sioen, et al. 2015. “Impact of Physical Activity, Sedentary Behaviour and Muscle Strength on Bone Stiffness in 2–10-Year-Old Children-Cross-Sectional Results From the IDEFICS Study.” *International Journal of Behavioral Nutrition and Physical Activity* 12, no. 1: 112. <https://doi.org/10.1186/s12966-015-0273-6>.
- Hilton, E. N., and T. R. Lundberg. 2021. “Transgender Women in the Female Category of Sport: Perspectives on Testosterone Suppression and Performance Advantage.” *Sports Medicine* 51, no. 2: 199–214. <https://doi.org/10.1007/s40279-020-01389-3>.
- Hirao, A., S. Murata, A. Kubo, M. Hachiya, N. Mitsumaru, and T. Asami. 2015. “Association Between Occlusal Force and Physical Functions in Preschool Children: A Comparison of Males and Females.” *Journal of Physical Therapy Science* 27, no. 12: 3729–3732. <https://doi.org/10.1589/jpts.27.3729>.
- Hoekstra, T., C. A. Boreham, L. J. Murray, and J. W. R. Twisk. 2008. “Associations Between Aerobic and Muscular Fitness and Cardiovascular Disease Risk: The Northern Ireland Young Hearts Study.” *Journal of Physical Activity and Health* 5, no. 6: 815–829. <https://doi.org/10.1123/jpah.5.6.815>.
- Hogrel, J.-Y., V. Decostre, C. Alberti, et al. 2012. “Stature Is an Essential Predictor of Muscle Strength in Children.” *BMC Musculoskeletal Disorders* 13, no. 1: 176. <https://doi.org/10.1186/1471-2474-13-176>.
- Holm, I., P. Fredriksen, M. Fosdahl, and N. Vøllestad. 2008. “A Normative Sample of Isotonic and Isokinetic Muscle Strength Measurements in Children 7 to 12 Years of Age.” *Acta Paediatrica* 97, no. 5: 602–607. <https://doi.org/10.1111/j.1651-2227.2008.00709.x>.
- Hunter, S. K., S. A. Angadi, A. Bhargava, et al. 2023. “The Biological Basis of Sex Differences in Athletic Performance: Consensus Statement for the American College of Sports Medicine.” *Medicine and Science in Sports and Exercise* 55, no. 12: 2328–2360. <https://doi.org/10.1249/mss.0000000000003300>.
- Hunter, S. K., and J. W. Senefeld. 2024. “Sex Differences in Human Performance.” *Journal of Physiology* 602, no. 17: 4129–4156. <https://doi.org/10.1113/jp284198>.
- Ignasiak, Z., T. Sławińska, and R. M. Malina. 2016. “Short Term Secular Change in Body Size and Physical Fitness of Youth 7–15 Years in Southwestern Poland: 2001–2002 and 2010–2011.” *Anthropological Review* 79, no. 3: 311–329. <https://doi.org/10.1515/anre-2016-0023>.
- Isaacs, L. D., and S. D. Frederick. 1985. “Response Time and Grip Strength as Possible Factors Affecting Children's Catching Performance.” *Perceptual and Motor Skills* 61, no. 2: 627–630. <https://doi.org/10.2466/pms.1985.61.2.627>.
- Isen, J., M. McGue, and W. Iacono. 2014. “Genetic Influences on the Development of Grip Strength in Adolescence.” *American Journal of Physical Anthropology* 154, no. 2: 189–200. <https://doi.org/10.1002/ajpa.22492>.
- Jacklin, C. N., E. E. Maccoby, C. H. Doering, and D. R. King. 1984. “Neonatal Sex-Steroid Hormones and Muscular Strength of Boys and Girls in the First Three Years.” *Developmental Psychobiology* 17, no. 3: 301–310. <https://doi.org/10.1002/dev.420170309>.
- Jacklin, C. N., M. E. Snow, and E. E. Maccoby. 1981. “Tactile Sensitivity and Muscle Strength in Newborn Boys and Girls.” *Infant Behavior and Development* 4: 261–268. [https://doi.org/10.1016/S0163-6383\(81\)80028-8](https://doi.org/10.1016/S0163-6383(81)80028-8).
- Jansson, E., and G. Hedberg. 1991. “Skeletal Muscle Fibre Types in Teenagers: Relationship to Physical Performance and Activity.” *Scandinavian Journal of Medicine and Science in Sports* 1: 31–44. <https://doi.org/10.1111/j.1600-0838.1991.tb00268.x>.
- Jürimäe, T., T. Hurbo, and J. Jürimäe. 2009. “Relationship of Handgrip Strength With Anthropometric and Body Composition Variables in Prepubertal Children.” *Homo* 60, no. 3: 225–238. <https://doi.org/10.1016/j.jchb.2008.05.004>.
- Jürimäe, T., and M. Saar. 2003. “Self-Perceived and Actual Indicators of Motor Abilities in Children and Adolescents.” *Perceptual and Motor Skills* 97, no. 3 Pt. 1: 862–866. <https://doi.org/10.2466/pms.2003.97.3.862>.
- Jürimäe, T., and V. Volbekiene. 1998. “Eurofit Test Results in Estonian and Lithuanian 11 to 17-Year-Old Children: A Comparative Study.” *European Journal of Physical Education* 3, no. 2: 178–184. <https://doi.org/10.1080/1740898980030206>.
- Katzmarzyk, P. T., R. M. Malina, and G. P. Beunen. 1997. “The Contribution of Biological Maturation to the Strength and Motor Fitness of Children.” *Annals of Human Biology* 24, no. 6: 493–505. <https://doi.org/10.1080/03014469700005262>.
- Katzmarzyk, P. T., L. Pérusse, D. C. Rao, and C. Bouchard. 2000. “Familial Risk Ratios for High and Low Physical Fitness Levels in the Canadian Population.” *Medicine and Science in Sports and Exercise* 32, no. 3: 614–619. <https://doi.org/10.1097/00005768-200003000-00010>.
- Ke, D., D. Wang, H. Huang, et al. 2022. “Study of the Reliability of Field Test Methods for Physical Fitness in Children Aged 2–3 Years.” *International Journal of Environmental Research and Public Health* 19, no. 12: 7522. <https://doi.org/10.3390/ijerph19127522>.
- Kenjle, K., S. Limaye, P. S. Ghugre, and S. A. Udiipi. 2005. “Grip Strength as an Index for Assessment of Nutritional Status of Children Aged 6–10 Years.” *Journal of Nutritional Science and Vitaminology* 51, no. 2: 87–92. <https://doi.org/10.3177/jnsv.51.87>.
- Khairullah, A., L. Cousino Klein, S. M. Ingle, et al. 2014. “Testosterone Trajectories and Reference Ranges in a Large Longitudinal Sample of Male Adolescents.” *PLoS One* 9, no. 9: e108838. <https://doi.org/10.1371/journal.pone.0108838>.
- Kidokoro, T., and K. Edamoto. 2021. “Improvements in Physical Fitness Are Associated With Favorable Changes in Blood Lipid Concentrations in Children.” *Journal of Sports Science and Medicine* 20, no. 3: 404–412. <https://doi.org/10.52082/jssm.2021.404>.
- Kidokoro, T., H. Tanaka, K. Naoi, et al. 2016. “Sex-Specific Associations of Moderate and Vigorous Physical Activity With Physical Fitness in Adolescents.” *European Journal of Sport Science* 16, no. 8: 1159–1166. <https://doi.org/10.1080/17461391.2016.1183050>.
- Kiviranta, P., T. Kuiri-Hänninen, A. Saari, M.-L. Lamidi, L. Dunkel, and U. Sankilampi. 2016. “Transient Postnatal Gonadal Activation and Growth Velocity in Infancy.” *Pediatrics* 138, no. 1: e20153561. <https://doi.org/10.1542/peds.2015-3561>.
- Köble, K., T. Postler, R. Oberhoffer-Fritz, and T. Schulz. 2022. “A Better Cardiopulmonary Fitness Is Associated With Improved Concentration Level and Health-Related Quality of Life in Primary School Children.” *Journal of Clinical Medicine* 11, no. 5: 1326. <https://doi.org/10.3390/jcm11051326>.
- Kocher, M. H., Y. Oba, I. F. Kimura, C. D. Stickley, C. F. Morgan, and R. K. Hetzler. 2019. “Allometric Grip Strength Norms for American Children.” *Journal of Strength and Conditioning Research* 33, no. 8: 2251–2261. <https://doi.org/10.1519/jsc.0000000000002515>.
- Kocher, M. H., R. K. Romine, C. D. Stickley, C. F. Morgan, P. B. Resnick, and R. K. Hetzler. 2017. “Allometric Grip Strength Norms for Children of Hawaiian Lineage.” *Journal of Strength and Conditioning Research* 31, no. 10: 2794–2807. <https://doi.org/10.1519/jsc.0000000000001711>.
- Kozielec, S., Z. Ignasiak, and E. Żądzińska. 2019. “Exposure to Parental Smoking During Pregnancy and Handgrip Strength in 7–10-Year Old Children.” *Early Human Development* 134: 7–11. <https://doi.org/10.1016/j.earlhumdev.2019.04.013>.
- Krammel, M., S. Schnaubelt, D. Weidenauer, et al. 2018. “Gender and Age-Specific Aspects of Awareness and Knowledge in Basic Life Support.” *PLoS One* 13, no. 6: e0198918. <https://doi.org/10.1371/journal.pone.0198918>.



- Krivickas, L. S., D. Suh, J. Wilkins, V. A. Hughes, R. Roubenoff, and W. R. Frontera. 2001. "Age- and Gender-Related Differences in Maximum Shortening Velocity of Skeletal Muscle Fibers." *American Journal of Physical Medicine and Rehabilitation* 80, no. 6: 447–455. <https://doi.org/10.1097/00002060-200106000-00012>.
- Kryst, Ł., M. Żegleń, P. Artymiak, M. Kowal, and A. Woronkiewicz. 2023. "Analysis of Secular Trends in Physical Fitness of Children and Adolescents (8–18 Years) From Kraków (Poland) Between 2010 and 2020." *American Journal of Human Biology* 35, no. 3: e23829. <https://doi.org/10.1002/ajhb.23829>.
- Kuczumski, R. J., C. L. Ogden, and S. S. Guo. 2002. *2000 CDC Growth Charts for the United States: Methods and Development*. Vital Health Statistics 11, No. 246. Hyattsville, MD, USA: National Center for Health Statistics.
- Kuijper, E., J. Ket, M. R. Caanen, and C. B. Lambalk. 2013. "Reproductive Hormone Concentrations in Pregnancy and Neonates: A Systematic Review." *Reproductive BioMedicine Online* 27, no. 1: 33–63. <https://doi.org/10.1016/j.rbmo.2013.03.009>.
- Lakens, D. 2013. "Calculating and Reporting Effect Sizes to Facilitate Cumulative Science: A Practical Primer for T-Tests and ANOVAs." *Frontiers in Psychology* 4: 863. <https://doi.org/10.3389/fpsyg.2013.00863>.
- Latorre Román, P. Á., D. M. López, B. B. Aguayo, A. R. Fuentes, F. García-Pinillos, and M. M. Redondo. 2017. "Handgrip Strength Is Associated With Anthropometrics Variables and Sex in Preschool Children: A Cross Sectional Study Providing Reference Values." *Physical Therapy in Sport* 26: 1–6. <https://doi.org/10.1016/j.ptsp.2017.04.002>.
- Legarra-Gorgoñon, G., Y. García-Alonso, R. Ramírez-Vélez, B. Erice-Echegaray, M. Izquierdo, and A. M. Alonso-Martínez. 2023. "Associations Between Basic Motor Competencies and Physical Fitness in Spanish Pre-Schoolers: A Cross-Sectional Study." *Italian Journal of Pediatrics* 49, no. 1: 97. <https://doi.org/10.1186/s13052-023-01504-w>.
- Lei, Y., D. Luo, X. Yan, et al. 2021. "The Mean Age of Menarche Among Chinese Schoolgirls Declined by 6 Months From 2005 to 2014." *Acta Paediatrica* 110, no. 2: 549–555. <https://doi.org/10.1111/apa.15441>.
- Leppänen, M. H., P. Henriksson, C. Delisle Nyström, et al. 2017. "Longitudinal Physical Activity, Body Composition, and Physical Fitness in Preschoolers." *Medicine and Science in Sports and Exercise* 49, no. 10: 2078–2085. <https://doi.org/10.1249/mss.0000000000001313>.
- Leppänen, M. H., C. D. Nyström, P. Henriksson, et al. 2016. "Physical Activity Intensity, Sedentary Behavior, Body Composition and Physical Fitness in 4-Year-Old Children: Results From the Ministop Trial." *International Journal of Obesity* 40, no. 7: 1126–1133. <https://doi.org/10.1038/ijo.2016.54>.
- Li, S., R. Zhang, G. Pan, L. Zheng, and C. Li. 2018. "Handgrip Strength Is Associated With Insulin Resistance and Glucose Metabolism in Adolescents: Evidence From National Health and Nutrition Examination Survey 2011 to 2014." *Pediatric Diabetes* 19, no. 3: 375–380. <https://doi.org/10.1111/pedi.12596>.
- Linderholm, H., B. Lindqvist, M. Ringqvist, and A. Wennström. 1971. "Isometric Bite Force in Children and Its Relation to Body Build and General Muscle Force." *Acta Odontologica Scandinavica* 29, no. 5: 563–568. <https://doi.org/10.3109/00016357109026334>.
- Lintu, N., K. Savonen, A. Viitasalo, et al. 2016. "Determinants of Cardiorespiratory Fitness in a Population Sample of Girls and Boys Aged 6 to 8 Years." *Journal of Physical Activity and Health* 13, no. 11: 1149–1155. <https://doi.org/10.1123/jpah.2015-0644>.
- Lirgg, C. D., R. Dibrezzo, M. Gray, and T. Esslinger. 2011. "The Effect of Climbing Wall Use on the Grip Strength of Fourth-Grade Students." *Research Quarterly for Exercise and Sport* 82, no. 2: 350–354. <https://doi.org/10.1080/02701367.2011.10599763>.
- Little, M. A. 2017. "Grip Strength and Body Composition in Turkana Pastoralist Children and Adolescents." *American Journal of Human Biology* 29, no. 2: e22922. <https://doi.org/10.1002/ajhb.22922>.
- Lundberg, T. R., R. Tucker, K. McGawley, et al. 2024. "The International Olympic Committee Framework on Fairness, Inclusion and Nondiscrimination on the Basis of Gender Identity and Sex Variations Does Not Protect Fairness for Female Athletes." *Scandinavian Journal of Medicine and Science in Sports* 34, no. 3: e14581. <https://doi.org/10.1111/sms.14581>.
- Luz, C., R. Cordovil, G. Almeida, and L. Rodrigues. 2017. "Link Between Motor Competence and Health Related Fitness in Children and Adolescents." *Sports* 5, no. 2: 41. <https://doi.org/10.3390/sports5020041>.
- Mačak, D., B. Popović, N. Babić, C. Cadenas-Sanchez, D. M. Madić, and N. Trajković. 2022. "The Effects of Daily Physical Activity Intervention on Physical Fitness in Preschool Children." *Journal of Sports Sciences* 40, no. 2: 146–155. <https://doi.org/10.1080/02640414.2021.1978250>.
- Malina, R. M., M. E. P. Reyes, S. K. Tan, and B. B. Little. 2010. "Secular Change in Muscular Strength of Indigenous Rural Youth 6–17 Years in Oaxaca, Southern Mexico: 1968–2000." *Annals of Human Biology* 37, no. 2: 168–184. <https://doi.org/10.3109/03014460903325193>.
- Manzano-Carrasco, S., J. Garcia-Unanue, J. Lopez-Fernandez, et al. 2022. "Differences in Body Composition and Physical Fitness Parameters Among Prepubertal and Pubertal Children Engaged in Extracurricular Sports: The Active Health Study." Supplement, *European Journal of Public Health* 32, no. S1: i67–i72. <https://doi.org/10.1093/eurpub/ckac075>.
- Martinez-Tellez, B., G. Sanchez-Delgado, C. Cadenas-Sanchez, et al. 2016. "Health-Related Physical Fitness Is Associated With Total and Central Body Fat in Preschool Children Aged 3 to 5 Years." *Pediatric Obesity* 11, no. 6: 468–474. <https://doi.org/10.1111/ijpo.12088>.
- Mathiowetz, V., D. M. Wiemer, and S. M. Federman. 1986. "Grip and Pinch Strength: Norms for 6- to 19-Year-Olds." *American Journal of Occupational Therapy* 40, no. 10: 705–711. <https://doi.org/10.5014/ajot.40.10.705>.
- Mathisen, F. K. S., S. Kokko, J. Tynjälä, T. Torsheim, and B. Wold. 2019. "Leisure-Time Physical Activity and Participation in Organized Sports: Changes From 1985 to 2014 in Finland and Norway." *Scandinavian Journal of Medicine and Science in Sports* 29, no. 8: 1232–1242. <https://doi.org/10.1111/sms.13431>.
- Mayorga, D., J. Viciania, and A. Cocca. 2012. "Relationship Between Physical Self-Concept and Health-Related Physical Fitness in Spanish Schoolchildren." *Procedia - Social and Behavioral Sciences* 69: 659–668. <https://doi.org/10.1016/j.sbspro.2012.11.458>.
- McCarthy, H. D., D. Samani-Radia, S. A. Jebb, and A. M. Prentice. 2014. "Skeletal Muscle Mass Reference Curves for Children and Adolescents." *Pediatric Obesity* 9, no. 4: 249–259. <https://doi.org/10.1111/j.2047-6310.2013.00168.x>.
- McQuiddy, V. A., C. R. Scheerer, R. Lavalley, T. McGrath, and L. Lin. 2015. "Normative Values for Grip and Pinch Strength for 6- to 19-Year-Olds." *Archives of Physical Medicine and Rehabilitation* 96, no. 9: 1627–1633. <https://doi.org/10.1016/j.apmr.2015.03.018>.
- Meijer, J. P., R. T. Jaspers, J. Rittweger, et al. 2015. "Single Muscle Fibre Contractile Properties Differ Between Body-Builders, Power Athletes and Control Subjects." *Experimental Physiology* 100, no. 11: 1331–1341. <https://doi.org/10.1113/ep085267>.
- Merino-De Haro, I., J. Mora-Gonzalez, C. Cadenas-Sanchez, et al. 2019. "Higher Socioeconomic Status Is Related to Healthier Levels of Fatness and Fitness Already at 3 to 5 Years of Age: The PREFIT Project." *Journal of Sports Sciences* 37, no. 12: 1327–1337. <https://doi.org/10.1080/02640414.2018.1558509>.
- Molenaar, H. M. T., R. W. Selles, M. J. Zuidam, S. P. Willemsen, H. J. Stam, and S. E. R. Hovius. 2010. "Growth Diagrams for Grip Strength in Children." *Clinical Orthopaedics and Related Research* 468, no. 1: 217–223. <https://doi.org/10.1007/s11999-009-0881-z>.
- Montalcini, T., Y. Ferro, M. A. Salvati, S. Romeo, R. Miniero, and A. Pujia. 2016. "Gender Difference in Handgrip Strength of Italian

- Children Aged 9 to 10 Years." *Italian Journal of Pediatrics* 42, no. 1: 16. <https://doi.org/10.1186/s13052-016-0226-y>.
- Montoye, H. J., and D. E. Lamphiear. 1977. "Grip and Arm Strength in Males and Females, Age 10 to 69." *Research Quarterly* 48, no. 1: 109–120. <https://doi.org/10.1080/10671315.1977.10762158>.
- Montpetit, R. R., H. J. Montoye, and L. Laeding. 1967. "Grip Strength of School Children, Saginaw, Michigan: 1899 and 1964." *Research Quarterly* 38, no. 2: 231–240. <https://doi.org/10.1080/10671188.1967.10613384>.
- Morita, N., J. Yamauchi, R. Fukuoka, et al. 2018. "Non-Linear Growth Trends of Toe Flexor Muscle Strength Among Children, Adolescents, and Young Adults: A Cross-Sectional Study." *European Journal of Applied Physiology* 118, no. 5: 1003–1010. <https://doi.org/10.1007/s00421-018-3827-x>.
- Murase, T., H. Kinoshita, K. Ikuta, S. Kawai, and T. Asami. 1996. "Discrimination of Grip Force for Preschool Children Aged 5 to 6 Years." *Perceptual and Motor Skills* 82, no. 1: 255–263. <https://doi.org/10.2466/pms.1996.82.1.255>.
- Müürsepp, I., J. Ereline, H. Gapeyeva, and M. Pääsuke. 2009. "Motor Performance in 5-Year-Old Preschool Children With Developmental Speech and Language Disorders." *Acta Paediatrica* 98, no. 8: 1334–1338. <https://doi.org/10.1111/j.1651-2227.2009.01294.x>.
- Naka, H., M. Iki, A. Morita, and Y. Ikeda. 2005. "Effects of Pubertal Development, Height, Weight, and Grip Strength on the Bone Mineral Density of the Lumbar Spine and Hip in Peripubertal Japanese Children: Kyoto Kids Increase Density in the Skeleton Study (Kyoto KIDS Study)." *Journal of Bone and Mineral Metabolism* 23, no. 6: 463–469. <https://doi.org/10.1007/s00774-005-0629-0>.
- Nara, K., P. Kumar, R. Kumar, and S. D. Singh. 2023. "Normative Reference Values of Grip Strength, the Prevalence of Low Grip Strength, and Factors Affecting Grip Strength Values in Indian Adolescents." *Journal of Physical Education and Sport* 23, no. 6: 1367–1375.
- Nelson, D. A., and D. A. Barondess. 1997. "Whole Body Bone, Fat and Lean Mass in Children: Comparison of Three Ethnic Groups." *American Journal of Physical Anthropology* 103, no. 2: 157–162. [https://doi.org/10.1002/\(sici\)1096-8644\(199706\)103:2<157::Aid-ajpa2>3.0.Co;2-r](https://doi.org/10.1002/(sici)1096-8644(199706)103:2<157::Aid-ajpa2>3.0.Co;2-r).
- Neu, C. M., F. Rauch, J. Rittweger, F. Manz, and E. Schoenau. 2002. "Influence of Puberty on Muscle Development at the Forearm." *American Journal of Physiology. Endocrinology and Metabolism* 283, no. 1: E103–E107. <https://doi.org/10.1152/ajpendo.00445.2001>.
- Ng, A. K., N. N. Hairi, M. Dahlui, T. T. Su, M. Y. Jalaludin, and H. Abdul Majid. 2020. "The Longitudinal Relationship Between Dietary Intake, Physical Activity and Muscle Strength Among Adolescents." *British Journal of Nutrition* 124, no. 11: 1207–1218. <https://doi.org/10.1017/S0007114520002202>.
- Niempoog, S., Y. Siripakarn, and T. Suntharapa. 2007. "An Estimation of Grip Strength During Puberty." *Journal of the Medical Association of Thailand* 90, no. 4: 699–705.
- Nieto-López, M., M. Sánchez-López, M. E. Visier-Alfonso, V. Martínez-Vizcaino, E. Jiménez-López, and C. Álvarez-Bueno. 2020. "Relation Between Physical Fitness and Executive Function Variables in a Pre-school Sample." *Pediatric Research* 88, no. 4: 623–628. <https://doi.org/10.1038/s41390-020-0791-z>.
- Nokoff, N. J., J. Senefeld, C. Krausz, S. Hunter, and M. Joyner. 2023. "Sex Differences in Athletic Performance: Perspectives on Transgender Athletes." *Exercise and Sport Sciences Reviews* 51, no. 3: 85–95. <https://doi.org/10.1249/jes.0000000000000317>.
- Nuzzo, J. L. 2023a. "Narrative Review of Sex Differences in Muscle Strength, Endurance, Activation, Size, Fiber Type, and Strength Training Participation Rates, Preferences, Motivations, Injuries, and Neuromuscular Adaptations." *Journal of Strength and Conditioning Research* 37, no. 2: 494–536. <https://doi.org/10.1519/jsc.00000000000004329>.
- Nuzzo, J. L. 2023b. "Sex Differences in Skeletal Muscle Fiber Types: A Meta-Analysis." *Clinical Anatomy* 37, no. 1: 81–91. <https://doi.org/10.1002/ca.24091>.
- Nuzzo, J. L., M. D. Pinto, and K. Nosaka. 2023. "Muscle Fatigue During Maximal Eccentric-Only, Concentric-Only, and Eccentric-Concentric Bicep Curl Exercise With Automated Drop Setting." *Scandinavian Journal of Medicine and Science in Sports* 33, no. 6: 857–871. <https://doi.org/10.1111/sms.14330>.
- Nuzzo, J. L., M. D. Pinto, K. Nosaka, and J. Steele. 2023. "The Eccentric: Concentric Strength Ratio of Human Skeletal Muscle *In Vivo*: Meta-Analysis of the Influences of Sex, Age, Joint Action, and Velocity." *Sports Medicine* 53, no. 6: 1125–1136. <https://doi.org/10.1007/s40279-023-01851-y>.
- Nuzzo, J. L., M. D. Pinto, K. Nosaka, and J. Steele. 2024. "Maximal Number of Repetitions at Percentages of the One Repetition Maximum: A Meta-Regression and Moderator Analysis of Sex, Age, Training Status, and Exercise." *Sports Medicine* 54, no. 2: 303–321. <https://doi.org/10.1007/s40279-023-01937-7>.
- Nuzzo, J. L., J. L. Taylor, and S. C. Gandevia. 2019. "CORP: Measurement of Upper and Lower Limb Muscle Strength and Voluntary Activation." *Journal of Applied Physiology* 126, no. 3: 513–543. <https://doi.org/10.1152/japplphysiol.00569.2018>.
- O'Brien, T. D., N. D. Reeves, V. Baltzopoulos, D. A. Jones, and C. N. Maganaris. 2009. "The Effects of Agonist and Antagonist Muscle Activation on the Knee Extension Moment-Angle Relationship in Adults and Children." *European Journal of Applied Physiology* 106, no. 6: 849–856. <https://doi.org/10.1007/s00421-009-1088-4>.
- O'Brien, T. D., N. D. Reeves, V. Baltzopoulos, D. A. Jones, and C. N. Maganaris. 2010. "In Vivo Measurements of Muscle Specific Tension in Adults and Children." *Experimental Physiology* 95, no. 1: 202–210. <https://doi.org/10.1113/expphysiol.2009.048967>.
- Oja, L., and T. Jürimäe. 2002. "Physical Activity, Motor Ability, and School Readiness of 6-Yr.-Old Children." *Perceptual and Motor Skills* 95, no. 2: 407–415. <https://doi.org/10.2466/pms.2002.95.2.407>.
- O'Keeffe, B. T., C. MacDonncha, H. Purtill, and A. E. Donnelly. 2020. "Profiling the Health-Related Physical Fitness of Irish Adolescents: A School-Level Sociodemographic Divide." *PLoS One* 15, no. 6: e0235293. <https://doi.org/10.1371/journal.pone.0235293>.
- Omar, M. T. A., A. Alghadir, and S. Al Baker. 2015. "Norms for Hand Grip Strength in Children Aged 6-12 Years in Saudi Arabia." *Developmental Neurorehabilitation* 18, no. 1: 59–64. <https://doi.org/10.3109/17518423.2014.967878>.
- Örjan, E., O. Kristjan, and E. Björn. 2005. "Physical Performance and Body Mass Index in Swedish Children and Adolescents." *Scandinavian Journal of Nutrition* 49, no. 4: 172–179. <https://doi.org/10.1080/11026480500441275>.
- Ortega, F. B., J. R. Ruiz, M. J. Castillo, et al. 2008. "Health-Related Physical Fitness According to Chronological and Biological Age in Adolescents. The AVENA Study." *Journal of Sports Medicine and Physical Fitness* 48, no. 3: 371–379.
- Ozaki, H., T. Abe, S. J. Dankel, et al. 2020. "The Measurement of Strength in Children: Is the Peak Value Truly Maximal?" *Children* 8, no. 1: 9. <https://doi.org/10.3390/children8010009>.
- Page, M. J., J. E. McKenzie, P. M. Bossuyt, et al. 2021. "The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews." *British Medical Journal* 372: n71. <https://doi.org/10.1136/bmj.n71>.
- Page, M. J., L. Shamseer, and A. C. Tricco. 2018. "Registration of Systematic Reviews in PROSPERO: 30,000 Records and Counting." *Systematic Reviews* 7, no. 1: 32. <https://doi.org/10.1186/s13643-018-0699-4>.



- Parízková, J., J. Cermák, and J. Horná. 1977. "Sex Differences in Somatic and Functional Characteristics of Preschool Children." *Human Biology* 49, no. 3: 437–451.
- Parker, D. F., J. M. Round, P. Sacco, and D. A. Jones. 1990. "A Cross-Sectional Survey of Upper and Lower Limb Strength in Boys and Girls During Childhood and Adolescence." *Annals of Human Biology* 17, no. 3: 199–211. <https://doi.org/10.1080/03014469000000962>.
- Pavlović, R., M. Marko, Ö. Eken, N. Radulovic, and D. Badau. 2023. "Gender Differences in Hand Grip Strength of Children in Bosnia and Herzegovina Aged 11 to 14 Years. A Cross - Sectional Study." *Balneo and PRM Research Journal* 14, no. 4: 606. <https://doi.org/10.12680/balneo.2023.606>.
- Peek, K., K. R. Ford, G. D. Myer, T. E. Hewett, and E. Pappas. 2022. "Effect of Sex and Maturation on Knee Extensor and Flexor Strength in Adolescent Athletes." *American Journal of Sports Medicine* 50, no. 12: 3280–3285. <https://doi.org/10.1177/03635465221118081>.
- Perna, F. M., K. Coa, R. P. Troiano, et al. 2016. "Muscular Grip Strength Estimates of the U.S. Oopulation From the National Health and Nutrition Examination Survey 2011–2012." *Journal of Strength and Conditioning Research* 30, no. 3: 867–874. <https://doi.org/10.1519/jsc.0000000000001104>.
- Perry, A. C., L. M. Tremblay, J. F. Signorile, T. A. Kaplan, and P. C. Miller. 1997. "Fitness, Diet and Coronary Risk Factors in a Sample of Southeastern U.S. Children." *Applied Human Science* 16, no. 4: 133–141. <https://doi.org/10.2114/jpa.16.133>.
- Peterson, M. D., P. M. Gordon, S. Smeding, and P. Visich. 2018. "Grip Strength Is Associated With Longitudinal Health Maintenance and Improvement in Adolescents." *Journal of Pediatrics* 202: 226–230. <https://doi.org/10.1016/j.jpeds.2018.07.020>.
- Peterson, M. D., P. Zhang, W. A. Saltarelli, P. S. Visich, and P. M. Gordon. 2016. "Low Muscle Strength Thresholds for the Detection of Cardiometabolic Risk in Adolescents." *American Journal of Preventive Medicine* 50, no. 5: 593–599. <https://doi.org/10.1016/j.amepre.2015.09.019>.
- Ploegmakers, J. J. W., A. M. Hepping, J. H. B. Geertzen, S. K. Bulstra, and M. Stevens. 2013. "Grip Strength Is Strongly Associated With Height, Weight and Gender in Childhood: A Cross Sectional Study of 2241 Children and Adolescents Providing Reference Values." *Journal of Physiotherapy* 59, no. 4: 255–261. [https://doi.org/10.1016/s1836-9553\(13\)70202-9](https://doi.org/10.1016/s1836-9553(13)70202-9).
- Puszczalowska-Lizis, E., M. Kaźmierczak, J. Omorczyk, S. Lizis, R. Lenková, and K. Pieniędz. 2023. "Sex-Related Differences in the Physical Fitness of Adolescents Aged 16 to 18 Years." *Journal of Kinesiology and Exercise Sciences* 103, no. 33: 1–7. <https://doi.org/10.5604/01.3001.0053.7363>.
- Ramírez-Vélez, R., O. Morales, J. C. Peña-Ibagón, et al. 2017. "Normative Reference Values for Handgrip Strength in Colombian Schoolchildren: The FUPRECOL Study." *Journal of Strength and Conditioning Research* 31, no. 1: 217–226. <https://doi.org/10.1519/jsc.0000000000001459>.
- Ramos-Sepúlveda, J. A., R. Ramírez-Vélez, J. E. Correa-Bautista, M. Izquierdo, and A. García-Hermoso. 2016. "Physical Fitness and Anthropometric Normative Values Among Colombian-Indian Schoolchildren." *BMC Public Health* 16, no. 1: 962. <https://doi.org/10.1186/s12889-016-3652-2>.
- Richards, A. B., L. Klos, N. Swindell, et al. 2022. "Associations Between Swimming & Cycling Abilities and Fitness in 9–11 Year Old Boys and Girls." *Journal of Sports Sciences* 40, no. 6: 658–666. <https://doi.org/10.1080/02640414.2021.2013616>.
- Riddoch, C., J. M. Savage, N. Murphy, G. W. Cran, and C. Boreham. 1991. "Long Term Health Implications of Fitness and Physical Activity Patterns." *Archives of Disease in Childhood* 66, no. 12: 1426–1433. <https://doi.org/10.1136/adc.66.12.1426>.
- Rostamzadeh, S., M. Saremi, A. Abouhossein, S. Vosoughi, and J. F. M. Molenbroek. 2021. "Normative Data for Handgrip Strength in Iranian Healthy Children and Adolescents Aged 7–18 Years: Comparison With International Norms." *Italian Journal of Pediatrics* 47, no. 1: 164. <https://doi.org/10.1186/s13052-021-01113-5>.
- Round, J. M., D. A. Jones, J. W. Honour, and A. M. Nevill. 1999. "Hormonal Factors in the Development of Differences in Strength Between Boys and Girls During Adolescence: A Longitudinal Study." *Annals of Human Biology* 26, no. 1: 49–62. <https://doi.org/10.1080/030144699282976>.
- Ryu, J.-S., H. R. Chung, B. M. Meador, Y. Seo, and K.-O. Kim. 2021. "The Associations Between Physical Fitness, Complex vs Simple Movement, and Academic Achievement in a Cohort of Fourth Graders." *International Journal of Environmental Research and Public Health* 18, no. 5: 2293. <https://doi.org/10.3390/ijerph18052293>.
- Saczuk, J., A. Wasiluk, and A. Wilczewski. 2018. "Body Height and Age at Menarche of Girls From Eastern Poland in the Period of Political Transformation." *Anthropological Review* 81, no. 2: 130–145. <https://doi.org/10.2478/anre-2018-0010>.
- Sanchez-Delgado, G., C. Cadenas-Sanchez, J. Mora-Gonzalez, et al. 2015. "Assessment of Handgrip Strength in Preschool Children Aged 3 to 5 Years." *Journal of Hand Surgery, European Volume* 40, no. 9: 966–972. <https://doi.org/10.1177/1753193415592328>.
- Santos, C., S. Pereira, O. Vasconcelos, et al. 2023. "Secular Trends in Physical Fitness of Peruvian Children Living at High-Altitude." *International Journal of Environmental Research and Public Health* 20, no. 4: 3236. <https://doi.org/10.3390/ijerph20043236>.
- Sartorio, A., C. L. Lafortuna, S. Pogliaghi, and L. Trecate. 2002. "The Impact of Gender, Body Dimension and Body Composition on Hand-Grip Strength in Healthy Children." *Journal of Endocrinological Investigation* 25, no. 5: 431–435. <https://doi.org/10.1007/bf03344033>.
- Sasayama, K., and M. Adachi. 2019. "Tracking of Objective Physical Activity and Physical Fitness in Japanese Children." *BMC Research Notes* 12, no. 1: 252. <https://doi.org/10.1186/s13104-019-4288-y>.
- Sember, V., G. Jurak, G. Starc, and S. A. Morrison. 2022. "Can Primary School Mathematics Performance Be Predicted by Longitudinal Changes in Physical Fitness and Activity Indicators?" *Frontiers in Psychology* 13: 796838. <https://doi.org/10.3389/fpsyg.2022.796838>.
- Senefeld, J. W., and S. K. Hunter. 2024. "Hormonal Basis of Biological Sex Differences in Human Athletic Performance." *Endocrinology* 165, no. 5: bqae036. <https://doi.org/10.1210/endo/bqae036>.
- Siegel, J. A., D. N. Camaione, and T. G. Manfredi. 1989. "The Effects of Upper Body Resistance Training on Prepubescent Children." *Pediatric Exercise Science* 1, no. 2: 145–154. <https://doi.org/10.1123/pes.1.2.145>.
- Soininen, S., V. Sidoroff, V. Lindi, et al. 2018. "Body Fat Mass, Lean Body Mass and Associated Biomarkers as Determinants of Bone Mineral Density in Children 6–8years of Age - The Physical Activity and Nutrition in Children (PANIC) Study." *Bone* 108: 106–114. <https://doi.org/10.1016/j.bone.2018.01.003>.
- Sokołowski, B., and M. Chrzanowska. 2012. "Development of Selected Motor Skills in Boys and Girls in Relation to Their Rate of Maturation - A Longitudinal Study." *Human Movement* 13, no. 2: 132–138. <https://doi.org/10.2478/v10038-012-0014-5>.
- Spreeen, O., and W. H. Gaddes. 1969. "Developmental Norms for 15 Neuropsychological Tests Age 6 to 15." *Cortex* 5, no. 2: 170–191. [https://doi.org/10.1016/s0010-9452\(69\)80028-6](https://doi.org/10.1016/s0010-9452(69)80028-6).
- Steene-Johannessen, J., S. A. Anderssen, E. Kolle, and L. B. Andersen. 2009. "Low Muscle Fitness Is Associated With Metabolic Risk in Youth." *Medicine and Science in Sports and Exercise* 41, no. 7: 1361–1367. <https://doi.org/10.1249/MSS.0b013e31819aaae5>.
- Stevenson, B. 2007. "Title IX and the Evolution of High School Sports." *Contemporary Economic Policy* 25, no. 4: 486–505. <https://doi.org/10.1111/j.1465-7287.2007.00080.x>.

- Stienen, G. J., J. L. Kiers, R. Bottinelli, and C. Reggiani. 1996. "Myofibrillar ATPase Activity in Skinned Human Skeletal Muscle Fibres: Fibre Type and Temperature Dependence." *Journal of Physiology* 493, no. Pt. 2: 299–307. <https://doi.org/10.1113/jphysiol.1996.sp021384>.
- Stoet, G., and D. C. Geary. 2019. "A Simplified Approach to Measuring National Gender Inequality." *PLoS One* 14, no. 1: e0205349. <https://doi.org/10.1371/journal.pone.0205349>.
- Streckis, V., A. Skurvydas, and A. Ratkevicius. 2007. "Children Are More Susceptible to Central Fatigue Than Adults." *Muscle & Nerve* 36, no. 3: 357–363. <https://doi.org/10.1002/mus.20816>.
- Sunnegårdh, J., L. E. Bratteby, L. O. Nordesjö, and B. Nordgren. 1988. "Isometric and Isokinetic Muscle Strength, Anthropometry and Physical Activity in 8 and 13 Year Old Swedish Children." *European Journal of Applied Physiology and Occupational Physiology* 58, no. 3: 291–297. <https://doi.org/10.1007/bf00417265>.
- Tan, U., R. Ors, M. Kürkcüoğlu, and N. Kutlu. 1992. "The Lateralization of the Grasp Reflex in Human Newborns." *International Journal of Neuroscience* 62, no. 1–2: 1–8. <https://doi.org/10.3109/00207459108999752>.
- Tanaka, C., Y. Hikihara, K. Ohkawara, and S. Tanaka. 2012. "Locomotive and Non-Locomotive Activity as Determined by Triaxial Accelerometry and Physical Fitness in Japanese Preschool Children." *Pediatric Exercise Science* 24, no. 3: 420–434. <https://doi.org/10.1123/pes.24.3.420>.
- Tanner, J. M. 1971. "Sequence, Tempo, and Individual Variation in the Growth and Development of Boys and Girls Aged Twelve to Sixteen." *Dædalus* 100, no. 4: 907–930.
- Taylor, R. W., E. Gold, P. Manning, and A. Goulding. 1997. "Gender Differences in Body Fat Content Are Present Well Before Puberty." *International Journal of Obesity and Related Metabolic Disorders* 21, no. 11: 1082–1084. <https://doi.org/10.1038/sj.ijo.0800522>.
- Thomas, E., and A. Palma. 2018. "Physical Fitness Evaluation of School Children in Southern Italy: A Cross Sectional Evaluation." *Journal of Functional Morphology and Kinesiology* 3, no. 14: 14. <https://doi.org/10.3390/jfkm3010014>.
- Thomas, J. R., and K. E. French. 1985. "Gender Differences Across Age in Motor Performance a Meta-Analysis." *Psychological Bulletin* 98, no. 2: 260–282. <https://doi.org/10.1037/0033-2909.98.2.260>.
- Thomas, J. R., and K. E. French. 1987. "References for Motor Tasks--Gender Differences Across Age in Motor Performance: A Meta-Analysis." *Perceptual and Motor Skills* 64, no. 2: 503–506. <https://doi.org/10.2466/pms.1987.64.2.503>.
- Tishukaj, F., I. Shalaj, M. Gjaka, et al. 2017. "Physical Fitness and Anthropometric Characteristics Among Adolescents Living in Urban or Rural Areas of Kosovo." *BMC Public Health* 17, no. 1: 711. <https://doi.org/10.1186/s12889-017-4727-4>.
- Tomlinson, C., H. Macintyre, C. A. Dorrian, S. F. Ahmed, and A. M. Wallace. 2004. "Testosterone Measurements in Early Infancy." *Archives of Disease in Childhood. Fetal and Neonatal Edition* 89, no. 6: F558–F559. <https://doi.org/10.1136/adc.2003.034017>.
- Torrijos-Niño, C., V. Martínez-Vizcaino, M. J. Pardo-Guijarro, J. C. García-Prieto, N. M. Arias-Palencia, and M. Sánchez-López. 2014. "Physical Fitness, Obesity, and Academic Achievement in School-children." *Journal of Pediatrics* 165, no. 1: 104–109. <https://doi.org/10.1016/j.jpeds.2014.02.041>.
- Trajković, N., D. Radanović, D. Madić, et al. 2021. "Normative Data for Handgrip Strength in Serbian Children Measured With a Bulb Dynamometer." *Journal of Hand Therapy* 34, no. 3: 479–487. <https://doi.org/10.1016/j.jht.2020.03.001>.
- Trudeau, F., R. J. Shephard, F. Arsenault, and L. Laurencelle. 2003. "Tracking of Physical Fitness From Childhood to Adulthood." *Canadian Journal of Applied Physiology* 28, no. 2: 257–271. <https://doi.org/10.1139/h03-020>.
- Tsimeas, P. D., A. L. Tsiokanos, Y. Koutedakis, N. Tsigilis, and S. Kellis. 2005. "Does Living in Urban or Rural Settings Affect Aspects of Physical Fitness in Children? An Allometric Approach." *British Journal of Sports Medicine* 39, no. 9: 671–674. <https://doi.org/10.1136/bjism.2004.017384>.
- Tsoukos, A., and G. C. Bogdanis. 2021. "The Effects of a Five-Month Lockdown Due to COVID-19 on Physical Fitness Parameters in Adolescent Students: A Comparison Between Cohorts." *International Journal of Environmental Research and Public Health* 19, no. 1: 326. <https://doi.org/10.3390/ijerph19010326>.
- Wang, Y.-C., R. W. Bohannon, X. Li, S.-C. Yen, B. Sindhu, and J. Kapellusch. 2019. "Summary of Grip Strength Measurements Obtained in the 2011–2012 and 2013–2014 National Health and Nutrition Examination Surveys." *Journal of Hand Therapy* 32, no. 4: 489–496. <https://doi.org/10.1016/j.jht.2018.03.002>.
- Wang, Z., G. Asokan, J.-P. Onnela, et al. 2024. "Menarche and Time to Cycle Regularity Among Individuals Born Between 1950 and 2005 in the US." *JAMA Network Open* 7, no. 5: e2412854. <https://doi.org/10.1001/jamanetworkopen.2024.12854>.
- Weedon, B. D., F. Liu, W. Mahmoud, et al. 2022. "Declining Fitness and Physical Education Lessons in UK Adolescents." *BMJ Open Sport and Exercise Medicine* 8, no. 1: e001165. <https://doi.org/10.1136/bmjsem-2021-001165>.
- Welk, G. J., P. F. Saint-Maurice, and T. Csányi. 2015. "Health-Related Physical Fitness in Hungarian Youth: Age, Sex, and Regional Profiles." Supplement, *Research Quarterly for Exercise and Sport* 86, no. S1: S45–S57. <https://doi.org/10.1080/02701367.2015.1043231>.
- Wen, J., J. Wang, Q. Xu, et al. 2020. "Hand Anthropometry and Its Relation to Grip/Pinch Strength in Children Aged 5 to 13 Years." *Journal of International Medical Research* 48, no. 12: 300060520970768. <https://doi.org/10.1177/0300060520970768>.
- Westerstahl, M., M. Barnekow-Bergkvist, G. Hedberg, and E. Jansson. 2003. "Secular Trends in Body Dimensions and Physical Fitness Among Adolescents in Sweden From 1974 to 1995." *Scandinavian Journal of Medicine and Science in Sports* 13, no. 2: 128–137. <https://doi.org/10.1034/j.1600-0838.2003.10274.x>.
- Westerstahl, M., M. Barnekow-Bergkvist, G. Hedberg, and E. Jansson. 2003. "Secular Trends in Sports: Participation and Attitudes Among Adolescents in Sweden From 1974 to 1995." *Acta Paediatrica* 92, no. 5: 602–609. <https://doi.org/10.1080/08035250310002713>.
- Weston, K. L., N. Pasecinic, and L. Basterfield. 2019. "A Preliminary Study of Physical Fitness in 8- to 10-Year-Old Primary School Children From North East England in Comparison With National and International Data." *Pediatric Exercise Science* 31, no. 2: 229–237. <https://doi.org/10.1123/pes.2018-0135>.
- Wick, K., S. Kriemler, and U. Granacher. 2022. "Associations Between Measures of Physical Fitness and Cognitive Performance in Preschool Children." *BMC Sports Science, Medicine & Rehabilitation* 14, no. 1: 80. <https://doi.org/10.1186/s13102-022-00470-w>.
- Widrick, J. J., J. E. Stelzer, T. C. Shoepe, and D. P. Garner. 2002. "Functional Properties of Human Muscle Fibers After Short-Term Resistance Exercise Training." *American Journal of Physiology - Regulatory, Integrative and Comparative Physiology* 283, no. 2: R408–R416. <https://doi.org/10.1152/ajpregu.00120.2002>.
- Wilcox, G., and D. Nordstokke. 2022. "Pediatric Co-Norms for Finger Tapping, Grip Strength, and Grooved Pegboard in a Community Sample." *Journal of the International Neuropsychological Society* 28, no. 1: 85–93. <https://doi.org/10.1017/s1355617721000175>.
- Woods, S., C. O'Mahoney, J. Maynard, et al. 2022. "Increase in Volitional Muscle Activation From Childhood to Adulthood: A Systematic Review and Meta-Analysis." *Medicine and Science in Sports and Exercise* 54, no. 5: 789–799. <https://doi.org/10.1249/mss.0000000000002853>.
- Xu, Y., M. Mei, H. Wang, Q. Yan, and G. He. 2020. "Association Between Weight Status and Physical Fitness in Chinese Mainland

- Children and Adolescents: A Cross-Sectional Study.” *International Journal of Environmental Research and Public Health* 17, no. 7: 2468. <https://doi.org/10.3390/ijerph17072468>.
- Yapici, H., M. Gulu, F. H. Yagin, O. Eken, T. Gabrys, and V. Knappova. 2022. “Exploring the Relationship Between Biological Maturation Level, Muscle Strength, and Muscle Power in Adolescents.” *Biology* 11, no. 12: 1722. <https://doi.org/10.3390/biology11121722>.
- Yim, S. Y., J. R. Cho, and I. Y. Lee. 2003. “Normative Data and Developmental Characteristics of Hand Function for Elementary School Children in Suwon Area of Korea: Grip, Pinch and Dexterity Study.” *Journal of Korean Medical Science* 18, no. 4: 552–558. <https://doi.org/10.3346/jkms.2003.18.4.552>.
- Yoshizawa, S., T. Ishizaki, and H. Honda. 1977. “Physical Fitness of Children Aged 5 and 6 Years.” *Journal of Human Ergology* 6: 41–51.
- Yuki, A., Y. Tamase, and M. Nakayama. 2023. “Association Between Decreased Grip Strength in Preschool Children and the COVID-19 Pandemic: An Observational Study From 2015 to 2021.” *Journal of Physiological Anthropology* 42, no. 1: 4. <https://doi.org/10.1186/s40101-023-00321-8>.
- Żegleń, M., Ł. Kryst, M. Kowal, and A. Woronkiewicz. 2020. “Changes in Physical Fitness Among Preschool Children From Kraków (Poland) From 2008 to 2018.” *Journal of Physical Activity and Health* 17, no. 10: 987–994. <https://doi.org/10.1123/jpah.2020-0199>.
- Zhang, F., C. Bi, X. Yin, et al. 2021. “Physical Fitness Reference Standards for Chinese Children and Adolescents.” *Scientific Reports* 11, no. 1: 4991. <https://doi.org/10.1038/s41598-021-84634-7>.
- Zhang, F., C. Bi, X. Yin, et al. 2022. “Roles of Age, Sex, and Weight Status in the Muscular Fitness of Chinese Tibetan Children and Adolescents Living at Altitudes Over 3600 m: A Cross-Sectional Study.” *American Journal of Human Biology* 34, no. 2: e23624. <https://doi.org/10.1002/ajhb.23624>.
- Zverev, Y., and M. Gondwe. 2001. “Growth of Urban School Children in Malawi.” *Annals of Human Biology* 28, no. 4: 384–394. <https://doi.org/10.1080/03014460010013016>.