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Child and adolescent sex differences in sit-and-reach flexibility: a meta-analysis

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ABSTRACT

The sit-and-reach assesses hamstrings extensibility, and to a lesser extent, lumbar extensibility. The sit-and-reach is arguably the most frequently performed test of flexibility in human history. Thus, the sit-and-reach provides, with high statistical power, a unique opportunity to explore sexual dimorphism of a proposed fitness attribute. In adults, greater female than male sit-and-reach flexibility is well established. However, the evolution of this sex difference throughout childhood and adolescence is less clear, and relevant meta-analyses are now 30-40 years old. The purpose of the current study was to use meta-analysis to update the question of sex differences in sit-and-reach flexibility in children and adolescents. The analysis included 407 effects from 95 studies. Studies were published between 1983–2023. The total sample was 944,292 (484,323 boys, 459,969 girls). At all ages assessed (3-16 years old), girls had greater sit-and-reach flexibility than boys. Between 4–10 years old, the effect size was fairly consistent and moderate in size (g = -30 to -0.50). This sex difference widened at age 11 (g = -0.59, 95% confidence intervals (CIs) [-0.75, -0.44]), peaked at age 12 (g = -0.78, 95% CIs [-0.96, -0.61]), then returned to pre-pubertal levels by age 16 (g = -0.42, 95% CIs [-0.61, -0.52]). Secondary analyses revealed that the sex difference in sit-and-reach flexibility is similar between countries and has remained relatively stable since the 1980s. Overall, the results confirm that sexual dimorphism in flexibility occurs early in human development, is impacted by puberty, and is broadly consistent across time and place.

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INTRODUCTION

Flexibility refers to the intrinsic properties of body tissues that determine maximal joint range of motion (ROM) without causing injury (Holt et al., 1996; Knudson et al., 2000). A common test of flexibility is the sit-and-reach. The sit-and-reach was created in 1952 (Wells & Dillon, 1952). Since its creation, the sit-and-reach has been included in various physical fitness test batteries around the world (Marques et al., 2021).

The sit-and-reach assesses hamstrings extensibility, and to a lesser extent, lumbar extensibility (Castro-Piñero et al., 2009; Chillón et al., 2010; Hartman & Looney, 2003; Mayorga-Vega et al., 2014; Muyor et al., 2014; Patterson et al., 1996). Concerns exist about the concurrent validity between sit-and-reach performance and meaningful health and performance outcomes. Consequently, some researchers have suggested that the sit-and-reach, and perhaps flexibility more broadly, be de-emphasized or altogether removed from fitness test batteries (Institute of Medicine, 2012; Nindl et al., 2015; Nuzzo, 2020; Reuben et al., 2013). Nevertheless, the sit-and-reach is arguably the most frequently performed test of flexibility in human history. Thus, it provides, with high statistical power, a unique opportunity to explore sexual dimorphism of a proposed fitness attribute.

In adults, sex differences in sit-and-reach flexibility are clear, with women significantly more flexible than men (Davis et al., 2008; Jackson & Langford, 1989; Katzmarzyk et al., 2000; Liemohn et al., 1994; Shephard et al., 1990). The development of this sex difference during childhood and adolescents is less clear. For example, it is unclear at what age the sex difference in sit-and-reach flexibility emerges and to what extent the size of the difference changes throughout development. Meta-analysis of all existing data can be used to clarify these questions.

In 1985, Thomas and French (1985) used meta-analysis to examine sex differences in flexibility and other physical attributes in boys and girls. They found that girls had greater sit-and-reach flexibility than boys (d = -0.29). Nevertheless, their analysis, which is now 40 years old, had limitations. First, it included only 13 effects from 2,069 boys and girls (Thomas & French, 1985). Originally, the researchers reported that these 13 effects came from five studies (Thomas & French, 1985), but they later revealed that these effects came from only four studies - one of which was not published in a journal (Thomas & French, 1987). Second, the ages of the participants who were included in the analysis of the sit-and-reach were not stated. Thus, how the sex difference in sit-and-reach flexibility might modulate throughout development was not examined.

A few years later, the same researchers conducted a more powerful analysis (Thomas et al., 1991). They generated effect sizes of the sex difference in sit-and-reach flexibility in a sample of over 12,000 boys and girls aged 6-18 years (Thomas et al., 1991). The effect size during early childhood was approximately d = -0.50. During puberty, it increased to approximately d = -1.00. At ages 17 and 18, it returned to pre-puberty levels (d = -0.60). Thus, Thomas et al. (1991) found that girls had greater sit-and-reach flexibility than boys at all ages assessed, but the magnitude of the difference changed throughout development.

These two seminal studies enhanced knowledge of sex differences in sit-and-reach flexibility in children and adolescents (Thomas & French, 1985; Thomas et al., 1991). Nevertheless, both analyses are now decades old and can be expanded in various ways. First, significantly more studies and effects are now available. Second, neither analysis included confidence intervals (CI) of the effect sizes, and such information is important for establishing confidence in any sex differences observed. Third, the two studies included sit-and-reach flexibility data only from children in the United States of America (USA). Sit-and-reach flexibility data are now available from boys and girls who reside in various countries, allowing for examination of how sex differences in sit-and-reach flexibility might differ between countries. Finally, given that the sit-and-reach test was created over 70 years ago (Wells & Dillon, 1952), secular changes in any sex differences in flexibility can now be explored.

Therefore, the primary aim of the current study was to use meta-analysis to provide an updated examination of sex differences in sit-and-reach flexibility in children and adolescents. The study also had two secondary, exploratory aims. The first exploratory aim was to examine if sex differences in sit-and-reach flexibility in children and adolescents have changed over time (i.e., secular analysis). The second exploratory aim was to examine if the size of the sex difference in sit-and-reach flexibility in children and adolescents differs between countries. Results from these analyses have potential to inform discussions about sex differences in proposed fitness attributes and the impact of such differences on male and female sports performances and policies (Brown et al., 2024; Hamilton et al., 2024; Hilton & Lundberg, 2021; Lundberg et al., 2024; Nokoff et al., 2023; Nuzzo, 2023; Tucker et al., 2024).

METHOD

Literature search

The literature search for this paper was performed in August of 2024. Many papers on the topic were already known to me based on searches conducted for other reviews (Nuzzo, 2020, 2024). The search strategy was similar to that described by Greenhalgh and Peacock (2005). The first component of the search involved checking personal digital files associated with previous research (Nuzzo, 2020). The second component involved performing relevant keyword searches in PubMed and Google Scholar. Example keyword searches included various combinations of words such as “children,” “boys,” “girls,” “youth,” “adolescents,” “flexibility,” “sit-and-reach,” “sit-reach,” “fitness,” and “physical fitness.” The third component involved “snowballing” strategies, such as reference and citation tracking. I have used these strategies successfully in previous reviews and meta-analyses (Nuzzo, 2023; Nuzzo, 2024; Nuzzo, Pinto, & Nosaka, 2023; Nuzzo, Pinto, Nosaka, et al., 2023; Nuzzo et al., 2024). Limitations of this approach are presented in the Discussion.

Eligibility

For a study to be included in the current meta-analysis, it needed to meet the following criteria: (a) published in an academic journal in 2023 or earlier; (b) published in English; (c) included male and female participants who were between the ages of birth to 16 years old, healthy, and not competitive athletes; (d) included sample sizes and sex-segregated means and standard deviations (SD) of sit-and-reach scores that were not statistically adjusted for covariates. Common reasons for exclusion were: (a) no sample sizes reported; (b) no means or SDs reported; (c) a test other than the sit-and-reach was performed (e.g., stand-and-reach); and (d) the age range of the cohort was beyond the established criteria (described below).

Data extraction and organization

Extracted data from eligible studies included year of publication, year of data collection (if provided), sample size, sample age, and means and SDs of sit-and-reach scores. Researchers reported their data in various ways. Consequently, I established the following criteria for data extraction and organization.

Year of data collection. Year of data *collection* is more scientifically valid for examining secular changes in sit-and-reach flexibility. Year of data collection represents the true time at which a measurement was taken. Year of *publication*, on the other hand, could be years after the measurement was taken. When researchers listed a single year for date of data collection, that year was used to represent that study in the current analysis. Some researchers reported dates of data collection that spanned two or more years. Often, their data were not reported by each year, but, instead, were aggregated as a single mean. When the duration of data collection spanned two years (e.g., 2007-2008), the first of the two years was used to represent that study in the current analysis. When the duration of data collection spanned *more* than two years (e.g., 2007-2009), the year in the middle (i.e., 2008) was used to represent that study in the current analysis. When year of data collection was not reported by researchers, the year of publication was used to represent that study in the current analysis.

Age category. Researchers presented information on participant age in different ways. Given these differences, I adopted eligibility and data extraction criteria that were liberal enough to allow for as much data as possible to be included in the analysis, while not compromising the validity of the current study's aims.

I treated age as a categorical variable (e.g., 6-year-olds) rather than a continuous variable (e.g., 6.2 years). This strategy prioritized data that were presented for categorical age groups that spanned only one year (e.g., "5-year-olds"). However, under certain conditions, the strategy also permitted sit-and-reach scores from studies in which age cohorts spanned multiple years. First, if the researcher reported sit-and-reach scores for a cohort whose age spanned four or more years (e.g., 10- to 15-year-olds), the study was ineligible for inclusion in the current analysis. Second, if the researcher reported sit-and-reach scores for a cohort whose age spanned three years (e.g., 10- to 12-year-olds), the middle age (i.e., 11 years old) was typically used to represent these data in the current analysis. Often, this middle age corresponded with the rounded down mean age of the cohort (e.g., 11.3 years in a cohort of 10- to 12-year-olds whose ages could have ranged from 10.0 to 12.9 years). Third, if the researcher reported sit-and-reach scores for a cohort whose age spanned two years (e.g., 10- to 11-year-olds), the younger of the two ages (i.e., 10 years old) was used to represent the study in the current analysis. Often, in such scenarios the rounded down mean corresponded more closely with the younger of the two ages (e.g., mean age of 10.3 years in a cohort of 10- and 11-year-olds whose ages could have ranged from 10.0 to 11.9 years). Finally, if any participants in a cohort were 17 years of age or older, the study was ineligible for the current analysis.

Study type. Sit-and-reach flexibility data were reported in studies of various designs. Common study designs included longitudinal studies on development, reliability studies on consistency of sit-and-reach scores, cross-sectional studies comparing cohorts of children who differed on some characteristic (e.g., body weight status), and intervention studies that compared sit-and-reach scores before and after interventions (e.g., exercise program).

For longitudinal studies, grip strength data from each year of development were included in the current analysis. For reliability studies, only grip strength data from the first trial or first day of testing were included in the current analysis. For cross-sectional studies that compared sit-and-reach scores in healthy children ("controls") and children with health conditions, only data from the healthy children were included in the current analysis. For intervention studies that involved baseline and post-intervention assessments of sit-and-reach flexibility, only data from the baseline assessments were included in the current analysis.

Data extraction from graphs. Researchers typically presented sit-and-reach scores in tables. When scores were presented in graphs, I used a graph digitzer (WebPlotDigitizer, https://apps.automeris.io/wpd/) to estimate them. With the digitizer, I calibrated the y-axis, inputting the sit-and-reach 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 generated a spreadsheet of the means and SDs calibrated against the y-axis. Standard errors, whether presented in graphs or tables, were converted to SDs by multiplying the standard error by the square root of the sample size.

Statistical analysis

The data spreadsheet and statistical results are available at the Open Science Framework (https://osf.io/yjexh/). Version 29 of the Statistical Software Package for the Social Sciences (SPSS, Armonk, USA) was used to complete the statistical analyses. Frequency counts were generated for the number of effects by age, country, and year of data collection. Random effects meta-analyses were used to generate effect sizes (Hedges *g*) with 95% confidence intervals (CI) and prediction intervals. Forest plots were used to graphically display the effect sizes for each study. Effect sizes equal to 0.2, 0.5, and 0.8 are often considered small, moderate, and large, respectively, but such benchmarks are arbitrary and should be interpreted cautiously (Lakens, 2013). Confidence intervals that do not cross zero indicate effects that are statistically significant (i.e., $p \leq 0.05$) (Cumming, 2009).

For the analysis of secular trends, cumulative effect sizes were generated for two large age cohorts (5-10- and 14-16-years-olds) and across each of the six decades from which data were available from these two cohorts (1980s, 1990s, 2000s, 2010s [i.e., 2010-2023]). 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 one cohort who is mostly pre-pubescent (5-10-year-olds) and another cohort who is mostly post-pubescent (14-16-year-olds). This segregation helped to minimize confounding of pubertal status on the effect of time. For example, if one decade or country included proportionally more samples of 5-10-year-olds, whereas other decades or countries included proportionally more samples of 14-16-year-olds, any observed difference over time or between countries would be confounded by pubertal status. Moreover, this segregation helped minimize a potentially confounding influence of secular changes in age at menarche (Gomula & Koziel, 2018; Lei et al., 2021; Wang et al., 2024) and differences in age at menarche between countries (Lei et al., 2021; Saczuk et al., 2018; Wang et al., 2024).

For the analysis that compared sex differences in sit-and-reach flexibility between countries, cumulative effect sizes were generated for 5-10-years-olds and 14-16-years-olds for each country. For some countries, few effects were available, rendering their inclusion into the comparison uninformative. Thus, only countries in which sufficient effects were available are discussed.

Results

Study characteristics

A total of 95 studies met the eligibility criteria and were included in the meta-analysis (Amado-Pacheco et al., 2019; Anselma et al., 2020; Armstrong et al., 2011; Ayán Pérez et al., 2020; Bae et al., 2015; Baquet et al., 2006; Bartkowiak et al., 2021; Batez et al., 2021; Benzo et al., 2023; Casajús et al., 2007; Chen et al., 2022; Cieśla et al., 2014; Cieśla et al., 2017; De la Cruz-Sánchez & Pino-Ortega, 2010; Deforche et al., 2003; Docherty & Bell, 1985; Eather et al., 2016; Estivaleti et al., 2022; Fang et al., 2017; Fiori et al., 2021; Flanagan et al., 2015; Fogelholm et al., 2008; Fortier et al., 2001; Godoy-Cumillaf et al., 2020; Golle et al., 2014; Gontarev et al., 2018; Gulías-González et al., 2014; Haapala et al., 2015; Haapala et al., 2016; Hands et al., 2009; Haugen et al., 2014; He et al., 2019; Henriques-Neto et al., 2022; Hong & Hamlin, 2005; Hsu et al., 2021; Huang & Malina, 2002; Jones et al., 2005; Jürimäe & Saar, 2003; Jürimäe & Volbekiene, 1998; Kamandulis et al., 2013; Karppanen et al., 2012; Katzmarzyk et al., 2000; Kidokoro et al., 2016; Kim & Park, 2017; Kondric et al., 2013; Koslow, 1987; Lehnhard et al., 1992; Lintu et al., 2016; Lo et al., 2017; Lovecchio, Giuriato, et al., 2019; Lovecchio et al., 2015; Lovecchio, Novak, et al., 2019; Mačak et al., 2022; Marshall et al., 1998; Martinho et al., 2022; McMillan & Erdmann, 2010; Moliner-Urdiales et al., 2010; Monyeki et al., 2005; Oja & Jürimäe, 1997, 2002; Örjan et al., 2005; Ortega et al., 2008; Panczyk et al., 2014; Pelicer et al., 2016; Pissanos et al., 1983; Podstawski & Borysławski, 2012; Puszczałowska-Lizis et al., 2023; Richards et al., 2022; Riddoch et al., 1991; Runhaar et al., 2010; Ruzbarsky et al., 2022; Ryu et al., 2021; Sacchetti et al., 2012; Safrit & Wood, 1987; Santos et al., 2023; Sasayama & Adachi, 2019; Sember et al., 2022; Siegel et al., 1989; Smith & Miller, 1985; Sokolowski & Chrzanowska, 2012; Tishukaj et al., 2017; True et al., 2021; Tsimeas et al., 2005; Tsoukos & Bogdanis, 2021; Vanhelst et al., 2017; Veraksa et al., 2021; Vitali et al., 2019; Vlahov et al., 2014; Volbekiene & Griciūte, 2007; Welk et al., 2015; Weston et al., 2019; Xu et al., 2020; Zhang et al., 2021)

The studies included a total of 407 effects from 944,292 children and adolescents (484,323 boys, 459,969 girls). The number of effects available by age and country are listed in Table 1.

Study publication dates ranged from 1983 to 2023. The earliest year of data collection was 1980. Numbers of effect available by decade of data collection and across all ages were as follows: 1980s (60 effects, 14.7%), 1990s (35 effects, 8.6%), 2000s (95 effects, 23.3%), and 2010s (217 effects, 53.3%).

The number of effects available by country and across all ages are listed in Table 2. Study samples from the Poland contributed the greatest number of effects to the meta-analysis (63 effects, 15.5%), followed by the USA (42 effects, 10.3%), South Africa (32 effects, 7.9%), Italy (27 effects, 6.6%), China (23 effects, 5.7%) and Spain (22 effects, 5.4%).

Sit-and-reach flexibility

Age. From age 3, sit-and-reach flexibility was greater in girls than boys (Fig. 1, Table 1). At age 3, only one effect was available. Consequently, the 95% CIs were much wider at age 3 than other ages. From age 4 to 10 years old, effect sizes were small-to-moderate in magnitude, typically ranging between g = -0.30 – -0.50. The effect size then increased at age 11 (g = -0.59, 95% CIs [-0.75, -0.44]) and peaked at age 12 (g = -0.78, 95% CIs [-0.96, -0.61]). Starting at age 13, the effect size began to decrease, and by age 16, it returned to pre-puberty levels (g = -0.42, 95% CIs [-0.61, -0.52]).

Secular changes. For the 5-10-year-olds, the mean effect size was broadly similar across decades, except in the 2000s when it decreased (g = -0.29, 95% CIs [-0.38, -0.20]) (Fig. 2, Table 3). For the 14-16-year-olds, the effect size was broadly similar across all decades ranging from g = -0.54 to -0.72, and substantial overlap existed between the 95% CIs of all decades (Fig. 3, Table 4).

Country. Effect sizes of the difference in sit-and-reach flexibility between boys and girls by age and country are presented in Table 4. The size of the sex difference in flexibility differed somewhat by country, but numbers of effects available from most countries were limited. For 5-10-year-olds, the effect sizes from China, Italy, Spain, South Africa, and the USA were broadly similar (g = -0.32 to -0.62) with much overlap in their 95% CIs. In Peru, however, the sex difference in sit-and-reach flexibility was smaller than in other countries and did not reach statistical significance (g = -0.12, 95% CIs [-0.31, 0.06]).

For the 14-16-year-olds, few countries had enough effects for robust between-country comparisons. Nevertheless, significant overlap in the 95% CIs existed between the USA, Lithuania, and Poland. China exhibited different results. The mean effect size from China was smaller than these three countries, such that the sex difference in sit-and-reach flexibility among 14-16-year-olds in China was not statistically significant (g = -0.73, 95% CIs [-0.51, 0.03]).

Discussion

Girls have greater sit-and-reach flexibility than boys at all ages. This sex difference in flexibility is small-to-moderate in size in early childhood, it increases with onset of female puberty, and it returns to levels observed in early childhood by age 16. The size of the sex difference in sit-and-reach flexibility is similar between countries and has remained mostly stable since the 1980s.

During development

The main novel aspect of the current meta-analysis was the large aggregate sample used to update the question of sex differences in sit-and-reach flexibility in children and adolescents. A total of 95 studies provided 407 effects from over 900,000 boys and girls. This represents a substantial enhancement in statistical power compared to the only other meta-analyses on the topic, which are now 30-40 years old (Thomas & French, 1985; Thomas et al., 1991).

Sit-and-reach data are available from children as young as 3 years old. At this age, girls have greater sit-and-reach flexibility than boys (g = -1.35). Nevertheless, this finding should be interpreted cautiously because only one effect was available (Koslow, 1987).

At older ages, confidence in the size of the sex difference in sit-and-reach flexibility is enhanced due to the large number of effects available. Between ages 4-10, girls have a small-to-moderate advantage in sit-and-reach flexibility (g = -0.30 – -0.50). Then, at age 11, the effect size increases (g = -0.59), likely due to onset of female puberty (Brix et al., 2019; Euling et al., 2008; Tanner, 1971). The effect size then peaks at age 12 (g = -0.78) before narrowing. By age 16, the sex difference in sit-and-reach flexibility returns to pre-puberty levels (g = -0.42).

These results are broadly consistent with the results from the two previous meta-analyses (Thomas & French, 1985; Thomas et al., 1991). In their sample of 12,000 boys and girls aged 6-18, Thomas et al. (1991) found greater sit-and-reach flexibility in girls than boys at all ages. They reported an effect size of about d = -0.50 during early childhood, a slight increase in the sex difference at age 11, a peak in the difference at ages 12-13, and a near-return to pre-puberty levels by age 17 (Thomas et al., 1991). However, the peak difference was smaller in the current analysis (g = -0.78) than the previous analysis (d = -1.1), and though both analyses revealed a narrowing of the difference from ages 15 to 16, the current study findings suggest a return to pre-puberty levels at age 16, whereas the previous analysis found a return to pre-puberty levels at age 17 (Thomas et al., 1991). Another difference between the two studies is that the former study included 6-year-olds as the youngest cohort (Thomas et al., 1991), whereas the current study included samples as young as 3 years old and was thus able to reveal that sex differences in sit-and-reach flexibility occur earlier than previously known.

Across time

A second novel aspect of the current work was the secular analysis. This analysis revealed that the sex difference in sit-and-reach flexibility has not changed much since the 1980s. This was particularly true for 14-16-year-olds, for whom there was significant overlap in the 95% CIs across all decades. For 5-10-year-olds, there was also overlap in the 95% CIs across decades, except for the 2000s. In the 2000s, the sex difference in sit-and-reach flexibility narrowed among 5-10-year-olds, before then returning in the 2010s to levels consistent with the 1980s and 1990s. The overall lack of change in the sex difference in sit-and-reach flexibility suggests little or no secular change in the underlying biological or social/environmental factors that impact sit-and-reach flexibility.

Female and male puberty impact the sex difference in sit-and-reach flexibility (Fig. 1). Consequently, in future research examining changes in sex differences in sit-and-reach flexibility across generations, secular changes in puberty onset warrant consideration. Secular decreases in the age of onset of some pubertal stages have been observed in girls, with results in boys less clear (Euling et al., 2008). If boys and girls experience dissimilar secular changes in puberty onset, this could impact the peaks and troughs of sex differences in sit-and-reach flexibility throughout development.

Between countries

A third novel aspect of the current work was the between-countries analysis. This analysis revealed that the sex difference in sit-and-reach flexibility is similar between countries. For 5-10-year-olds, effect sizes from China, Italy, Spain, and South Africa were broadly similar. One exception is Peru, where the sex difference in sit-and-reach flexibility in 5-10-year-olds is not statistically different. Why a sex difference is not present in Peru is unclear.

For 14-16-year-olds, fewer effects are available. Substantial overlap in the 95% CIs exists between the USA, Lithuania, and Poland. China is an exception, as its sex difference in sit-and-reach flexibility in 14-16-year-olds is not statistically different. Why a sex difference is not present in China is unclear. Moving forward, larger datasets of sit-and-reach flexibility will allow for more precise conclusions regarding between-countries sex differences in sit-and-reach flexibility, particularly among 14-16-year-olds. As the average age at menarche is not the same in all countries (Lei et al., 2021; Saczuk et al., 2018; Wang et al., 2024), differences in puberty patterns between countries warrant consideration in future research that explores sex differences in flexibility around the world.

Role of physical activity

What causes the sex difference in sit-and-reach flexibility? One possible cause is a sex difference in physical activity participation, as participation in some sports and exercise can increase flexibility (Afonso et al., 2021; Bennell et al., 2001; Wang et al., 2023).

Throughout childhood and adolescents, girls report greater interest and more frequent participation in yoga, gymnastics, and dancing – activities known to target or rely heavily on flexibility (Anderson et al., 2017; Centers for Disease Control and Prevention, 2023; Deaner et al., 2012; Harrell et al., 2003; National Federation of State High School Associations, 2019; O'Neill et al., 2011; Woods & U.S. Bureau of Labor Statistics, 2017). Flexibility is also the only component of fitness in which girls rate their self-confidence equal to boys' self-confidence (Klomsten et al., 2004). Girls' greater self-confidence and interest in flexibility-based activities compared to boys likely stems from girls' greater flexibility and joint laxity at early ages (Haley et al., 1986; Jansson et al., 2004; Kondratek et al., 2007; Remvig et al., 2007; Rikken-Bultman et al., 1997). This sex difference in flexibility often appears *prior* to an age when rigorous exercise training is likely. Moreover, even when boys and girls participate in the same sport, girls still exhibit greater flexibility (Aedo-Munoz et al., 2019; Eisenmann & Malina, 2003; Khan et al., 1997). Thus, sex differences in physical activity participation do not seem to fully explain differences in flexibility between boys and girls.

Instead, girls appear to have a biological propensity for flexibility that occurs early in development. This predisposition, coupled with the fact that activities which require high flexibility levels are viewed by boys and girls as being feminine (Schmalz & Kerstetter, 2006), likely leads girls to participate in flexibility-based activities more often than boys. In adults, interest to have one's flexibility measured and to participate in flexibility programs is greater in women than men (Nuzzo & Deaner, 2023). Women's greater interest in being measured on flexibility and wanting to enhance flexibility likely reflects a desire to display, affirm, accentuate, or receive feedback on an aspect of femininity (Nuzzo & Deaner, 2023).

Though greater female interest and participation in flexibility activities has potential to exacerbate baseline sex differences in flexibility, the sex difference in sit-and-reach flexibility is consistent between ages of 4-10, and the difference modulates with key biological events (e.g., female puberty). Such findings, in combination with results that sex differences in sit-and-reach flexibility are broadly similar across time and place (Fig. 2, 3, Table 4), suggest that sex differences in sit-and-reach flexibility are primarily rooted in biology rather than social or environmental factors. Biological factors that warrant consideration are body anthropometrics and muscle stiffness.

Role of body height and limb length

Body height increases with age in boys and girls. Boys are taller than girls until about age 11, which is when girls become taller than boys (USA data) (Kuczmarski et al., 2002). At age 14, girls' body height begins to plateau, while boys' body height continues to increase (Kuczmarski et al., 2002). At age 16, boys' median body height is significantly greater than girls' median body height (Kuczmarski et al., 2002).

Sex differences in body height probably do not contribute significantly to sex differences in sit-and-reach flexibility because body height (in adults) either does not correlate with sit-and-reach flexibility (Mathews et al., 1957; Mathews et al., 1959) or it correlates weakly in the negative direction (Simoneau, 1998). Leg length (Mathews et al., 1957; Mathews et al., 1959; Wear, 1963) and arm length (Simoneau, 1998) also do correlate strongly with sit-and-reach flexibility, though individuals with long legs and short arms and trunk are disadvantaged in the traditional sit-and-reach (Hoeger & Hopkins, 1992; Hoeger et al., 1990; Wear, 1963). Nonetheless, sex differences in arm-to-leg ratios, should they exist, are unlikely to fully explain greater sit-and-reach performance in females than males. This is because (a) the finger-to-box distance in the sit-and-reach test accounts for only 13% of the variance in sit-and-reach performance (Hoeger & Hopkins, 1992; Hoeger et al., 1990), (b) girls maintain their flexibility advantage over boys even when the modified version of the sit-and-reach, which accounts for finger-to-box distance, is performed (Castro-Piñero et al., 2009), (c) the modified and traditional versions of the sit-and-reach correlate similarly with hamstrings extensibility in children and adolescents (Castro-Piñero et al., 2009), and (d) females often have greater ROM than males during joint actions that are not confounded by limb length (Grimston et al., 1993; Kawaguchi et al., 2024; McKay et al., 2017).

Roles of body mass and fat

Body mass increases with age in boys and girls. Girls have lower body masses than boys until about age 11 (Kuczmarski et al., 2002). At age 11, girls begin to weigh more than boys (Kuczmarski et al., 2002). However, at age 14, boys regain their body mass advantage, and by age 16, body mass is significantly greater among boys than girls (Kuczmarski et al., 2002).

Sex differences in body mass and fat probably do not contribute to sex differences in sit-and-reach flexibility. Children and adolescents who are overweight and obese have sit-and-reach flexibility scores equal to their youth counterparts who are not overweight or obese (Aijsafe et al., 2018; Deforche et al., 2003; Woll et al., 2013). Also, though girls and women have higher body fat percentages than boys and men (Garnett et al., 2004; Nelson & Barondess, 1997; Taylor et al., 1997; Wells, 2007), body fatness does not correlate with sit-and-reach performance (Minck et al., 2000). In adult women, body mass also does not significantly correlate with toe touch test scores (Broer & Galles, 1958).

Roles of muscle mass and stiffness

The sit-and-reach test primarily examines hamstrings extensibility, as evident by the moderate correlations between sit-and-reach and passive straight leg test scores (Castro-Piñero et al., 2009; Hartman & Looney, 2003; Mayorga-Vega et al., 2014; Muyor et al., 2014; Patterson et al., 1996). Two determinants of hamstrings extensibility include hamstrings muscle stiffness and pain tolerance to hamstrings stretch. During the passive straight leg test, men exhibit more muscle stiffness and less hip flexion ROM, and men report higher levels of pain from the stretch compared to women (Marshall & Siegler, 2014). Men also appear to report slightly higher levels of discomfort during the sit-and-reach compared to women, though this was not formally assessed with a test of statistical significance (Hui & Yuen, 2000).

Thus, in adults, lower sit-and-reach flexibility in males than females can be explained partly by greater hamstrings muscle stiffness and lower pain tolerance to hamstrings stretch in males (Blackburn et al., 2009; Blackburn et al., 2004; Gajdosik et al., 1990; Granata et al., 2002; Marshall & Siegler, 2014; McHugh et al., 1992). Lesser hip ROM on the passive straight leg test among boys than girls (Castro-Piñero et al., 2009; Hartman & Looney, 2003; Muyor et al., 2014; Patterson et al., 1996) suggests that sex differences in hamstrings muscle stiffness and pain tolerance probably also play a role in explaining sex differences in sit-and-reach flexibility in children and adolescents.

In adults, the cause of the sex difference in hamstrings muscle stiffness is believed to be greater hamstrings muscle cross-sectional area in men than women (Blackburn et al., 2004; Gajdosik et al., 1990; Nuzzo, 2023). Blackburn et al. (2004) speculated that greater muscle mass in men than women might be due to (a) men having a greater amount of connective tissue that would be resistant to stretch, and (b) men having a greater number of cross-bridges available for spontaneous re-attachment during stretch.

Compared to pre-pubertal girls, pre-pubertal boys have more fat-free or lean mass, less fat mass, and lower body fat percentages (Arfai et al., 2002; Garnett et al., 2004; He et al., 2002; Leppänen et al., 2017; McCarthy et al., 2014; Nelson & Barondess, 1997; Soininen et al., 2018; Taylor et al., 1997). Thus, prior to puberty, greater hamstrings muscle mass in boys could play a role in their lower flexibility. During male puberty, boys experience a 20-30-fold increase in testosterone and a substantial increase in muscle mass (Courant et al., 2010; Elmlinger et al., 2005; Handelsman et al., 2018; Khairullah et al., 2014; Round et al., 1999).

Because of the disproportionate increase in muscle mass in boys during and after puberty, one might expect the sex difference in sit-and-reach flexibility to widen. Yet, the sex difference in sit-and-reach flexibility *narrows* after male puberty (Fig. 1). One possible explanation for the return of the sex difference in sit-and-reach flexibility to pre-puberty levels by age 16 is the sex-specific change in lumbar flexion that occurs during development. Hamstrings extensibility is largely responsible for sit-and-reach performance, but sit-and-reach performance is also weakly correlated with *lumbar* extensibility (Hartman & Looney, 2003; Mayorga-Vega et al., 2014; Patterson et al., 1996). Studies on spinal mobility in boys and girls have reported somewhat mixed results, but overall, they appear to show greater lumbar flexion ROM among girls than boys in early childhood (Haley et al., 1986; Kondratek et al., 2007; Penha et al., 2008), followed by greater lumbar flexion among *boys* than girls after about age 14 (Oksanen & Salminen, 1996; Sullivan et al., 1994; van Adrichem & van der Korst, 1973). Kondratek et al. (2007) speculated that girls' decline in lumbar flexion ROM at a younger age compared to boys could be due to earlier maturation in girls than boys. Thus, greater male than female trunk flexion ROM after puberty might help explain why the sex difference in sit-and-reach flexibility decreases from peak levels observed at age 12.

To the extent that girls have greater spinal mobility than boys in early development, this may be due, in part, to smaller vertebral cross-sectional areas in girls. Newborn girls have significantly smaller vertebral cross-sectional areas than newborn boys (Gilsanz et al., 2018; Ponrartana et al., 2015). This reduced vertebral size is thought to be "programmed" and representative of a female adaptation to the necessity of fetal load (Gilsanz et al., 2018; Ponrartana et al., 2015). Smaller vertebral cross-sectional areas in children and adolescents correlate with greater lumbar lordosis (Wren et al., 2017), and pre-pubertal girls have smaller vertebra and less paraspinous muscles than boys, with 22% of the difference in vertebral cross-sectional area explained by sex-related differences in paraspinous musculature (Arfai et al., 2002). Thus, smaller vertebral cross-sectional areas and paraspinous musculature in girls than boys might be other biological factors that contribute to sex differences in sit-and-reach flexibility.

Limitations

The current study has limitations. First, the literature search did not follow a formal flow diagram. Consequently, study replication will be challenging. However, the aim of the research was to update two meta-analyses that are now 30-40 years old (Thomas & French, 1985; Thomas et al., 1991). This aim was accomplished, as the current analysis includes 407 effects from 95 studies with over 900,000 participants.

Second, the current study was only concerned with sit-and-reach flexibility. Therefore, the results are specific to sex differences in hamstrings extensibility, and to a lesser extent, lumbar extensibility (Castro-Piñero et al., 2009; Chillón et al., 2010; Hartman & Looney, 2003; Mayorga-Vega et al., 2014; Muyor et al., 2014; Patterson et al., 1996). The results are not directly applicable to other muscles or joint actions.

Third, the cause of the sex difference in sit-and-reach flexibility was not assessed. Converging lines of evidence suggest that the sex difference in sit-and-reach flexibility before, during, and after puberty is caused primarily by biological factors. Nevertheless, longitudinal studies that examine factors such as muscle stiffness, tolerance to stretch, muscle and vertebral cross-sectional areas, and physical activity participation will be required to identify the causes of the sex difference in sit-and-reach flexibility in children and adolescents.

Conclusion

Girls have greater sit-and-reach flexibility than boys at all ages. Between 3-10 years old, the sex difference in sit-and-reach flexibility is fairly consistent and moderate in size. This difference widens at age 11, peaks at age 12, and then narrows such that by age 16 it equals pre-puberty levels. The sex difference in sit-and-reach flexibility is similar between countries and has remained largely unchanged since the 1980s. Overall, the results confirm that sexual dimorphism in flexibility occurs early in human development, is impacted by puberty, and is broadly consistent across time and place.

Data availability statement

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

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I have no conflicts of interest to report.

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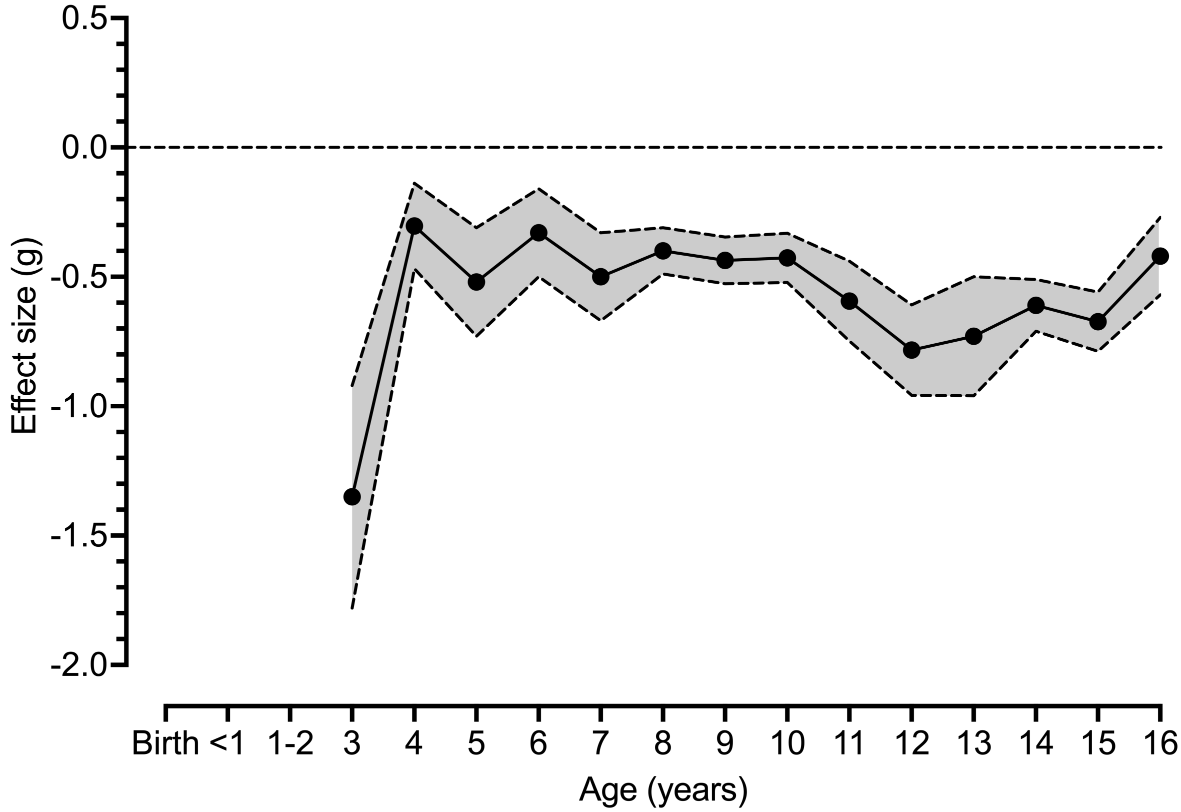

Figure 1. Effect sizes (Hedges *g*) of differences in sit-and-reach flexibility between boys and girls from birth to age 16. Black circles represent cumulative effect sizes for each age. The number of effects making up each cumulative effect size are listed in Table 1. Dashed lines around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CIs). Girls had greater sit-and-reach flexibility than boys at all ages. The large effect size at age 3 is due to only one large effect being available at that age. From 4 to 10 years, the effect size generally ranged between *g* = -30 to -0.50, and it became more consistent between the ages of 8 to 10 due, in part, to the greater number of effects available at those ages. The "dip" in the effect size at ages 11 and 12 represent an increase in the sex difference in sit-and-reach flexibility. This dip is likely due to girls reaching puberty earlier than boys. After boys reach puberty, the sex difference in sit-and-reach flexibility narrows to pre-puberty levels.

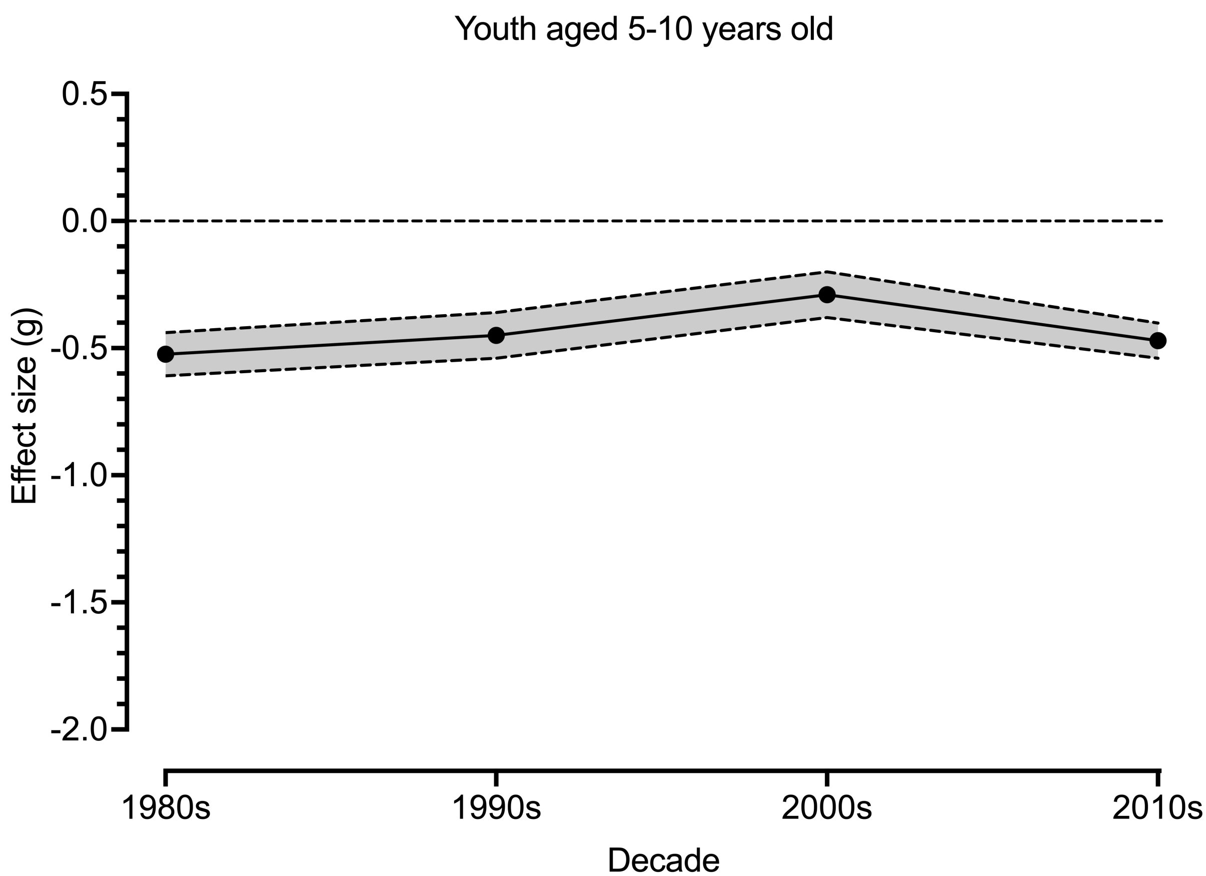

Figure 2. Effect sizes (Hedges *g*) of differences in sit-and-reach flexibility between 5-10-year-old boys and girls from the 1980s to today. The black circles are cumulative effect sizes for all relevant study effects. The number of effects making up each cumulative effect size are listed in Table 3. The dashed lines around the effect sizes represent the upper and lower limits of the 95% confidence intervals (CI). Girls had greater sit-and-reach flexibility than boys in all decades. This sex difference has remained mostly stable since the 1980s, as evident by the overlap of the 95% CIs for most decades. However, a small decrease in the sex difference in sit-and-reach flexibility is noted in the 2000s.

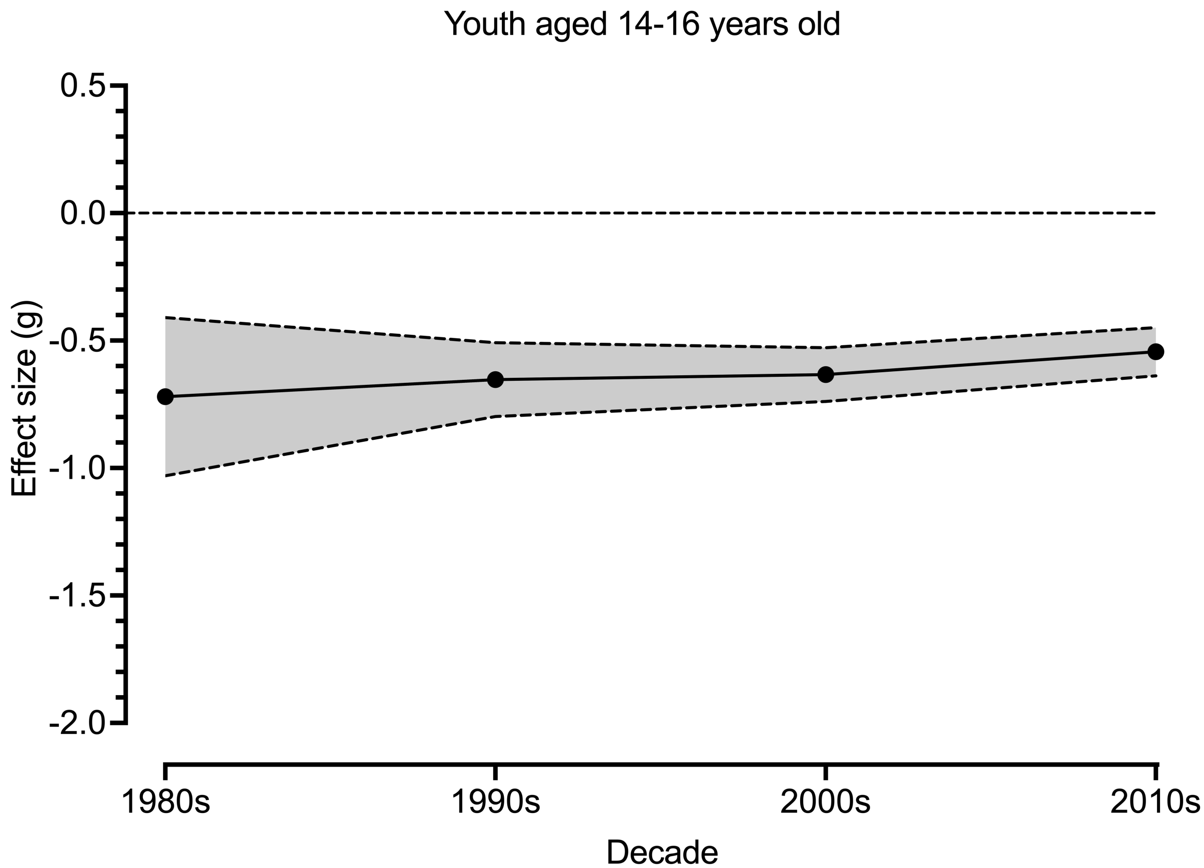

Figure 3. Effect size (Hedges *g*) of differences in sit-and-reach flexibility between 14-16-years-ol boys and girls from the 1980s to today. The black circles are cumulative effect sizes for all relevant study effects. The number of effects making up each cumulative effect size are listed in Table 3. The dashed lines around the effect sizes represent the upper and lower limits of the 95% CIs. Girls had greater sit-and-reach flexibility than boys in all decades. This sex difference has remained mostly stable since the 1980s, as evident by the overlap of the 95% CIs for most decades. The narrowing of the 95% CIs in the 2010s is due, in part, to the greater amount of data available in the 2010s compared to previous decades.

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

Age group	No. effects	Hedges *g*	*p*	95% CI		95% PI	
				Lower	Upper	Lower	Upper
3 yr	1	-1.35	<.001	-1.78	-0.92	NA	NA
4 yr	6	-0.30	<.001	-0.47	-0.14	-0.76	0.15
5 yr	5	-0.52	<.001	-0.73	-0.31	-1.23	0.19
6 yr	21	-0.38	<.001	-0.47	-0.14	-0.83	0.07
7 yr	24	-0.50	<.001	-0.67	-0.33	-1.39	0.38
8 yr	37	-0.40	<.001	-0.49	-0.31	-0.89	0.08
9 yr	33	-0.43	<.001	-0.53	-0.35	-0.89	0.03
10 yr	41	-0.43	<.001	-0.52	-0.33	-0.94	0.09
11 yr	51	-0.59	<.001	-0.75	-0.44	-1.70	0.52
12 yr	53	-0.78	<.001	-0.96	-0.61	-2.07	-0.50
13 yr	36	-0.73	<.001	-0.96	-0.50	-2.14	-0.68
14 yr	46	-0.61	<.001	-0.71	-0.51	-1.26	0.03
15 yr	33	-0.67	<.001	-0.79	-0.56	-1.26	-0.09
16 yr	20	-0.42	<.001	-0.57	-0.27	-1.06	0.21
Overall	407	-0.57	<.001	-0.61	-0.52	-1.46	0.33

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

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

Country or region	No. effects	Percent
Australia	2	0.5
Belgium	4	1.0
Brazil	11	2.7
Canada	12	2.9
China	23	5.7
Chile	3	0.7
Columbia	1	0.2
Croatia	9	2.2
England	2	0.5
Estonia	12	2.9
Europe (multiple countries)	3	0.7
Finland	6	1.5
France	7	1.7
Germany	4	1.0
Greece	5	1.2
Hungary	6	1.5
Ireland	6	1.5
Italy	27	6.6
Japan	6	1.5
Korea (South)	15	3.7
Kosovo	2	0.5
Lithuania	16	3.9
Macedonia	9	2.2
Netherlands	14	3.4
New Zealand	2	0.5
Norway	3	0.7
Peru	12	2.9
Poland	63	15.5
Portugal	10	2.5
Russia	1	0.2
South Africa	32	7.9
Serbia	3	0.7
Slovakia	4	1.0
Spain	22	5.4
Sweden	3	0.7
Taiwan	4	1.0
United States of America	42	10.3
Wales	1	0.2
Total	407	100.0

Table 3. Effect sizes of the difference in grip strength between boys and girls by age and decade.

Age group, decade	No. effects	Hedges *g*	*p*	95% CI Lower	95% CI Upper
5-10 yr old					
1980s	29	-0.52	<.001	-0.61	-0.44
1990s	8	-0.45	<.001	-0.54	-0.36
2000	44	-0.29	<.001	-0.38	-0.20
2010s	80	-0.47	<.001	-0.54	-0.40
Overall	161	-0.43	<.001	-0.48	-0.38
14-16 yr old					
1980s	11	-0.72	<.001	-1.03	-0.41
1990s	12	-0.65	<.001	-0.80	-0.51
2000	18	-0.63	<.001	-0.74	-0.53
2010s	58	-0.54	<.001	-0.64	-0.45
Overall	99	-0.60	<.001	-0.66	-0.53

CI = confidence interval.

Table 4. Effect sizes of the difference in sit-and-reach flexibility between boys and girls by age and country.

Age group, country	No. effects	Hedges *g*	*p*	95% CI	
				Lower	Upper
5-10 yr old					
China	8	-0.48	.005	-0.81	-0.14
Italy	9	-0.62	<.001	-0.68	-0.56
Peru	10	-0.12	.200	-0.31	0.06
Poland	24	-0.35	<.001	-0.43	-0.27
South Africa	19	-0.32	<.001	-0.46	-0.26
Spain	12	-0.44	<.001	-0.57	-0.32
United States of America	26	-0.58	<.001	-0.68	-0.47
14-16 yr old					
China	8	-0.24	0.082	-0.51	0.03
Lithuania	11	-0.55	<.001	-0.73	-0.38
Poland	20	-0.63	<.001	-0.80	-0.47
United States of America	4	-0.73	<.001	-0.91	-0.54

CI = confidence interval.