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A Systematic Analysis of Temporal Trends in the Handgrip Strength of 2,216,320 Children and Adolescents Between 1967 and 2017

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Running title

Temporal trends in children's handgrip strength

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Abstract

Objective: To estimate national and international temporal trends in handgrip strength for children and adolescents, and to examine relationships between trends in handgrip strength and trends in health-related and sociodemographic indicators.

Methods: Data were obtained through a systematic search of studies reporting temporal trends in the handgrip strength for apparently healthy 9–17 year-olds, and by examining large national fitness datasets. Temporal trends at the country-sex-age level were estimated by sample-weighted regression models relating the year of testing to mean handgrip strength. International and national trends were estimated by a post-stratified population-weighting procedure. Pearson's correlations quantified relationships between trends in handgrip strength and trends in health-related/sociodemographic indicators.

Results: 2,216,320 children and adolescents from 13 high-, 5 upper-middle-, and 1 low-income countries/special administrative regions between 1967 and 2017 collectively showed a moderate improvement of 19.4% (95%CI: 18.4 to 20.4) or 3.8% per decade (95%CI: 3.6 to 4.0). The international rate of improvement progressively increased over time, with more recent values (post-2000) close to two times larger than those from the 1960s/1970s. Improvements were larger for children (9–12 years) compared to adolescents (13–17 years), and similar for boys and girls. Trends differed between countries, with relationships between trends in handgrip strength and trends in health-related/sociodemographic indicators negligible-to-weak and not statistically significant.

Conclusions: There has been a substantial improvement in absolute handgrip strength for children and adolescents since 1967. There is a need for improved international surveillance of handgrip strength, especially in low- and middle-income countries, to more confidently determine true international trends.

PROSPERO registration number: CRD42013003657.

Key points

- There has been a moderate international improvement in handgrip strength for children and adolescents since 1967, with the rate of improvement progressively increasing over time and more recent values (post-2000) close to two times larger than those from the 1960s and 1970s
- Internationally, improvements in handgrip strength were nearly twice as large for children compared to adolescents, yet similar for boys and girls. Nationally, trends varied in magnitude and direction
- Collectively, the relationships between trends in handgrip strength and trends in health-related/sociodemographic indicators were negligible-to-weak and not statistically significant

1 Introduction

Most of the research on the health-related benefits of physical fitness relates to cardiorespiratory fitness.[1,2] Considerable evidence has recently emerged indicating that muscular strength—the ability of a muscle or muscle group to generate force in a single contraction[3]—is also a powerful marker of good health.[4–8] In adults, reduced muscular strength is significantly associated with all-cause, cardiovascular, and non-cardiovascular mortality[5,9,10] (independent of body size, physical activity levels, and other covariates[5]), cancer,[9] stroke,[5] type 2 diabetes,[11] hypertension,[11] hospitalization,[12] surgical complications,[13] disability,[13] functional deficits[14] (in both instrumental activities and activities of daily living[15,16]), and cognitive declines.[16,17] Compelling evidence from the Prospective Urban-Rural Epidemiology (PURE) study[5]—a large longitudinal population study of 139,691 adults (35–70 years) across 17 countries over a median of four years—indicated that every 5 kg decrease in handgrip strength was associated with 16–17% higher hazard ratios for all-cause, cardiovascular, and non-cardiovascular mortality. In children and adolescents, muscular strength is significantly associated with current[7,8] and future[4,18,19,20] health independent of cardiorespiratory fitness[21–23] and physical activity.[23] Low muscular strength cut-points for the detection of high cardiometabolic risk[22,24,25] and poor bone health[26] have been used to identify at-risk children and adolescents in need of intervention. This evidence underscores why national[27–29] and international[30] physical activity guidelines now recommend children and adolescents participate in muscle and bone-strengthening activities (in addition to aerobic activity) at least three times per week. For these reasons, temporal trends in muscular strength provide important insights into corresponding trends in population health.

Muscular strength cannot be defined by a single measurement because tests are often specific to the muscle group, the type of muscle action, muscle contraction, contraction velocity, equipment, and joint range of motion. However, handgrip strength—characterized as a maximal isometric grip force task—is a practical, feasible, and scalable functional measure of overall strength for clinical and population screening and surveillance.[31] It has high-to-very high construct validity with upper-body, lower-body, and overall strength in children, adolescents and adults,[31,32] high-to-very high test-retest reliability[33–35], as well as negligible test-retest learning and fatigue effects.[36] The test is safe and there is no evidence of adverse events associated with test administration.[37] Handgrip strength testing has also been endorsed by both North American[37] and European[38] experts for its predictive utility and recommended for school-based fitness testing.

Temporal trends in physical fitness have largely focused on cardiorespiratory fitness, with several large systematic analyses recently published on both pediatric[39] and adult populations.[40] Much less, however, is known about temporal trends in muscular strength for children and adolescents. While reports of trends in handgrip strength for children and adolescents have recently emerged with varying results (e.g., Canada,[42–44] Mexico,[45] Mozambique,[46] Poland,[47–49] Turkey,[50] the UK,[51] and the US[42,43]), there has not yet been a comprehensive study to synthesize national and international trends. Recent studies have also identified a strong negative association between national trends in cardiorespiratory fitness and trends in income inequality (Gini index) among children and adolescents,[39] meaning countries with a widening gap between rich and poor residents had less favorable trends (i.e., large declines) in cardiorespiratory fitness. Examining the associations between national trends in handgrip strength and trends in health-related and sociodemographic indicators could provide further insight into the importance of these indicators and their potential population health implications.

The primary aim of this study was to systematically analyze national (country-specific) and international (pooled global data) temporal trends in handgrip strength for children and adolescents. The secondary aim was to examine relationships between national trends in handgrip strength and trends in health-related and sociodemographic indicators.

2 Methods

2.1 Protocol and Registration

The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42013003657). This review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement.[52]

2.2 Eligibility Criteria

One large systematic review of temporal trends in children's muscular fitness (i.e., muscular strength [operatioanlized as handgrip strength] and local muscular endurance [operationalized as sit-ups performance]) was initially undertaken before being divided into two smaller reviews. For this study, studies were included if they explicitly reported on temporal trends in children's maximal strength (operationalized as handgrip strength). Candidate studies, including refereed journal articles and graduate research theses, were eligible if they reported on temporal trends in the handgrip strength (using matched testing protocols) of apparently healthy (free from known disease/injury) age- and sex-matched children and adolescents (aged 9–17 years) across at least two time points spanning a minimum of five years.[39] Temporal trends must have been reported in each study as absolute, percent or standardized changes in means at the country-sex-age level, or as descriptive data (e.g., sample sizes, means and standard deviations) at the country-sex-age-year level in order to calculate temporal trends. At the national level, a minimum of four country-sex-age groups (e.g., 9-year-old Australian boys) was required for inclusion.

2.3 *Information Sources*

A systematic electronic database search was performed on the 30th of October 2018 using the EBSCO interface in Cumulative Nursing and Allied Health Literature (CINAHL), MEDLINE, and SPORTDiscus, without date or language restrictions. The search strategy was developed with the help of an academic librarian experienced in systematic literature searching. Additional studies were located by searching the reference lists of the included studies, topical systematic reviews, and the personal library of the senior author (GRT). Large datasets comprising nationally representative fitness survey data suitable to temporal trends analysis were also considered.

2.4 Search Strategy

The electronic database search was limited to keywords, title, and abstract. Search terms within a group were combined with a Boolean OR and were searched concurrently with other search groups using the Boolean AND. Proximity operators ("*") were used to search for root words. The first group of search terms identified the fitness measure (physical fitness OR muscular fitness OR muscular strength OR muscular endurance OR musculoskeletal fitness OR aerobic fitness OR cardiovascular fitness OR cardiorespiratory fitness). The second group identified the population (child* OR youth OR young OR adolescen*). The third group identified the trend over time (temporal OR secular OR trend*). The search strategy for databases is shown in Supplement 1.

2.5 Study Selection

All database records were imported into RefWorks (v2.0; ProQuest LLC, Ann Arbor, MI, USA) and de-duplicated. At the first level, two researchers (FLD and TK) independently screened the titles and abstracts against inclusion criteria, with consensus required for further screening. At the second level, full text copies were obtained and independently screened by two researchers against inclusion criteria, with consensus required for final inclusion. A third researcher (GRT) resolved discrepancies if consensus was not reached.

2.6 Data Collection Process

Descriptive data were extracted into a spreadsheet by one researcher using a standardized study-specific template,[39] and reviewed by a second researcher for accuracy. If required, additional information was requested from the corresponding authors via email (e.g., to clarify published results or to avoid double counting data).

2.7 Data Items

The following study-specific descriptive data were extracted: title, country, years of testing, sex, age (or age range), and test protocol. If available, the absolute (in kg), percent, and/or standardized changes in mean handgrip strength (±95% confidence intervals [CIs]) were extracted; if not, then all sample sizes, means, and standard deviations for measured handgrip were extracted in order to calculate temporal trends.

2.8 Summary Measures and Synthesis of Results

Temporal trends were analyzed at the country-sex-age level using best-fitting sample-weighted linear or polynomial (quadratic or cubic) regression models relating the year of testing to mean handgrip strength.[39,40] Trends in mean handgrip strength were expressed as percent changes (i.e., change in means expressed as a percentage of the overall mean) and as standardized effect sizes (ES) (i.e., change in means divided by the pooled standard deviation). To interpret the magnitude of change, ES of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with ES<0.2 considered to be negligible.[41] Positive temporal trends indicated increases in mean handgrip strength and negative temporal trends indicated declines in mean handgrip strength.

International and national temporal trends (for boys, girls, children [9–12 year-olds], adolescents [13–17 year-olds] and all [9–17 year-old boys and girls]) were calculated using a post-stratified population-weighting procedure that has been described in detail elsewhere.[39,40,53,54] Population estimates were standardized to the year 2000—a common testing year to the vast majority of country-sex-age groups—using United Nations data.[55] The post-stratification population-weighting procedure helps correct the trends for systematic bias associated with over- and under-sampling, and standardizes the trends to underlying country-sex-age-specific demographics.

Relationships between national temporal trends in handgrip strength and national temporal trends in pre-specified health-related and sociodemographic indicators were quantified using Pearson's correlation coefficients, with 95%CIs estimated using Fisher's *z*-transformation. National trends for three health-related (childhood and adolescent body mass index [BMI],[56] moderate-to-vigorous physical activity [MVPA],[57] and vigorous physical activity [VPA] levels[57]) and three sociodemographic (Gini index,[58] Human Development Index [HDI],[59] and urbanization[60]) indicators were analyzed using linear regression models (as described above). Trends in these broad health-related and sociodemographic indicators were examined because they were thought to be meaningfully related to trends in handgrip strength and because it was possible to calculate temporal trends using the same criteria as for handgrip strength (e.g., across at least two time points spanning a minimum of 5 years) for the majority of the included countries. To interpret the magnitude of correlation, ES of 0.1, 0.3, 0.5, 0.7, and 0.9 were used as thresholds for weak, moderate, strong, very strong, and nearly perfect, respectively, with ES<0.1 considered to be negligible.[41]

3 Results

A total of 1,416 unique records were identified through the electronic database search, with 28 retained after the first level of screening (title and abstract review) and six retained after the second level of screening (full-text review) (Figure 1). These six studies were combined with: (a) 12 additional studies identified from the senior author's personal library and the reference lists of included articles (11/12) and topical systematic reviews (1/12), and (b) four large national datasets comprising nationally representative handgrip data suitable for temporal trends analysis, resulting in 22 included studies/datasets (Figure 1).

Insert Figure 1 here

Temporal trends in handgrip strength were estimated from 2,230,658 children and adolescents aged 9–17 years from 18 countries and one special administrative region (Hong Kong) between 1835 and 2017 (Table 1). Trends prior to 1967 were removed because they were only available for 16% (3/19) of countries representing <1% of all data points (e.g., Belgium: 1835–2010; Bulgaria: 1960–1999; USA: 1899–2009). As a result, trends between 1967 and 2017, representing 2,216,320 children (n=914,277) and adolescents (n=1,302,044), were calculated. Trends were available for 13 high-income, 5 upper-middle-income, and 1 low-income countries/special administrative regions[143] (or 14 very high, 4 high, and 1 low human development countries/special administrative regions),[59] representing five continents, ~34% of the world's population,[55] and ~33% of the world's land area.[144] Trends were calculated for 254 country-sex-age groups (children [aged 9–12 years]: 124; adolescents [aged 13–17 years]: 130; boys: 126; girls: 128), with a median sample size of 835 (range 23–75,407) across a median span of 23 years (range 5–50). Trends were available for the following test protocols: maximum of the dominant hand (45% or 10/22 studies), sum of the maxima for both hands (27% or 6/22), maximum of the right hand (14% or 3/22), average of the maxima for both hands (9% or 2/22), and maximum across both hands (5% or 1/22) (Supplement 2). Most test protocols required a straight arm, allowed multiple trials per hand, and used a mechanical handgrip dynamometer adjusted for hand size.

Insert Table 1 here

Collectively, there was a moderate improvement in mean handgrip strength over the 1967–2017 period (change in means [95%CI]: 19.4% [18.4 to 20.4]; ES 0.72 [0.68 to 0.76]) (Figure 2). There was a large international improvement in mean handgrip strength in children (change in means [95%CI]: 24.4% [22.8 to 26.0]; ES 0.86 [0.81 to 0.91]) that was 1.8-fold larger than the moderate improvement in adolescents (change in means [95%CI]: 13.7% [12.5 to 14.9]; ES 0.56 [0.51 to 0.61). The moderate international improvement in boys (change in means [95%CI]: 19.4% [18.2 to 20.6]; ES 0.77 [0.72 to 0.82]) was similar to that observed in girls (change in means [95%CI]: 19.0% [17.4 to 20.6]; ES 0.65 [0.60 to 0.70]) (Figure 2).

Insert Figure 2 here

The international rate of improvement was not uniform over time, with the rate of improvement increasing (albeit negligibly) from the 1960s/1970s (change in means [95%CI]: 1.8% per decade [1.5 to 2.1]; ES 0.07 [0.06 to 0.08]), through the 1980s/1990s (change in means [95%CI]: 2.4% per decade [2.1 to 2.7]; ES 0.09 [0.08 to 0.10]), to the 2000s/2010s (change in means [95%CI]: 3.8% per decade [3.4 to 4.2]; ES 0.14 [0.13 to 0.15]) (Figure 2). The rate of improvement peaked in the 2000s/2010s across all age and sex groups, with rates increasing over time in children, adolescents and boys, and rates slowing from the 1960s/1970s to the 1980s/1990s and increasing thereafter in girls (Figure 2).

National trends in handgrip strength ranged from a large improvement for France (11.2% per decade between 1985 and 2008) to a large decline for Turkey (−11.5% per decade between 1983–2013), with trends in other countries typically negligible to small (12/19 or 63%) and positive (i.e., improvements) (11/19 or 58%) (Figure 3). Figure 3 shows that while uniform (linear) and non-uniform (curvilinear) trends were evenly split across countries, some countries experienced a decrease or stabilization of the rate of change (e.g., Belgium, China and Turkey), an increase in the rate of change (e.g., Australia, Italy and the US), or a reversal of the direction of change (e.g., Poland). Within-country trends were very strongly related between sexes (*r*

[95%CI]: 0.74 [0.43 to 0.89]) but weakly related between age groups (*r* [95%CI]: 0.19 [−0.36 to 0.64]).

Insert Figure 3 here

Despite not reaching statistical significance at the 95% level, there were weak positive correlations between national trends in handgrip strength and national trends in urbanization, BMI, MVPA, VPA, and HDI. The trend for Gini index was negligible (Table 2).

Insert Table 2 here

4 Discussion

This study estimated temporal trends from 1967 to 2017 in handgrip strength for 2.2 million children and adolescents from 19 countries/special administrative regions. The main findings were that: (a) there was a moderate international improvement in handgrip strength since 1967, equivalent to an improvement of ~20%, ~0.7 standard deviations or ~3–9 kg for 9–17-year-olds using Eurofit's dominant hand protocol;[145] (b) the international rate of improvement progressively increased with more recent rates of increase close to two times larger than those from the 1960s/1970s; (c) international improvements were observed for all age and sex groups, with the rate of increase over the entire period nearly twice as large for children compared to adolescents, and similar for boys and girls; (d) national trends varied in magnitude and direction; and (e) national trends in health and sociodemographic indicators were, at best, weakly and not significantly correlated with national trends in handgrip strength. Because handgrip strength demonstrates high-to-very high construct validity,[31,32] our finding of improved handgrip strength is suggestive of improved overall strength capacity; specifically however, it reflects an improved ability of children and adolescents to perform everyday high intensity gripping tasks. This may be meaningful to public health given previous findings of significant cross-sectional and longitudinal relationships between handgrip strength and health indicators among children and adolescents.[4,7,8,18–26]

It has previously been argued that trends in cardiorespiratory fitness among children and adolescents have probably been caused by a network of environmental, social, behavioral, psychosocial and physiological factors.[39,40,54] Trends in the handgrip strength among children and adolescents are potentially explained by a similar causal network. Consider first the potential impact of body size on muscular strength.[8,146,147] Temporal trends in body size and biological maturation are thought to be influenced by improved living conditions, better nutrition, and reduced infectious disease.[148] Numerous public health initiatives (e.g., health promotion campaigns, clean water technologies, food fortification, pasteurization) have contributed to improved environmental and nutritional conditions for children and adolescents across the study period,[149,150] although it is difficult to estimate the effect of such factors on trends in handgrip strength. Several recent studies have found that temporal trends in handgrip strength were independent of trends in body size, operationalized as height and mass,[51] height, mass and BMI,[47] and fat mass and fat-free mass.[148] Our trends, therefore, likely reflect trends in both muscle function and body size. Underlying trends in muscle function are expected given that handgrip strength demonstrates high-to-very high construct validity, although these validity coefficients reduce to low-to-moderate when controlled for body mass.[31,32] International increases in childhood and adolescent BMI are well established,[56] reflecting both increases in fat mass and fat-free mass.[151] Increases in fat-free mass should result in a general increase in handgrip strength given that the capacity to generate force by a muscle is proportional to its cross-sectional area.[152] Given BMI increased over the period 1975–2016 in all 19 included countries/special administrative regions,[56] concurrent increases in handgrip strength would be expected, although Figure 3 shows between-country variation in both direction and magnitude. Our analysis revealed that the relationship between trends in handgrip strength and trends in BMI was weak and not statistically significant, suggesting that trends in other factors are likely also involved.

Temporal trends in handgrip strength are also likely influenced by concurrent trends in biological maturation.[148,153] To our knowledge, only one study has examined temporal trends in handgrip strength while statistically controlling for trends in maturation. Moliner-Urdiales et al.[154] observed declines in handgrip strength for Spanish youth between 2001 and 2007 independent of changes in fat mass, fat-free mass, age and pubertal status (assessed by the Tanner-Whitehouse scale). However, several studies have reported that trends in handgrip strength have coincided with trends in maturation. For example, Saczuk et al.[48] found that the trend towards earlier maturation in Polish girls between 1986 and 2006 coincided with improved handgrip strength. Whereas, Malina et al.[45] suggested that earlier maturation explained part of the sex-related temporal differences in the handgrip strength among Mexican youth. While trends in maturation have varied over time and between countries, estimates indicate that the age of menarche advanced by ~0.3 years per decade over most of the 20th century, and the age at which boys' voices break by ~0.2 years per decade.[155] Over the 50-year period between 1967 and 2017, this equates to 1.0 and 1.5 years for boys and girls, respectively. Tomkinson et al.[145] found that handgrip strength improved with each year of age by ~16% in boys and ~15% in girls between the ages of 9 and 12, and by ~11% in boys and ~3% in girls between the ages of 13 and 17. Between 1967 and 2017, we found that mean handgrip strength improved internationally by

~24% and ~14% in children and adolescents, respectively. When corrected for trends in biological maturation, the underlying improvement in handgrip strength is reduced to ~1–8% in children (i.e., 24% minus 16% in boys and 24% minus 1.5 multiplied by 15% in girls) and ~3–9% in adolescents (i.e., 14% minus 11% in boys and 14% minus 1.5 multiplied by 3% in girls). Advances in biological maturation could help explain why improvements in handgrip strength were larger for children compared to adolescents.

In a recent systematic review, Smith et al.[156] reported that muscular fitness was positively related to objectively measured MVPA, VPA, and organized sport participation. However, they acknowledged that associations between handgrip strength and MVPA, VPA, and organized sport participation were less consistent than for other strength measures (e.g., standing broad jump, push-ups, composite strength).[156] Because of the difficulty in obtaining accurate measurements and temporal differences in sampling and methodology, trend data on the physical activity levels of children and adolescents are scarce. Currently there is no compelling evidence for international increases in MVPA, VPA, or organized sport participation,[57,157–159] and to our knowledge, no study has examined temporal trends in handgrip strength while statistically controlling for trends in physical activity levels. Recently however, Sandercock and Cohen[51] reported that the decline in 10-year-old English children's handgrip strength between 2008 and 2014 coincided with a decline in self-reported physical activity. Our findings suggested only weak, non-statistically significant, correlations between trends in handgrip strength and self-reported trends in MVPA/VPA indicating that trends in absolute handgrip strength poorly reflect trends in MVPA/VPA. Perhaps this describes the fact that childhood and adolescent physical activities do not typically involve exposure to gripping tasks that stimulate an increase in finger flexor strength (i.e., handgrip strength).

In the absence of concurrent trend data, it is difficult to explain why the improvements in handgrip strength were generally larger for children than adolescents. Apart from advances in biological maturation, which are more likely to have influenced trends in handgrip strength for children rather than adolescents (see above), it is possible that age-related temporal differences in body size (i.e., BMI) and MVPA/VPA are involved. Although we were unable to estimate age-related temporal differences in BMI or MVPA/VPA, a secondary analysis of the relationships between trends in handgrip strength and trends in BMI and MVPA/VPA showed moderate-to-large age-related differences. For example, trends in children's handgrip strength were strongly correlated with BMI (*r* [95%CI]: 0.55 [0.03 to 0.84]), and strongly but not significantly correlated with MVPA (*r* [95%CI]: 0.56 [−0.24 to 0.91]) and VPA (*r* [95%CI]: 0.59 [−0.20 to 0.91]); in contrast, they were negligibly-to-moderately but not significantly correlated in adolescents (*r* [95%CI]: BMI, 0.21 [−0.36 to 0.67]); VPA, −0.34 [−0.84 to 0.48]; and VPA, −0.08 [−0.74 to 0.66]). This suggests that childhood trends in handgrip strength, but not adolescent trends, are good markers of trends in BMI and MVPA/VPA. Assuming these ecological correlations are causal, this temporal connection suggests that strategies (e.g., national and international physical activity guidelines[27–30]) promoting the development of fat-free muscle mass and MVPA/VPA (including gripping activities) might be a better population approach to improving handgrip strength in children than in adolescents. It is also possible that any given increase in BMI or MVPA/VPA results in a larger increase in handgrip strength in children than in adolescents. In a large nationally representative sample of Canadian children and adolescents aged 6–17 years, the positive relationship between BMI and handgrip strength was stronger/steeper in children than adolescents.[160] In addition, trends in handgrip strength were strongly associated with trends in HDI among children (*r* [95%CI]: 0.59 [0.09 to 0.85]) but negligibly associated among adolescents (*r* [95%CI]: 0.03 [−0.51 to 0.55]). This suggests that trends in the economic and development status of a country are associated with trends in children's strength levels, perhaps because of better quality and/or quantity of opportunities for organized sport and physical activity. For instance, country-specific human development was a strong-to-very strong positive correlate of physical activity opportunities at the school and community/environment levels, and a moderate positive correlate of organized sport and physical activity, among children and adolescents across 49 countries.[161] Age-related differences in motivation levels may also be involved.

This study represents the most comprehensive analysis to date investigating the national and international temporal trends in handgrip strength for children and adolescents. We used a detailed statistical approach, including weighted regression and a post-stratification population weighting procedure, which helped adjust our trends for sampling bias by incorporating the underlying population demographics. Furthermore, a sensitivity analysis showed that the removal of countries with very large samples (n>300,000 e.g., China, Japan, and Poland, which collectively comprised 93% of all data points) (Table 1) had a negligible effect (ES<0.2) on the international trends, providing support that these countries did not substantially bias the reported international trend in handgrip strength.

Despite the strengths of this study, there are several limitations. First, because we estimated trends in handgrip strength from descriptive data rather than raw data, we were unfortunately unable to statistically remove the effects of factors (e.g., body size) known to influence muscular strength. Previously, absolute handgrip strength has been both positively[162] and negatively[163] associated with cardiometabolic health in children and adolescents, whereas strength relative to body mass appears to be a more consistent positive predictor.[23,164] Because our study was unable to estimate temporal trends in relative handgrip strength, caution should be taken when inferring corresponding trends in population health. Nevertheless, absolute handgrip strength in adolescence is reliably associated with other health outcomes (e.g., bone health),[165,166] and the predictive value of absolute and relative handgrip strength for cardiometabolic risk is comparable.[167] Therefore, there is currently no reason to assume the pooled international improvement in absolute handgrip strength represents a decline in population health. Second, the international trends are largely representative of high- and upper-middle-income countries/special administrative regions (18/19 or 95%), which limits the generalizability of our results to low-income and middle-income countries that may be experiencing a physical activity transition.[168] Third, we have low confidence in our country-level correlations (Table 2) because: (a) of the small number of included countries; (b) the homogeneity in the available trend data between countries; (c) the time span over which trends in handgrip strength were calculated did not always match the time span over which the trends in health-related/sociodemographic indicators were calculated; (d) the correlations between trends in handgrip strength and trends in MVPA/VPA were limited to only European countries; and (e) there is potential for ecological fallacy. Fourth, handgrip data were collected using different sampling strategies and sampling frames and were not always nationally representative. In the absence of nationally representative data, trends were estimated using state/provincial and community level data as they provided the best-available insight into national trends. Furthermore, trends were estimated from available country-sex-age-specific data, which may not be representative of all sex and age groups within a country. Fifth, while differences in test protocols (e.g., dynamometer, number of trials, optimal grip span adjustment, elbow angle, etc.) will affect the variability of the test results, they should not have affected our temporal trends because the included study-level trends were estimated using matched protocols (Supplement 3). Finally, temporal trends in mean handgrip strength could be systematically biased if concurrent trends in skewness occurred, although this is unlikely given that Tremblay et al.[44] reported negligible differences between trends in mean and median handgrip strength in nationally representative samples of Canadian youth tested between 1981 and 2009.

We have previously made recommendations to facilitate data pooling and to improve national and international surveillance of cardiorespiratory fitness.[145,169,170] Here, in order to best track temporal trends in the muscular fitness (e.g., handgrip strength) of children and adolescents, we recommend that:

1 researchers or governments routinely measure handgrip strength (e.g., every 5–10 years) using (where possible) nationally representative data. Care should be taken to minimize temporal variability in sampling and testing procedures;

2 to better synthesize national and international temporal trends, researchers should report temporal trends as absolute, percent, and standardized changes in means at the sex-age level or as descriptive data at the sex-age-year level to allow temporal trends to be

calculated. In addition, they should accurately report the sampling strategy/frame, test protocol, and years of testing;

3 to better understand true underlying causal mechanisms, temporal trends should be adjusted for trends in factors known to influence handgrip strength (e.g., body size, biological maturation), with subsequent changes to trend estimates quantified. For example, allometric scaling has been used to adjust trends in handgrip strength for trends in body size (i.e., height and mass),[51] and adjusting for trends in measures of fat mass and fat-free mass may help explain a significant extra proportion of the residual variance;[154]

4 temporal trends should be examined alongside trends in other health-related outcomes (e.g., traditional cardiovascular risk factors) in order to better understand the effect of trends in muscular fitness on trends in health-related outcomes; and

5 temporal trends in measures of centrality (e.g., means, medians) should be complemented by trends in measures of variability (e.g., standard deviations, coefficients of variation), and asymmetry (e.g., skewness) to identify whether the trends were uniform or non-uniform across the distribution, especially given the recent identification of health-related criterion-referenced cut-points for handgrip strength.[22,24–26]

5 Conclusion

This study found a moderate international improvement in absolute handgrip strength for children and adolescents since 1967, with the rate of improvement progressively increasing over time, with more recent values being two times larger than those in the 1960s/1970s. Generally, improvements in the international handgrip strength were nearly twice as large for children than adolescents, yet similar for boys and girls. Trends in handgrip strength varied between countries, with the national trends being negligibly-to-weakly but not significantly related to national trends in health and sociodemographic indicators. There is a need for improved national and international surveillance of handgrip strength, especially among low- and middle-income countries, in order to more confidently determine true international trends among children and adolescents. In addition, researchers should continue to explore the relationships between absolute handgrip strength and health-related outcomes in children and adolescents to help contextualize our findings.

Disclaimer

The content and views expressed in this article are those of the authors and do not necessarily reflect those of the Government of Canada.

Data availability statement

The datasets analyzed in this review are available from the corresponding author on reasonable request.

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Author Contributions

GRT and FLD developed the research question and designed the study. GRT and FLD had full access to all the data in the study and take responsibility for the integrity of the data. GRT and FLD led the statistical analysis, synthesis of results, and writing of the report. All authors contributed to the interpretation of results, editing and critical reviewing of the final report, and approved the final report.

Compliance with Ethical Standards

Faith L. Dooley, Tori Kaster, John S. Fitzgerald, Tanis J. Walch, Madison Annandale, Katia Ferrar, Justin J. Lang, Jordan J. Smith, and Grant R. Tomkinson declare they have no conflicts of interest

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References

1 Ross R, Blair SN, Arena R, Church TS, Després J, Franklin BA, et al. Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. Circulation. 2016;134(24):e653–99.

2 Harber MP, Kaminsky LA, Arena R, Blair SN, Franklin BA, Myers J, et al. Impact of cardiorespiratory fitness on all-cause and disease-specific mortality: advances since 2009. Prog Cardiovasc Dis. 2017;60(1):11–20.

3 American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 10th ed. Baltimore, MD: Lippincott Williams & Wilkins; 2018.

4 García-Hermoso A, Ramírez-Campillo R, Izquierdo M. Is muscular fitness associated with future health benefits in children and adolescents? A systematic review and meta-analysis of longitudinal studies. Sports Med. 2019;49(7):1079–94.

5 Leong DP, Teo KK, Rangarajan S, Lopez-Jaramillo P, Avezum A, Orlandini A, et al. Prognostic value of grip strength: findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet. 2015;386(9990):266–73.

6 McGrath RP, Kraemer WJ, Snih SA, Peterson MD. Handgrip strength and health in aging adults. Sports Med. 2018;48(9):1993–2000.

7 Ortega FB, Ruiz JR, Castillo MJ, Sjoström M. Physical fitness in childhood and adolescence: a powerful marker of health. Int J Obes (Lond). 2008;32(1):1–11.

8 Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: a systematic review and meta-analysis. Sports Med. 2014;44(9):1209–23.

9 Gale CR, Martyn CN, Cooper C, Sayer AA. Grip strength, body composition, and mortality. Int J Epidemiol. 2007;36(1):228–35.

10 Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB, et al. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci. 2006;61(1):72–7.

11 Mainous AG, Tanner RJ, Anton SD, Jo A. Grip strength as a marker of hypertension and diabetes in healthy weight adults. Am J Prev Med. 2015;49(6):850–8.

12 Hamasaki H, Kawashima Y, Katsuyama H, Sako A, Goto A, Yanai H. Association of handgrip strength with hospitalization, cardiovascular events, and mortality in Japanese patients with type 2 diabetes. Sci Rep. 2017;7(1):7041.

13 Bohannon RW. Hand-grip dynamometry predicts future outcomes in aging adults. J Geriatr Phys Ther. 2008;31(1):3–10.

14 Chan BK, Marshall LM, Winters KM, Faulkner KA, Schwartz AV, Orwoll ES. Incident fall risk and physical activity and physical performance among older men: the Osteoporotic Fractures in Men Study. Am J Epidemiol. 2006;165(6):696–703.

15 McGrath R, Robinson-Lane SG, Peterson MD, Bailey RR, Vincent BM. Muscle strength and functional limitations: preserving function in older Mexican Americans. J Am Med Dir Assoc. 2018;19(5):391–8.

16 Taekema DG, Gussekloo J, Maier AB, Westendorp RG, de Craen AJ. Handgrip strength as a predictor of functional, psychological and social health. A prospective population-based study among the oldest old. Age Ageing. 2010;39(3):331–7.

17 Buchman AS, Wilson RS, Boyle PA, Bienias JL, Bennett DA. Grip strength and the risk of incident Alzheimer's disease. Neuroepidemiology. 2007;29(1–2):66–73.

18 Fraser BJ, Blizzard L, Schmidt MD, Juonala M, Dwyer T, Venn AJ, et al. Childhood cardiorespiratory fitness, muscular fitness and adult measures of glucose homeostasis. J Sci Med Sport. 2018;21(9):935–40.

19 Grøntved A, Ried-Larsen M, Ekelund U, Froberg K, Brage S, Andersen LB. Independent and combined association of muscle strength and cardiorespiratory fitness in youth with insulin resistance and beta-cell function in young adulthood: the European Youth Heart Study. Diabetes Care. 2013;36(9):2575–81.

20 Ortega FB, Silventoinen K, Tynelius P, Rasmussen F. Muscular strength in male adolescents and premature death: cohort study of one million participants. BMJ. 2012;345:e7279.

21 Artero EG, Ruiz JR, Ortega FB, España-Romero V, Vicente-Rodríguez G, Molnar D, et al. Muscular and cardiorespiratory fitness are independently associated with metabolic risk in adolescents: the HELENA study. Pediatr Diabetes. 2011;12(8):704–12.

22 Castro-Piñero J, Perez-Bey A, Cuenca-Garcia M, Cabanas-Sanchez V, Gómez-Martínez S, Veiga OL, et al. Muscle fitness cut points for early assessment of cardiovascular risk in children and adolescents. J Pediatr. 2019;206:134–41.

23 Peterson MD, Gordon PM, Smeding S, Visich P. Grip strength is associated with longitudinal health maintenance and improvement in adolescents. J Pediatr. 2018;202:226–30.

24 Peterson MD, Zhang P, Saltarelli WA, Visich PS, Gordon PM. Low muscle strength thresholds for the detection of cardiometabolic risk in adolescents. Am J Prev Med. 2016;50(5):593–99.

25 Ramírez-Vélez R, Peña-Ibagon JC, Martínez-Torres J, Tordecilla-Sanders A, Correa-Bautista JE, Lobelo F, et al. Handgrip strength cutoff for cardiometabolic risk index among Colombian children and adolescents: the FUPRECOL Study. Sci Rep. 2017;7:42622.

26 Saint-Maurice PF, Laurson K, Welk G, Eisenmann J, Gracia-Marco L, Artero EG, et al. Grip strength cutpoints for youth based on a clinically relevant bone health outcome. Arch Osteoporos. 2018;13(1):92.

27 Australian Government Department of Health. Australian 24-hour movement guidelines for children (5–12 years) and young people (13–17 years): an integration of physical activity, sedentary behaviour, and sleep. https://www.health.gov.au/internet/main/publishing.nsf/Content/health-24-hours-phys-act-guidelines. Accessed 7 July 2019.

28 Canadian Society for Exercise Physiology. Canadian 24-hour movement guidelines for children and youth (ages 5–17 years): an integration of physical activity, sedentary behaviour and sleep. https://csepguidelines.ca/children-and-youth-5-17/. Accessed 7 July 2019.

29 U.S. Department of Health and Human Services. Physical activity guidelines for Americans. 2nd ed. Washington, DC: U.S. Department of Health and Human Services; 2018.

30 World Health Organization. Global recommendations on physical activity for health. Geneva: WHO Press; 2010.

31 Milliken LA, Faigenbaum AD, Loud RL, Westcott WL. Correlates of upper and lower body muscular strength in children. J Strength and Cond Res. 2008;22(4):1339–46.

32 Wind AE, Takken T, Helders PJ, Engelbert RH. Is grip strength a predictor for total muscle strength in healthy children, adolescents, and young adults? Eur J Pediatr. 2010;169(3):281–87.

33 Artero EG, España-Romero V, Castro-Piñero J, Ortega FB, Suni J, Castillo-Garzon MJ, et al. Reliability of field-based fitness tests in youth. Int J Sports Med. 2011;32(3), 159–69.

34 Mathiowetz V, Weber K, Volland G, Kashman N. Reliability and validity of grip and pinch strength evaluations. J Hand Surg Am. 1984;9(2):222–6.

35 Vermeulen J, Neyens JC, Spreeuwenberg MD, van Rossum E, Hewson DJ, de Witte LP. Measuring grip strength in older adults: comparing the grip-ball with the Jamar dynamometer. J Geriatr Phys Ther. 2015;38(3):148–53.

36 Ortega FB, Artero EG, Ruiz JR, Vicente-Rodriguez G, Bergman P, Hagströmer M, et al. Reliability of health-related physical fitness tests in European adolescents. The HELENA Study. Int J Obesity (Lond). 2008;32(Suppl 5):S49–57.

37 Institute of Medicine. Fitness measures and health outcomes in youth. Washington, DC: The National Academies Press; 2012.

38 Ruiz JR, Castro-Piñero J, España-Romero V, Artero EG, Ortega FB, Cuenca MM, et al. Field-based fitness assessment in young people: the ALPHA health-related fitness test battery for children and adolescents. Br J Sports Med. 2011;45(6):518–24.

39 Tomkinson GR, Lang JJ, Tremblay MS. Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. Br J Sports Med. 2019;53(8):478–86.

40 Lamoureux NR, Fitzgerald JS, Norton KI, Sabato T, Tremblay MS, Tomkinson GR. Temporal trends in the cardiorespiratory fitness of 2,525,827 adults between 1967 and 2016: a systematic review. Sports Med. 2019;49(1):41–55.

41 Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Mahwah, NJ: Lawrence Erlbaum; 1988.

42 Silverman IW. The secular trend for grip strength in Canada and the United States. J Sports Sci. 2011;29(6):599–606.

43 Silverman IW. Age as a moderator of the secular trend for grip strength in Canada and the United States. Ann Hum Biol. 2015;42(3):199–209.

44 Tremblay MS, Shields M, Laviolette M, Craig CL, Janssen I, Connor Gorber S. Fitness of Canadian children and youth: results from the 2007–2009 Canadian Health Measures Survey. Health Rep. 2010;21(1):7–20.

45 Malina RM, Reyes ME, Tan SK, Little BB. Secular change in muscular strength of indigenous rural youth 6–17 years in Oaxaca, southern Mexico: 1968–2000. Ann Hum Biol. 2010;37(2):168–84.

46 Dos Santos FK, Prista A, Gomes TN, et al. Secular trends in physical fitness of Mozambican school-aged children and adolescents. *Am J Hum Biol*. 2015; 27(2):201–206.

47 Ignasiak Z, Sławińska T, Malina RM. Short term secular change in body size and physical fitness of youth 7–15 years in Southwestern Poland: 2001–2002 and 2010–2011. Anthropol Rev. 2016;79(3):311–29.

48 Saczuk J, Wasiluk A. Changes in the somatic and fitness variables in girls over two decades. Biomed Hum Kinet. 2010;2(1):102–5.

49 Saczuk J, Wasiluk A, Zalech M. Generation changes over the period of 1986–2006 in the physical fitness of boys aged 7–19 from eastern Poland at particular stages of education. Biomed Hum Kinet. 2012;4:112–6.

50 Haslofça F, Kutlay E, Haslofça E. 11–12 yaş Türk çocuklarının bazı fiziksel uygunluk değerlerindeki otuz yıllık değişimlerin incelenmesi (Analysis of three decade changes in physical fitness characteristics of Turkish children aged between 11 and 12). Spor Hekimliği Dergisi (Turk J Sports Med). 2017;52(4):137–45.

51 Sandercock GRH, Cohen DD. Temporal trends in muscular fitness of English 10-year-olds 1998–2014: an allometric approach. J Sci Med Sport. 2019;22(2):201–5.

52 Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339:b2535.

53 Tomkinson GR, Macfarlane D, Noi S, Dae-Yeon K, Wang Z, Hong R. Temporal changes in long-distance running performance of Asian children between 1964 and 2009. Sports Med. 2012;42(4):267–79.

54 Tomkinson GR, Olds TS. Secular changes in pediatric aerobic fitness test performance: The global picture. Med Sport Sci. 2007;50:46–66.

55 United Nations, Department of Economic and Social Affairs, Population Division. World population prospects 2019: data booklet (ST/ESA/SER.A/424). New York: United Nations; 2019.

56 NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. Lancet. 2017;390(10113):2627–42.

57 Inchley J, Currie D, Jewell J. Adolescent obesity and related behaviours: trends and inequalities in the WHO European region, 2002–2014. Observations from the Health Behaviour in School-aged Children (HBSC) WHO collaborative cross-national study. Copenhagen: World Health Organization; 2017.

58 World Bank. GINI index (World Bank estimate). https://data.worldbank.org/indicator/si.pov.gini. Accessed 27 Jun 2019.

59 United Nations Development Programme. Human development indices and indicators: 2018 statistical update. New York: United Nations Development Programme; 2018.

60 World Bank. Urban population growth (annual %). https://data.worldbank.org/indicator/SP.URB.GROW. Accessed 27 Jun 2019.

61 Catley MJ, Tomkinson GR. Normative health-related fitness values for children: analysis of 85347 test results on 9–17-year-old Australians since 1985. Br J Sports Med. 2013;47(2):98–108.

62 Malina RM. Secular changes in growth, maturation, and physical performance. Exerc Sport Sci Rev. 1978;6:203–55.

63 Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis LK, Fitzgerald JS, et al. European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2 779 165 Eurofit performances representing 30 countries. Br J Sports Med. 2018;52(22):1445–56.

64 Dimitrova D. Fizicheska deesposobnost na podrastvashtite vuv vruska s vuzrastovite promeni v telesnite razmeri I sustava na telesnata masa (Physical fitness of children and adolescents in relation with age-specific changes in body composition). Doctoral dissertation. Sofia: National Sports Academy; 2001.

65 Slanchev P, Janev B, Genov F, Shterev P, Boev P, Sepetliev D, et al. Fizichesko razvitie, fizicheska deesposobnost I nervo-psichichna reaktivnost na naselenieto na Bulgaria: III Nacionalno izsledvane (1980–1982) (Physical development, physical fitness and neuropsychic reactivity of Bulgarian population: III National Project [1980–1982]). Sofia: Bulgarian Union for Physical Education and Sports; 1992.

66 Yanev B, Shterev P, Boev P, Genov F, Sepetliev D, Popov I, et al. Fizichesko razvitie, fizicheska deesposobnost I nervo-psichichna reaktivnost na naselenieto (Physical development, physical fitness and neuropsychic reactivity of the Bulgarian people from birth up to age 60). Sofia: Bulgarian Union for Physical Education and Sports; 1982.

67 Yanev B, Shterev P, Boev P, Semerdjieva R, Sepetliev D. Fizichesko razvitie I deesposobnost na naselenieto na Bulgaria ot rajdaneto do 26 godini, tom I (Physical development and fitness of Bulgarian people from the birth up to the age of 26, volume I). Sofia: Bulgarian Academy of Sciences; 1965.

68 Fortier MD, Katzmarzyk PT, Malina RM, Bouchard C. Seven-year stability of physical activity and musculoskeletal fitness in the Canadian population. Med Sci Sports Exerc. 2001;33(11):1905–111.

69 Silverman IW. The secular trend for grip strength in Canada and the United States. J Sports Sci. 2011;29(6):599–606.

70 Silverman IW. Age as a moderator of the secular trend for grip strength in Canada and the United States. Ann Hum Biol. 2015;42(3):199–209.

71 Tremblay MS, Shields M, Laviolette M, Craig CL, Janssen I, Connor Gorber S. Fitness of Canadian children and youth: results from the 2007–2009 Canadian Health Measures Survey. Health Rep. 2010;21(1):7–20.

72 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the Physical Fitness and Health Research of Chinese School Students 2000. Beijing: Higher Education Press; 2002.

73 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the Physical Fitness and Health Research of Chinese School Students 2005. Beijing: Higher Education Press; 2007.

74 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the Physical Fitness and Health Research of Chinese School Students 2010. Beijing: Higher Education Press; 2012.

75 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the Physical Fitness and Health Research of Chinese School Students 2014. Beijing: Higher Education Press; 2016.

76 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 1999–2000. https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html. Accessed 23 Sept 2018.

77 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2003–2004. https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html. Accessed 23 Sept 2018.

78 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2005–2006. https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html. Accessed 23 Sept 2018.

79 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2010–2011. https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html. Accessed 23 Sept 2018.

80 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2015–2016. https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html. Accessed 23 Sept 2018.

81 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1968.

82 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1969.

83 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1970.

84 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1971.

85 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1972.

86 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1973.

87 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1974.

88 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1975.

89 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1976.

90 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1977.

91 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1978.

92 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1979.

93 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1980.

94 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1981.

95 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1982.

96 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1983.

97 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1984.

98 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1985.

99 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1986.

100 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1987.

101 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1988.
102 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1989.
103 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1990.
104 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1991.
105 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1992.
106 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1993.
107 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1994.
108 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1995.
109 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1996.
110 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1997.

111 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1998.
112 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1999.
113 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2000.
114 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2001.
115 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2002.
116 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2003.
117 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2004.
118 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2005.
119 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2006.
120 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2007.

121 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2008.

122 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2009.

123 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2010.

124 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2011.

125 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2012.

126 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2013.

127 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2014.

128 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2015.

129 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2016.

130 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2017.

131 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2018.

132 Malina RM, Reyes ME, Tan SK, Little BB. Secular change in muscular strength of indigenous rural youth 6–17 years in Oaxaca, southern Mexico: 1968–2000. Ann Hum Biol. 2010;37(2):168–84.

133 Dos Santos FK, Prista A, Gomes TN, et al. Secular trends in physical fitness of Mozambican school-aged children and adolescents. *Am J Hum Biol*. 2015; 27(2):201–206.

134 Ignasiak Z, Sławińska T, Malina RM. Short term secular change in body size and physical fitness of youth 7–15 years in Southwestern Poland: 2001–2002 and 2010–2011. Anthropol Rev. 2016;79(3):311–29.

135 Przeweda R, Dobosz J. Growth and physical fitness of Polish youths in two successive decades. J Sports Med Phys Fitness. 2003;43(4):465–74.

136 Saczuk J, Wasiluk A. Changes in the somatic and fitness variables in girls over two decades. Biomed Hum Kinet. 2010;2(1):102–5.

137 Saczuk J, Wasiluk A, Zalech M. Generation changes over the period of 1986–2006 in the physical fitness of boys aged 7–19 from eastern Poland at particular stages of education. Biomed Hum Kinet. 2012;4:112–6.

138 Klanarong S. Socio-demographic distribution of health-related fitness of Thai children. Doctoral dissertation. Adelaide, SA: University of South Australia; 2005.

139 Haslofça F, Kutlay E, Haslofça E. 11–12 yaş Türk çocuklarının bazı fiziksel uygunluk değerlerindeki otuz yıllık değişimlerin incelenmesi (Analysis of three decade changes in physical fitness characteristics of Turkish children aged between 11 and 12). Spor Hekimliği Dergisi (Turk J Sports Med). 2017;52(4):137–45.

140 Sandercock GRH, Cohen DD. Temporal trends in muscular fitness of English 10-year-olds 1998–2014: an allometric approach. J Sci Med Sport. 2019;22(2):201–5.

141 Espenchade AS, Meleney HE. Motor performances of adolescent boys and girls of today in comparison with those 24 years ago. Res Q. 1961;32(2):186–9.

142 Montpetit RR, Montoye HJ, Laeding, L. Grip strength of school children, Saginaw, Michigan: 1899 and 1964. Res Q. 1967;38(2):231–40.

143 World Bank. World Bank country and lending groups. http://data.worldbank.org/about/country-and-lending-groups. Accessed 27 Jun 2019.

144 World Bank. Land area (sq. km). https://data.worldbank.org/indicator/AG.LND.TOTL.K2. Accessed 27 Jun 2019.

145 Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis LK, Fitzgerald JS, et al. European normative values for physical fitness in children and adolescents aged 9-17 years: results from 2 779 165 Eurofit performances representing 30 countries. Br J Sports Med. 2018;52(22):1445–56.

146 Malina RM. Anthropometric correlates of strength and motor performance. Exerc Sport Sci Rev. 1975;3:249–74.

147 Malina RM. Anthropometry, strength and motor fitness. In: Ulijaszek SJ, Mascie-Taylor CGN, editors. Anthropometry: the individual and the population. Cambridge: Cambridge University Press; 1994. pp. 160–77.

148 Malina RM. Secular trends in growth, maturation and physical performance: a review. Anthropol Rev. 2004;67:3–31.

149 Backstrand JR. The history and future of food fortification in the United States: a public health perspective. Nutr Rev. 2002;60(1):15–26.

150 Cutler D, Miller G. The role of public health improvements in health advances: the twentieth-century United States. Demography. 2005;42(1):1–22.

151 Olds TS. One million skinfolds: secular trends in the fatness of young people 1951–2004. Eur J Clin Nutr. 2009;63(8):934–46.

152 Fukunaga T, Miyatani M, Tachi M, Kouzaki M, Kawakami Y, Kanehisa H. Muscle volume is a major determinant of joint torque in humans. Acta Physiol Scand. 2001;172(4):249–55.

153 Malina RM, Bouchard C, Bar-Or O. Growth, maturation and physical activity. 2nd ed. Champaign, IL: Human Kinetics; 2004.

154 Moliner-Urdiales D, Ruiz JR, Ortega FB, Jiménez-Pavón D, Vicente-Rodriguez G, Rey-López JP, et al. Secular trends in health-related physical fitness in Spanish adolescents: the AVENA and HELENA studies. J Sci Med Sport. 2010;13(6):584–8.

155 Roche AF. Secular trends in stature, weight, and maturation. Monogr Soc Res Child Dev. 1979;44(3–4):3–27.

156 Smith JJ, Eather N, Weaver RG, Riley N, Beets MW, Lubans DR. Behavioral correlates of muscular fitness in children and adolescents: a systematic review. Sports Med. 2019;49(6):887–904.

157 Booth VM, Rowlands AV, Dollman J. Physical activity temporal trends among children and adolescents. J Sci Med Sport 2015;18(4):418–25.

158 Ekelund U, Tomkinson G, Armstrong N. What proportion of youth are physically active? Measurement issues, levels and recent time trends. Br J Sports Med. 2011;45(11):859–65.

159 Knuth AG, Hallal PC. Temporal trends in physical activity: a systematic review. J Phys Act Health. 2009;6(5):548–59.

160 Lang JJ, Larouche R, Tremblay MS. The association between physical fitness and health in a nationally representative sample of Canadian children and youth aged 6 to 17 years. Health Promot Chronic Dis Prev Can. 2019;39(3):104–11.

161 Aubert S, Barnes JD, Abdeta C, Abi Nader P, Adeniyi AF, Aguilar-Farias N, et al. Global Matrix 3.0 physical activity report card grades for children and youth: results and analysis from 49 countries. J Phys Act Health. 2018;15(Suppl 2):S251–73.

162 Rioux BV, Kuwornu P, Sharma A, Tremblay MS, McGavock JM, Sénéchal M. Association between handgrip muscle strength and cardiometabolic z-score in children 6 to 19 years of age: results from the Canadian Health Measures Survey. Metab Syndr Relat Disord. 2017;15(7):379–84.

163 Zaqout M, Michels N, Bammann K, Ahrens W, Sprengeler O, Molnar D, et al. Influence of physical fitness on cardio-metabolic risk factors in European children. The IDEFICS study. Int J Obes (Lond). 2016;40(7):1119–25.

164 Artero EG, España-Romero V, Jiménez-Pavón D, Martinez-Gómez D, Warnberg J, Gómez-Martínez S, et al. Muscular fitness, fatness and inflammatory biomarkers in adolescents. Pediatr Obes. 2014;9(5):391–400.

165 Delvaux K, Lefevre J, Philippaerts R, Dequeker J, Thomis M, Vanreusel B, et al. Bone mass and lifetime physical activity in Flemish males: a 27-year follow-up study. Med Sci Sports Exerc. 2001;33(11):1868–75.

166 Vicente-Rodríguez G, Urzanqui A, Mesana MI, Ortega FB, Ruiz JR, Ezquerra J, et al. Physical fitness effect on bone mass is mediated by the independent association between

lean mass and bone mass through adolescence: a cross-sectional study. J Bone Miner Metab. 2008;26(3):288–94.

167 Ramírez-Vélez R, Tordecilla-Sanders A, Correa-Bautista JE, Peterson MD, Garcia-Hermoso A. Handgrip strength and ideal cardiovascular health among Colombian children and adolescents. J Pediatr. 2016;179:82–9.

168 Katzmarzyk PT, Mason C. The physical activity transition. J Phys Act Health. 2009;6(3):269–80.

169 Tomkinson GR, Lang JJ, Tremblay MS, Dale M, LeBlanc AG, Belanger K, et al. International normative 20 m shuttle run values from 1 142 026 children and youth representing 50 countries. Br J Sports Med. 2017;51(21):1545–54.

170 Tomkinson GR, Lang JJ, Blanchard J, Léger LA, Tremblay MS. The 20-m shuttle run: assessment and interpretation of data in relation to youth aerobic fitness and health. Pediatr Exerc Sci. 2019;31(2):152–63.

Tables

Table 1. Summary of the included studies by country.

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI
Australia[61]	F (49.5%) M (50.5%)	9–12	1985–1999	2,912	P	N/S/O	0.939 (very high)
Belgium[62–63]	F (47.7%) M (52.3%)	9–17	1835–2010	27,868	P/NP	S/O	0.916 (very high)
Bulgaria[64–67]	F (50.7%) M (49.3%)	9–17	1960–1999	28,058	P	N/O	0.813 (very high)
Canada[68–71]	F (49.7%) M (50.3%)	9–17	1967–2009	6,884	P/NP	N/O	0.926 (very high)
China[72–75]	F (49.9%) M (50.1%)	9–17	2000–2014	656,162	P	N	0.752 (high)
Estonia[63]	F (53.4%) M (46.6%)	10–17	1992–2002	4,338	P/NP	S/O	0.871 (very high)
France[63]	F (52.1%) M (47.9%)	11,13,14	1985–2008	572	P/NP	O	0.901 (very high)
Greece[63]	F (48.7%) M (51.3%)	13–15	1990–2008	2,188	P/NP	N/O	0.870 (very high)
Hong Kong[76–80]	F (48.6%) M (51.4%)	9–12	2000–2015	17,653	P	N	0.933 (very high)
Italy[63]	F (50.9%) M (49.1%)	12–16	1992–2008	5,643	P/NP	S/O	0.880 (very high)
Japan[81–131]	F (49.4%) M (50.6%)	9–17	1967–2017	1,043,672	P	N	0.909 (very high)
Mexico[132]	F (49.8%) M (50.2%)	9–17	1968–2000	2,463	NP	O	0.774 (high)
Mozambique[133]	F (53.0%) M (47.0%)	9–17	1992–2012	3,283	P	O	0.437 (low)
Poland[63,134–137]	F (49.1%) M (50.9%)	9–17	1979–2011	367,320	P/NP	N/S/O	0.865 (very high)
Spain[63]	F (51.3%) M (48.7%)	9–17	1984–2010	19,948	P/NP	S/O	0.891 (very high)
Thailand[138]	F (51.0%) M (49.0%)	9–12	1990–2003	15,235	P	N	0.755 (high)
Turkey[139]	F (30.8%) M (69.2%)	11–12	1983–2013	1,195	NP	O	0.791 (high)
UK[63,140]	F (57.6%) M (42.4%)	9–13,15,17	1981–2014	17,842	P/NP	N/S/O	0.922 (very high)
USA[69,70,141,142]	F (46.8%) M (53.2%)	9–17	1899–2009	7,153	NP	S/O	0.924 (very high)

Note: UK=United Kingdom; USA=United States of America; M=male; F=female; P=probability sampling (i.e., random selection); NP=non-probability sampling (i.e., non-random selection); N=national sampling; S=state/provincial sampling; O=other sampling (i.e., city, local area, or school-level sampling); HDI=Human Development Index (2017 estimate) with HDI values of 0.800, 0.700 and 0.550 used as thresholds for very high, high and medium human development, respectively;[59] Hong Kong is a special administrative region of the People's

Republic of China, and because it maintains a separate governing and economic system, national temporal trends in handgrip strength were estimated separately from China.

Table 2. Potential health-related and sociodemographic correlates of the trends in handgrip strength for children and adolescents.

Variable	Data source	Description	Correlation (95%CI)
Health			
Body mass index (BMI)	NCD-RisC[56] Trend data available for 19/19 (100%) countries/special administrative regions between 1975 and 2016.	Calculated as the change (per decade) in mean country-level BMI of boys and girls aged 5–19 years (age standardized). With increasing handgrip strength, a positive correlation (next column) indicated an increase in mean BMI and a negative correlation indicated a decline.	0.18 (−0.30 to 0.59)
Moderate-to-vigorous physical activity (MVPA) and vigorous physical activity (VPA)	Inchley et al.[57] Data originally obtained from Health Behaviour in School-aged Children (HBSC) World Health Organization (WHO) collaborative cross-national study. Trend data available for 10 European countries (10/19 or 53% of all countries) between 2002 and 2014.	Calculated as the change (per decade) in mean country-level percentage of boys and girls aged 11-, 13-, and 15-years old that achieved at least 60 minutes of MVPA everyday or VPA at least four times per week. With increasing handgrip strength, a positive correlation indicated an increase in the mean percentage of moderately-to-vigorously or vigorously active children and a negative correlation indicated a decline.	MVPA 0.14 (−0.54 to 0.71) VPA 0.15 (−0.53 to 0.71)
Sociodemographic			
Gini index	World Bank[58] Trend data available for 17/19 (89%) countries/special administrative regions between 1990 and 2017.	Summarizes the change (per decade) in the distribution of income among individuals in a country where 0 represents perfect equality and 100 implies perfect inequality. With increasing handgrip strength, a positive correlation indicated a trend towards perfect inequality and a negative correlation a trend towards perfect equality..	0.04 (−0.45 to 0.51)

Human development index (HDI)	United Nations[59] Trend data available for 18/19 (95%) countries/special administrative regions between 1990 and 2017.	Calculated as the change (per decade) in mean country-level human development (i.e., achievements in health, education and income). With increasing handgrip strength, a positive correlation indicated an increase in the mean human development and a negative correlation indicated a decline.	0.15 (−0.34 to 0.58)
Urbanization	World Bank[60] Trend data available for 19/19 (100%) countries/special administrative regions between 1967 and 2017.	Calculated as the change (per decade) in the percentage of people living in urban areas. With increasing handgrip strength, a positive correlation indicated an increase in urbanization and a negative correlation indicated a decline.	0.27 (−0.21 to 0.65)

Figure captions

Figure 1. PRISMA flow chart outlining the flow of studies through the review.

Figure 2. International temporal trends in mean handgrip strength between 1967 and 2017.

Note: data were standardized to the year 2000=100%, with higher values (>100%) indicating better handgrip strength and negative values (<100%) indicating poorer handgrip strength; the solid lines represent the international changes in mean handgrip strength, and the shaded areas represent the 95%CIs, with upward sloping lines indicating increases over time and downward sloping lines indicating declines over time; mean (95%CI) percent changes (per decade) are shown at the top of each panel.

Figure 3. National temporal trends in mean handgrip strength between 1967 and 2017.

Note: data were standardized to the year 2000=100%, with higher values (>100%) indicating better handgrip strength and negative values (<100%) indicating poorer handgrip strength; the solid lines represent the national changes in mean handgrip strength, and the shaded areas represent the 95%CIs, with upward sloping lines indicating increases over time and downward sloping lines indicating declines over time; mean (95%CI) percent changes (per decade) are shown at the top of each panel; for this study, national temporal trends in mean handgrip strength for China and Hong Kong (a special administrative region of the People's Republic of China) were estimated separately.

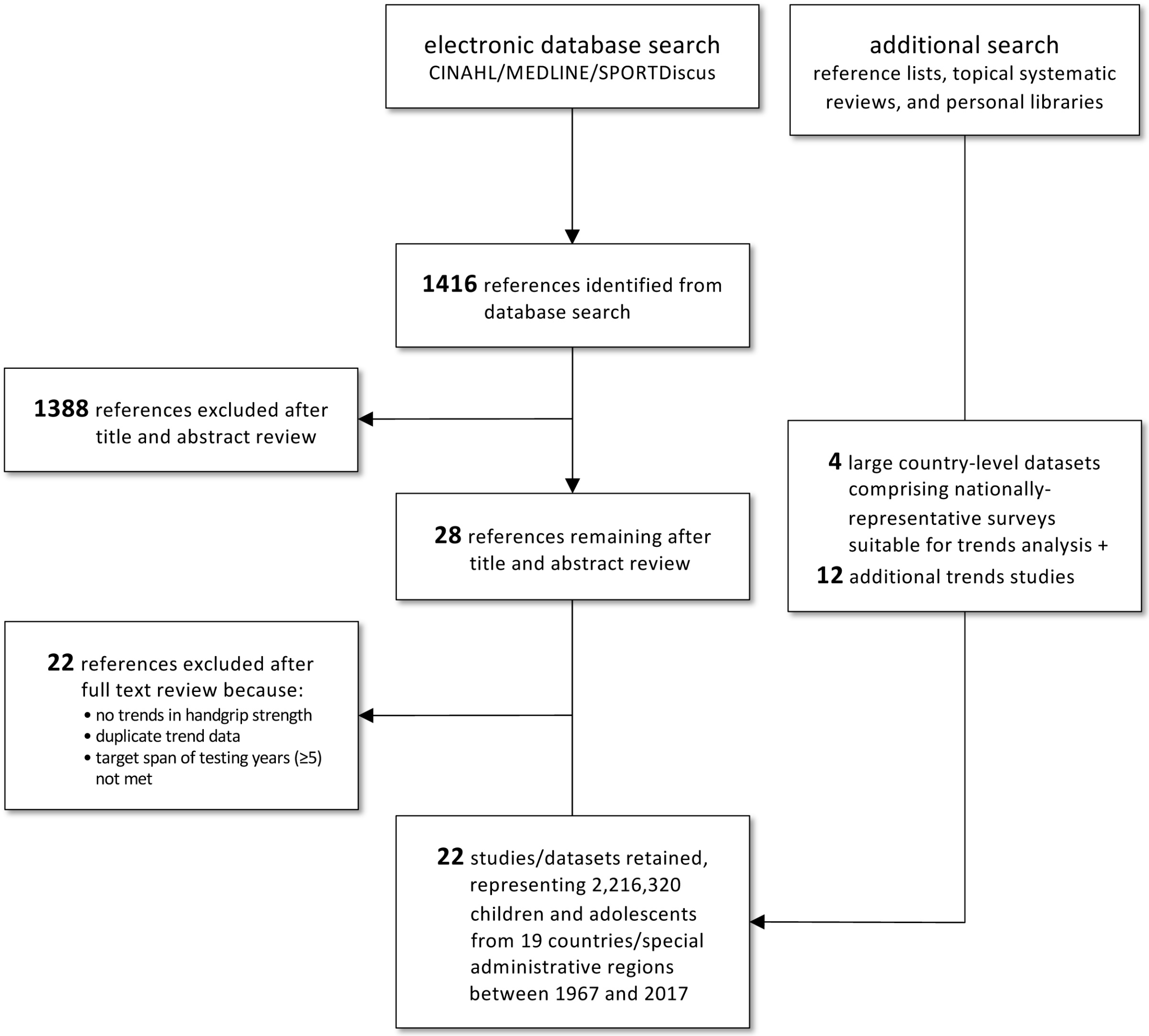
electronic database search
CINAHL/MEDLINE/SPORTDiscus
additional search
reference lists, topical systematic reviews, and personal libraries
1416 references identified from database search
1388 references excluded after title and abstract review
28 references remaining after title and abstract review
4 large country-level datasets comprising nationally-representative surveys suitable for trends analysis +
12 additional trends studies
22 references excluded after full text review because:
• no trends in handgrip strength
• duplicate trend data
• target span of testing years (≥5) not met
22 studies/datasets retained, representing 2,216,320 children and adolescents from 19 countries/special administrative regions between 1967 and 2017

Figure 1.

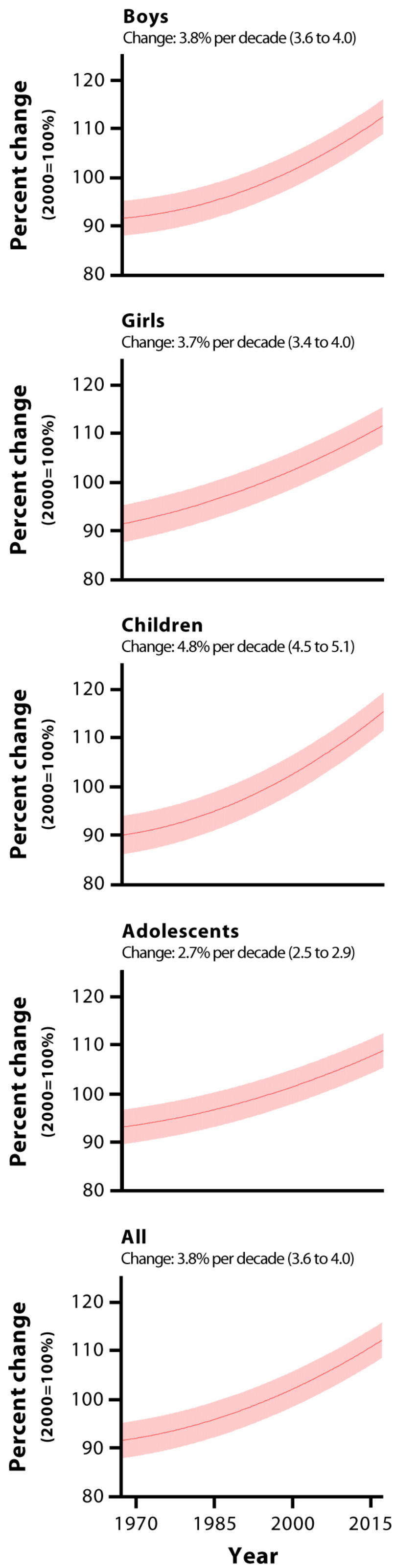
Boys
Change: 3.8% per decade (3.6 to 4.0)
Girls
Change: 3.7% per decade (3.4 to 4.0)
Children
Change: 4.8% per decade (4.5 to 5.1)
Adolescents
Change: 2.7% per decade (2.5 to 2.9)
All
Change: 3.8% per decade (3.6 to 4.0)
Percent change
(2000=100%)
120
110
100
90
80
1970
1985
2000
2015
Year

Figure 2.

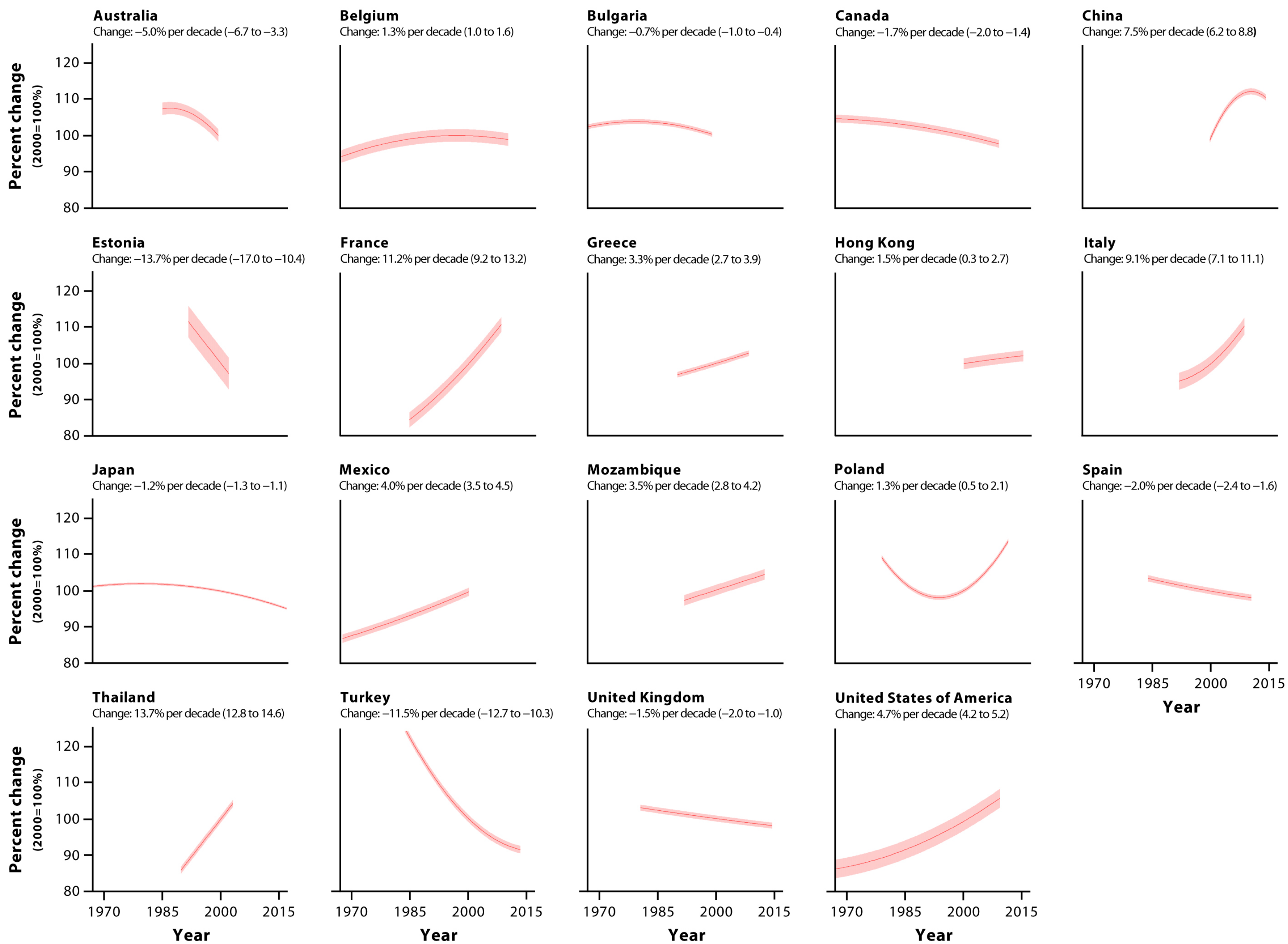
Australia
Change: −5.0% per decade (−6.7 to −3.3)
Belgium
Change: 1.3% per decade (1.0 to 1.6)
Bulgaria
Change: −0.7% per decade (−1.0 to −0.4)
Canada
Change: −1.7% per decade (−2.0 to −1.4)
China
Change: 7.5% per decade (6.2 to 8.8)
Estonia
Change: −13.7% per decade (−17.0 to −10.4)
France
Change: 11.2% per decade (9.2 to 13.2)
Greece
Change: 3.3% per decade (2.7 to 3.9)
Hong Kong
Change: 1.5% per decade (0.3 to 2.7)
Italy
Change: 9.1% per decade (7.1 to 11.1)
Japan
Change: −1.2% per decade (−1.3 to −1.1)
Mexico
Change: 4.0% per decade (3.5 to 4.5)
Mozambique
Change: 3.5% per decade (2.8 to 4.2)
Poland
Change: 1.3% per decade (0.5 to 2.1)
Spain
Change: −2.0% per decade (−2.4 to −1.6)
Thailand
Change: 13.7% per decade (12.8 to 14.6)
Turkey
Change: −11.5% per decade (−12.7 to −10.3)
United Kingdom
Change: −1.5% per decade (−2.0 to −1.0)
United States of America
Change: 4.7% per decade (4.2 to 5.2)
Percent change
(2000=100%)
80
90
100
110
120
1970
1985
2000
2015
Year

Figure 3.

Supplementary Material

Article title: A systematic analysis of temporal trends in the handgrip strength of 2,216,320 children and adolescents between 1967 and 2017; **Journal name:** Sports Medicine; **Author names and affiliations:** Faith L. Dooley (University of North Dakota), Tori Kaster (University of North Dakota), John S. Fitzgerald (University of North Dakota), Tanis J. Walch (University of North Dakota), Madison Annandale (University of South Australia), Katia Ferrar (University of South Australia), Justin J. Lang (Public Health Agency of Canada and Children's Hospital of Eastern Ontario Research Institute), Jordan J. Smith (University of Newcastle), and Grant R. Tomkinson (University of North Dakota and University of South Australia); **E-mail address of the corresponding author:** grant.tomkinson@und.edu.

Supplement 1. Search strategy for databases.

Search terms

(physical fitness OR muscular fitness OR muscular strength OR muscular endurance OR musculoskeletal fitness OR aerobic fitness OR cardiovascular fitness OR cardiorespiratory fitness) AND (child* OR youth OR young OR adolescen*) AND (temporal OR secular OR trend*).

Databases

CINAHL (1991 to 30 October 2018): 208 studies identified.

MEDLINE (1974 to 30 October 2018): 793 studies identified.

SPORTDiscus (1956 to 30 October 2018): 415 studies identified.

Article title: A systematic analysis of temporal trends in the handgrip strength of 2,216,320 children and adolescents between 1967 and 2017; **Journal name:** Sports Medicine; **Author names and affiliations:** Faith L. Dooley (University of North Dakota), Tori Kaster (University of North Dakota), John S. Fitzgerald (University of North Dakota), Tanis J. Walch (University of North Dakota), Madison Annandale (University of South Australia), Katia Ferrar (University of South Australia), Justin J. Lang (Public Health Agency of Canada and Children's Hospital of Eastern Ontario Research Institute), Jordan J. Smith (University of Newcastle), and Grant R. Tomkinson (University of North Dakota and University of South Australia); **E-mail address of the corresponding author:** grant.tomkinson@und.edu.

Supplement 2. Handgrip strength test protocols for the 22 included studies/datasets.

Web reference(s)	Country	Which hand was used?	How was handgrip strength calculated?	What was the elbow position?	How many trials were allowed per hand?	Which dynamometer was used?	Was the dynamometer adjusted for hand size?
61	Australia	Both	Average of maxima	Bent	1	Mechanical	Yes
62	Belgium	Right	Maximum	NA	NA	Mechanical	NA
63	Belgium/Estonia/France/Greece/Italy/Poland/Spain/UK	Dominant	Maximum	Straight	2	NA	Yes
64–67	Bulgaria	Right	Maximum	NA	NA	NA	NA
68	Canada	Both	Sum of maxima	Straight	2	Mechanical	Yes
69	Canada/USA	Both	Sum of maxima	NA	NA	NA	NA
70	Canada/USA	Both	Sum of maxima	NA	NA	NA	NA
71	Canada	Both	Sum of maxima	Straight	2	Mechanical	Yes
72–75	China	Dominant	Maximum	Straight	2	Mechanical	Yes
76–80	Hong Kong	Both	Sum of maxima	Straight	3	Mechanical	Yes
81–131	Japan	Both	Average of maxima	Straight	2	Mechanical	Yes
132	Mexico	Both	Sum of maxima*	NA	3	Mechanical	Yes

133	Mozambique	Dominant	Maximum	Straight	2	Mechanical	Yes
134	Poland	Right	Maximum	NA	2	Hydraulic	NA
135	Poland	Dominant	Maximum	Straight	2	NA	Yes
136	Poland	Dominant	Maximum	Straight	3	NA	Yes
137	Poland	Dominant	Maximum	Straight	3	NA	Yes
138	Thailand	Dominant	Maximum	Straight	2	NA	Yes
139	Turkey	Dominant	Maximum	Straight	2	Mechanical	Yes
140	UK	Dominant	Maximum	NA	3	Mechanical	Yes
141	USA	Dominant	Maximum	Bent	NA	NA	NA
142	USA	Both	Maximum	Straight	2	Mechanical	NA

Note: NA=Not available;*=temporal data were available for maximum of right hand, maximum of left hand, and sum of the maxima for both hands, with trends estimated in this study using the sum of the maxima for both hands.