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TITLE

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Running title

Temporal trends in adult handgrip strength

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ABSTRACT

Background: Handgrip strength (HGS) is an excellent marker of functional capability and health in adults, although little is known about temporal trends in adult HGS.

Objectives: The aim of this study was to systematically analyze national (country-level) temporal trends in adult HGS, and to examine relationships between national trends in adult HGS and national trends in health-related and socioeconomic/demographic indicators.

Methods: Data were obtained from a systematic search of studies reporting temporal trends in HGS for adults (aged ≥20 years) and by examining national fitness datasets. Trends in mean HGS were estimated at the country-sex-age group level by best-fitting sample-weighted linear/polynomial regression models, with national and sub-regional (pooled data across geographically similar countries) trends estimated by a post-stratified population-weighting procedure. Pearson's correlations quantified relationships between national trends in adult HGS and national trends in health-related and socioeconomic/demographic indicators.

Results: Data from 10 studies/datasets were extracted to estimate trends in mean HGS for 2,592,714 adults from 12 high- and 2 upper-middle-income countries (from Asia, Europe and North America) between 1960 and 2017. National trends were few, mixed and generally negligible pre-2000, whereas most countries (75% or 9/12) experienced negligible-to-small declines ranging from an effect size of 0.05 to 0.27, or 0.6 to 6.3%, per decade post-2000. Sex- and age-related temporal differences were negligible. National trends in adult HGS were not significantly related to national trends in health and socioeconomic/demographic indicators.

Conclusions: While trends in adult HGS are currently limited to 14 high- and upper-middle-income countries from 3 continents, adult HGS appears to have declined since 2000 (at least among most of the countries in this analysis), which is suggestive of corresponding declines in functional capability and health.

PROSPERO registration number: CRD42013003678.

KEY POINTS

- National (country-level) trends in adult handgrip strength (HGS) were few, mixed and generally negligible pre-2000, and generally negligible and indicated declines post-2000
- Sex- and age-related temporal differences in adult HGS were negligible-to-small at the country level and negligible at the regional level
- National trends in adult HGS were not significantly related to national trends in health and socioeconomic/demographic indicators

1 INTRODUCTION

Muscular strength refers to maximal force that the motor system (neural and muscle function) can generate during a specific task. Handgrip strength (HGS)—a maximal isometric grip force task—is a simple, inexpensive, convenient, widely-used, and scalable measure of functional strength capacity that has utility for clinical screening and population health surveillance [1]. In adults, HGS has moderate-to-high construct validity with total body and knee extensor strength [2,3], high-to-very high test-retest reliability [4,5], and is generally safe [6].

Low adult HGS is significantly and independently associated with an increased risk of all-cause, cardiovascular and non-cardiovascular mortality (independent of age, sex, smoking status, body mass index [BMI], physical activity levels, dietary intake, comorbidities, and other covariates) [7,8], stroke [7], cancer (e.g., colorectal, lung and breast cancer) [8], type 2 diabetes [9], depression [10], and fractures [11], cognitive declines [11], and functional limitations [12] among older adults. Low HGS is also an important component of validated frailty assessments [13] and decision algorithms for determining sarcopenia and dynapenia [14,15]. Longitudinal data from the Prospective Urban-Rural Epidemiology (PURE) study [7], which followed 139,691 adults from 17 countries for a median of four years, indicated that every 5-kilogram (kg) decrease in adult HGS was significantly associated with a 16–17% greater risk for all-cause, cardiovascular and non-cardiovascular mortality. Furthermore, adult HGS was a stronger predictor of all-cause and cardiovascular mortality than systolic blood pressure [7]. This health-related evidence highlights the importance of temporal trends in adult HGS as a potential proxy of corresponding trends in functional capability and health.

While little is known about temporal trends in adult HGS, much of what is known about temporal trends in HGS comes from studies on children and adolescents, where schools have provided opportunities for population-based testing that do not normally exist for adults. In our recent systematic analysis of temporal trends in HGS for 2,216,320 children and adolescents (aged 9–17 years) between 1967 and 2017 [16], we found that 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. In contrast, and specific to adults, in a systematic analysis of temporal trends in cardiorespiratory fitness (CRF) for 2,525,827 adults between 1967 and 2016 [17], we found that CRF improved in the 1960s and 1970s, and progressively declined at an increasing rate thereafter. Unfortunately, there has not yet been a comprehensive study that has synthesized temporal trends in adult HGS. Furthermore, because trends in HGS are probably influenced by a network of physiological, physical, behavioral, social and/or environmental factors [16], an examination of the relationships between national (country-specific) trends in adult HGS and national trends in such factors may improve our understanding of their importance to population health and fitness. For example, we recently identified a very strong negative correlation (r [95%CI]: −0.77 [−0.96 to −0.03]) between national trends in adult CRF and national trends in adult obesity levels [17], suggesting that countries with the largest increases in adult obesity had the largest declines in adult CRF.

The primary aim of this study was to systematically analyze national temporal trends in adult HGS through an exhaustive literature review and pooling data from studies using novel analytical techniques. The secondary aim was to explore the relationships between national trends in adult HGS and national trends in health-related and socioeconomic/demographic indicators.

2 METHODS

2.1 Protocol and registration

The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42013003678). The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement was followed for this review where possible [18].

2.2 Eligibility criteria

Only studies reporting on temporal trends in HGS for adults (aged ≥20 years) [19] measured using handgrip dynamometry were included. An exception to this age minimum was made if the age range extended no more than 2 years below the minimum (e.g., trend data on 19-to 29-year-olds were considered). Studies were eligible for inclusion if they reported on temporal trends in HGS (using matched test protocols) for sex-age group-matched apparently healthy adults (free from known disease/injury) across at least two time points spanning a minimum span of 5 years. However, studies specifically reporting trends on apparently healthy adults belonging to special interest groups (e.g., those with an athletic predisposition or those from a single racial/ethnic group) were excluded. Temporal trends must have been reported as changes in means at the country-sex-age group level (e.g., 20-to 29-year-old United States [US] men), or as descriptive data (e.g., sample sizes, means and standard deviations) at the country-sex-age group-year level (e.g., 20-to 29-year-old US men tested in 1985) in order to calculate temporal trends. Collective trends reported for geographically similar countries (e.g., Northern European adults from Denmark and Sweden) were included, despite not being reported as separate country-level trends.

2.3 Information sources

Studies were identified by searching electronic databases, reference lists, topical systematic analyses/reviews, and personal libraries [18]. The electronic database search strategy was developed in consultation with an academic librarian experienced in systematic literature searching. The electronic database search was conducted on the 8th of August 2019, and updated on the 11th of August 2020, using the Elton B. Stephens Co. (EBSCO) interface and included the Cumulative Nursing and Allied Health Literature (CINAHL), Education Resources Information Center (ERIC), MEDLINE, and SPORTDiscus databases. No date restrictions were imposed, with only studies published in English included. Additional searches of reference lists, topical systematic analyses/reviews, and the personal library of the senior author were conducted to identify studies not captured in the electronic database search. Large nationally representative fitness survey data suitable for temporal trends analysis were also considered.

2.4 Search

The electronic database search was limited to abstract, title and keywords. Search terms within pre-specified groups were combined using the Boolean OR and were searched in combination with other search groups using the Boolean AND, with proximity operators ("*") used to search for root words. The first search group identified the fitness measure (physical fitness OR muscular strength OR muscular endurance OR aerobic fitness OR cardio* fitness OR cardio* endurance) (Note, the search terms aerobic fitness, cardio* fitness, and cardio* endurance were included to capture relevant studies for which trends in HGS were not the primary outcome). The second group identified the population (adult* OR men OR man OR woman OR women OR male OR female) and the third group identified the trend (secular OR temporal OR historical). The search strategy for electronic databases is shown in Electronic Supplementary Material Appendix S1.

2.5 Study selection

All electronic database records were imported into RefWorks® reference management software (v2.0; ProQuest LLC, Ann Arbor, MI, USA) and de-duplicated. Record screening comprised two levels. Level 1 involved two researchers independently screening the titles and abstracts against inclusion criteria, with consensus required for further screening. Level 2 involved two researchers independently screening the full texts against inclusion criteria, with consensus required for final inclusion. When necessary, discrepancies between reviewers were resolved by a third reviewer prior to reaching consensus.

2.6 Data collection process

A standardized study-specific template was used to extract all reported data [17], with data extracted by a single researcher and checked for accuracy by a second researcher. Additional data, when necessary, were requested from corresponding authors via email.

2.7 Data items

The following study-specific descriptive data were extracted: title, country, sampling information, years of testing, sex, age group, test protocol, and sample size. We extracted HGS results if temporal trends were reported as any of the following: changes in mean HGS as absolute [in kg], percent, and/or standardized units, including corresponding standard errors and/or changes in 95% confidence intervals (95%CI). Note, means and standard deviations at each time point were extracted if change in mean HGS and/or corresponding standard errors/95%CIs were not reported.

2.8 Summary measures and synthesis of results

Temporal trends in mean HGS were analyzed at the country-sex-age group level (or the sub-regional-sex-age group level in the case of one study where trend data were pooled across geographically similar countries) using best fitting and most parsimonious linear or polynomial (quadratic or cubic) regression models weighted by the square root of sample size via XLSTAT (v19.03, Addinsoft, Paris, France) [16,17]. The square root of sample size was chosen as the sample-weighting method because our confidence in the estimation of each group mean (i.e., the standard error) is proportional to the square root of the sample size. Trends in mean HGS (per decade) were expressed as percent changes (i.e., change in means expressed as a percentage of the overall mean), and to facilitate comparisons between different country/sub-region, sex and age groups, as standardized (Cohen's) effect sizes (ES) (i.e., changes in means expressed relative to 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 [20]. Positive trends indicated increases in mean HGS and negative trends indicated declines in mean HGS.

Temporal trends were calculated as follows: starting with the first year (Y_1) covered by any relevant study-country-sex-age group, every group including Y_1 in its span of years was located, with every change (dx_1, absolute, percent or standardized change per year) recorded. This process was applied to all years for which change data were available (Y_1 ... Y_n), yielding a series of yearly changes. The post-stratified population-weighted mean yearly change was calculated for year (Y_1) and repeated for Y_2, Y_3, Y_4… until the last year covered by any study, Y_n. This process yielded a series of population-weighted mean yearly changes (dx_1, …, dx_n) that collectively described the trends for men, women, young adults [20–39 year-olds], middle-aged adults [40–64 year-olds], older adults [≥65 years old], and all adults [≥20 years old]) at the regional (i.e., Asia, Europe, and North America), sub-regional (i.e., Northern, Southern, and Western Europe), and national levels [21]. Population estimates were standardized to the year 2005, which is a common testing year for all but one country, using United Nations data [22]. Temporal trends were visualized using an iterative procedure described by Tomkinson and Olds [23].

Relationships between national trends in adult HGS and national trends in pre-specified health-related and socioeconomic/demographic indicators were quantified using Pearson's correlation coefficients, with 95%CIs estimated using Fisher's z-transformation. National trends for health-related (adult BMI [24]) and three socioeconomic/demographic (Gini index [25], Human Development Index [HDI] [26], and urbanization [27]) indicators were analyzed using linear regression models as described above. 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 [20].

3 RESULTS

3.1 Study selection

A total of 473 unique records were identified through electronic database and additional searching, with 30 articles retained following level 1 of screening and 7 articles retained after level 2. We also identified 3 large country-level fitness datasets comprising nationally representative HGS data suitable for temporal trends analysis. In total, we included 10 studies/datasets in this study. Figure 1 illustrates the PRISMA flowchart for included studies.

Insert Figure 1 about here*

3.2 Study characteristics

Temporal trends in HGS were estimated for 2,592,714 adults from 14 countries across 3 continents (Asia, Europe and North America) between 1960 and 2017 (Tables 1 and 2). These 14 countries represented 12 high-income and 2 upper-middle-income countries [28] or 12 very high and 2 high human development countries [26], 31% of the world's population [22], and 25% of the world's land area [29]. Trends were estimated for 144 country-sex-age groups (men: 72; women: 72; young adults: 28; middle-aged adults: 42; older adults: 74) with a median sample size of 1171 adults (range: 34–120,222) across a median measurement span of 14 years (range: 8–50). Trends were available for the following test protocols: sum of the maxima for both hands (40% or 4/10 studies/datasets), maximum across both hands (20% or 2/10), maximum of the dominant hand (20% or 2/10), maximum of the right hand (10% or 1/10), and the average of the maxima for both hands (10% or 1/10) (Electronic Supplementary Material Table S1). Most test protocols required that HGS be measured while standing, with a straight arm, allowed multiple trials per hand, and used a mechanical handgrip dynamometer adjusted for hand size.

Insert Tables 1 and 2 about here

3.3 Synthesis of results

Prior to the year 2000, national trends in adult HGS were few, mixed, and generally negligible in magnitude (i.e., ES<0.20 for 80% or 4/5 countries), with a small (per decade) improvement for Mexico, a negligible improvement for Japan, a negligible decline for Canada, and no meaningful change for Northern Europe and the US (Figure 2 and Table 3). Post-2000, national trends were generally negligible in magnitude (62% or 8/13 countries) and negative in direction (i.e., declines for 69% or 9/13 countries) with: negligible (per decade) declines for Western Europe (Belgium, Germany, the Netherlands, and Switzerland), Japan and the US; small declines for Canada, China and Northern Europe (England); a negligible improvement for Northern Europe (Denmark and Sweden); and a small improvement for Southern Europe (Italy and Spain).

Insert Figure 2 and Table 3 about here

3.3.1 Temporal trends in HGS for Asian adults

Temporal trends in adult HGS were estimated for two East Asian countries: China (719,885 adults aged 20–69 years between 2000 and 2014) and Japan (1,786,118 adults aged 20–79 years between 1967 and 2017) (Table 1). Collectively, there were negligible (per decade) sex- and age-related temporal differences in Asia: a negligible improvement for men (change in means per decade [95%CI]: 0.05 ES [0.04 to 0.06]; 1967–2017), a negligible decline for women (change in means per decade [95%CI]: −0.07 ES [−0.08 to −0.06]; 1967–2017), a negligible decline for young adults (change in means per decade [95%CI]: −0.05 ES [−0.06 to −0.04]; 1967–2017), a negligible improvement for middle-aged adults (change in means per decade [95%CI]: 0.03 ES

[0.02 to 0.04]; 1967–2017), and no meaningful change for older adults (change in means per decade [95%CI]: 0.01 ES [−0.01 to 0.03]; 1998–2017).

Over the period 1967–2017, there was a negligible (per decade) improvement in HGS for Japanese adults (change in means per decade [95%CI]: 0.03 ES [0.02 to 0.04]), with the rate of improvement reducing to zero from the late 1960s to the mid-1990s, before shifting to a decline thereafter (Figure 2 and Table 3). Similarly, there was a steady decline in HGS for Chinese adults over the 2000–2014 period, with the magnitude of decline (change in means per decade [95%CI]: −0.21 ES [−0.20 to −0.22]) 4-fold larger compared to the post-2000 decline for Japan. Sex- and age-related temporal differences at the country level were negligible.

3.3.2 Temporal trends in HGS for European adults

Over the period from 1998 to 2015, temporal trends in adult HGS were estimated for three European sub-regions: Northern Europe (24,323 adults aged 50–90+ years from Denmark, England, and Sweden), Southern Europe (9632 adults aged 50–90+ years from Spain and Italy), and Western Europe (20,710 adults aged 50–90+ years from Belgium, Germany, the Netherlands, and Switzerland) (Table 1). Across Europe, there were negligible (per decade) sex- and age-related temporal differences: no meaningful change for men (change in means per decade [95%CI]: 0.00 ES [−0.03 to 0.03]) and women (change in means per decade [95%CI]: 0.04 ES [0.00 to 0.08]), a negligible decline for middle-aged adults (change in means per decade [95%CI]: −0.04 ES [−0.07 to −0.01]), and a negligible improvement for older adults (change in means per decade [95%CI]: 0.05 ES [0.02 to 0.08]).

Compared to Asia (Section 3.3.1) and North America (Section 3.3.3), the time window over which temporal trends in adult HGS were estimated was considerably smaller for Europe (Figure 2 and Table 3). Collectively, there was a negligible (per decade) decline in HGS for Northern European adults (change in means per decade [95%CI]: −0.10 ES [−0.13 to −0.07]), with contrasting trends of a small decline for English adults (change in means per decade [95%CI]: −0.27 ES [−0.30 to −0.24]) and a negligible improvement for Danish and Swedish adults (change in means per decade [95%CI]: 0.13 ES [0.11 to 0.15]). There was also a small improvement for Southern European adults (change in means per decade [95%CI]: 0.33 ES [0.29 to 0.37]) and a negligible decline in HGS for Western European adults (change in means per decade [95%CI]: −0.11 ES [−0.14 to −0.08]). Sex- and age-related temporal differences at the country level were negligible, except for the small age-related difference in Southern European adults (change in means per decade [95%CI]: middle-aged adults, 0.20 ES [0.18 to 0.22]; older adults, 0.40 ES [0.35 to 0.45]).

3.3.3 Temporal trends in HGS for North American adults

For North America, temporal trends in adult HGS were estimated for Canada (22,998 adults aged 20–79 years between 1981 and 2016), Mexico (654 adults aged 19–60+ years between 1978 and 2000), and the US (8394 adults aged 20–79 years between 1960 and 2006) (Table 1). There were negligible (per decade) sex- and age-related temporal differences in North America: no meaningful change for men (change in means per decade [95%CI]: −0.01 ES [−0.03 to 0.01]; 1960–2016), a negligible decline for women (change in means per decade [95%CI]: −0.03 ES [−0.05 to −0.01]; 1978–2016), no meaningful change for young adults (change in means per decade [95%CI]: −0.02 ES [−0.04 to 0.00]; 1960–2016) and middle-aged adults (change in means per decade [95%CI]: 0.02 ES [0.00 to 0.04]; 1968–2016), and a negligible decline for older adults (change in means per decade [95%CI]: −0.07 ES [−0.10 to −0.04]; 1968–2016).

For Canadian adults, there was a negligible (per decade) decline in HGS (change in means per decade [95%CI]: −0.17 ES [−0.19 to −0.15]; 1981–2016), with the rate of decline 2-fold larger post-2000 in comparison with pre-2000 (Figure 2 and Table 3). In contrast, there was no meaningful change for US adults (change in means per decade [95%CI]: 0.00 ES [−0.02 to 0.02]; 1960–2006) and a small improvement in Mexican adults (change in means per decade [95%CI]: 0.21 ES [0.19 to 0.23]; 1978–2000). Sex- and age-related temporal differences at the country level were negligible, except for the small age-related difference between middle-aged Mexican adults (change in means per decade [95%CI]: 0.14 ES [0.12 to 0.16]) and older Mexican adults (change in means per decade [95%CI]: −0.14 ES [−0.18 to −0.10]).

3.3.4 Correlations between national trends in HGS and national trends in health-related and socioeconomic/demographic indicators

Correlations between national trends in adult HGS and national trends in health-related (i.e., BMI) and socioeconomic/demographic (i.e., Gini index, HDI, and urbanization) were weak-to-moderate in magnitude and failed to reach statistical significance at the 95% level (Table 4).

Insert Table 4 here

4 DISCUSSION

This study systematically analyzed national temporal trends in HGS for 2,592,714 adults from 14 countries between 1960 and 2017. The principal findings were that: (a) pre-2000, national trends in adult HGS were few, mixed, and generally negligible, whereas post-2000, national trends were generally negative (indicating declines) and negligible; (b) sex- and age-related temporal differences in adult HGS were always negligible at the regional level and almost always negligible at the country level; and (c) national trends in adult HGS were not significantly related to national trends in health and socioeconomic/demographic indicators. Our finding of a recent (post-2000) decline in adult HGS, at least among most of the high- and upper-middle-income countries included in this analysis, is suggestive of a corresponding decline in functional strength capacity. This may be meaningful to public health given that adult HGS is significantly associated with functional capability and health [7–15], which is especially important given the world's population is ageing [95]. We also identified a gap in the literature, with available trends in adult HGS limited to only high- and upper-middle-income countries. While considerable progress is needed before HGS measurement becomes a routine part of population health surveillance globally, the ability to track trends in HGS (at least among the 14 countries in this analysis) not only highlights the importance of HGS as a marker of population health but also highlights potential opportunities for low and lower-middle-income countries to engage in a cost effective health surveillance strategy. This is especially important given the fact that some low and lower-middle-income countries may be experiencing an epidemiological transition [96].

4.1 Explanation of main findings

It is probable that trends in a network of physiological, physical, behavioral, social and/or environmental factors underlie the observed trends in adult HGS [16,17]. Because body size is positively and significantly related to HGS cross-sectionally [87], we expected that trends in adult HGS corresponded with trends in mean body size. However, we found a moderate, statistically insignificant, negative relationship between national trends in adult HGS and national trends in mean BMI. While two included studies reported concurrent trends in adult HGS and body size (operationalized as standing height and body mass [93], and BMI [88]), two others reported temporal differences [87,92]. For example, Dodds et al. [87] reported that the decline in mean HGS for English adults aged 50–89 years between 2004 and 2012 was independent of an increase in mean BMI, as well as trends in other confounders such as self-reported physical activity levels, socioeconomic position and smoking history. Despite not statistically controlling for concurrent trends in body size, Shields et al. [92] reported that the decline in mean HGS for Canadian adults aged 20–69 years between 1981 and 2009 coincided with increases in mean BMI, waist circumference, and sum of 5 skinfolds. Taken together, these two studies suggest that trends in other factors may be involved.

It is not exactly clear why Dodds et al. [87] and Shields et al. [92] found temporal differences in adult HGS and body size. Despite convincing evidence of an international increase in adult BMI [24], it is possible that temporal differences in fat mass and fat-free mass have occurred, and that the recent decline in adult HGS, which was observed for most of the included countries, reflects that adults have become fatter, or less muscular, at the same BMI. There is mounting evidence from high-income countries that adults are now fatter at the same BMI, with reports of increases in abdominal [97–102] and subcutaneous [100] fatness independent of increases in BMI. However, evidence of temporal trends in fat-free mass is scarce. Although not generalizable to the general population, a temporal analysis of the body size of US Army recruits between 1975 and 2013 indicated that increased body mass was due to increases in both fat mass and fat-free mass (note, they also showed that trends in muscular strength corresponded with trends in fat-free mass) [103]. Alternatively, the temporal differences in HGS and body size may be the result of long-term exposure to increased BMI, which is significantly associated with low HGS later in life [104,105] (even after controlling for fat mass [104] or age, sex, education, smoking, alcohol use, physical activity, several chronic diseases, and current body mass [105]), possibly due to the chronic effects of inflammation and/or insulin resistance [105].

Physical activity also positively influences muscular strength in adults [106,107], suggesting that the recent decline in adult HGS observed for most of the included countries has coincided with a general decrease in overall physical activity levels. Although trend data on adult physical activity levels are rare (because of the difficulty in obtaining accurate measurements and sampling/methodological variability), there is no compelling evidence for an international decline in overall physical activity levels [109,110]. Despite most of the available adult trend data being limited to high-income countries, trend data illustrate a mixed picture of increased leisure-time physical activity [111–120], in contrast with increased sedentary behavior [111,115] and decreased occupational physical activity [111,118,120–123]. Unfortunately, few studies have examined concurrent trends in adult HGS and physical activity levels. To our knowledge, two studies [85,124] have reported a temporal coincidence, while only one study [87] has directly examined trends in adult HGS while statistically controlling for trends in self-reported physical activity levels, indicating that the decline in HGS among English adults between 2004 and 2012 was independent of the increase in self-reported physical activity levels. Perhaps this highlights that typical adult physical activities do not involve exposure to gripping tasks that stimulate an increase in maximal isometric finger flexor strength (i.e., HGS). It may also illustrate that the instruments used to monitor trends in physical activity (e.g., self-report questionnaires) do not adequately capture trends in the prevalence of muscle-strengthening activities involving the upper body, which trends in HGS are more likely to capture given that upper-body resistance training requiring gripping has been shown to positively influence adult HGS [108].

While trend data on the prevalence of muscle-strengthening guidelines are scarce, Australian [125] and US [126] data indicate a significant increase in the prevalence of muscle-strengthening activity among adults (four or more times per week between 2001 and 2010 for Australian adults [125] and two or more times per week between 1998 and 2016 for US adults [126]). Assuming that the relationship between trends in the prevalence of muscle-strengthening activity and trends in adult HGS is causal, then we would expect to have seen corresponding increases in HGS for both Australian and US adults. Unfortunately, we could not estimate trends in HGS for Australian adults, and our estimate of trends in HGS for US adults is now dated and limited to the period 1960–2006. Nonetheless, despite the short overlapping time window from 1998 to 2006, our finding of a negligible decline in HGS corresponded with a negligible change in the prevalence of muscle-strengthening activity [126]. While this temporal coincidence is potentially circumstantial, it does at least suggest that strategies promoting increased participation in muscle-strengthening activities (e.g., national and global muscle-strengthening guidelines for adults [127,128]), which include both lower- and upper-body and core muscle-strengthening exercises, might be a suitable population approach to improving functional strength capacity in adults. However, evidence from a recent meta-analysis on older adults [108] suggests that current national and global muscle-strengthening guidelines may not provide adequate prescription details needed to optimize gains in muscular strength capacity as assessed by HGS. Of the 24 studies reviewed, the only studies demonstrating large exercise training effects included tasks with a substantial gripping component (e.g., exercising with dumbbells, gripping Nordic walking polls, squeezing pool noodles) [108]. Since HGS is a marker of general muscular strength and the mechanisms linking HGS to health outcomes are not completely understood [129], it is unknown if muscle-strengthening interventions need to be designed to specifically target HGS to achieve the health-related benefits associated with the measure. Albeit, the task-specific nature of strength acquisition should be considered when designing population-based interventions to improve functional strength capacity.

4.2 Comparisons with other studies on trends in fitness

Although few studies have examined temporal trends in adult fitness levels, the most comprehensive analysis to date is a systematic analysis of temporal trends in CRF of 2,525,827 adults (aged 18–59 years) from eight high- and upper-middle-income countries between 1967 and 2016 [17]. The results indicated that adult CRF declined across all 8 countries, and collectively improved in the 1960s and 1970s before declining at a rate of 0.19 ES, or 2.2%, per decade thereafter [17]. In combination with recent (post-2000) declines in adult HGS, which we observed for most countries/sub-regions in this study, these recent trends are suggestive of corresponding declines in both functional strength (HGS) and functional endurance (CRF).

In contrast, HGS for children and adolescents has trended upward in recent decades. In a recent systematic analysis of temporal trends in the HGS of 2,216,320 children and adolescents from 19 high- and upper-middle-income countries/special administrative regions between 1967 and 2017 [16], we found a collective improvement of 0.14 ES, or 3.8%, per decade, with the rate of improvement progressively increasing over time. It is challenging to explain why there has been a recent (post-2000) improvement in childhood and adolescent HGS [16] and a decline in adult HGS (this study). It is possible that the trend in childhood and adolescent HGS, but not the trend in adults HGS, was influenced by a concurrent trend in biological maturation, which tends to favor children and adolescents of the same chronological age in more recent years [130]. When adjusted for trends in biological maturation, we estimated that the improvement in childhood and adolescent HGS was reduced by 32–94% [16], which may partly explain the age-related temporal difference in HGS. Between-study differences among the included countries may also be involved. Further examination of the country-level temporal trends in HGS, for which data are available for both children/adolescents and adults, indicated similar trends (i.e., consistent direction) for Canada, Belgium, England, Italy, Japan, and Mexico, yet dissimilar trends (i.e., opposite direction) for only China and the US. The age-related temporal correspondence observed for Canada, Belgium, England, Italy, Japan, and Mexico suggests that current trends in HGS for children and adolescents might continue in subsequent decades when today's children and adolescents become adults. Alternatively, because the transition from adolescence into adulthood marks a period of significant life change when everyday physical activities and behaviors are restructured, it is possible that the age-related temporal difference observed for China and the US reflects age-related temporal differences in mechanistic factors such as fatness, physical activity levels, and sedentary behaviors [17].

4.3 Strengths and limitations

This study represents the most comprehensive analysis to date of national and international temporal trends in adult HGS. It used a systematic analytical approach—a method by which data from different sources are pieced together to create an overall temporal picture using analytical techniques beyond those used in a typical meta-analysis—that has been previously used in other studies on temporal trends in fitness [16,17,131–133]. We estimated trends in adult HGS measured using handgrip dynamometry (a valid, reliable, feasible, and scalable measure of functional strength capacity) [2–5], which is significantly associated with functional capability and health [7–15]. The weighted regression and post-stratification population weighting procedures helped control for sampling bias by incorporating the underlying population demographics, and our stratified trends analysis enabled us to assess and control for potential confounding factors (e.g., age, sex, and country).

Despite the many strengths, this study was not without limitations. First, while differences in HGS protocols (e.g., dynamometer, calibration, number of trials, scoring method, optimal grip span adjustment, elbow angle, practice etc.) will affect the variability of HGS results, such differences are unlikely to have biased our trends because all within-study/dataset trends used matched HGS protocols. Second, while most studies/datasets used probability sampling, few used nationally representative adult HGS data. Nonetheless, we included studies/datasets that estimated trends using state/provincial-, city-, and/or community-level data as they provided the best available estimate of national trends in those countries. Third, while trends were estimated from available country-sex-age group-specific HGS data, which may not be representative of all adults within a country, it is likely that our national trends in adult HGS are broadly generalizable given our finding of negligible-to-small sex- and age-related temporal differences at the country level. Fourth, while we estimated trends in mean HGS, we unfortunately did not estimate trends in distributional variability or asymmetry, which have rarely been reported in the literature. This limited us from understanding if trends have improved or declined evenly across the entire distribution of performance, or if the tails/ends of the distribution are driving the overall trends. While one study reported negligible differences between trends in mean and median HGS in nationally representative samples of Canadian adults between 1981 and 2009 [92], another reported that the improvement in mean HGS for representative samples older Japanese adults between 1998 and 2017 corresponded with a decline in distributional variability (indicating that the magnitude of variability [i.e., the standard deviation] decreased in relation to the mean over time) [124], suggesting that the recent trend in mean HGS was not uniform across the entire distribution. It is therefore challenging to estimate the likely impact of trends in distributional characteristics on trends in means. Future trends studies should complement trends in means with trends in measures of distributional variability (e.g., standard deviations, coefficients of variation) and/or asymmetry (e.g., skewness). Fifth, we were unable to statistically remove the effects of trends in potential mechanistic factors such as body size and physical activity levels, because we estimated trends in adult HGS using only descriptive data, and corresponding descriptive data were not always reported for such factors. Sixth, because our trends in adult HGS were limited to high- and upper-middle-income countries, they are not generalizable to low-income and lower-middle-income countries. Last, we have low confidence in our correlations (Table 4) because national trends in adult HGS were limited to only 14 countries, and were not always estimated over time periods that entirely overlapped the trends in health-related and socioeconomic/demographic indicators.

CONCLUSION

This is the first study to systematically analyze national temporal trends in adult HGS. We estimated that national trends in adult HGS were few, mixed, and generally negligible pre-2000, and were generally negligible and indicated declines post-2000. Sex- and age-related temporal differences in adult HGS were always negligible at the regional level and almost always negligible at the country level. National trends in adult HGS were not significantly related to national trends in health and socioeconomic/demographic indicators. Given the utility of HGS for population surveillance, the tracking of trends in adult HGS should continue in high- and upper-middle-income countries, and be strongly encouraged in low and lower-middle-income countries. Population surveillance of HGS could help track trends in population health, provide potential insight for interventions, assess the impact of healthy public policy, and potentially predict future trends.

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.

Compliance with Ethical Standards

Author Contributions

GRT developed the research question and designed the study. GRT and TD designed the systematic review strategy, had full access to the data, take responsibility for the integrity of the data, and led the statistical analyses, synthesis of results, and drafted the manuscript. All authors contributed to the interpretation of results, edited and critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, agree to be accountable for all aspects of the work, and agree with the order of presentation of the authors.

Conflicts of Interest

Trevor J. Dufner, John S. Fitzgerald, Justin J. Lang, and Grant R. Tomkinson declare they have no conflicts of interest.

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TABLES

Table 1. Summary of the included studies by country.

Region/sub-region	Country	Sex	Age span (years)	Span of testing years	Sample size	Sampling strategy	Sample base	HDI
Asia								
	China [30–33]	F (50.0%) M (50.0%)	20–69	2000–2014	719,885	P	N	0.752 (high)
	Japan [34–84]	F (49.2%) M (50.8%)	20–79	1967–2017	1,786,118	NP	N	0.909 (very high)
Europe								
Northern Europe	Denmark/Sweden [85,86]	F (57.4%) M (42.6%)	50–90+	1998–2013	12,847	P	N/NN	0.929–0.933 (very high)
	England [87]	F (54.1%) M (45.9%)	50–89	2004–2012	11,476	P	N	0.922 (very high)
Southern Europe	Italy/Spain [85]	F (50.0%) M (50.0%)	50–90+	2004–2013	9632	P	NN	0.880–0.891 (very high)
Western Europe	Belgium/Germany/ Netherlands [85]	F (50.0%) M (50.0%)	50–90+	2004–2013	16,820	P	NN	0.916–0.936 (very high)
	Switzerland [88]	F (58.0%) M (42.0%)	66–71	2005–2015	3890	P	NN	0.944 (very high)
North America								
	Canada [89–92]	F (52.7%) M (47.3%)	20–79	1981–2016	22,998	P/NP	N/NN	0.926 (very high)
	Mexico [93]	F (56.9%) M (43.1%)	19–60+*	1978–2000	654	NP	NN	0.774 (high)
	USA [91]	F (43.5%) M (56.5%)	20–79	1960–2006	8394	NP	NN	0.924 (very high)

Note: USA=United States of America; M=male; F=female; P=probability sampling (i.e., using random selection); NP=non-probability sampling (i.e., using non-random selection); N=national sampling; NN=non-national sampling (i.e., state/provincial-, city-, or community-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 [26]; HDI value for the United Kingdom was assumed for England; Temporal data from Ahrenfeldt et al. [85] were reported at the sub-region level in contrast to the country level, hence why some trends were reported for Northern Europe (Denmark/Sweden), Southern Europe (Italy/Spain), and Western Europe (Belgium/Germany/Netherlands); Countries were classified using the United Nations geoscheme [94]; Northern America, the Caribbean, and Central America together form the geographic continent of North America [94]; *=Trends in the youngest age group were reported for 19-to 29-year-olds.

Table 2. Sub-region/country-level distribution of surveys from which temporal trends in adult HGS were estimated.

Year of testing	Asia		Europe					North America		
			Northern Europe		*Southern Europe*	*Western Europe*				
	China	Japan	Denmark/ Sweden	England	Italy/ Spain	Belgium/ Germany/ Netherlands	Switzerland	Canada	Mexico	USA
1960										•
1961										
1962										
1963										
1964										
1965										
1966										
1967		•								•
1968		•								•
1969		•								•
1970		•						•		
1971		•								
1972		•								
1973		•								
1974		•								
1975		•								
1976		•								
1977		•								
1978		•							•	
1979		•								
1980		•						•		
1981		•						•		
1982		•								
1983		•						•		•
1984		•								•
1985		•						•		

1986		•								
1987		•								•
1988		•						•		
1989		•						•		
1990		•						•		
1991		•								
1992		•								
1993		•						•		•
1994		•								
1995		•								•
1996		•						•		
1997		•						•		•
1998		•	•					•		•
1999		•								•
2000	•	•							•	
2001		•								•
2002		•								•
2003		•								•
2004		•	•	•	•	•		•		
2005	•	•					•			•
2006		•								•
2007		•								
2008		•		•				•		
2009		•								
2010	•	•	•				•	•		
2011		•								
2012		•		•						
2013		•	•		•	•				
2014	•	•						•		
2015		•					•			
2016		•						•		
2017		•								

Table 3. National/sub-regional temporal trends in mean HGS for 2,592,714 adults from 14 countries between 1960 and 2017.

		Percent changes per decade (95%CI)		**Standardized changes per decade (95%CI)**	
Region/sub-region	**Country**	**Pre-2000**	**Post-2000**	**Pre-2000**	**Post-2000**
Asia					
	China		−4.0 (−4.3 to −3.7)		−0.21 (−0.22 to −0.20)
	Japan	1.2 (1.1 to 1.3)	−0.6 (−0.9 to −0.3)	0.08 (0.07 to 0.09)	−0.05 (−0.07 to −0.03)
Europe					
Northern Europe	Denmark/Sweden	0.1 (0.0 to 0.2)	3.3 (2.8 to 3.8)	0.00 (0.00 to 0.01)	0.16 (0.14 to 0.18)
	England		−6.3 (−7.2 to −5.4)		−0.27 (−0.30 to −0.24)
Southern Europe	Italy/Spain		7.0 (6.1 to 7.9)		0.33 (0.29 to 0.37)
Western Europe	Belgium/Germany/Netherlands		−2.3 (−3.0 to −1.6)		−0.11 (−0.14 to −0.08)
	Switzerland		−2.3 (−3.4 to −1.1)		−0.12 (−0.18 to −0.06)
North America					
	Canada	−2.2 (−2.7 to −1.7)	−4.7 (−5.3 to −4.1)	−0.10 (−0.12 to −0.08)	−0.22 (−0.25 to −0.19)
	Mexico	3.3 (2.8 to 3.8)		0.21 (0.19 to 0.23)	
	USA	0.0 (−0.4 to 0.4)	−1.5 (−2.3 to −0.7)	0.00 (−0.02 to 0.02)	−0.07 (−0.11 to −0.03)

Note: HGS=handgrip strength; 95%CI=95% confidence interval; USA=United States of America; positive changes in means indicate improvements in HGS and negative changes indicates declines in HGS.

Table 4. Potential health-related and socioeconomic/demographic correlates of temporal trends in adult HGS.

Variable	Data source	Description	Correlation (95%CI)
Health			
Body mass index (BMI)	NCD-RisC [24] Trend data available for 14/14 (100%) countries between 1975 and 2016	Calculated as the change (per decade) in mean country-level BMI of men and women aged 20-90+ years (age standardized). With increasing HGS, a positive correlation (next column) indicated an increase in mean BMI and a negative correlation indicated a decline.	−0.31 (−0.72 to 0.26)
Socioeconomic/demographic			
Gini Index	World Bank [25] Trend data available for 13/14 (93%) countries between the years 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 HGS, a positive correlation indicated a trend towards perfect inequality and a negative correlation a trend towards perfect equality.	0.40 (−0.19 to 0.78)
Human Development index (HDI)	United Nations [26] Trend data available for 14/14 (100%) countries 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 HGS, a positive correlation indicated an increase in the mean human development and a negative correlation indicated a decline.	−0.15 (−0.63 to 0.41)
Urbanization	World Bank [27] Trend Data available for 14/14 (100%) countries between 1960 and 2017	Calculated as the change (per decade) in the percentage of people living in urban areas. With increasing HGS, a positive correlation indicated an increase in urbanization and a negative correlation indicated a decline.	−0.27 (−0.70 to 0.30)

FIGURE CAPTIONS

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

Note: HGS=handgrip strength.

Figure 2. National/sub-regional temporal trends in adult HGS from 1960 to 2017.

Note: Data were standardized to the year 2005=0, with positive values indicating better HGS and negative values indicating poorer HGS; the solid lines are the LOWESS (LOcally WEighted Scatter-plot Smoother) curves (tension=66), which represent the national/sub-regional changes in mean HGS, with upward sloping lines indicating improvements in means and downward sloping lines indicating declines in means. HGS=handgrip strength; ES=effect size.

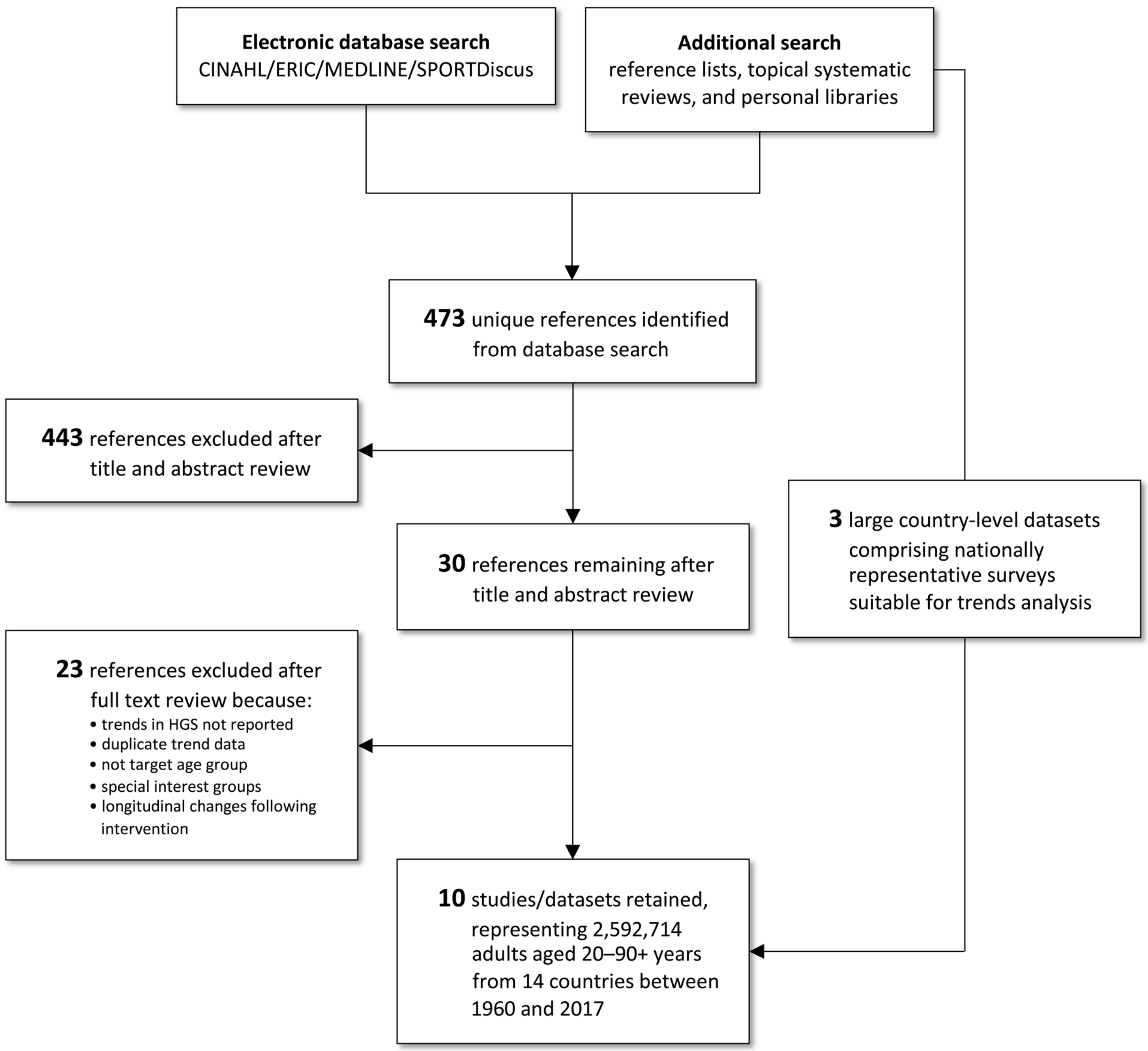
Electronic database search
CINAHL/ERIC/MEDLINE/SPORTDiscus
Additional search
reference lists, topical systematic reviews, and personal libraries
473 unique references identified from database search
443 references excluded after title and abstract review
30 references remaining after title and abstract review
3 large country-level datasets comprising nationally representative surveys suitable for trends analysis
23 references excluded after full text review because:
• trends in HGS not reported
• duplicate trend data
• not target age group
• special interest groups
• longitudinal changes following intervention
10 studies/datasets retained, representing 2,592,714 adults aged 20–90+ years from 14 countries between 1960 and 2017

Figure 1.

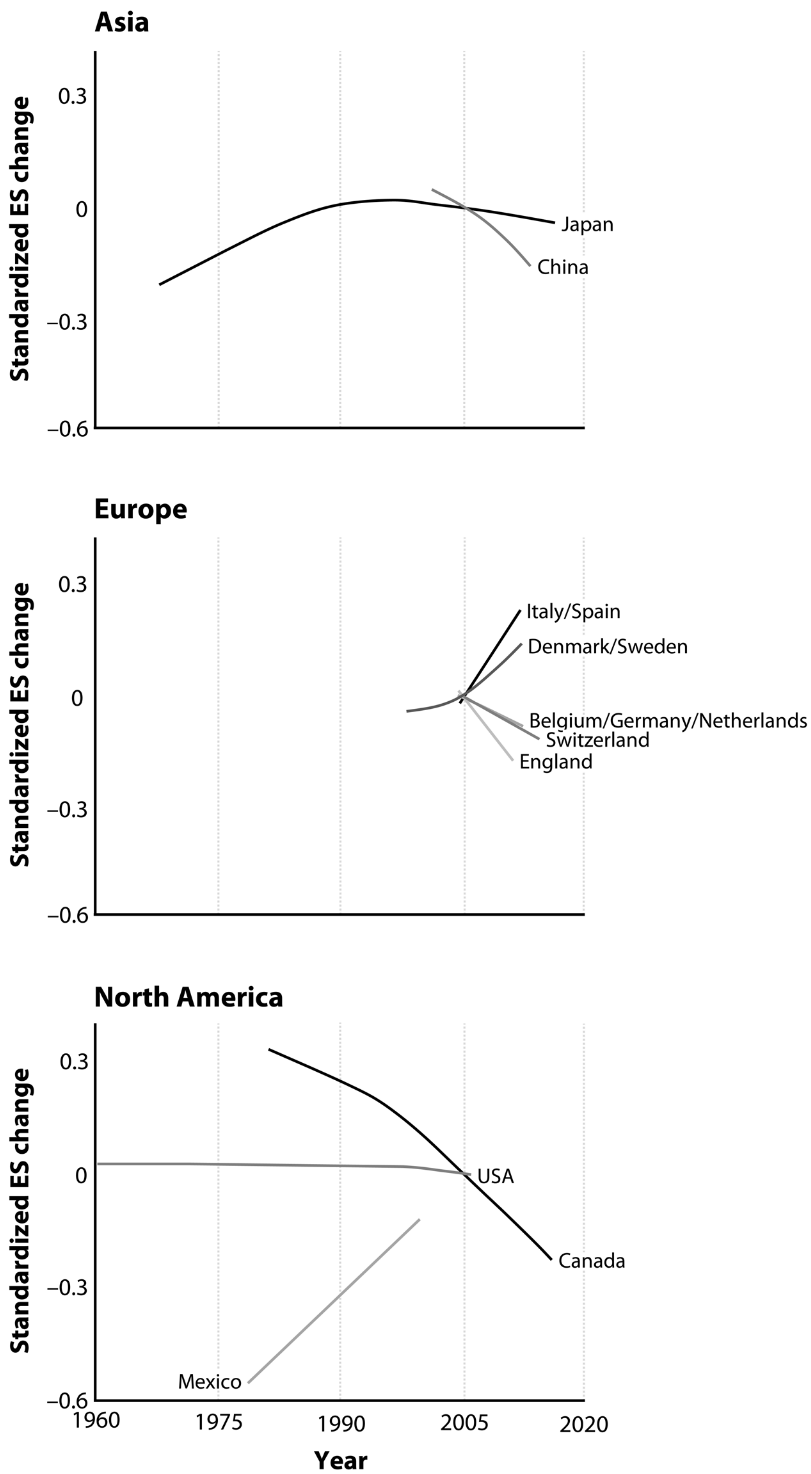
Asia
Standardized ES change
0.3
0
−0.3
−0.6
Japan
China
Europe
Standardized ES change
0.3
0
−0.3
−0.6
Italy/Spain
Denmark/Sweden
Belgium/Germany/Netherlands
Switzerland
England
North America
Standardized ES change
0.3
0
−0.3
−0.6
USA
Canada
Mexico
1960
1975
1990
2005
2020
Year

Figure 2.

ELECTRONIC SUPPLEMENTARY MATERIAL APPENDIX S1

Article title: Temporal trends in the handgrip strength of 2,592,714 adults from 14 countries between 1960 and 2017: A systematic analysis; **Journal name:** Sports Medicine; **Author names and affiliations:** Trevor J. Dufner (University of North Dakota), John S. Fitzgerald (University of North Dakota), Justin J. Lang (Public Health Agency of Canada and Children's Hospital of Eastern Ontario Research Institute), and Grant R. Tomkinson (University of North Dakota and University of South Australia); **E-mail address of the corresponding author:** grant.tomkinson@und.edu.

Appendix S1. Search strategy for electronic databases.

Electronic databases searched: CINAHL, ERIC, MEDLINE and SPORTDiscus.

Original search performed: 8 August 2019 and updated on 11 August 2020.

Search strategy: EBSCO SPORTDiscus, 1956 to 11 August 2020.

TX (physical fitness OR muscular strength OR muscular endurance OR aerobic fitness OR cardio* fitness OR cardio* endurance) AND TX (adult* OR men OR man OR woman OR women OR male OR female) AND TX (secular OR temporal OR historical)

Limiters: Language: English; **Expanders:** Apply equivalent subjects; **Search modes:** Find all my search terms.

ELECTRONIC SUPPLEMENTARY MATERIAL TABLE S1

Article title: Temporal trends in the handgrip strength of 2,592,714 adults from 14 countries between 1960 and 2017: A systematic analysis; **Journal name:** Sports Medicine; **Author names and affiliations:** Trevor J. Dufner (University of North Dakota), John S. Fitzgerald (University of North Dakota), Justin J. Lang (Public Health Agency of Canada and Children's Hospital of Eastern Ontario Research Institute), and Grant R. Tomkinson (University of North Dakota and University of South Australia); **E-mail address of the corresponding author:** grant.tomkinson@und.edu.

Table S1. Handgrip strength test protocols for included studies/datasets.

Region/Sub-region/Country	Reference(s)	Which hand was used?	How was handgrip strength calculated?	What was the elbow position?	What was the body position?	How many trials were allowed per hand?	Which dynamometer was used?	Was the dynamometer adjusted for hand size?
Asia								
China	30–33	Dominant	Maximum	Straight	Standing	2	Mechanical	Yes
Japan	34–84	Both	Average of maxima	Straight	Standing	2	Mechanical	Yes
Europe								
Northern Europe								
Denmark/Sweden	85	Both	Maximum	Bent	Standing[#]	2	Mechanical	Yes
Denmark	86	Dominant	Maximum	NA	NA	3	Mechanical	NA
England	87	Both	Maximum	NA	Standing[#]	3	Mechanical	NA
Switzerland	88	Right	Maximum	Bent	Seated	3	Hydraulic	NA
Southern Europe								
Italy/Spain	85	Both	Maximum	Bent	Standing[#]	2	Mechanical	Yes
Western Europe								

Belgium/Germany/ Netherlands	85	Both	Maximum	Bent	Standing[#]	2	Mechanical	Yes
Switzerland	88	Right	Maximum	Bent	Seated	3	Hydraulic	NA
North America								
Canada	89,90,92	Both	Sum of maxima	Straight	Standing	2	Mechanical	Yes
	91	Both	Sum of maxima	NA	NA	NA	NA	NA
Mexico	93	Both	Sum of maxima[*]	NA	NA	3	Mechanical	Yes
USA	91	Both	Sum of maxima	NA	NA	NA	NA	NA

Note: USA=United States of America; 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;[#]=HGS was measured when standing for the majority of adults, however HGS was measured seated for those who chose to sit or were unable to stand.

Compliance with Ethical Standards

Author Contributions

GRT developed the research question and designed the study. GRT and TD designed the systematic review strategy, had full access to the data, take responsibility for the integrity of the data, and led the statistical analyses, synthesis of results, and drafted the manuscript. All authors contributed to the interpretation of results, edited and critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, agree to be accountable for all aspects of the work, and agree with the order of presentation of the authors.

Conflicts of Interest

Trevor J. Dufner, John S. Fitzgerald, Justin J. Lang, and Grant R. Tomkinson declare they have no conflicts of interest.

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