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A Systematic Analysis Of Temporal Trends In Handgrip Strength For 2,584,978 Adults Between 1960 And 2017

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A SYTEMATIC ANALYSIS OF TEMPORAL TRENDS IN HANDGRIP STRENGTH FOR 2,584,978 ADULTS BETWEEN 1960 AND 2017

by

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This thesis, submitted by Trevor J Dufner in partial fulfillment of the requirements for the Degree of Master of Science in Kinesiology from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Trevor James Dufner

05/04/2020

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To my mom Donna and my dad Terry,

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ABSTRACT

Purpose: To systematically analyze temporal trends in handgrip strength (HGS) for adults. Methods: Four electronic databases, along with researcher's personal libraries, were searched up to August 2019 for studies reporting on temporal trends in mean HGS for apparently healthy adults who were broadly representative of their source population. Temporal trends in mean HGS were analyzed at the country-sex-age group level using sample-weighted linear or polynomial (quadratic or cubic) regression models. Results: Data from eight studies/datasets were extracted to estimate trends in mean HGS for 2,584,978 adults aged 20–90+ years from 13 different countries (across three continents) between 1960 and 2017. There was a general declining trend in HGS among adults in recent decades (post-2000), with negligible age- and sex-related temporal trends. Conclusion: The recent decline in HGS may reflect recent declines in functional capability and general health.

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 safe, simple, inexpensive, convenient, and widely-used measure of muscular strength 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 (independent of weight, age, and sex)[2,3,4] and high-to-very high test-retest reliability.[4]

Low HGS is significantly and independently associated with an increased risk of all-cause, cardiovascular and non-cardiovascular mortality (independent of body size, physical activity levels, and other covariates),[6] stroke,[6] diabetes,[7,8] cancer (e.g., colorectal, lung and breast cancer),[9] hypertension,[7] and falls risk[10] and functional/cognitive limitations among older adults.[11] Low HGS is an important component of validated frailty assessments[12] and decision algorithms for determining sarcopenia and dynapenia.[13,14] Longitudinal data from the Prospective Urban-Rural Epidemiology (PURE) study[6] which followed 139,691 adults from 17 countries, indicated that every 5 kg decrease in HGS was significantly associated with a 16–17% greater risk for all-cause, cardiovascular and non-cardiovascular mortality. Furthermore, HGS was a stronger predictor of all-cause and cardiovascular mortality than systolic blood pressure.[6] This health-related evidence highlights the importance of temporal trends in HGS as a potential proxy of corresponding trends in population health.

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 typically exist for adults. In a recent systematic analysis of temporal trends in HGS for 2,216,320 children and adolescents (aged 9–17 years) between 1967 and 2017,[15] results indicated 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, a separate systematic analysis of temporal trends in cardiorespiratory fitness (CRF) for 2,525,827 adults between 1967 and 2016 [16] observed 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 HGS among adults. Furthermore, recent systematic analysis of temporal trends in adult CRF[16] also identified a very strong negative correlation between national (country-specific) trends in adult CRF and national trends in adult obesity levels, suggesting that countries with the largest increases in obesity had the largest declines in CRF. Examination of the relationships between national trends in adult HGS and national trends in health-related and socioeconomic/demographic indicators may improve our understanding of the importance of such indicators to population health and fitness.

The primary aim of this study was to systematically analyze national (country-level) temporal trends in HGS among adults 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 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.[17]

2.2 Eligibility criteria

Only studies reporting on temporal trends in HGS for adults (≥20 years) measured using handgrip dynamometry were included. Studies were eligible for inclusion if they reported on temporal trends in HGS (using matched test protocols) for sex-age group-matched adults across a minimum span of 5 years. Adults must have been apparently healthy (free from known disease/injury) and broadly representative of their source population. Temporal trends must have been reported as absolute, percent, or standardized changes in means at the country-sex-age group level (e.g., 20–29-year-old United States men), or as descriptive data (e.g., sample sizes, means and standard deviations) at the country-sex-age group-year level (e.g., 20–29-year-old United States men tested in 1985) in order to calculate temporal trends. Age group data spanning ≤10 years (e.g., 20–29-year-olds) were included, as too were collective trends reported for geographically similar countries (e.g., Denmark and Sweden) despite not being reported as separate country-level trends.

2.3 Information sources

This search strategy was developed in consultation with an academic librarian experienced in systematic literature searching. The systematic search was conducted on the 8th of August 2019 using the EBSCO interface and including Cumulative Nursing and Allied Health Literature (CINAHL), Education Resources Information Center (ERIC), MEDLINE, and SPORTDiscus databases. No date restrictions were imposed, but only studies published in English were included. Reference lists, topical systematic analyses/reviews, and the personal library of the senior author were reviewed to identify additional studies not captured in database search. Large nationally representative fitness survey data suitable to temporal trends analysis were also considered.

2.4 Search

The 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); 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).

2.5 Study Selection

All database records were imported into RefWorks® reference management software (v2.0; ProQuest LLC, Ann Arbor, MI, USA) and then 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.[16] All data were extracted by a single researcher and checked for accuracy by a second researcher. Additional data, when necessary, was requested from the corresponding authors via email.

2.7 Data Items

The following study-specific data were extracted: title, country, sampling information, years of testing, sex, age, 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 using linear or polynomial (quadratic or cubic) regression models weighted by the square root of sample size.[16] 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 were expressed as standardized effect sizes (ES), where absolute changes in means were 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.[18] Positive trends indicated increases in mean HGS and negative trends indicated declines in mean HGS.

Regional (across three geographical continents [Asia, Europe and North America and further divided into national and sub-regional levels] for men, women, young adults [20–39 year-olds], middle-aged adults [40–64 year-olds], older adults [≥65 years old], and all [≥20 years old]) and national and sub-regional (i.e., Northern, Central and Southern Europe) trends were calculated using a post-stratified population-weighting procedure[19] that has been described in detail elsewhere.[16] Population estimates were standardized to the year 2005, which is a common testing year for all but one country, using United Nations data.[20]

Relationships between national trends in 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 body mass index [BMI][21]) and three socioeconomic/demographic (Gini index,[22] Human Development Index [HDI][23] and urbanization[24]) 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.[25]

3 RESULTS

3.1 Study selection

A total of 422 unique records were identified through the database search, with 22 articles retained following level 1 of screening, and four articles retained after level 2. We also identified one additional study from the senior author's personal library and three large country-level fitness datasets comprising nationally representative HGS data suitable for temporal trends analysis. In total, we included eight studies/datasets in this study. Figure 1 illustrates the PRISMA flowchart for included studies.

3.2 Study characteristics

Temporal trends in HGS were estimated for 2,584,978 adults aged 20–90+ years from 13 countries across three continents (Asia, Europe and North America) between 1960 and 2017 (Tables 1 and 2). These 13 countries represented 11 high-income and two upper-middle-income countries[26] or 11 very high and two high human development countries,[27] 31% of the world's population,[28] and 25% of the world's land area.[29] Trends were estimated for 140 country-sex-age groups (men: 70; women: 70; young adults: 28; middle-aged adults: 42; older adults: 70) with a median sample size of 1044 adults (range: 34–120,222) across a median span of 14 years (range: 8–50).

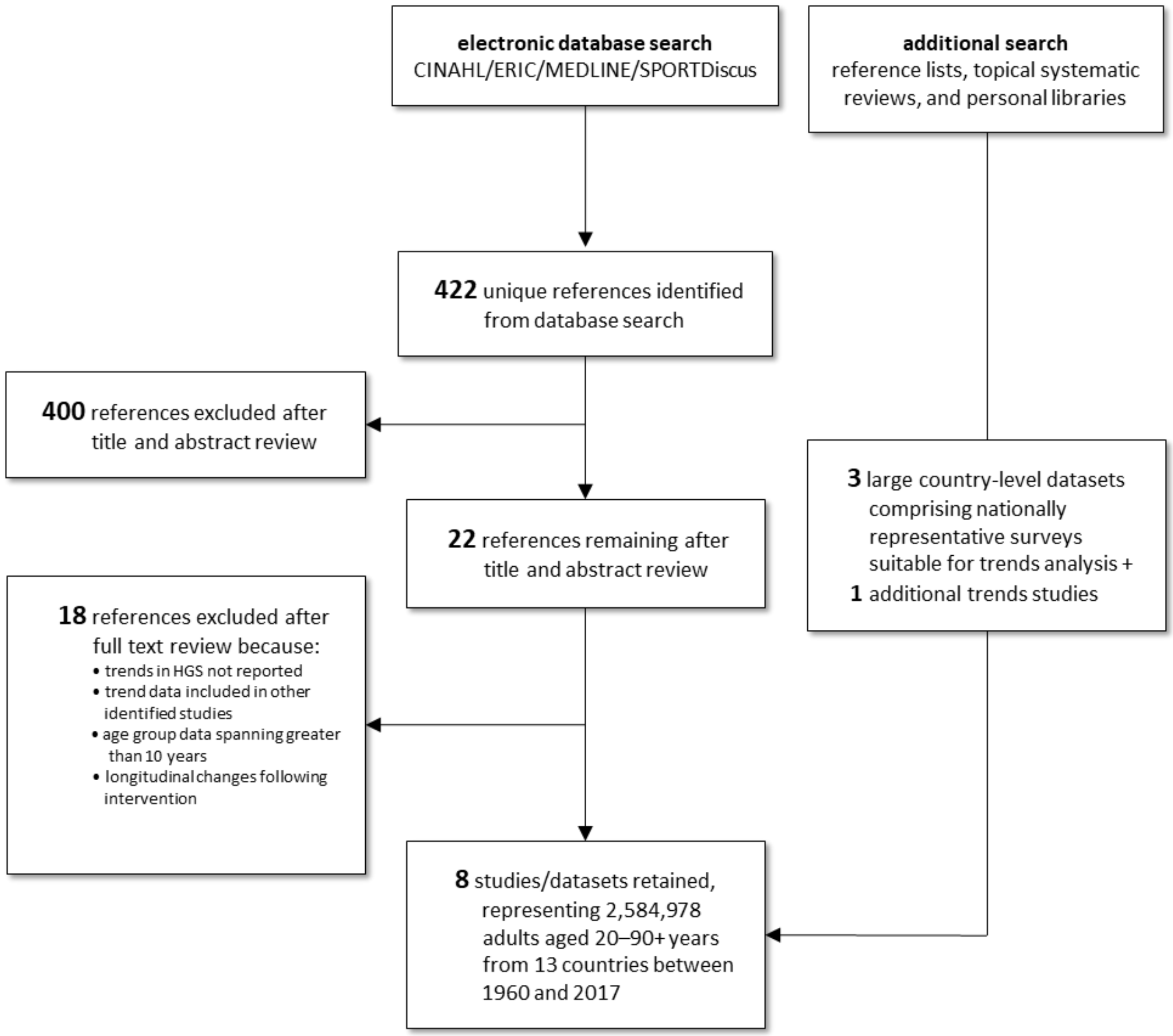

Figure 1. PRISMA flow chart outlining flow of studies through review.

Note: HGS=handgrip strength.

3.3 Synthesis of results

Prior to the year 2000, temporal trends in HGS were mixed, with small improvements for Japan and Mexico, a negligible change for the US, and a small decline for Canada (Figure 2 and Table 3). Post-2000, HGS declined for adults from 67% (8/12) of countries, with negligible declines in Central Europe (Belgium, Germany and the Netherlands), Japan and the US; small declines in Canada, China and England; and small improvements in Northern (Denmark and Sweden) and Southern (Italy and Spain) Europe.

3.3.1 Temporal trends in HGS for Asian adults

Temporal trends in HGS were estimated for adults from 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 was a moderate sex-related temporal difference over the 50-year period, with a small improvement for men (change in means per decade [95%CI]: 0.05 ES [0.04 to 0.06]) and a small decline for women (change in means per decade [95%CI]: −0.07 ES [−0.08 to −0.06]). There were also negligible-to-small age-related temporal differences, with a small decline for young adults (change in means per decade [95%CI: −0.05 ES [−0.06 to −0.04]; 1967–2017) and a negligible change for middle-aged adults (change in means per decade [95%CI]: 0.03 ES [0.02 to 0.04]; 1967–2017) and 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 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 declines thereafter (Figure 2 and Table 3). Similarly, there was a steady decline in HGS for Chinese adults over the period 2000–2014, although the magnitude of decline (change in means per decade [95%CI]: −0.21 ES [−0.20 to −0.22]) was somewhat larger compared to Japan.

3.3.2 Temporal trends in HGS for European adults

Over the period from 2004 to 2013, temporal trends in HGS were estimated for adults from three European sub-regions: Northern Europe (20,477 adults aged 50–90+ years from Denmark, England, and Sweden), Central Europe (16,820 adults aged 50–90+ years from Belgium, Germany, and the Netherlands) and Southern Europe (9632 adults aged 50–90+ years from Spain and Italy) (Table 1). Across Europe, there were negligible sex- and age-related temporal differences over the 9-year period, with negligible improvements for women (change in means per decade [95%CI]: 0.06 ES [0.02 to 0.10]) and older adults (change in means per decade [95%CI]: 0.08 ES [0.05 to 0.11]), no change for men (change in means per decade [95%CI]: 0.01 ES [−0.02 to 0.04]), and a negligible decline for middle-aged adults (change in means per decade [95%CI]: −0.04 ES [−0.07 to −0.01]).

While the time periods over which temporal trends in HGS were estimated was considerably narrower for Europe compared to Asia and North America, there were negligible declines in

HGS for Northern (change in means per decade [95%CI]: −0.15 ES [−0.19 to −0.11]) and Central (change in means per decade [95%CI]: −0.11 ES [−0.14 to −0.08]) European adults, which were in contrast to the small improvement for Southern European adults (change in means per decade [95%CI]: 0.33 ES [0.29 to 0.37]).

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								
East 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								
Central 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)
Northern Europe	England[86]	F (54.1%) M (45.9%)	50–89	2004–2012	11,476	P	N	0.922 (very high)
	Denmark/Sweden[85]	F (50.0%) M (50.0%)	50–90+	2004–2013	9001	P	NN	0.929–0.933 (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)
North America								
	Canada[87–90]	F (52.7%) M (47.3%)	20–79	1981–2016	22,998	P/NP	N/NN	0.926 (very high)
	Mexico[91]	F (56.9%) M (43.1%)	20–69	1978–2000	654	NP	NN	0.774 (high)
	USA[88]	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[23]; 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 collective trends were reported here for Central Europe (Belgium/Germany/Netherlands), Northern Europe (Denmark/Sweden) and Southern Europe (Italy/Spain).

Table 2. Sub-region/country-level distribution of surveys from which temporal trends in adult HGS were estimated. Each dot represents a testing year.

	Asia		**Europe**				**North America**		
Year of testing	China	Japan	Belgium/ Germany/ Netherlands	England	Denmark/ Sweden	Italy/ Spain	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		•					•		

Temporal trends in adult handgrip strength

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		•							

Note: HGS=handgrip strength; USA=United States of America; each dot represents a testing year.

Table 3. National/sub-regional temporal trends in mean HGS for 2,584,978 adults aged 20–90+ years from 13 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					
East 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					
Central Europe	Belgium/Germany/Netherlands		−2.3 (−3.0 to −1.6)		−0.11 (−0.14 to −0.08)
Northern Europe	England		−6.3 (−7.2 to −5.4)		−0.27 (−0.30 to −0.24)
	Denmark/Sweden		4.3 (3.8 to 4.80)		0.21 (0.19 to 0.23)
Southern Europe	Italy/Spain		7.0 (6.1 to 7.9)		0.33 (0.29 to 0.37)
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.

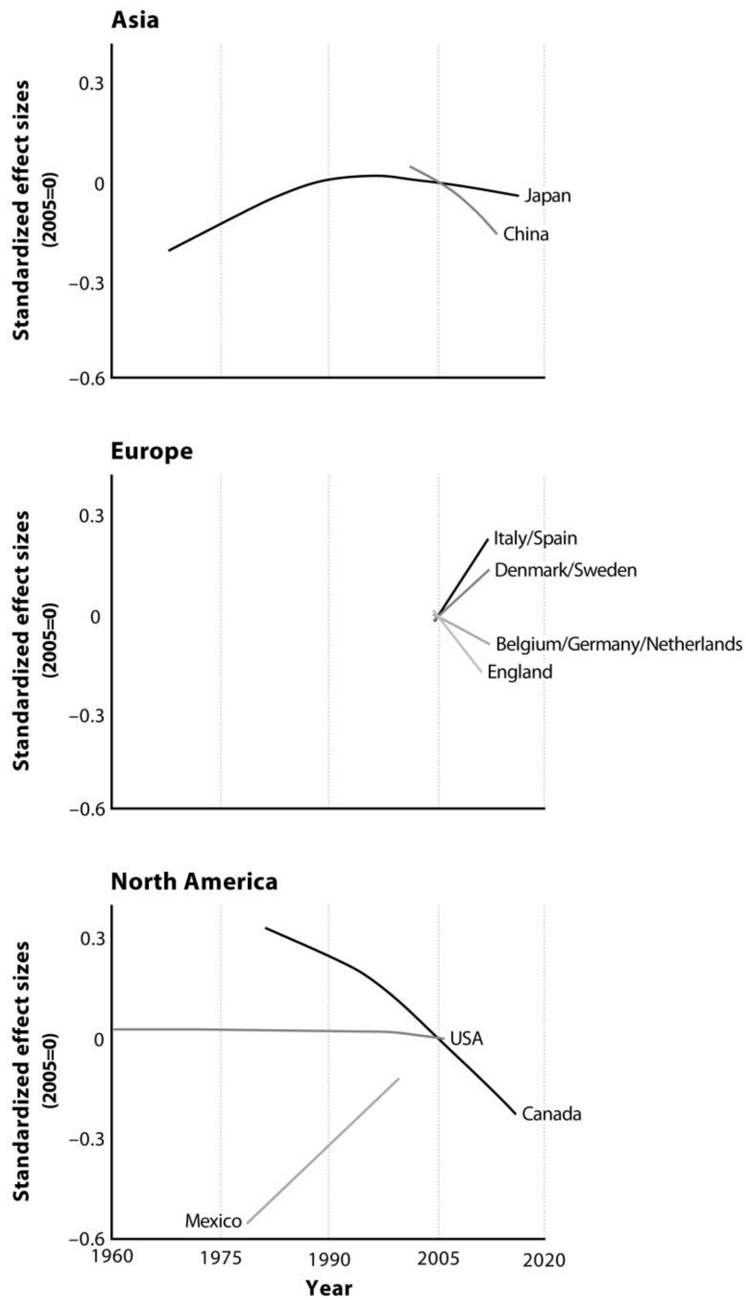

Figure 2. National temporal trends in mean handgrip strength from 1960 to 2017.

Note: HGS=handgrip strength. Data were standardized to the year 2005=0, with higher values (>0) indicating better HGS and negative values (<0) indicating poorer HGS; the solid lines represent the national changes in mean HGS, with upward sloping lines indicating temporal improvements and downward sloping lines indicating temporal declines.

3.3.3 Temporal trends in HGS for North American adults

For North America, temporal trends in HGS were estimated for adults from Canada (22,998 adults aged 20–79 years between 1981 and 2016), Mexico (654 adults aged 20–69 years between 1978 and 2000) and the United States of America (8394 adults aged 20–79 years between 1960 and 2006) (Table 1). There was a negligible sex-related temporal difference over the 56-year period in North America, with negligible changes for both men (change in means per decade [95%CI]: −0.01 ES [−0.03 to 0.01]; 1960–2016) and women (change in means per decade [95%CI]: −0.03 ES [−0.05 to −0.01]; 1978–2016). In contrast, there were small age-related temporal differences in North America, with a negligible change for young adults (change in means per decade [95%CI]: −0.02 ES [−0.04 to 0.00]; 1960–2016), a negligible improvement for middle-aged adults (change in means per decade [95%CI]: 0.02 ES [0.00 to 0.04]; 1968–2016), and a small 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 large decline in HGS between 1981 and 2016 (change in means per decade [95%CI]: −0.17 ES [−0.19 to −0.15]), with the rate of decline 2-fold larger post-2000 in comparison with pre-2000 (Figure 2 and Table 3). In contrast, there was a negligible change for United States adults between 1960 and 2006 (change in means per decade [95%CI]: 0.00 ES [−0.02 to 0.02]), and a small improvement in Mexican adults between 1978 and 2000 (change in means per decade [95%CI]: 0.21 ES [0.19 to 0.23]).

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

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

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

Variable	**Data Source**	**Description**	**Correlation (95%CI)**
Health			
Body mass index (BMI)	NCD-RisC [21] Trend data available for 13/13 (100%) countries/subregions 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.	−0.36 (−0.76 to 0.24)
Socioeconomic/demographic			
Gini Index	World Bank [22] Trend data available for 12/13 (92%) countries/subregions 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.	0.42 (−0.24 to 0.81)
Human Development index (HDI)	United Nations [23] Trend data available for 13/13 (100%) countries/subregions between 1990 and 2017	Calculated as the change (per decade) in mean country-level human development (i.e. achievements in health, education,	−0.15 (−0.67 to 0.46)

		and income). With increasing HGS, a positive correlation indicated an increase in the mean human development and a negative correlation indicated a decline.	
Urbanization	World Bank [24] Trend Data available for 13/13 countries/subregion between 1990 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.	−0.17 (−0.68 to 0.45)

4 DISCUSSION

This study estimated temporal trends in HGS for 2,584,978 adults from 13 countries across three continents between 1960 and 2017. The principal findings were that: (a) pre-2000, trends in HGS were few and mixed, whereas post-2000, HGS declined for adults from most countries/sub-regions, with negligible-to-small changes across countries; (b) sex- and age-related trends in HGS were negligible-to-small; and (c) national trends in HGS were not significantly related to national trends in health and socioeconomic/demographic indicators. Given the significant associations between HGS and both physical function and health, and evidence indicating HGS demonstrates moderate-to-high construct validity, our finding of recent (post-2000) declines in adult HGS across most countries included in this analysis is suggestive of corresponding declines in strength capacity and general health, at least among adults from high- and upper-middle-income countries included in this analysis.

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 HGS.[15,16] Because body size is positively and significantly related to HGS cross-sectionally,[86] we would expect that trends in mean HGS have corresponded with trends in mean body size. Unfortunately, we did not find a statistically significant relationship between national trends in mean HGS and national trends in mean BMI. While one included study reported concurrent increases in HGS and body size (operationalized as standing height and body mass),[91] two others reported temporal differences.[86,90] For example, Dodds et al.[86] 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.[90] 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 five skinfolds. Taken together, these two studies suggest that there may be other aspects involved in describing trends in HGS. Moreover, it is not exactly clear why these two studies have reported temporal differences in HGS and body size. Despite convincing evidence of an international increase in adult BMI,[21] it is possible that temporal differences in fat mass and fat-free mass have occurred, and that the recent decline in 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[92–97] and subcutaneous[95] fatness independent of increases in BMI. However, evidence of temporal trends in fat-free mass are scarce. Although not generalizable at the population level, 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).[98] 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[99,100] (even after controlling for fat mass[99] or age, sex, education, smoking, alcohol use, physical activity, several chronic diseases, and current body mass[100]), possibly due to the chronic effects of inflammation and/or insulin resistance.[100]

Physical activity also positively influences muscular strength in adults[101,102], suggesting that the recent decline in 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.[103,104] 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[105–114], in contrast with increased sedentary behavior[105,109] and decreased occupational physical activity.[105,112,114–117] Unfortunately, few studies have examined concurrent trends in HGS and physical activity levels. To our knowledge, two studies[85,118] have reported a temporal coincidence, while only one study[86] has directly examined trends in 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 reflect given that upper-body resistance training has been shown to positively influence HGS in adults.[119]

While trend data on the prevalence of muscle-strengthening guidelines are scarce, Australian[120] and US[121] 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[120], and two or more times per week between 1998 and 2016 for US adults[121]). Assuming that the relationship between trends in the prevalence of muscle-strengthening activity and trends in 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.[121] 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[122,123], especially muscle-strengthening involving the upper body[119]) might be a suitable population approach to improving adult HGS.

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.[16] The results indicated that adult CRF declined across all eight countries, and improved internationally in the 1960s and 1970s before declining at a rate of 2.2%, or 0.19 ES, per decade thereafter.[16] In combination with recent declines in adult HGS, which we observed for most countries/sub-regions in this study, these recent trends are suggestive of corresponding declines in functional capability (i.e., functional strength capacity [HGS] and endurance [CRF]) and general health.

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,[15] results suggested a moderate improvement of 3.8%, or 0.14 ES, per decade, with the international rate of improvement progressively increasing over time. While it is challenging to explain why there has been a recent (post-2000) improvement in HGS for children and adolescents[15] and a decline in HGS for adults (this study), it is possible that the age-related temporal difference is due to between-study differences in included countries. 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 fatness, physical activity levels, and sedentary behaviors.[16]

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.[15,16 ,124–126] We estimated trends in HGS measured using handgrip dynamometry (a valid, reliable, feasible, and scalable measure of strength capacity),[2-5] which is significantly associated with health outcomes and functional capability.[6–14] The weighted regression and post-stratification population weighting procedures helped adjust our trends 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, it is unlikely our temporal trends were biased because all within-study/dataset trends used matched HGS protocols. Second, while most studies/datasets used probability sampling, few used nationally representative 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-specific HGS data, which may not be representative of all sex and age adult groups within a country, it is likely that our national trends in HGS are broadly generalizable given our finding of negligible-to-small age-related temporal differences in adult HGS. 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 full distribution of performance, or if the tail 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,[90] 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),[118] suggesting that the recent trend in HGS was not uniform across the distribution. It is therefore challenging to estimate the likely impact of trends in distributional characteristics on trends in means. Fifth, we were unable to statistically remove the effects of trends in potential mechanistic factors such as body size and physical activity levels, because: (a) we estimated trends in HGS using only descriptive data, and (b) corresponding descriptive data were not always reported for such factors. Sixth, because our trends in HGS were limited to only adults from 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 HGS: (a) were limited to only 13 countries; (b) 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 international temporal trends in adult HGS. We estimated that trends in HGS were mixed pre-2000, with HGS typically declining at the country-level post-2000. Sex- and age-related trends in HGS were negligible-to-small. National trends in adults 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 temporal trends in 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 to potentially predict future trends.

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