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TEMPORAL TRENDS IN THE GRIP STRENGTH OF CHILDREN AND ADOLESCENTS

by

Faith LaVoy Dooley

Bachelor of Science, University of North Dakota, 2017

A Thesis

Submitted to the Graduate Faculty

of the

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for the degree of

Master of Science

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This thesis, submitted by Faith LaVoy Dooley in partial fulfillment of the requirement for the Degree of Master of Science 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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This thesis is being submitted by the appointed advisory committee as having met all the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

Dr. Chris Nelson

Associate Dean, School of Graduate Studies

Date

PERMISSION

Title	Temporal Trends in the Grip Strength of Children and Adolescents
Department	Kinesiology
Degree	Master’s

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Faith Dooley

07-25-2019

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ABSTRACT

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

Methods: Data were obtained in two ways: (a) through a systematic electronic database search for studies reporting on temporal trends in the handgrip strength of apparently healthy 9–17-year-olds, (b) pearling reference lists, topical systematic reviews and personal libraries, and (c) by examining large national fitness datasets suitable to temporal trends analysis. Sample-weighted temporal trends were estimated using best-fitting regression models relating the year of testing to mean handgrip strength. Post-stratified population-weighted mean changes in percent and standardized handgrip strength were estimated. Pearson's correlations were used to quantify relationships between linear trends in handgrip strength and linear trends in health-related and sociodemographic indicators.

Results: Trend data from 22 studies/datasets representing 2,216,589 children and adolescents from 13 high-, five upper-middle-, and one low-income country collectively showed a moderate improvement in mean handgrip strength of 19.4% (95%CI: 18.4 to 20.4) or 3.8% per decade (95%CI: 3.6 to 4.0) between 1967 and 2017. The international rate of improvement in handgrip strength increased over time, doubling since the 1960s and 1970s. Improvements were larger for children (9–12 years) than adolescents (13–17 years) and similar for boys and girls. Trends differed in magnitude and direction between countries, with most experiencing improvements. Trends in handgrip strength were negligibly-to-moderately related to trends in health-related and sociodemographic indicators.

Conclusions: There has been a meaningful improvement in the handgrip strength of children and adolescents since 1967, which has progressively increased in magnitude over time and is suggestive of a corresponding improvement in muscle and bone health. There is a need for improved international surveillance of handgrip strength, especially in children and adolescents from low- and middle-income countries, given the meaningful associations between handgrip strength and health-related outcomes.

PROSPERO registration number: CRD42013003657

INTRODUCTION

Muscular fitness (MF) is a multidimensional construct used to represent muscular strength, endurance, and power. Generally defined, muscular strength is the ability to generate force with a muscle or group of muscles; muscular endurance is the ability to perform repeated contractions with a muscle or group of muscles under sub-maximal load; and muscular power is the rate at which a muscle or group of muscles perform work [1,2,3]. Handgrip strength is a quick and easy measure of the maximum voluntary muscular force of the finger flexors and is a good marker of overall body strength [4].

Reduced handgrip strength in adulthood has been significantly associated with an increased risk of all-cause, cardiovascular and non-cardiovascular disease mortality [5,6,7], stroke [6], type 2 diabetes [8], hypertension [8], surgical complications [9], disability [9], falls [9], accelerated dependency in activities of daily living [11], and cognitive decline [11]. In children and adolescents, low musculoskeletal strength, as measured by handgrip strength and standing broad jump, has been linked to cardiometabolic outcomes [12] and all-cause mortality in later life [13], with adolescents falling in the bottom decile for muscular strength having the greatest risk of all-cause mortality in later life [13]. In line with this evidence, global physical activity guidelines now recommend muscular and bone strengthening activities (in addition to aerobic activity) at least three times per week for children and adolescents [14]. Global data show that currently one-third of adults and four out of five adolescents are not sufficiently active [15].

Handgrip strength has a strong, positive correlation with overall muscular strength in children, adolescents and young adults, which reduces to a moderate correlation when adjusted for body mass [4]. Artero, et al. [16] reported very strong test-retest reliability coefficients for handgrip strength ranging from 0.84 to 0.98 in children and adolescents (aged 8–18 years). The test is safe, easy, and simple to administer; it can be conducted in a timely and efficient manner; it imposes little preparation burden on both participants and testers; it can be administered with acceptable privacy, minimal equipment and space; performance is independent of test familiarity and prior practice (e.g., test-retest differences in means are negligible in children and adolescents) [17,2].

Given the association between muscular strength and health, estimating temporal trends in muscular strength should provide helpful information about concurrent trends in health. Strength surveillance might be a beneficial complement to existing health surveillance programs (e.g., the World health Organization's global action plan on physical activity) [18]. This study extends existing research on temporal trends in the explosive muscular strength (i.e., jumping ability) and CRF of children and adolescents [19] to maximal strength (i.e., handgrip strength). The primary aim therefore was to systematically analyze national and international temporal trends in the handgrip strength of children and adolescents. The secondary aim was to examine relationships between temporal trends in handgrip strength and temporal trends in health-related and sociodemographic indicators across countries. It was hypothesized that handgrip strength had improved over time, and that country trends in health-related and sociodemographic indicators would be meaningfully associated with temporal trends in handgrip strength.

METHODS

Protocol and Registration

The review protocol was registered with the International Prospective Register of Systematic Review (PROSPERO; registration number CRD42013003657). This review was written following the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 statement [20]

Eligibility criteria

One large systematic review of temporal trends in children's muscular fitness was initially undertaken before being divided into three smaller reviews. For this study, studies were included if they reported on: (a) temporal trends in children's maximal strength (operationalized as handgrip strength performance). Candidate studies were eligible if they reported on temporal trends in the handgrip strength of apparently healthy (free from known disease/injury) children (aged 9–17) across at least two time points spanning a minimum of five years. Temporal trends must have been reported as absolute, percent or standardized changes in means at the country-sex-age level, or as descriptive data (e.g., sample sizes, means and standard deviations) at the country-sex-age-year level to allow for the calculation of temporal trends. At the country level, trends across a minimum of four country-sex-age groups (e.g., 9-year-old boys from the United States) were required for inclusion.

Information sources

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

Search strategy

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

Study selection

All database records were imported into RefWorks (v2.0; ProQuest LLC, Ann Arbor, MI, USA) and de-duplicated. At the first level, two researchers independently screened the titles and abstracts of all bibliographic records against inclusion criteria, with consensus required for further screening. At the second level, full text copies were obtained and independently screened by two researchers against inclusion criteria, with consensus required for final inclusion. The full search strategies for each database are shown in Supplement 1.

Data collection process

Descriptive data were extracted into a spreadsheet by one researcher using a standardized study-specific template [21], and reviewed by a second researcher for accuracy. If required, additional information was requested from the corresponding authors via email (e.g., to clarify published results or to avoid double counting data).

Data items

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

Summary measures and synthesis of results

Temporal trends were analyzed at the country-sex-age level using best-fitting sample-weighted linear or polynomial (quadratic or cubic) regression models relating the year of testing to mean handgrip strength [22,23,24,25]. Trends in mean handgrip strength were expressed as percent changes (i.e., change in means expressed as a percentage of the overall mean) and as standardized effect sizes (ES) (i.e., change in means divided by the pooled standard deviation). To interpret the magnitude of change, ES of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with ES<0.2 considered to be negligible and ES≥0.2 considered to be meaningful. Positive trends indicated increases in mean handgrip strength and negative trends indicated declines in mean handgrip strength.

Post-stratified population-weighted temporal trends were calculated for all children and adolescents, as well as for separate age, sex and country groups using the detailed procedure described elsewhere [22,23,24,25]. Population estimates were standardized to the year 2000—a common testing year to the vast majority of country-sex-age groups—using United Nations data [26]. The post-stratification population-weighting procedure helped to correct the trends for systematic bias associated with over- and under-sampling, and to standardize the trends to underlying country-sex-age-specific demographics. Trends were graphically displayed using an iterative procedure described by Tomkinson and Olds [25].

Relationships between linear temporal trends in handgrip strength and linear temporal trends in health-related and sociodemographic indicators across countries were quantified using Pearson's correlation coefficients, with 95% CIs estimated using Fisher's *z*-transformation. National trends for five health-related (children's body mass index [BMI] [27] and vigorous physical activity [VPA] [27]) and sociodemographic (Gini index [28], the Human Development Index [HDI] [29], and urbanization [30]) indicators were analyzed using linear regression models (as described above). Trends in these health-related and sociodemographic indicators were examined because they were thought to be meaningfully related to trends in handgrip strength and because it was possible to calculate temporal trends using the same criteria as for handgrip strength (e.g., across at least two time points spanning a minimum of 5 years) across the majority of the included countries. To interpret the magnitude of correlation, ES of 0.1, 0.3, 0.5, 0.7, and 0.9 were used as thresholds for weak, moderate, strong, very strong, and nearly perfect, respectively, with ES<0.1 considered to be negligible and ES≥0.1 considered to be meaningful.

RESULTS

The electronic database search returned 1,416 unique sources of which 28 sources were retained for full-text review following title and abstract screening (Figure 1). Of these, six were retained and combined with 16 additional articles or datasets suitable for temporal trends analysis, which were located through the principal advisor's personal library and the reference lists of included articles, resulting in 22 included studies/datasets (Figure 1).

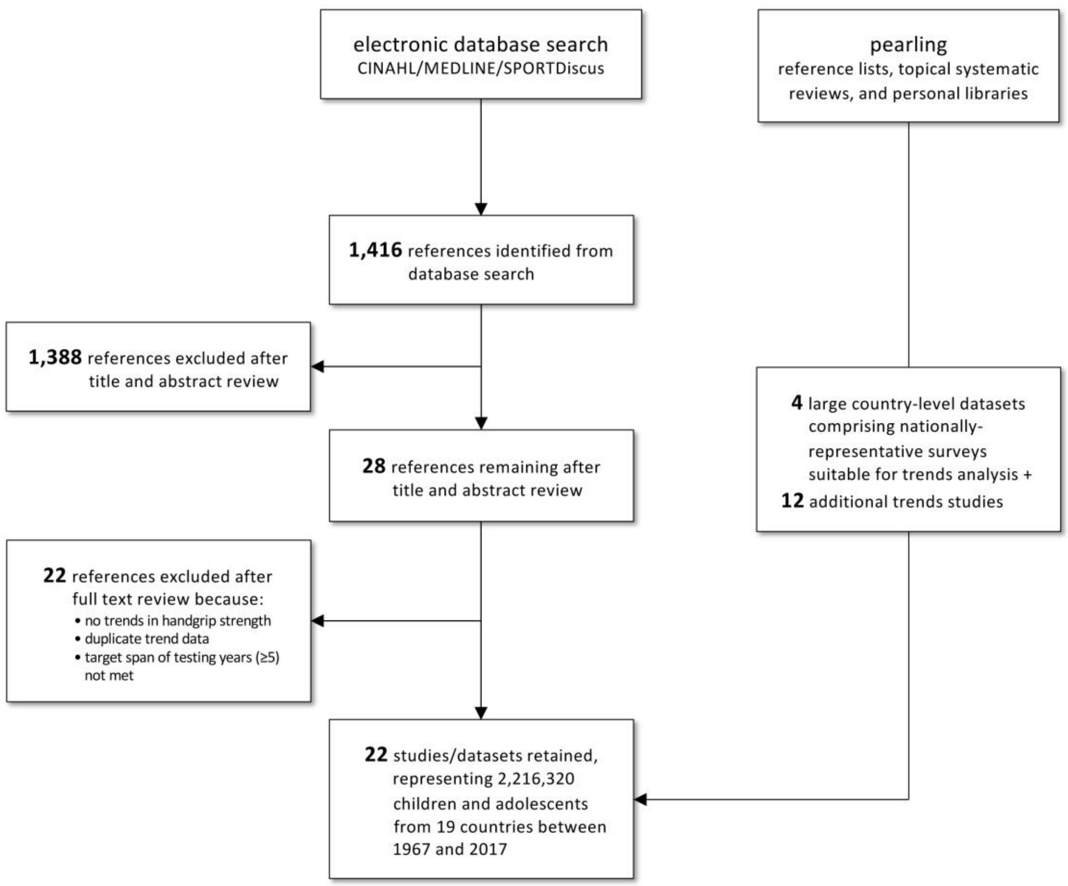

Figure 1. PRISMA flow chart outlining the flow of studies through the review.

Temporal trends in grip strength were estimated from 2,230,658 children and adolescents aged 9–17 years from 19 countries (2,085 country-sex-age-year groups) between 1835 and 2017 (Table 1). Trends prior to 1967 were removed because they were only available for 16% (3/19) of countries representing <1% of all data points (e.g., Belgium: 1835–2010; Bulgaria: 1960–1999; USA: 1899–2009). As a result, trends between 1967 and 2017, representing 2,216,320 children and adolescents, were calculated. Trends were available for 13 high-income, 5 upper-middle-income, and 1 low-income countries (or 14 very high countries, four high countries, and one low human development countries) [31,32], representing five continents, 34% of the world's population [33], and 33% of the world's land area [34]. Trends were calculated for 254 country-sex-age groups (children [aged 9–12 years]: 124; adolescents [aged 13–17 years]: 130; boys: 126; girls: 128), with a median sample size of 835 (range 23–75,407) across a median span of 23 years (range 5–50).

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

Table 1. Summary of the included studies by country.

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI	Test protocol
Australia[w1]	F (49.5%) M (50.5%)	9–12	1985–1999	2,912	P	N/S/O	0.939 (very high)	Average of both hands
Belgium [w2–w3]	F (47.7%) M (52.3%)	9–17	1835–2010	27,868	P/NP	S/O	0.916 (very high)	Dominant hand
Bulgaria [w4–w7]	F (50.7%) M (49.3%)	9–17	1960–1999	28,058	P	N/O	0.813 (very high)	Average of both hands
Canada [w8–w11]	F (49.7%) M (50.3%)	9–17	1967–2009	6,884	P/NP	N/O	0.926 (very high)	Sum of both hands
China [w12–w15]	F (49.9%) M (50.1%)	9–17	2000–2014	656,162	P	N	0.752 (high)	Dominant hand
Estonia [w3]	F (53.4%) M (46.6%)	10–17	1992–2002	4,338	P/NP	S/O	0.871 (very high)	Dominant hand
France [w3]	F (52.1%) M (47.9%)	11,13,14	1985–2008	572	P/NP	O	0.901 (very high)	Dominant hand
Greece [w3]	F (48.7%) M (51.3%)	13–15	1990–2008	2,188	P/NP	N/O	0.870 (very high)	Dominant hand
Hong Kong [w16–w20]	F (48.6%) M (51.4%)	9–12	2000–2015	17,653	P	N	0.933 (very high)	Sum of both hands
Italy [w3]	F (50.9%) M (49.1%)	12–16	1992–2008	5,643	P/NP	S/O	0.880 (very high)	Dominant hand
Japan [w21–w71]	F (49.4%) M (50.6%)	9–17	1967–2017	1,043,672	P	N	0.909 (very high)	Average of both hands
Mexico [w72]	F (49.8%) M (50.2%)	9–17	1968–2000	2,463	NP	O	0.774 (high)	Sum of both hands
Mozambique [w73]	F (53.0%) M (47.0%)	9–17	1992–2012	3,552	P	O	0.437 (low)	Dominant hand
Poland [w3,w74–w77]	F (49.1%) M (50.9%)	9–17	1979–2011	367,320	P/NP	N/S/O	0.865 (very high)	Dominant hand

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI	Test protocol
Spain [w3]	F (51.3%) M (48.7%)	9–17	1984–2010	19,948	P/NP	S/O	0.891 (very high)	Dominant hand
Thailand [w78]	F (51.0%) M (49.0%)	9–12	1990–2003	15,235	P	N	0.755 (high)	Dominant hand
Turkey [w79]	F (30.8%) M (69.2%)	11–12	1983–2013	1,195	NP	O	0.791 (high)	Dominant hand
UK [w3,w80]	F (57.6%) M (42.4%)	9–13,15,17	1981–2014	17,842	P/NP	N/S/O	0.922 (very high)	Dominant hand
USA [w9–w9,w81,w82]	F (46.8%) M (53.2%)	9–17	1899–2009	7,153	NP	S/O	0.924 (very high)	Sum of both hands

Note: UK=United Kingdom; USA=United States of America; M=male; F=female; P=probability sampling; NP=non-probability sampling; N=national sample; S=state/provincial sample; O=other sample (e.g., city, local, or school level); HDI=Human Development Index (2017 estimate [31]) with HDI values of 0.800, 0.700 and 0.550 used as thresholds for very high, high and medium human development, respectively.

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

National trends ranged from a large improvement in handgrip strength in France (1985–2008) to a large decline in Turkey (1983–2013), with trends typically negligible to small (12/19 or 63%) and positive (i.e., improvements) (11/19 or 58%) (Figure 3). Figure 3 shows that while uniform (linear) and non-uniform (curvilinear) trends were evenly split across countries, some countries experienced a decrease or stabilization of the rate of change (e.g., Belgium, China and Turkey), an increase in the rate of change (e.g., Australia, Italy and the US), or a reversal of the direction of change (e.g., Poland). Country trends were very strongly related between boys and girls (r [95%CI]: 0.74 [0.43 to 0.89]) but weakly related between children and adolescents (r [95%CI]: 0.19 [−0.36 to 0.64]).

There were weak positive correlations between trends in handgrip strength and trends in urbanization, BMI, VPA and HDI, and a negligible correlation with Gini index (Table 2).

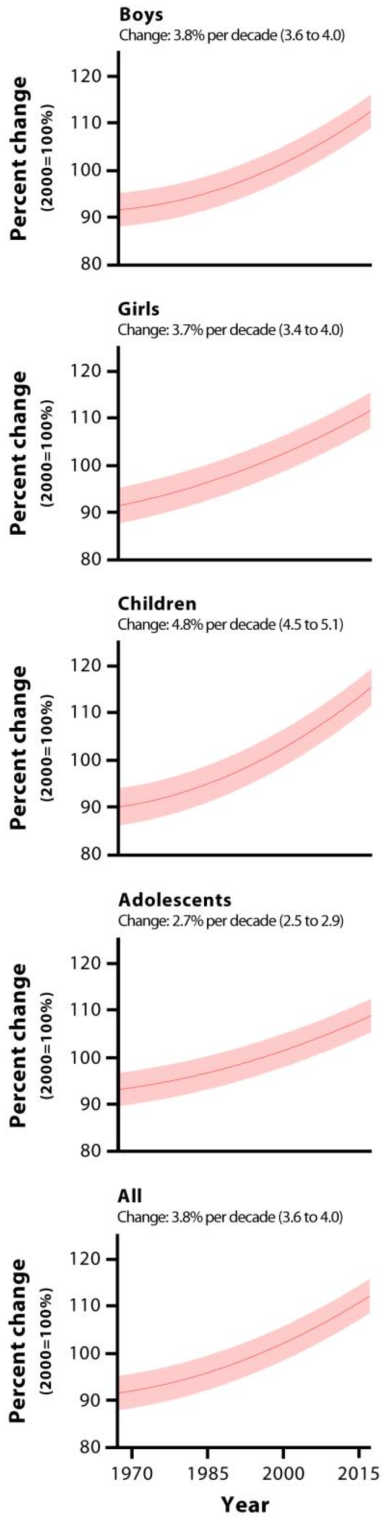

Figure 2. International temporal trends in mean handgrip strength between 1967 and 2017.

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

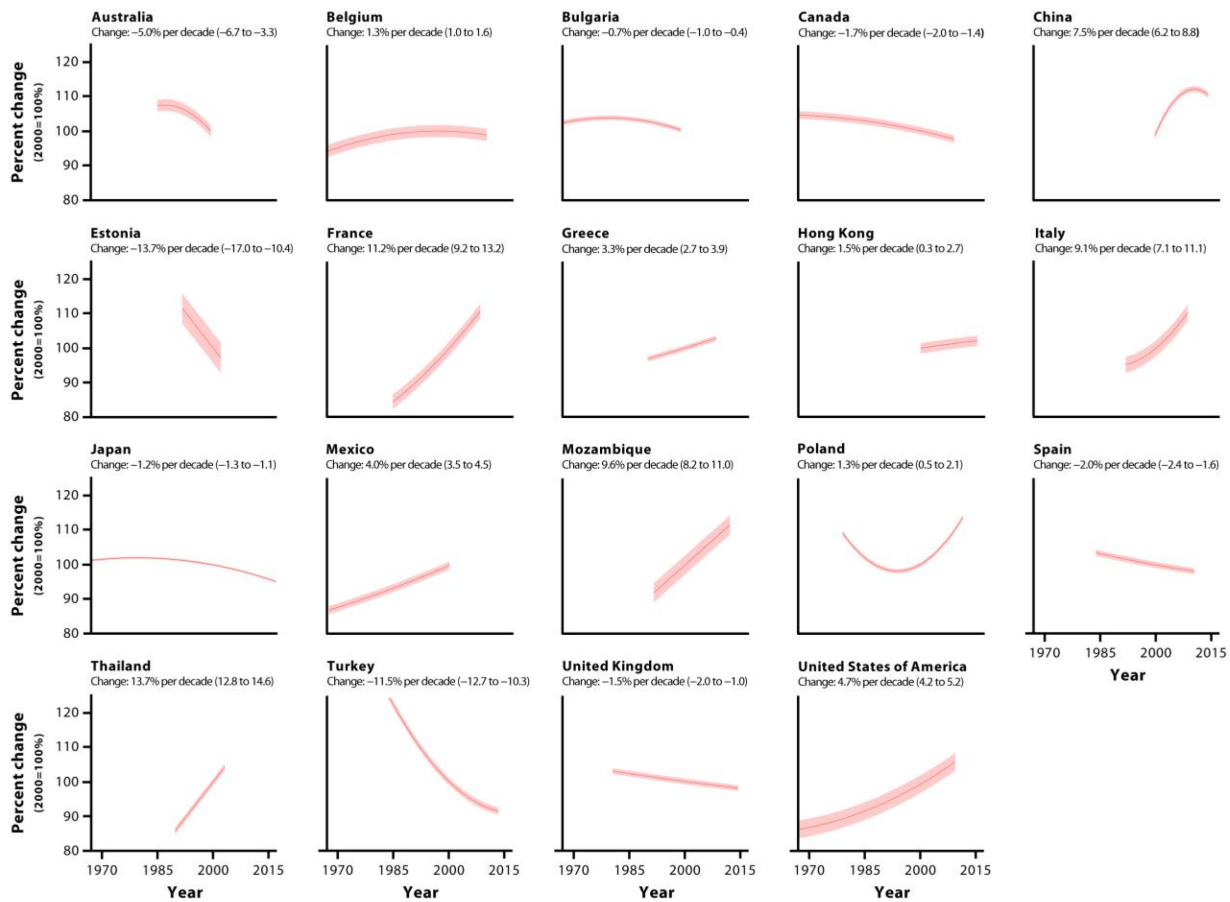

Figure 3. National temporal trends in mean handgrip strength between 1967 and 2017.

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

Table 2. Potential correlates of the trends in the handgrip strength of children and adolescents.

Variable	Data source	Description	Correlation (95%CI)
Health			
Body mass index (BMI)	NCD RisC [27]. Trend data available for 19/19 (100%) countries between 1975 and 2016.	Calculated as the change (per decade) in mean country-level BMI of boys and girls aged 5–19 years (age standardized). A positive change indicated an increase in mean BMI and a negative change indicated a decline.	0.18 (−0.30 to 0.59)
Vigorous physical activity (VPA)	Inchley et al. [35]. Data originally obtained from Health Behaviour in School-aged Children (HBSC) World Health Organization (WHO) collaborative cross-national study. Trend data available for 10 European countries (10/19 or 53% of all countries) between 2002 and 2014.	Calculated as the change (per decade) in mean country-level percentage of boys and girls aged 11-, 13-, and 15-years old that achieved VPA at least four times per week. A positive change indicated an increase in the mean percentage of vigorously active children and a negative change indicated a decline.	0.15 (−0.53 to 0.71)
Sociodemographic			
Human development index (HDI)	The United Nations [29]. Trend data available for 18/19 (95%) countries between 1990 and 2017.	Calculated as the change (per decade) in mean country-level achievement in a variety of indicators related to standards of living. A positive change indicated an increase in the mean standard of living and a negative change indicated a decline.	0.15 (−0.34 to 0.58)

Gini index	The World Bank [28]. Trend data available for 17/19 (89%) countries between 2000 and 2015.	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. A positive change indicated a trend towards perfect inequality and a negative change a trend towards perfect equality.	0.04 (−0.45 to 0.51)
Urbanization	World Bank [30] Trend data available for 19/19 (100%) countries between 1967 and 2017.	Calculated as the change (per decade) in the percentage of people living in urban areas. A positive change indicated an increase in urbanization and a negative change indicated a decline.	0.27 (−0.21 to 0.65)

DISCUSSION

This study reported on the national and international temporal trends in the handgrip strength of 2.2 million children and adolescents from 19 different countries over the period 1967–2017. The main findings were: (a) a moderate international improvement with the rate of increase now twice as large as the rate in the 1960s/1970s; (b) international improvements were found for all ages and sex groups, with the rate twice as large for children than adolescents, and similar for boys and girls; (C) national trends varied in magnitude and direction; and (d) national trends in handgrip strength were weakly related to national trends in health and sociodemographic indicators. Given the importance of handgrip strength to good health, these trends can be used to reflect trends in general health.

It has previously been argued that trends in children's cardiorespiratory fitness have probably been caused by a network of environmental, social, behavioral, physical, psychosocial and physiological factors [22,23,25]. Trends in children's handgrip strength are also probably explained by a similar causal network. Consider first the potential impact of body size, which is meaningfully associated with muscular strength [3,36,37]. Several studies have examined temporal trends in handgrip strength after controlling for trends in body size [38,39]. Ignasiak et al. [38] observed improved handgrip strength in 7–15-year-old Polish youth between 2001 and 2011 independent of changes in height, mass and BMI, and Sandercock and Cohen [39] observed declines in the handgrip strength of English 10-year-olds from 1998 to 2014 independent of changes in height and mass. Unfortunately, the effect of body size on handgrip strength could not be removed in this study because the trends in mean handgrip strength were estimated from descriptive data rather than raw data, meaning that only trends in absolute handgrip strength could be estimated. The trends therefore likely reflect trends in both muscle function and body size. Underlying trends in muscle function are expected given the handgrip strength demonstrates high-to-very high construct validity, although these validity coefficients reduce to low-to moderate when controlled for body mass [4,40]. International increases in childhood and adolescent BMI are well established [27], reflecting both increases in fat mass and fat-free mass [41]. Increases in fat-free mass should result in a general increase in handgrip strength given that the force generation capacity of muscle is proportional to its cross-sectional area [42]. Given BMI increased over the period 1975–2016 in all 19 included countries, concurrent increases in handgrip strength would be expected, although Figure 3 shows variation in both direction and magnitude. The analysis revealed that trends in BMI were weakly and positively correlated with trends in handgrip strength, suggesting that trends in other factors are likely also involved. Nonetheless, the trends in absolute handgrip strength are reflective of trends in functional upper-body strength, i.e., the ability of children and adolescents to perform maximal isometric gripping tasks in their daily lives.

Because muscular strength in childhood and adolescence is positively related to biological maturation [43], temporal trends in handgrip strength are probably influenced by concurrent trends in biological maturation [44]. No studies examining temporal trends in handgrip strength have statistically controlled for trends in maturation. While trends in maturation have varied over time and between countries, estimates indicates that the age of menarche advanced by ~0.3 years per decade over most of the 20th century, and the age at which boys' voices break by ~0.2 years per decade [45]. Over the 50-year period between 1967 and 2017, this equates to 1.0 and 1.5 years for boys and girls. Because older children perform better than younger children, presumably because of improved physical and neuromuscular maturation, temporal increases in handgrip strength would be expected based on maturational advances alone. For example, between 1967 and 2017 mean handgrip strength improved internationally by ~24% and ~14% in children and adolescents. Cross-sectional data from Tomkinson et al. [46] indicate that handgrip strength improves with each year of age by ~16% in boys and ~15% in girls between the ages of 9 and 12, and by ~11% in boys and ~3% in girls between the ages of 13 and 17. When corrected for trends in biological maturation, the underlying improvement in handgrip strength is reduced to ~1–8% in children (i.e., 24% minus 16% in boys and 24% minus 1.5 multiplied by 15% in girls) and ~3–9% in adolescents (i.e., 14% minus 11% in boys and 14% minus 1.5 multiplied by 3% in girls). Advances in biological maturation could help explain why improvements in handgrip strength were found to be larger for children than adolescents.

In their recent systematic review on behavioral correlates of muscular fitness in children and adolescents, Smith et al. [3] reported that muscular fitness was positively related to objectively measured VPA and organized sport participation. However, they acknowledged that associations between handgrip strength and VPA or organized sport participation were less consistent than for other strength measures (e.g., standing broad jump, push-ups, and composite strength) [3]. Currently, there is no compelling evidence for international increases in VPA or organized sport participation [47–49] and while no study examining temporal trends in handgrip strength has statistically controlled for trends in physical activity levels, Sandercock and Cohen [39] reported that the decline in 10-year-old English children's handgrip strength between 2008 and 2014 coincided with a decline in self-reported physical activity levels. Using data from the Health Behavior in School-aged Children (HBSC) World Health Organization (WHO) collaborative cross-national study, trends in VPA for 11-, 13- and 15-year-old children from 10 European countries between 2002 and 2014 were correlated with trends in handgrip strength, with a weak, positive correlation observed. This result indicates that trends in absolute handgrip strength poorly reflect trends in children's exposure to VPA, perhaps because children's physical activities do not typically involve exposure to gripping tasks that stimulate an increase in finger flexor strength. On the other hand, because relative (i.e., mass adjusted) strength, but not absolute strength, is significantly associated with children's physical activity levels, [50] it is possible that trends in VPA better reflect trends in relative handgrip strength.

In the absence of concurrent trend data, it is difficult to explain why the improvements in handgrip strength were generally larger for children than adolescents. Apart from advances in biological maturation, which are more likely to have influenced trends in the handgrip strength of children rather than adolescents (see above), it is possible that age-related temporal differences in body size (i.e., BMI) and VPA may have played a role.

Although age-related temporal differences were not able to be estimated for BMI or VPA, a secondary analysis of the relationships between trends in handgrip strength and trends in BMI and VPA showed moderate-to-large age-related differences. For example, in children, trends in handgrip strength were strongly and positively correlated with BMI (*r* [95% CI]: 0.55 [0.03 to 0.84]) and VPA (*r* [95% CI]: 0.59 [−0.20 to 0.91]), whereas in adolescents, they were negligibly-to-weakly correlated. This suggests that childhood trends, but not adolescent trends, in handgrip strength are good markers of trends in BMI and VPA. Assuming these ecological correlations are causal, then this temporal connection suggests that country-level improvements in childhood handgrip strength are strongly influenced by increases in BMI (presumably reflecting increases in muscle mass and therefore increased force generation capacity) and VPA (presumably reflecting increased opportunities for grip strengthening activities). In addition, trends in handgrip strength were also strongly associated with trends in HDI in children (*r* [95% CI]: 0.59 [0.09 to 0.85]) but not in adolescents (*r* [95% CI]: 0.03 [−0.51 to 0.55]). This suggests that changes in the economic and development status of a country is associated with changes in children's strength levels, perhaps because of better quality and/or quantity of opportunities for organized sport and physical activity. Cross-sectionally, country-specific human development was a strong-to-very strong positive correlate of physical activity opportunities at the school and community/environment levels across 49 countries [51]. Age-related differences in motivation levels may also be involved.

This study represents the most comprehensive analysis to date of national and international temporal trends in children's muscular strength. Using a systematic review approach, this study analyzed only studies/datasets on apparently healthy children and adolescents who were directly measured for muscular strength using the highly valid handgrip strength test. It relied on a detailed statistical approach, including weighted regression and a post-stratification population weighting procedure, which adjusted for sampling bias and underlying demographics, resulting in high confidence in the trends. Furthermore, a sensitivity analysis showed that the removal of countries with very large samples (e.g., China, Japan, and Poland which collectively comprised 93% of all data points) (Table 1) had a negligible effect (ES<0.2) on the international trends, providing support that the reported international trend in handgrip strength was not substantially biased by these countries.

Although this is the first systematic analysis of temporal trends in children's handgrip strength, it used a statistical approach previously adopted in another review on trends in children's muscular power (or "explosive strength"), allowing for direct comparison between separate components of muscular fitness. In a large systematic analysis of over 20 million children and adolescents (6–19 years) from 23 countries, Tomkinson et al. [19] indicated a very small international improvement in muscular power (operationalized as standing broad jump performance) of 0.3% per decade between 1958 and 2003. However, this trend was curvilinear, with standing broad jump performance improving from the late 1950s to the mid 1980s and declining thereafter. Similarly, there was an international improvement in children's handgrip strength from the late 1960s through to the mid-1980s, however in contrast, the rate of improvement accelerated and peaked in the 2000s and 2010s rather than shifting to a decline. While the underlying reasons for this apparent temporal divergence from the mid-1980s onwards are unclear, it is possible that temporal increases in fat mass and fat-free mass are involved, [41] both of which affect the balance between supply and demand. While increased fat-free mass will improve the force generation capacity of the exercising muscles, resulting in improved handgrip and standing broad jump performance, the increase in fat mass will increase the energy demand associated with moving a heavier body through space, resulting in a decrease in standing broad jump performance but no change to handgrip strength.

There are several limitations to this study. First, the international trends are practically representative of high- and upper-middle-income countries (18/19 or 95%) and it is unclear whether similar trends exist for other high- and upper-middle-income countries or for low-income countries that may be experiencing a physical activity transition [52]. This limits the generalizability of our results to low-income and middle-income countries. Second, the small number of included countries and the homogeneity in the available trend data between countries reduced the confidence in the reported correlations (Table 2). Third, included data were collected using different sampling strategies and sampling frames and were not always nationally representative. In the absence of nationally representative data, trends were estimated using state/provincial and community level data as they provided the best-available insight into temporal trends. Furthermore, trends were estimated from available country-sex-age-specific data, which may not represent trends across all sex and age groups within a country. Fourth, it is possible that assessment procedures (e.g., dynamometer, calibration, number of trials, optimal grip span adjustment, elbow angle, level of encouragement, diurnal variation) varied over time, although the large number of included data points should have minimized these methodological issues. Finally, temporal trends in mean handgrip strength could be systematically biased if concurrent trends in skewness occurred, although this is unlikely given that Tremblay et al. [53] reported negligible differences between trends in mean and median handgrip strength in nationally-representative samples of Canadian youth tested between 1981 and 2007–9.

CONCLUSION

This study found a moderate international improvement in the handgrip strength of children and adolescents since 1967, with the rate of improvement progressively increasing over time and now twice as large as in the 1960s/1970s. International improvements in handgrip strength were nearly twice as large for children than adolescents, yet similar for boys and girls. Although it is unclear why age-related temporal differences in handgrip strength exist, it is possible that trends in biological maturation, and age-related differences in relationships between trends in BMI, VPA and HDI and trends in handgrip strength, are involved. Another key finding was that national trends in handgrip strength varied in magnitude and direction, although at best, national trends in handgrip strength were only weakly related to national trends in health and sociodemographic indicators. Because trends in handgrip strength were estimated from descriptive data, the effect of body size and biological maturation on the trends could be removed. Importantly, trends in absolute handgrip strength reflect trends in children's functional upper-body strength. This study also identified a gap in the handgrip trend data for low-income and middle-income countries. Given the meaningful associations between handgrip strength and health-related outcomes, there is an important need for improved national and international surveillance of handgrip strength, especially among low- and middle-income countries, in order to track trends in population health and fitness and to guide national and international action.

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SUPPLEMENT 1

Search Completed: 30th of October

CINAHL: 208 Studies

Medline: 793 Studies

SPORTDiscus: 415 Studies

SUPPLEMENT 2

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