January 2019

A Systematic Analysis Of Temporal Trends In The Sit-Ups Performance Of 9,939,289 Children And Adolescents Between 1964 And 2017 Representing 31 Countries

Tori Kaster

A SYSTEMATIC ANALYSIS OF TEMPORAL TRENDS IN THE SIT-UPS PERFORMANCE OF 9,939,289 CHILDREN AND ADOLESCENTS BETWEEN 1964 AND 2017 REPRESENTING 31 COUNTRIES

by

Tori Elaine Kaster

Bachelor of Science, University of North Dakota, 2017

Master of Science, University of North Dakota, 2019

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

August

2019

This thesis, submitted by Tori Elaine Kaster in partial fulfillment of the requirements 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.

____
Dr. Grant Tomkinson, Committee Chairperson

____
Dr. John Fitzgerald, Committee Member

____
Dr. Tanis Walch, Committee Member

This thesis is being submitted by the appointed advisory committee as having met all of 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: A systematic analysis of temporal trends in the sit-ups performance of 9,939,289 children and adolescents between 1964 and 2017 representing 31 countries

Department: Kinesiology and Public Health Education

Degree: Master of Science

In presenting this thesis in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my thesis work or, in his absence, by the Chairperson of the department or the dean of the School of Graduate Studies. It is understood that any copying or publication or other use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of North Dakota in any scholarly use which may be made of any material in my thesis.

Tori Elaine Kaster
Date: July 25th, 2019

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

ACKNOWLEDGEMENTS

I would like to thank Zen and Lilly for their snuggles and comfort during times of stress and their understanding of the need to sometimes postpone a trip to the dog park.

I would like to thank my parents for their undying love and support and for always answering late-night phone calls to provide me with words of encouragement.

I would like to thank my advisory committee for their guidance and tremendous amount of time and effort they provided me with throughout this entire process.

To Zen, Lilly, and my parents

ABSTRACT

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

Methods: Data were obtained in three ways: (a) through a systematic electronic database search of studies reporting on temporal trends in the handgrip strength of apparently healthy 9–17 year-olds, (b) by pearling reference lists, topical systematic reviews and personal libraries, and (c) by examining large country-level fitness datasets suitable to temporal trends analysis. Sample-weighted temporal trends (expressed as percent and standardized trends) were estimated at the country-sex-age level using best-fitting regression models relating the year of testing to mean sit-ups performance. International and national trends were estimated by post-stratified population-weighted mean changes standardized to the year 2000. Pearson's correlations were used to quantify relationships between linear trends in sit-ups performance and linear trends in health-related and sociodemographic indicators.

Results: Trend data from 27 studies/datasets representing 9,939,289 children and adolescents representing 31 countries (25 high-, 5 upper-middle-, and 1 low-income countries) between 1964 and 2017 collectively showed a large improvement in mean sit-ups performance of 38.4% (95%CI: 36.8 to 40.0) or 7.1% per decade (95%CI: 6.8 to 7.4). Large international improvements were experienced by all age and sex groups, with the rate of improvement slowing from 1964 to 2000, stabilizing near zero until 2010, before declining thereafter. Trends differed in magnitude and direction between countries, with most experiencing improvements. Trends in vigorous physical activity levels were a strong positive correlate of trends in sit-ups performance.

Conclusions: There has been a large international improvement in children's sit-ups performance since 1967, which has progressively diminished in magnitude over time. Sit-ups data are needed from children in low-income and middle-income countries in order to better monitor national and international trends in muscular fitness.

PROSPERO registration number: CRD42013003657.

CHAPTER 1

INTRODUCTION

Muscular fitness is an important summative marker of good health.[1–4] In childhood and adolescence, muscular fitness is meaningfully related with cardiometabolic disease risk, adiposity, bone health, mental health, and cognition,[3,4] independent of cardiorespiratory fitness.[5] Direct evidence indicates that low muscular fitness in adolescence is significantly associated with cardiometabolic disease risk,[1,6,7] bone health,[1] and all-cause mortality later in life.[8,9] It is also a good predictor of youth sports and athletic performance.[10] In adulthood, muscular fitness is significantly associated with all-cause and cardiovascular mortality,[11–13] cancer, [11] stroke,[12] diabetes,[14] hypertension,[14] disability,[15] falls risk,[16] mental health,[17] and overall quality of life.[17] It is also an important marker of functional capacity in older adults[18,19], which in turn is predictive of future disability and mortality.[20,21] This health-related evidence supports the recent promotion of muscle- and bone-strengthening activities (in addition to aerobic activity) in national and international physical activity guidelines.[22–25]

Muscular fitness is a multidimensional construct that reflects the ability of a muscle or muscle group to exert force maximally (strength), explosively (power), or without fatigue (endurance).[26] While strength, power, and endurance represent separate components of muscular fitness, evidence indicates that muscular strength and power are strongly related.[27] Muscular endurance on the other hand represents a unique component of muscular fitness. Because no single test exists to assess overall muscular endurance, numerous measures of local muscular endurance have been used in children and adolescents, including the sit-ups, curl-ups and plank tests for abdominal/core endurance, and the push-ups, pull-ups and the bent/flexed arm hang for upper body endurance.[28–30] Many of these tests are practical, feasible and scalable for population surveillance, with the sit-ups test probably the most widely used test in schoolchildren.[30] Several protocol variants exist, including the timed sit-ups (normally lasting 30 seconds to several minutes) and the sit-ups to exhaustion, both which have been performed with bent or straight legs using external or self-pacing. The sit-ups test demonstrates high test-retest reliability and low validity,[31] the latter of which may be in part due to the problem of identifying appropriate criterion measures of abdominal/core endurance. It is safe and there is no evidence of adverse events associated with test administration.[32]

Research into the relationship between muscular fitness and health has often failed to distinguish between separate components.[33] Despite limited evidence linking muscular endurance to health, low muscular endurance (sit-ups performance) is significantly associated with mortality in Canadian adults[13] and Japanese men[34] independent of cardiorespiratory fitness, adiposity and other covariates.[13] Theoretically, strong, fatigue-resistant abdominal muscles should help maintain proper pelvic and lumbar position and support the thoracolumbar fascia during static and dynamic spinal flexion.[35] Despite strong anatomical logic, evidence linking abdominal/core endurance with low back pain is uncertain.[1,4,31] Nonetheless, the National Academy of Medicine (formerly called the Institute of Medicine) recommend that schools consider measures of abdominal/core endurance in addition to other field-based strength measures.[29]

Much of the evidence examining temporal trends in children's physical fitness has focused on cardiorespiratory fitness,[36–38] with little known about temporal trends in children's muscular endurance. Reports on trends in children's sit-ups performance have shown mixed results over recent decades, including declines in Brazil,[39] Sweden,[40] and the UK,[41] improvements in Finland,[42] New Zealand,[43] Poland,[44–46] and Turkey,[47] and no meaningful change in Lithuania,[48] and Norway.[49] However, there has not yet been a comprehensive study to assess national and international trends in children's sit-ups performance. The primary aim of this study therefore was to systematically analyze national and international temporal trends in the sit-ups performance of children and adolescents. The secondary aim was to examine relationships between trends in sit-ups performance and trends in health-related and sociodemographic indicators across countries. It was hypothesized that sit-ups performance had improved over time, and that country trends in health-related and sociodemographic indicators would be meaningfully associated with country trends in sit-ups performance.

CHAPTER 2

METHODS

2.1 Protocol and Registration

The review protocol was prospectively registered with the International Prospective Register of Systematic Review (PROSPERO; registration number CRD42013003657). This review was conducted and reported in accordance with the Preferred Reporting Items for Systematic review and Meta-analysis Protocols (PRISMA-P) statement for reporting systematic reviews.[50]

2.2 Eligibility Criteria

One large systematic review of temporal trends in children's muscular fitness (i.e., handgrip, standing broad jump, and sit-ups) was initially undertaken. For this study, studies were eligible if they explicitly reported on temporal trends in the abdominal endurance (operationalized as sit-ups performance). Candidate studies, including refereed journal articles and graduate research theses, were eligible if they reported on temporal trends in the sit-ups performance (using matched test protocols) of apparently healthy (free from known disease/injury) age- and sex-matched children and adolescents (aged 9–17 years) across at least two time points spanning a minimum of five years. Temporal trends must have been reported as absolute, percent or standardized changes in means at the country-sex-age level, or as descriptive statistics (e.g., sample sizes, means and standard deviations) at the country-sex-age-year level in order to calculate temporal trends.

2.3 Information Sources

A systematic literature search was conducted on 30th of October 2018 using Cumulative Nursing and Allied Health Literature (CINAHL), MEDLINE, and SPORTDiscus. There were no date or language restrictions. An academic librarian experienced in systematic literature searching assisted with the development of the search strategy. Additional studies were identified by pearling the reference lists of the included studies, topical systematic reviews, and the personal library of the principal advisor. Large country-level datasets comprising nationally representative fitness survey data suitable to temporal trends analysis were also considered.

2.4 Search Strategy

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

2.5 Study Selection

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

2.6 Data Collection Process

Descriptive data were extracted into a spreadsheet by a single researcher using a standardized study-specific template[38] and checked for accuracy by a second reviewer. If required, additional information was requested from the corresponding authors via email (e.g., to clarify published results or to avoid double counting data).

2.7 Data Items

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

2.8 Summary Measures and Synthesis of Results

Temporal trends were analyzed at the country-sex-age level (e.g., 9-year-old Australian boys) using best-fitting sample-weighted linear or polynomial (quadratic or cubic) regression models relating the year of testing to mean sit-ups.[38,51] Trends in mean sit-ups performance were expressed as (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 sit-ups performance and negative trends indicated declines in mean sit-ups performance.

International and national temporal trends (for boys, girls, children [9–12 year-olds], adolescents [13–17 year-olds] and all [9–17 year-old boys and girls]) were calculated using a post-stratified population-weighting procedure that has been described in detail elsewhere.[38,51] Population estimates were standardized to the year 2000—a year common to most country-sex-age groups—using United Nations data.[52] The post-stratification population-weighting procedure corrects for systematic bias associated with over- and under-sampling, and standardizes trends to underlying country-sex-age-specific demographics. Trends were graphically displayed using the iterative procedure described by Tomkinson and Olds.[37]

Relationships between linear temporal trends in sit-ups performance 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][53] and vigorous physical activity [VPA] levels[54]) and sociodemogrphic (Gini index,[55] the Human Development Index [HDI],[56] and urbanization[57]) indicators were analyzed using linear regression models as described above. Trends in these broad health-related and sociodemographic indicators were examined because they were thought to be meaningfully related to trends in sit-ups performance and because it was possible to calculate temporal trends using the same criteria as for sit-ups performance 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 $ES\geq0.1$ considered to be meaningful.

CHAPTER 3

RESULTS

A total of 1,416 unique records were identified through bibliographic database searching, with 28 retained after the first level of screening (title and abstract review) and eight retained after the second level of screening (full-text review) (Figure 1). These eight studies were combined with: (a) 14 additional studies that were identified from the principal advisor's personal library and the reference lists of included articles and topical systematic reviews, and (b) five large country-level datasets comprising nationally representative sit-ups data suitable for temporal trends analysis, for a total of 27 included studies/datasets (Figure 1).

Temporal trends in sit-ups performance were estimated from 9,939,289 children and adolescents aged 9–17 years from 31 countries (2,591 country-sex-age-year groups) between 1964 and 2017 (Table 1). Trends were available for 25 high-income, 5 upper-middle-income, and 1 low-income countries (or 26 very high, four high, and one low human development countries),[56,58] representing 6 continents, 32% of the world's population,[52] and 32% of the world's land area.[59] Trends were calculated for 369 country-sex-age groups (children [aged 9–12 years]: 164; adolescents [aged 13–17 years]: 205; boys: 180; girls: 189), with a median sample size of 1,090 (range 43–379,294) across a median span of 18 years (range 6–35). Country trends were available for various sit-ups tests, including: the number of completed sit-ups in 30 seconds, 60 seconds, 180 seconds, and in total (without a time limit) (Table 1).

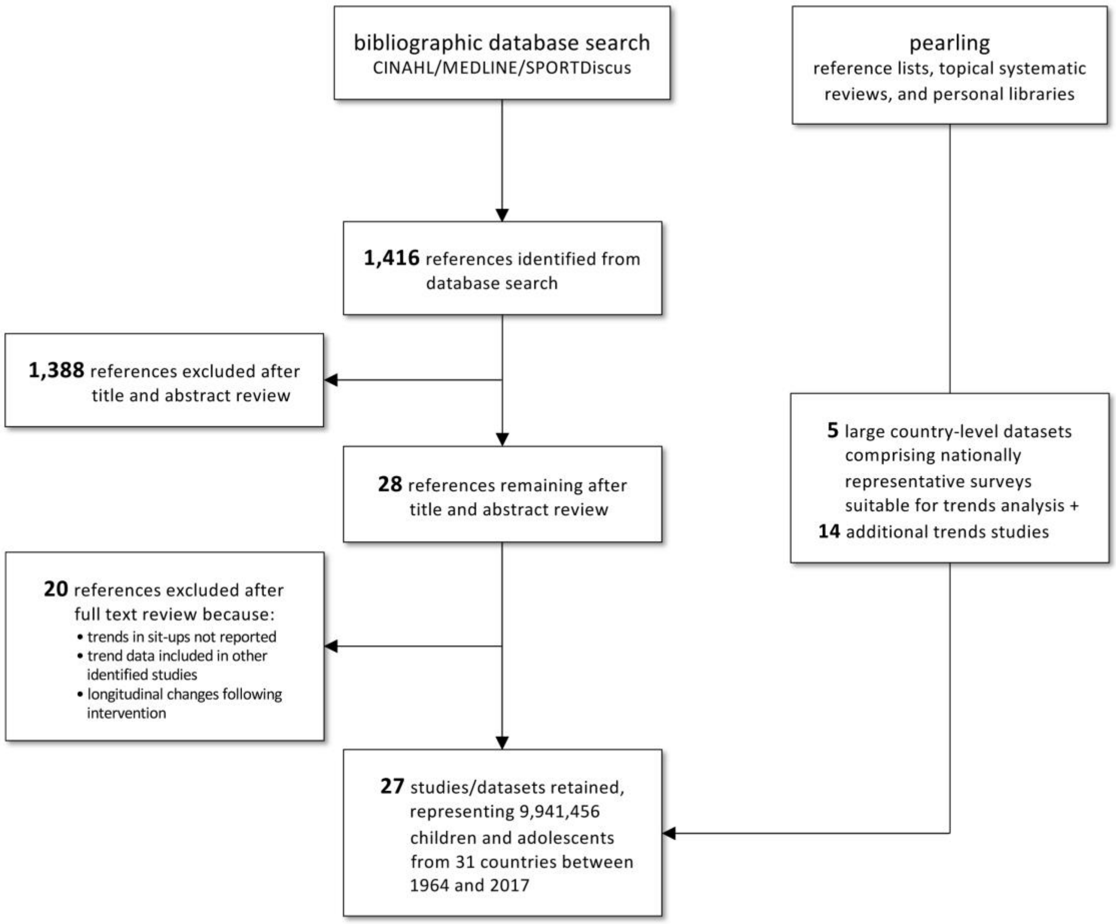


Figure. 1 PRISMA flow chart outlining the flow of studies through the review.

There was a large international improvement in mean sit-ups performance between 1964 and 2017 (change in means [95% CI]: 38.4% [36.8 to 40.0]; ES 1.09 [1.04 to 1.15]) (Figure 2). Similarly, large international improvements were observed for all age and sex groups: (a) children (change in means [95% CI]: 32.0% [29.9 to 34.2]; ES 0.86 [0.81 to 0.91]), (b) adolescents (change in means [95% CI]: 45.2% [43.6 to 46.8]; ES 1.33 [1.27 to 1.39), (c) boys (change in means [95% CI]: 24.9% [23.2 to 26.6]; ES 0.84 [0.78 to 0.88]), and (d) girls (change in means [95% CI]: 44.5% [42.3 to 46.7]; ES 1.20 [1.14 to 1.26]) (Figure 2).

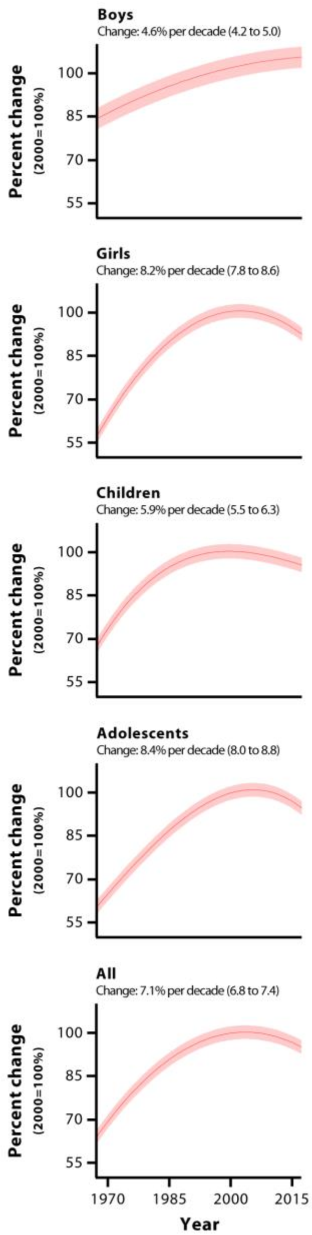
Table 1. Summary of the included studies by country.

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI	Test protocol
Australia[w1]	F (48.6%) M (51.4%)	9–15	1985–2000	8,504	P	N/S/O	0.939 (very high)	SUP in 180s
Belgium[w2]	F (49.4%) M (50.6%)	9–17	1990–2010	19,063	P/NP	S	0.916 (very high)	SUP in 30s
Brazil[w3]	F (42.7%) M (57.3%)	12–17	2008–2014	6,923	NP	N	0.759 (high)	SUP in 60s
Bulgaria[w4–w7]	F (49.7%) M (50.3%)	9–17	1980–1999	7,008	P	N/O	0.813 (very high)	SUP in 30s
Canada[w8,w9]	F (47.9%) M (52.1%)	9–17	1964–1988	14,638	P/NP	N/O	0.926 (very high)	SUP in 60s
China[w10–w17]	F (100%)	9–17	1979–2014	674,130	P	N	0.752 (high)	SUP in 60s
Estonia[w2]	F (53.0%) M (47.0%)	11–17	1992–2002	6,207	P/NP	S/O	0.871 (very high)	SUP in 30s
Finalnd[w18]	F (49.3%) M (50.7%)	13–17	1976–2001	1,222	P	N	0.920 (very high)	SUP in 30s
France[w2]	F (48.0%) M (52.0%)	9,11–12	1984–2000	2,706	P/NP	N/O	0.901 (very high)	SUP in 30s
Greece[w2]	F (49.6%) M (50.4%)	9–17	1990–2014	260,576	P/NP	N/S/O	0.870 (very high)	SUP in 30s
Hong Kong[w19–w28]	F (48.8%) M (51.2%)	9–17	1999–2015	43,246	P	N	0.933 (very high)	SUP in 60s
Iceland[w2]	F (47.9%) M (52.1%)	10–15	1985–1998	6,849	NP	N/O	0.935 (very high)	SUP in 30s
Israel[w29]	F (54.1%) M (45.9%)	16–17	1970–1984	1,816	P	S	0.903 (very high)	SUP in 30s
Italy[w2]	F (48.5%) M (51.5%)	10–17	1985–2008	14,706	P/NP	S/O	0.880 (very high)	SUP in 30s
Japan[w30–w80]	F (49.9%)	9–17	1999–2017	444,277	P	N	0.909	SUP in 30s

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI	Test protocol
	M (50.1%)						(very high)	
Lithuania[w81]	F (50.2%) M (49.8%)	11–17	1992–2012	16,158	P	N	0.858 (very high)	SUP in 30s
Mozambique[w82]	F (56.9%) M (43.1%)	9–17	1992–2012	1,944	P	O	0.437 (low)	SUP in 60s
New Zealand[w83]	F (42.9%) M (57.1%)	10–13	1991–2003	4,499	NP	O	0.917 (very high)	SUP in 60s
Norway[w84]	F (49.5%) M (50.5%)	15	1968–1997	2,224	P	S	0.953 (very high)	SUP in total
Poland[w2,w85–w88]	F (49.1%) M (50.9%)	9–17	1979–2011	495,433	P/NP	N/S/O	0.865 (very high)	SUP in 30s
Republic of Korea[w89–w113]	F (49.2%) M (50.8%)	9–17	1979–2010	1,535,955	P	N	0.903 (very high)	SUP in 60s
Singapore[w114]	F (59.3%) M (40.7%)	12–17	1980–1992	3,398	P	N	0.932 (very high)	SUP in 60s
Slovakia[w2]	F (46.4%) M (53.6%)	9–11	1993–2015	1,183	P/NP	N/S/O	0.855 (very high)	SUP in 60s
Slovenia[w115]	F (50.0%) M (50.0%)	9–17	1987–2012	467,306	P	N	0.896 (very high)	SUP in 60s
Spain[w2]	F (49.1%) M (50.9%)	9–17	1984–2010	20,213	P/NP	S/O	0.891 (very high)	SUP in 30s
Sweden[w116]	F (49.0%) M (51.0%)	16	1974–1995	980	P	S	0.933 (very high)	SUP in total
Switzerland[w2]	F (51.8%) M (48.2%)	11	1996–2005	535	P	S/O	0.944 (very high)	SUP in 30s
Taiwan[w117]	F (48.2%) M (51.8%)	10–17	1997–2013	5,857,636	P	N	0.907 (very high)	SUP in 60s
Thailand[w118]	F (50.8%) M (49.2%)	9–12	1990–2003	17,635	P	N	0.755 (high)	SUP in 30s
Turkey[w119]	F (42.4%)	11–12	1983–2003	403	NP	O	0.791	SUP in 30s

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI	Test protocol
	M (57.6%)						(high)	
UK[w120]	F (48.6%) M (51.4%)	10	1998–2014	916	NP	S	0.922 (very high)	SUP in 30s

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); SUP=sit-ups; 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;[56] Because the United Nations does not recognize Taiwan as a sovereign state, its HDI was calculated by the Taiwanese government.[60]



The international trends in sit-ups performance were not uniform over time, with the rate of improvement slowing from 1964 to 2000, stabilizing near zero until 2010, before declining thereafter. The rate of improvement diminished from 16.4% in the 1960s and 1970s (95% CI: 15.4 to 17.4; ES: small), 11.1% in the 1980s (95% CI: 10.5 to 11.7; ES: small), to 4.3% in the 1990s (95% CI: 3.9 to 4.7; ES: negligible), before stabilizing at −0.4% in the 2000s (95% CI: −0.8 to 0.0; ES: negligible) and declining at −4.1% in the 2010s (95% CI: −4.7 to −3.5; ES: negligible). This trend was consistent across different sex and age groups, except for boys in recent decades.

Figure 2. National temporal trends in mean sit-ups between 1967 and 2017.

Note: data were standardized to the year 2000=100%, with higher values (>100%) indicating better sit-ups performance and negative values (<100%) indicating poorer sit-ups performance; the solid lines represent the national changes in mean sit-ups performance, 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.

Country trends ranged from a large improvement in sit-ups performance in Singapore (1980–1992) to a large decline in Switzerland (1996–2005), with trends typically negligible to small (28/31 or 90%) and positive (i.e., improvements) (20/31 or 65%) (Figure 3). While most country trends were approximately uniform (linear), several countries experienced non-uniform (curvilinear) trends evidenced by a slowing or stabilizing of the trend, or a shift in direction, near to the year 2000 (e.g., Belgium, China, Hong Kong, Japan, Poland, and Slovenia).

There was a strong positive correlation between trends in sit-ups performance and trends in VPA (*r* [95%CI]: 0.51 [0.07 to 0.78]), indicating that countries (European countries only) with improvements in children's VPA levels between 2002 and 2014 had the largest improvements in sit-ups performance (Table 2). Trends in HDI were a moderate positive correlate of trends in sit-ups performance, with trends in urbanization a moderate negative correlate. Trends in Gini index and BMI were weak and negligible positive correlates, respectively.

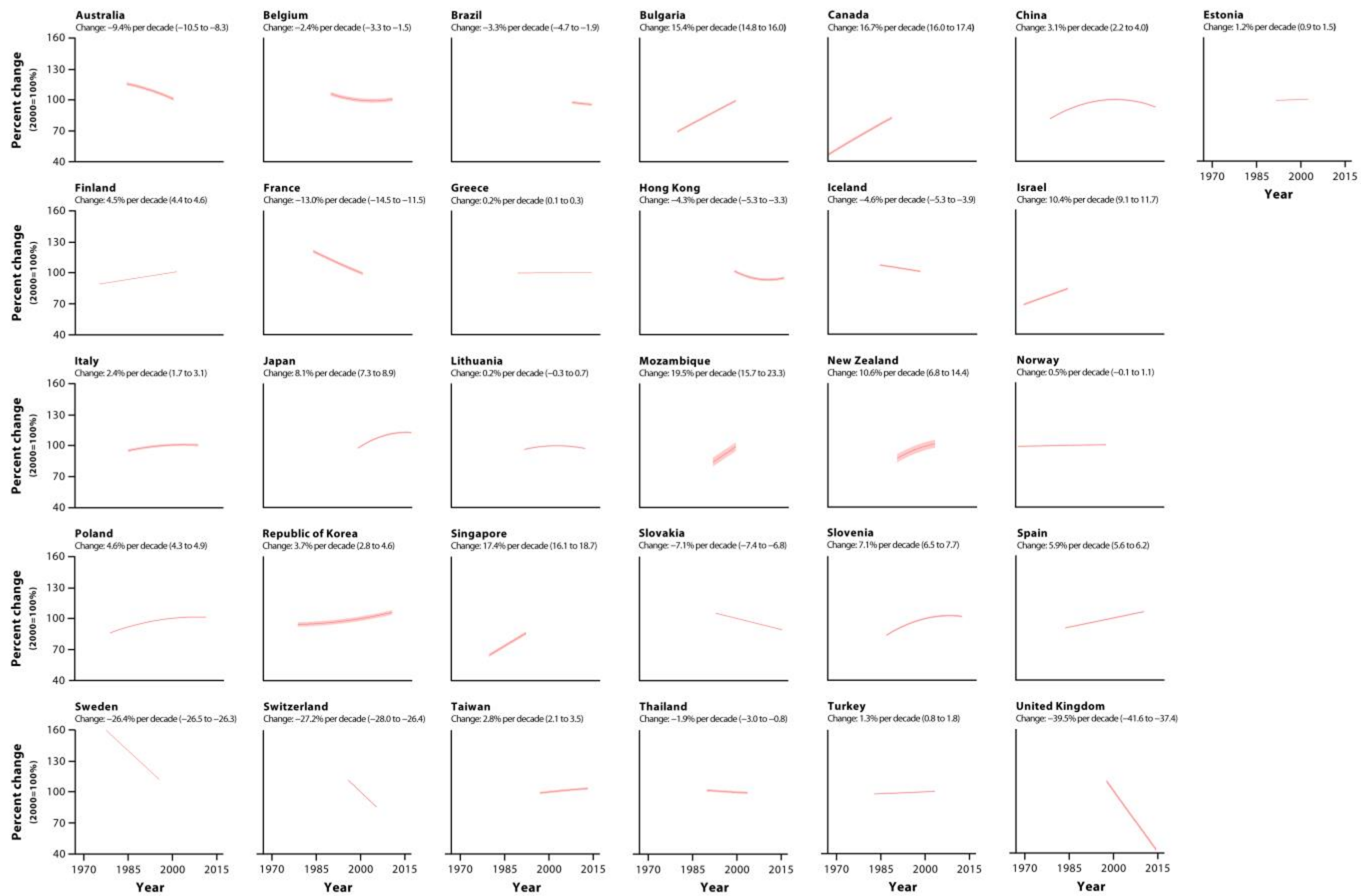


Figure. 3 National temporal trends in mean sit-ups between 1967 and 2017.

Note: data were standardized to the year 2000=100%, with higher values (>100%) indicating better sit-ups performance and negative values (<100%) indicating poorer sit-ups performance; the solid lines represent the national changes in mean sit-ups performance, 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 sit-ups performance of children and adolescents.

Variable	Data source	Description	Correlation (95%CI)
Health			
Body mass index (BMI)	NCD RisC[53] 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.	0.06 (−0.31 to 0.41)
Vigorous physical activity (VPA)	Inchley et al.[54] 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.	0.51 (0.07 to 0.78)
Sociodemographic			
Gini index	World Bank[55] Trend data available for 17/19 (89%) countries between 1990 and 2017.	Summarizes the change (per decade) in the distribution of income among individuals in a country where 0 represents perfect equality and 100 implies perfect inequality. A positive change indicated a trend towards perfect inequality and a negative change a trend towards perfect equality.	0.12 (−0.28 to 0.48)
Human development index (HDI)	United Nations[56]	Calculated as the change (per decade) in mean	0.35 (−0.01 to 0.63)

	Trend data available for 18/19 (95%) countries between 1990 and 2017.	country-level human development (i.e., achievements in health, education and income). A positive change indicated an increase in the mean human development and a negative change indicated a decline.	
Urbanization	World Bank[57] 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.	−0.32 (−0.61 to 0.05)

CHAPTER 4

DISCUSSION

Using data from 27 studies/datasets, this study estimated temporal trends in the sit-ups performance of 9,939,289 children and adolescents aged 9–17 years from 31 countries between 1964 and 2017 and found: (a) there was a large international improvement, with the rate of improvement slowing from 1964 to 2000, stabilizing near zero until 2010, and declining thereafter; (b) large international improvements were observed for all age and sex groups, with a shift from improvements to declines occurring in recent decades in all groups except boys; (c) while national trends varied in magnitude and direction, most typically showed improvements; and (d) national trends in sit-ups performance were strongly related to national trends in VPA.

What is causing the apparent temporal trend in sit-ups performance? While numerous factors positively influence muscular endurance, including biological maturation,[61] body size,[4,62] and VPA,[63] apart from trends in body size, trends in these factors have rarely been statistically controlled for in studies examining trends in sit-ups performance. Unfortunately in this study the effect of trends in these factors could not be statistically removed because trends in sit-ups performance were estimated from descriptive data and not raw data, making it impossible to determine the underlying causal factors. Despite a lack of agreement on criterion measures for muscular endurance, available data suggest that the sit-ups has low validity,[31] suggesting that trends in sit-ups performance poorly reflect trends in true muscular endurance. Trends in sit-ups performance reflect trends in functional abdominal/core endurance capability, i.e., the ability of children and adolescents to support their body weight and repeatedly contract the abdominals to flex the spine.

Consider first trends in biological maturation. No study to date examining temporal trends in sit-ups performance has statistically controlled for trends in biological maturation. Westerstahl et al.[64] reported that trends in a "maturity index" (not biological maturity, rather a score based on a child's grade and enrolment in school physical education) did not contribute to declining sit-ups performance of Swedish 16-year-old boys and girls between 1974 and 1995. Saczuk et al.[65] found that the trend towards earlier maturation in Polish girls between 1986 and 2006 coincided with improved sit-ups performance. While trends in biological maturation have varied over time and between countries, the potential impact of advancing maturation on trends in sit-ups performance can be estimated using 20th century trends, which indicate that the age of menarche has advanced by ~0.3 years per decade and the age at which boys' voices break by ~0.2 years per decade.[66,67] Over the 53-year period between 1964 and 2017, these data suggest that biological maturation has advanced by ~1.0 years in boys and ~1.5 years in girls. Temporal increases in sit-ups performance would be expected based on maturational advances alone, because older children typically outperform younger children, presumably because of improved physical and neuromuscular maturation. Cross-sectional data from Tomkinson et al.[30] indicate that sit-ups (no. in 30 s) performance improves with each year of age by ~6% in boys and ~3% in girls between the ages of 9 and 12, and by ~4% in boys and ~1.5% in girls between the ages of 13 and 17. Between 1964 and 2017, sit-ups performance improved internationally by ~32% in children and ~45% in adolescents. When corrected for trends in biological maturation, the underlying improvement in sit-ups performance is reduced to ~26–27% in children (i.e., 32% minus 6% in boys and 32% minus 1.5 × 3% in girls) and ~41–43% in adolescents (i.e., 45% minus 4% in boys and 45% minus 1.5 × 1.5% in girls). While only an estimate, from this example it appears that trends in biological maturation explain only a small proportion of the trends in sit-performance.

Several studies have reported that temporal trends in sit-ups performance were independent of trends in body size (i.e., height, mass, BMI).[41,48,64,68] Other studies, while not statistically controlling for trends in body size, have found that trends in sit-ups performance have coincided with trends in BMI.[42,43,47,69] International increases in childhood and adolescent BMI are well established,[53] reflecting both increases in fat mass and fat-free mass.[70] Mechanistically, increases in fat mass and fat-free mass will influence sit-ups performance in different ways: increased fat-free mass will increase the force generation capacity of the exercising muscles,[71] while increased fat mass, which is largely metabolically inert, constitutes a “dead” load that will need to be overcome in order to repeatedly flex the spine. While this study found that sit-ups performance improved internationally from 1964 to 2000, before stabilizing for a decade and declining thereafter, it is possible that differential trends in fat mass and fat-free mass are involved, and that the recent decline in sit-ups performance reflects that children are now becoming fatter at the same BMI. There is some evidence for this from high-income countries, where trend data indicate a noticeable stabilization in BMI from the mid-1990s onwards.[72] In contrast, there does not appear to have been a stabilization in skinfold thicknesses, at least until 2004.[70] In the same study, Olds[70] showed there has been a shift towards central accumulation of body fat, which might hinder sit-ups performance. However, while BMI includes (but does not separate) both fat and fat-free mass components, this study found that trends in BMI were a negligible correlate of trends in sit-ups performance.

Although no study examining temporal trends in sit-ups performance has statistically controlled for trends in physical activity, several studies have reported a temporal coincidence.[41,42,73] Sandercock and Cohen[41] reported that the decline in 10-year-old English children's sit-ups performance between 2008 and 2014 coincided with a decline in self-reported physical activity. Huotari et al.[42] reported that improved sit-ups performance of 13- to 16-year-old Finnish adolescents between 1976 and 2001 coincided with increased organized sport participation and leisure-time physical activity (≥2 times per week). Smpokos et al.[73] found concurrent increases in sit-ups performance, moderate-to-vigorous physical activity, and VPA in first grade children from Greece between 1992 and 2007. These data support the findings from this study, which indicate that trends in VPA were strongly and positively associated with trends in sit-ups performance; meaning that countries with the largest increases in VPA experienced the largest improvements in sit-ups performance. Assuming this ecological correlation is causal, this temporal connection suggests that strategies aimed at increasing VPA levels in children and adolescents (e.g., VPA and muscle and bone strengthening activities as recommended in national and international physical activity guidelines[22–25]) might be a suitable population approach to improving abdominal/core endurance and hence sit-ups performance. It is also possible that improvements in fundamental movement skills (e.g., locomotor, object-control, resistance training) have improved neuromuscular facilitation of the abdominal/core muscles leading to a temporal increase in sit-ups performance.

This study represents the most comprehensive analysis to date of national and international temporal trends in children's muscular endurance. It used a systematic review approach, including only data on apparently healthy children and adolescents who were directly measured for abdominal/core endurance using the sit-ups test. It also used a detailed statistical approach previously adopted several other systematic reviews of trends in children's fitness.[10,36,37,38,51] The use of weighted regression and post-stratification population weighting meant that trends were adjusted for sampling bias and underlying demographics. Furthermore, a sensitivity analysis showed that the removal of countries with very large samples (n>400,000, e.g., China, Japan, Poland, Republic of Korea, Slovenia, and Taiwan, which collectively comprised 95% of all data points) (Table 1) had a negligible effect (ES<0.1) on the international trends, increasing confidence that the reported international trend in sit-ups performance was not meanigfully biased by these countries.

So how do temporal trends in sit-ups performance compare to trends in other muscular fitness components? Data from Tomkinson,[74] indicate there was a small improvement of 0.3% per decade in the muscular power (operationalized as standing broad jump performance) of over 20 million children and adolescents (6–19 years) from 23 countries between 1958 and 2003. This improvement was not uniform over time however, with standing broad jump performance improving until the mid-1980s and declining thereafter. Similarly, this study showed that children's sit-ups performance improved until 2000 and plateaued for a decade before declining. While the magnitude of improvement was much larger for sit-ups than for standing broad jump, the temporal pattern was similar, albeit with the shift from improvements to declines occurring about 20 years later for sit-ups.

There are several limitations to this study. First, trends in sit-ups performance are largely representative of high- and upper-middle-income countries (30/31 or 97%), which limit the generalizability of the findings to low-income and middle-income countries that may be experiencing a physical activity transition.[75] Second, although the international trends in sit-ups performance were estimated using tests that potentially imposed different physiological and psychosocial demands (see Table 1 for different test types), it could be that the trends (percent and standardized) for one test do not equate to the trends for another. Third, it is also possible that methodological drift occurred (e.g., differences in knee position and/or feet anchoring, repetition "bouncing", subjective scoring, level of encouragement, diurnal variation), although the large number of included data points should have minimized these methodological issues. Fourth, sit-ups data were collected using different sampling strategies and sampling frames and were not always nationally representative, with trends estimated using state/provincial and community level data included as they provided the best available estimate of national trends when national level data were missing. Finally, temporal trends in mean sit-ups performance could be systematically biased if concurrent trends in skewness occurred. Because there is evidence of temporal trends in both positive skew (i.e., an increase in the mean-median difference)[42,43] and negative skew (i.e., a decrease in the mean-median difference)[40] it is difficult to estimate the likely impact.

CHAPTER 5

CONCLUSION

This study found a large international improvement in the sit-ups performance of children and adolescents over the past half a century, with the rate of improvement slowing from 1964 to 2000, stabilizing near zero until 2010, and declining thereafter. Large improvements were also found across all age and sex groups. National trends in sit-ups performance were strongly and positively associated with national trends in VPA, with the largest national improvements in sit-ups performance observed in countries with the largest increases in VPA. Because almost all countries reporting trends in sit-ups performance were high- and upper-middle-income, there is a important need for temporal data from low- and middle-income countries in order to monitor population trends in muscular fitness.

References

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

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

3 Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjostrom, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. International Journal of Obesity (2005), 32(1), 1–11.

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

5 Artero EG, Ruiz JR, Ortega FB, et al. Muscular and cardiorespiratory fitness are independently associated with metabolic risk in adolescents: the HELENA study. Pediatr Diabetes. 2011;12(8):704–12.

6 Fraser, B. J., Blizzard, L., Schmidt, M. D., Juonala, M., Dwyer, T., Venn, A. J., & Magnussen, C. G. (2018). Childhood cardiorespiratory fitness, muscular fitness and adult measures of glucose homeostasis. Journal of Science and Medicine in Sport, 21, 935–940.

7 Grontved, A., Ried-Larsen, M., Ekelund, U., Froberg, K., Brage, S., & Andersen, L. B. (2013). Independent and combined association of muscle strength and cardiorespiratory fitness in youth with insulin resistance and beta-cell function in young adulthood: The European youth heart study. Diabetes Care, 36(9), 2575–2581.

8 Ortega, F. B., Silventoinen, K., Tynelius, P., & Rasmussen, F. (2012). Muscular strength in male adolescents and premature death: cohort study of one million participants. British Medical Journal, 345, e7279.

9 Sato M, Kodama S, Sugawara A, et al. Physical fitness during adolescence and adult mortality. Epidemiology 2009;20:463–4.

10 Armstrong N, Tomkinson G, Ekelund U. Aerobic fitness and its relationship to sport, exercise training and habitual physical activity during youth. Br J Sports Med 2011;45:849–58.

11 Gale, C.R., Martyn, C.N., Cooper, C., & Sayer, A.A. (2006). Grip strength, body composition, and mortality. International Journal of Epidemiology, 36, 228–235.

12 Leong, D.P., Teo, K.K., Rangarajan, S., Lopez-Jaramillo, P., Avezum, A., Orlandini, A., Seron, P., Ahmed, S.H., Rosengren, A., Kelishadi, R., Rahman, O., Swaminathan, S., Iqbal, R., Gupta, R., Lear, S.A., Oguz, A., Yusoff, K., Zatonska, K., Chifamba, J., Igumbor, E,, Mohan, V., Anjana, R.M., Gu, H., Li, W., Yusuf, S.; Prospective Urban Rural Epidemiology (PURE) Study investigators. (2015).

Prognostic value of grip strength: Findings from the Prospective Urban Rural Epidemiology (PURE) study. Lancet, 386, 266–273.

13 Katzmarzyk PT, Craig CL. Musculoskeletal fitness and risk of mortality. Med Sci Sports Exerc. 2002;34(5):740–4.

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

15 Bohannon, R.W. (2008). Hand-grip dynamometry predicts future outcomes in aging adults. Journal of Geriatric Physical Therapy, 31, 3–10.

16 Chan, B.K., Marshall, L.M., Winters, K.M., Faulkner, K.A., Schwartz, A.V., & Orwoll, E.S. (2006). Incident fall risk and physical activity and physical performance among older men: The Osteoporotic Fractures in Men Study. American Journal of Epidemiology, 165, 696–703.

17 Payne N, Gledhill N., Katzarmzyk PT, Jamnik V, Ferguson S. Health implications of musculoskeletal fitness. Can J Appl Physiol. 2000;25(2):114–126.

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

19 Salem GJ, Wang MY, Young JT, Marion M, Greendale GA. Knee strength and lower- and higher-intensity functional performance in older adults. Med Sci Sports Exerc. 2000;32(10):1679–84.

20 Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. N Engl J Med. 1995;332(9):556–61.

21 Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, Scherr PA, Wallace RB. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. J Gerontol. 1994;49(2):M85–94.

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

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

24 U.S. Department of Health and Human Services. Physical activity guidelines for americans (2nd ed.). Washington, DC: U.S. Department of Health and Human Services; 2018.

25 World Health Organization. (2010). Global recommendations on physical activity for health. Geneva, Switzerland: WHO Press.
26 American College of Sports Medicine. (2018). ACSM's guidelines for exercise testing and prescription (10th ed.). Baltimore, MD: Lippincott Williams & Wilkins.
27 Ingle L, Sleap M, Tolfrey K. The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys. J Sports Sci. 2006;24(9):987–97.
28 Bianco A, Jemni M, Thomas E, Patti A, Paoli A, Ramos Roque J, Palma A, Mammina C, Tabacchi G. A systematic review to determine reliability and usefulness of the field-based test batteries for the assessment of physical fitness in adolescents — The ASSO Project. Int J Occup Med Environ Health. 2015;28(3):445–78.
29 Institute of Medicine. Fitness measures and health outcomes in youth. Washington (DC): The National Academies Press, 2012.
30 Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis ., Fitzgerald JS, Lang JJ, Ortega, FB. European normative values for physical fitness in children and adolescents aged 9–17 years: Results from 2 779 165 Eurofit performances representing 30 countries. Br J of Sports Med. 2018;55(22):1445–56.
31 Plowman SA. Muscular strength, endurance, and flexibility assessments. In: Plowman SA, Meredith MD, editors. FITNESSGRAM®/ACTIVITYGRAM® reference guide. Updated 4th ed. Dallas, TX: Cooper Institute; 2014. p. 8-1–8-55.
32 Contreras MA, Schoenfeld B. To crunch or not to crunch: An evidence-based examination of spinal flexion exercises, their potential risks, and their applicability to program design. Strength Cond J. 2011;33(4):8–18.
33 Stodden D, Sacko R, Nesbitt D. A review of the promotion of fitness measures and health outcomes in youth. Am J Lifestyle Med. 2017;11(3):232–42.
34 Fujita Y, Nakamura Y, Hiraoka J, Kobayashi K, Sakata K, Nagai M, Yanagawa H. Physical-strength tests and mortality among visitors to health-promotion centers in Japan. J Clin Epidemiol. 1995;48(11):1349–59.
35 Plowman SA. Top 10 research questions related to musculoskeletal physical fitness testing in children and adolescents. Res Q Exerc Sport. 2014;85(2):174–87.
36 Tomkinson GR, Léger LA, Olds TS, Cazorla G. Secular trends in the performance of children and adolescents (1980–2000): an analysis of 55 studies of the 20 m shuttle run test in 11 countries. Sports Med. 2003;33(4):285–300.
37 Tomkinson GR, Olds TS. Secular changes in pediatric aerobic fitness test performance: the global picture. Med Sport Sci. 2007;50:46–66.
38 Tomkinson GR, Lang JJ, Tremblay MS. Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. Br J Sports Med. 2019; 53(8):478-86.

39 Gaya AR, Dias AF, Lemes VB, Gonçalves JC, Marques PA, Guedes G. Brand C, Gaya ACA. Aggregation of risk indicators to cardiometabolic and musculoskeletal health in Brazilian adolescents in the periods 2008/09 and 2013/14. J Pediatr (Rio J). 2018;94(2):177–83.

40 Westerstahl M, Barnekow–Bergkvist M, Hedberg G, Jansson E. Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. Scand J Med Sci Sports. 2003;13:128–37.

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

42 Huotari PRT, Nupponen H, Laakso L, Kujala UM. Secular trends in muscular fitness among Finnish adolescents. Scand J Public Health. 2010;38:739–47.

43 Albon HM, Hamlin MJ, Ross JJ. Secular trends and distributional changes in health and fitness performance variables of 10–14-year-old children in New Zealand between 1991 and 2003. Br J Sports Med. 2010;44(4):263–69.

44 Przeweda R, Dobosz J. Growth and physical fitness of Polish youths in two successive decades. J Sports Med Phys Fitness. 2003;43(4):465–474.

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

46 Saczuk J, Wasiluk A, Zalech M. Generation changes over the period of 1986–2006 in the physical fitness of boys aged 7–19 from eastern Poland at particular stages of education. Biomed Hum Kinet. 2012;4:112–16.

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

48 Venckunas T, Emeljanovas A, Mieziene B, Volbekiene V. Secular trends in physical fitness and body size in Lithuanian children and adolescents between 1992 and 2012. J Epidemiol Community Health. 2017;71(2):181–7.

49 Sjolie A, Mønness E. Truncus endurance, hip and ankle mobility and aerobic fitness in 15-year-old Norwegian adolescents in 1968 and 1997. Scand J Med Sci Sports. 2007;17(5):488–96.

50 Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev. 2015;4:1.

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

52 United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Data Booklet (ST/ESA/SER.A/424). New York: United Nations; 2019.

53 NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. Lancet. 2017;390(10113):2627–42.
54 Inchley J, Currie D, Jewell J. Adolescent obesity and related behaviours: trends and inequalities in the WHO European region, 2002–2014. Observations from the Health Behaviour in School-aged Children (HBSC) WHO collaborative cross-national study. Copenhagen, Denmark: World Health Organisation, 2017.
55 World Bank. GINI index (World Bank estimate). https://data.worldbank.org/indicator/si.pov.gini. Accessed 27 Jun 2019.
56 United Nations Development Programme. Human development indices and indicators: 2018 statistical update. New York: United Nations Development Programme; 2018.
57 World Bank. Urban population growth (annual %). https://data.worldbank.org/indicator/SP.URB.GROW. Accessed 27 Jun 2019.
58 World Bank. World Bank country and lending groups. http://data.worldbank.org/about/country-and-lending-groups. Accessed 27 Jun 2019.
59 World Bank. Land area (sq. km). https://data.worldbank.org/indicator/AG.LND.TOTL.K2. Accessed 27 Jun 2019.
60 2018中華民國人類發展指數(HDI)" (Excel) (in Chinese). Directorate General of Budget, Accounting and Statistics, Executive Yuan, R.O.C. 2018. Retrieved 4 May 2019.
61 Malina RM, Bouchard C, Bar-Or O. Growth, maturation and physical activity, 2nd edition. Champaign, IL: Human Kinetics; 2004.
62 Lang JJ, Larouche R, Tremblay MS. The association between physical fitness and health in a nationally representative sample of Canadian children and youth aged 6 to 17 years. Health Promot Chronic Dis Prev Can. 2019;39(3):104–111.
63 Smith JJ, Eather N, Morgan PJ, Plotnikoff RC, Faigenbaum AD, Lubans DR. The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. Sports Med. 2014;44(9):1209–23.
64 Westerstahl M, Barnekow–Bergkvist M, Hedberg G, Jansson E. Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. Scand J Med Sci Sports. 2003;13:128–137.
65 Saczuk J, Wasiluk A, Changes in the somatic and fitness variables in girls over two decades. Biomed Hum Kinet. 2010;2:102–105.
66 Roche AF. Secular trends in stature, weight, and maturation. Monogr Soc Res Child Dev. 1979;44(3/4):3–27. Malina RM. Secular trends in growth, maturation and physical performance: A review. Anthropol Rev. 2004;67:3–31.

67 Malina RM. Secular trends in growth, maturation and physical performance: A review. Anthropol Rev. 2004;67:3–31.
68 Ignasiak Z, Sławińska T, Malina RM. Short term secular change in body size and physical fitness of youth 7–15 years in Southwestern Poland: 2001–2002 and 2010–2011. Anthropol Rev. 2016;79(3):311–29.
69 Lo KY, Wu MC, Ho CC, Hsieh CC, Tung SC. Assessment of physical fitness among Taiwanese adolescents: a cohort study from 1997 to 2013. Sports Exerc Res. 2015;17(4):443–60.
70 Olds TS. One million skinfolds: Secular trends in the fatness of young people 1951–2004. Eur J Clin Nutr. 2009;63(8):934–46.
71 Fukunaga T, Miyatani M, Tachi M, Kouzaki M, Kawakami Y, Kanehisa H. Muscle volume is a major determinant of joint torque in humans. Acta Physiol Scand. 2001;172(4):249–55.
72 Olds T, Maher C, Zumin S, et al. Evidence that the prevalence of childhood overweight is plateauing: data from nine countries. Int J Pediatr Obes. 2011;6(5–6):342–60.
73 Smpokos EA, Linardakis M, Papadaki A, Lionis C, Kafatos A. Secular trends in fitness, moderate-to-vigorous physical activity, and TV-viewing among first grade school children of Crete, Greece between 1992/93 and 2006/07. J Sci Med Sport. 2012;15(2):129–35.
74 Tomkinson GR. Global changes in anaerobic fitness test performance of children and adolescents (1958–2003). Scand J Med Sci Sports. 2007;17(5):497–507.
75 Katzmarzyk PT, Mason C. The physical activity transition. J Phys Act Health. 2009;6(3):269–80.

Supplementary Material

Supplement 1. Search strategy for databases.

Search terms

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

Databases

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

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

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

Supplement 2. Included study references.

w1 Catley MJ, Tomkinson GR. Normative health-related fitness values for children: analysis of 85347 test results on 9–17-year-old Australians since 1985. Br J Sports Med. 2013;47(2):98–108.

w2 Tomkinson GR, Carver KD, Atkinson F, Daniell ND, Lewis LK, Fitzgerald JS, Lang JJ, Ortega FB. European normative values for physical fitness in children and adolescents aged 9–17 years: results from 2 779 165 Eurofit performances representing 30 countries. Br J Sports Med. 2018;52(22):1445–1456.

w3 Gaya AR, Dias AF, Lemes VB, Gonçalves JC, Marques PA, Guedes G. Brand C, Gaya ACA. Aggregation of risk indicators to cardiometabolic and musculoskeletal health in Brazilian adolescents in the periods 2008/09 and 2013/14. J Pediatr (Rio J). 2018;94(2):177–183.

w4 Dimitrova D. Fizicheska deesposobnost na podrastvashtite vuv vruska s vuzrastovite promeni v telesnite razmeri I sustava na telesnata masa (Physical fitness of children and adolescents in relation with age-specific changes in body composition). Doctoral dissertation. National Sports Academy, 2001.

w5 Slanchev P, Janev B, Genov F, Shterev P, Boev P, Sepetliev D, Zahariev B. Fizichesko razvitie, fizicheska deesposobnost I nervo-psichichna reaktivnost na naselenieto na Bulgaria: III Nacionalno izsledvane (1980–1982) (Physical development, physical fitness and neuropsychic reactivity of Bulgarian population: III National Project [1980–1982]). Sofia: Bulgarian Union for Physical Education and Sports, National Sports Academy, 1992.

w6 Yanev B, Shterev P, Boev P, Genov F, Sepetliev D, Popov I, Zahariev B. Fizichesko razvitie, fizicheska deesposobnost I nervo-psichichna reaktivnost na naselenieto (Physical development, physical fitness and neuropsychic reactivity of the Bulgarian people from birth up to age 60). Sofia: Bulgarian Union for Physical Education and Sports, 1982.

w7 Yanev B, Shterev P, Bonev P, Semerdjieva R, Sepetliev D. Fizichesko razvitie I deesposobnost na naselenieto na Bulgaria ot rajdaneto do 26 godini, tom I (Physical development and fitness of Bulgarian people from the birth up to the age of 26, volume I). Sofia: Bulgarian Academy of Sciences, 1965.

w8 Fortier MD, Katzmarzyk PT, Malina RM, Bouchard C. Seven-year stability of physical activity and musculoskeletal fitness in the Canadian population. Med Sci Sports Exerc. 2001;33(11):1905–1911.

w9 Conger PR, Quinney HA, Gauthier R, Massicotte D. Comparison of the CAHPER fitness performance test: results compared with data: 1966–1980. CAHPER J. 1982;49(1):6–11.

w10 Chinese Science and Technology Institute. A report of scientific findings: a study on morphology and physical fitness of Chinese children and adolescents. Beijing: Scientific Documents Publishing House; 1982.

w11 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the physical fitness and health research of Chinese school students 1985. Beijing: Higher Education Press; 1987.

w12 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the physical fitness and health research of Chinese school students 1991. Beijing: Higher Education Press; 1993.

w13 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the physical fitness and health research of Chinese school students 1995. Beijing: Higher Education Press; 1997.

w14 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the physical fitness and health research of Chinese school students 2000. Beijing: Higher Education Press; 2002.

w15 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the physical fitness and health research of Chinese school students 2005. Beijing: Higher Education Press; 2007.

w16 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the physical fitness and health research of Chinese school students 2010. Beijing: Higher Education Press; 2012.

w17 Research Group of Physical Fitness and Health Research of Chinese School Students. Reports on the Physical Fitness and Health Research of Chinese School Students 2014. Beijing: Higher Education Press; 2016.

w18 Huotari PRT, Nupponen H, Laakso L, Kujala UM. Secular trends in muscular fitness among Finnish adolescents. Scand J Public Health. 2010;38:739–747.

w19 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Secondary: 1998–1999 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w20 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 1999–2000 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w21 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Secondary: 2002–2003 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w22 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2003–2004 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w23 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Secondary: 2004–2005 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w24 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2005–2006 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w25 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Secondary: 2009–2010 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w26 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2010–2011 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w27 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Secondary: 2014–2015 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w28 Education Bureau, Government of the Hong Kong Special Administrative Region. Physical education—surveys on 'physical fitness status of Hong Kong school pupils'. Primary: 2015–2016 [online]. Available from URL: https://www.edb.gov.hk/en/curriculum-development/kla/pe/references_resource/fitness-survey/index.html [Accessed 23 Sept 2018].

w29 Ben-Sira D. A survey of the level of physical fitness of Israeli high school students. In: Ruskin H, Simkin A, editors. Physical fitness and the ages of man: Proceedings of the symposium of the International Council for Physical Fitness Research, 29 Sept–1 Oct, 1986, Jerusalem. Jerusalem: Academon Press; 1987. p. 164–177.

w30 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1968.

w31 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1969.

w32 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1970.

w33 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1971.

w34 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1972.

w35 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1973.

w36 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1974.

w37 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1975.

w38 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1976.

w39 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1977.

w40 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1978.
w41 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1979.
w42 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1980.
w43 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1981.
w44 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1982.
w45 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1983.
w46 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1984.
w47 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1985.
w48 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1986.
w49 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1987.
w50 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1988.
w51 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1989.
w52 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1990.

w53 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1991.
w54 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1992.
w55 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1993.
w56 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1994.
w57 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1995.
w58 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1996.
w59 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1997.
w60 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1998.
w61 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 1999.
w62 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2000.
w63 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2001.
w64 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2002.
w65 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2003.

w66 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2004.
w67 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2005.
w68 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2006.
w69 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2007.
w70 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2008.
w71 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2009.
w72 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2010.
w73 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2011.
w74 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2012.
w75 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2013.
w76 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2014.
w77 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2015.
w78 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2016.

w79 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2017.
w80 Ministry of Education, Culture, Sports, Science and Technology. Report book on the survey of physical fitness and athletic ability. Tokyo: Ministry of Education, Culture, Sports, Science and Technology; 2018.
w81 Venckunas T, Emeljanovas A, Mieziene B, Volbekiene V. Secular trends in physical fitness and body size in Lithuanian children and adolescents between 1992 and 2012. J Epidemiol Community Health. 2017;71(2):181–187.
w82 Dos Santos FK, Prista A, Gomes TN, Daca T, Madeira A, Katzmarzyk PT, Maia JA. Secular trends in physical fitness of Mozambican school-aged children and adolescents. Am J Hum Biol. 2015;27(2):201–206.
w83 Albon HM, Hamlin MJ, Ross JJ. Secular trends and distributional changes in health and fitness performance variables of 10–14-year-old children in New Zealand between 1991 and 2003. Br J Sports Med. 2010;44(4):263–269.
w84 Sjolie A, Mønness E. Truncus endurance, hip and ankle mobility and aerobic fitness in 15-year-old Norwegian adolescents in 1968 and 1997. Scand J Med Sci Sports. 2007;17(5):488–496.
w85 Ignasiak Z, Sławińska T, Malina RM. Short term secular change in body size and physical fitness of youth 7–15 years in Southwestern Poland: 2001–2002 and 2010–2011. Anthropol Rev. 2016;79(3:311–329.
w86 Przeweda R, Dobosz J. Growth and physical fitness of Polish youths in two successive decades. J Sports Med Phys Fitness. 2003;43(4):465–474.
w87 Saczuk J, Wasiluk A, Changes in the somatic and fitness variables in girls over two decades. Biomed Hum Kinet. 2010;2:102–105.
w88 Saczuk J, Wasiluk A, Zalech M. Generation changes over the period of 1986–2006 in the physical fitness of boys aged 7–19 from eastern Poland at particular stages of education. Biomed Hum Kinet. 2012;4:112–116.
w89 Ministry of Culture and Tourism. National survey of physical fitness. Seoul: Korean Sport Science Institute; 1993.
w90 Ministry of Culture and Tourism. National survey of physical fitness. Seoul: Korean Sport Science Institute; 1996.
w91 Ministry of Culture and Tourism. National survey of physical fitness. Seoul: Korean Sport Science Institute; 1999.
w92 Ministry of Culture and Tourism. National survey of physical fitness. Seoul: Korean Sport Science Institute; 2002.
w93 Ministry of Culture and Tourism. National survey of physical fitness. Seoul: Korean Sport Science Institute; 2005.
w94 Ministry of Culture and Tourism. National survey of physical fitness. Seoul: Korean Sport Science Institute; 2008.

w95 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1980. Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1981.
w96 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1982.
w97 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1983.
w98 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1984.
w99 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1985.
w100 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1986.
w101 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 1998.
w102 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2000.
w103 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2001.
w104 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2002.
w105 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2003.
w106 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2004.
w107 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2005.
w108 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2006.
w109 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2007.
w110 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2008.
w111 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2009.
w112 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2010.
w113 Ministry of Education, Health, Recreation and Dance. Statistical yearbook of education. Seoul: Ministry of Education, Health, Recreation and Dance; 2011.

w114 Quek JJ, Menon J, Tan S, Wang B. Review of National Physical Fitness Award (NAPFA) norms. In: No editors listed. Optimising performance: Proceedings of the International Sports Science Conference, 9–11 Jun 1993, Singapore. Singapore: Singapore Sports Council; 1993. p. 161–212.

w115 Active Healthy Kids Slovenia. The 2018 Republic of Slovenia report card on physical activity of children and youth. Ljubljana, Slovenia: Active Healthy Kids Slovenia.

w116 Westerstahl M, Barnekow–Bergkvist M, Hedberg G, Jansson E. Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. Scand J Med Sci Sports. 2003;13:128–137.

w117 Lo KY, Wu MC, Ho CC, Hsieh CC, Tung SC. Assessment of physical fitness among Taiwanese adolescents: a cohort study from 1997 to 2013. Sports Exerc Res. 2015;17(4):443–460.

w118 Klanarong S. Socio-demographic distribution of health-related fitness of Thai children. Doctoral dissertation. Adelaide, SA: University of South Australia, 2005.

w119 Haslofça F, Kutlay E, Haslofça E. 11–12 yaş Türk çocuklarının bazı fiziksel uygunluk değerlerindeki otuz yıllık değişimlerin incelenmesi (Analysis of three decade changes in physical fitness characteristics of Turkish children aged between 11 and 12). Spor Hekimliği Dergisi (Turk J Sports Med). 2017;52(4):137–145.

w120 Sandercock GRH, Cohen DD. Temporal trends in muscular fitness of English 10-year-olds 1998–2014: an allometric approach. J Sci Med Sport. 2019;22(2):201–205.