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Temporal trends in the sit-ups performance of 9,939,289 children

Tori Kaster

Faith L. Dooley

John S. Fitzgerald
University of North Dakota, john.s.fitzgerald@UND.edu

Tanis J. Walch
University of North Dakota, tanis.walch@und.edu

Madison Annandale

See next page for additional authors

Authors

Tori Kaster, Faith L. Dooley, John S. Fitzgerald, Tanis J. Walch, Madison Annandale, Katia Ferrar, Justin J. Lang, Jordan J. Smith, and Grant R. Tomkinson

Title

Temporal trends in the sit-ups performance of 9,939,289 children and adolescents between 1964 and 2017

Authors

Tori KASTER[1]
Faith L. DOOLEY[1]
John S. FITZGERALD[1] (ORCID: https://orcid.org/0000-0001-8694-0228)
Tanis J. WALCH[1] (ORCID: https://orcid.org/0000-0002-0557-7867)
Madison ANNANDALE[2]
Katia FERRAR[2] (ORCID: https://orcid.org/0000-0003-3042-9230)
Justin J. LANG[3,4] (ORCID: https://orcid.org/0000-0002-1768-319X)
Jordan J. SMITH[5]
Grant R. TOMKINSON[*1,2] (ORCID: https://orcid.org/0000-0001-7601-9670)

Institutional affiliations

[1]Department of Education, Health and Behavior Studies, University of North Dakota, Grand Forks, ND, USA

[2]Alliance for Research in Exercise, Nutrition and Activity (ARENA), School of Health Sciences, University of South Australia, Adelaide, SA, Australia

[3]Centre for Surveillance and Applied Research, Public Health Agency of Canada, Ottawa, ON, Canada

[4]Healthy Active Living and Obesity Research Group, Children's Hospital of Eastern Ontario Research Institute, Ottawa, ON, Canada

[5]Priority Research Centre for Physical Activity and Nutrition, School of Education, University of Newcastle, Callaghan, NSW, Australia

Corresponding author

Dr. Grant R. TOMKINSON[*]

✉ Department of Education, Health and Behavior Studies
University of North Dakota
2751 2nd Avenue North, Stop 8235
Grand Forks, ND, 58202, USA

☎ +1 701-777-4041

grant.tomkinson@und.edu

Abstract

We estimated international/national temporal trends in sit-ups performance for children and adolescents, and examined relationships between national trends in sit-ups performance and national trends in health-related/sociodemographic indicators. Data were obtained by systematically searching studies reporting on temporal trends in sit-ups performance for apparently healthy 9–17 year-olds, and by examining nationally representative fitness datasets. Trends at the country-sex-age level were estimated by sample-weighted regression models relating the testing year to mean sit-ups performance. International/national trends were estimated by a post-stratified population-weighting procedure. Pearson's correlations quantified relationships between national trends in sit-ups performance and national trends in health-related/sociodemographic indicators. A total of 9,939,289 children and adolescents from 31 countries/special administrative regions between 1964 and 2017 collectively showed a large improvement 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. Trends differed between countries, with national trends in vigorous physical activity a strong, positive correlate of national trends in sit-ups performance. More sit-ups data are needed from low- and middle-income countries to better monitor trends in muscular fitness.

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1 Introduction

Muscular fitness is an important marker of health.[1,2] In childhood and adolescence, muscular fitness is meaningfully related to cardiometabolic disease risk, adiposity, bone health, mental health, and cognition,[1,2] independent of cardiorespiratory fitness.[3] Direct evidence indicates that low muscular fitness in adolescence is significantly associated with cardiometabolic disease risk,[1] bone health,[1] and all-cause mortality later in life.[4] It is also a good predictor of youth sports and athletic performance.[5] In adulthood, low muscular fitness is significantly associated with all-cause, cardiovascular and non-cardiovascular mortality[6–8] (independent of body size, physical activity levels, and other covariates[8]), cancer,[6] stroke,[8] diabetes,[9] hypertension,[9] falls,[10] poor mental health,[11] poor overall quality of life,[11] and functional limitations,[12] which in turn is predictive of future disability and mortality.[13] This health-related evidence supports the recent addition of muscle-strengthening activities (in combination with aerobic activity) in national and global physical activity guidelines.[14,15]

Muscular fitness is a multidimensional construct that reflects the ability of a muscle or a group of muscles to exert force maximally (strength), explosively (power), or continuously without fatigue (endurance).[16] While strength, power, and endurance represent separate components of muscular fitness, evidence indicates that strength and power are strongly related.[17] On the other hand, endurance represents a unique component of muscular fitness. No single test provides an assessment of overall muscular endurance, and as a result, 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 tests for upper body endurance.[18,19] Many of these tests are practical, feasible, ecologically valid, and scalable for population surveillance, with the sit-ups test a widely used measure of abdominal/core endurance among schoolchildren.[19] Several protocols exist, including the timed sit-ups (normally lasting 30 seconds to several minutes) and the sit-ups to volitional fatigue, 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,[20] with such low validity coefficients thought to be partially due to the lack of appropriate criterion measures for abdominal/core endurance.[20] Sit-up tests are safe to perform by children and adolescents with no evidence of adverse events.[21]

Research into the relationship between muscular fitness and health has often failed to distinguish between separate components.[22] Despite limited evidence linking muscular endurance to health in children and adolescents, low abdominal/core endurance (sit-ups performance) is significantly associated with mortality in adults independent of cardiorespiratory fitness, adiposity and other covariates.[7] Furthermore, low back pain has become a major public health problem worldwide, with the Global Burden of Diseases Study[23] identifying low back pain as the leading cause of years lived with disability (YLDs), contributing 42.5 million of total YLDs. Theoretically, strong and fatigue-resistant abdominals should help protect against low back pain by maintaining proper pelvic and lumbar position.[23] Despite strong anatomical logic, evidence linking abdominal/core endurance with low back pain is unclear.[1,2,20] Regardless, the National Academy of Medicine (formerly called the Institute of Medicine) recommends that schools consider measures of abdominal/core endurance, in addition to other field-based strength measures, as valuable educational tools.[18] Paediatric resistance training experts have recommended youth strength and conditioning programs include activities that target the abdominals/core to prevent the occurrence and/or severity of sports-related low back injuries.[25] Moreover, good abdominal/core strength/endurance is important for optimal force production and postural control,[23,26] efficient and effective function of the upper and lower extremities,[26] athletic/sports performance,[25,27] and mastery of fundamental movement skills,[28] which collectively help to optimise function in everyday physical activities.

Much of the evidence examining temporal trends in fitness among children and adolescents has focused on cardiorespiratory fitness,[29,30] with little known about trends in local muscular endurance. Reports of national trends in abdominal/core endurance operationalized as sit-ups performance for children and adolescents have shown mixed results over recent decades, including declines in Brazil,[31] Sweden,[32] and the UK,[33] improvements in Finland,[34] New Zealand,[35] Poland,[36,37] and Turkey,[38] and no meaningful change in Lithuania[39] and Norway.[40] However, there has not yet been a comprehensive study to synthesize national and international trends in sit-ups performance for children and adolescents. Therefore, the primary aim of this study was to systematically analyse national (country-specific) and international (pooled global data) temporal trends in sit-ups performance for children and adolescents. The secondary aim was to examine relationships between national trends in sit-ups performance and national trends in health-related and sociodemographic indicators, as such relationships may illustrate the importance of these indicators to trends in population fitness.

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), and followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement.[41]

2.2 Eligibility Criteria

One large systematic review of temporal trends in muscular fitness (i.e., muscular strength, explosive muscular strength, and local muscular endurance) for children and adolescents was initially undertaken before being separated into three smaller reviews. For this study, we included studies if they explicitly reported on temporal trends in abdominal/core endurance operationalized as sit-ups performance for children and adolescents. 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 (pre-specified as aged 9–17 years) across at least two time points spanning a minimum of five years.[30] Temporal trends must have been reported as absolute, percent or standardized changes in means at the country-sex-age level (e.g., 9-year-old Australian boys), or as descriptive data (e.g., sample sizes, means and standard deviations) at the country-sex-age-year level (e.g., 9-year-old Australian boys tested in 1985) 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 helped develop the search strategy. Additional studies were identified by searching reference lists, topical systematic reviews, and the personal library of the senior author. Large datasets comprising nationally representative fitness survey data suitable to temporal trends analysis were also considered.

2.4 Search Strategy

The online 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 cardiovascular fitness OR cardiorespiratory fitness) (Note, the search terms aerobic fitness, cardiovascular fitness, and cardiorespiratory fitness were included to capture relevant studies where trends in sit-ups performance were reported but were not the primary focus). 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 search strategy for databases is shown in Supplement 1.

2.5 Study Selection

All database records were imported into RefWorks (v2.0; ProQuest LLC, Ann Arbor, MI, USA) and de-duplicated. At the first level, two researchers independently screened the titles and abstracts against inclusion criteria, with consensus required for further screening. At the second level, full text copies were independently screened by two researchers against inclusion criteria, with consensus required for final inclusion. 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[30] and checked for accuracy by a second researcher. 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 data were extracted: title, country, years of testing, sex, age or age range, and test protocol. If available, the absolute (number of completed sit-ups), percent, and/or standardized changes in mean sit-ups performance (±95% confidence intervals [95% CIs]) were extracted; if not, then all descriptive sit-ups data were extracted to calculate temporal trends.

2.8 Summary Measures and Synthesis of Results

Temporal trends were analysed 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 sit-ups performance.[30] Trends in mean sit-ups performance 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.[42] Positive temporal trends indicated increases in mean sit-ups performance and negative temporal 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-olds]) were calculated using a post-stratified population-weighting procedure that has been described in detail elsewhere.[30] Population estimates were standardized to the year 2000—a year common to most country-sex-age groups—using United Nations data.[43] The post-stratification population-weighting procedure helped correct for sampling bias and standardized the trends to underlying population demographics.

Relationships between national temporal trends in pre-specified health-related/sociodemographic indicators and national temporal trends in sit-ups performance were quantified using Pearson's correlation coefficients, with 95% CIs estimated using Fisher's *z*-transformation. National trends for three health-related (childhood and adolescent body mass index [BMI],[44] moderate-to-vigorous physical activity [MVPA],[45] and vigorous physical activity [VPA][45]) and three sociodemographic (Gini index,[46] Human Development Index [HDI],[47] and urbanization[48]) indicators were analysed using linear regression models as described above. To interpret the magnitude of correlation, ES of 0.1, 0.3, 0.5, 0.7, and 0.9 were used as thresholds for weak, moderate, strong, very strong, and nearly perfect, respectively, with ES<0.1 considered to be negligible.[42]

3 Results

A total of 1,416 unique records were identified through online database searching, with 28 retained after the first level of screening and eight retained after the second level (Figure 1). These eight studies were combined with: (a) 14 additional studies identified from reference lists and the senior author's personal library (13/14) and topical systematic reviews (1/14), 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.

Insert Figure 1 here

Temporal trends in sit-ups performance were estimated for 9,939,289 children and adolescents aged 9–17 years from 30 countries and one special administrative region (Hong Kong) (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/special administrative regions [49] (or 26 very high, 4 high, and 1 low human development countries/special administrative regions),[47] representing 6/7 continents and 32% of the world's population.[43] Trend data were available for 369 country-sex-age groups, with a median sample size of 1,090 (range 43–379,294) across a median span of 18 years (range 6–35). National trends were available for different test protocols which were either externally or self-paced, including the number of completed sit-ups in 30 seconds (55% or 17/31 countries), 60 seconds (36% or 11/31 countries), 180 seconds (3% or 1/31 countries), and to volitional fatigue (6% or 2/31 countries) (Table 1).

Insert Table 1 here

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]; 1.09 ES [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% [29.8 to 34.2]; 0.86 ES [0.81 to 0.91]), (b) adolescents (change in means [95% CI]: 45.2% [43.6 to 46.8]; 1.33 ES [1.27 to 1.39), (c) boys (change in means [95% CI]: 24.9% [23.2 to 26.6]; 0.84 ES [0.78 to 0.88]), and (d) girls (change in means [95% CI]: 44.5% [42.3 to 46.7]; 1.20 ES [1.14 to 1.26]) (Figure 2).

Insert Figure 2 here

The international trends in sit-ups performance were curvilinear over time, with the rate of improvement slowing from 1964 to 2000, stabilizing near zero until 2010, and declining thereafter (Figure 2). The rate of improvement diminished from 16.4% per decade (95% CI: 15.4 to 17.4) in the 1960s and 1970s, 11.1% (95% CI: 10.5 to 11.7) in the 1980s, to 4.3% (95% CI: 3.9 to 4.7) in the 1990s, before stabilizing at −0.4% (95% CI: −0.8 to 0.0) in the 2000s and declining at −4.1% (95% CI: −4.7 to −3.5) in the 2010s. This trend was consistent across different sex and age groups, except for boys, where the rate of improvement progressively diminished and then stabilized, but did not shift from an improvement to a decline (Figure 2).

National trends ranged from a large improvement in sit-ups performance in Mozambique (19.5% or 0.42 ES per decade between 1992 and 1999) to a large decline in the United Kingdom (−39.5% or −1.06 ES per decade between 1998 and 2014), with trends typically negligible to small (28/31 or 90%) and positive (i.e., improvements) (20/31 or 65%), especially prior to 2000 (Figure 3). While most national trends were approximately linear, several countries experienced 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). Within-country trends were nearly perfectly related between the sexes (*r* [95% CI]: 0.92 [0.84 to 0.96]) and very strongly related between age groups (*r* [95% CI]: 0.77 [0.50 to 0.90]).

Insert Figure 3 here

There was a strong, positive, significant (at the 95% level) correlation between national trends in sit-ups performance and national trends in VPA (*r* [95% CI]: 0.51 [0.07 to 0.78]), indicating that countries (Europe only) with improvements in VPA among children and adolescents between 2002 and 2014 had the largest improvements in sit-ups performance (Table 2). Despite not reaching statistical significance, 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, MVPA, and BMI were negligible-to-weak, non-significant positive correlates.

Insert Table 2 here

4 Discussion

This study estimated temporal trends in abdominal/core muscular endurance operationalized as sit-ups performance for 9,939,289 children and adolescents aged 9–17 years from 31 countries/special administrative regions between 1964 and 2017. The main findings were that: (a) there was a large international improvement observed across the full period for all age and sex groups, equivalent to 38%, 1.1 ES, or 4–9 completed sit-ups using the Eurofit's 30-second protocol;[19] (b) the international rate of improvement slowed from 1964 to 2000, stabilized near zero until 2010, and declined thereafter; (c) while national trends varied, most typically showed improvements; and (d) national trends in sit-ups performance were strongly and positively related to national trends in VPA (Europe only).

While numerous factors positively influence muscular endurance, including biological maturation,[51] body size,[2,52] and VPA,[53] apart from trends in body size, trends in these factors have not been directly controlled for in studies examining trends in sit-ups performance. For instance, Westerstahl et al.[32] reported that trends in a "maturity index" (not biological maturity, rather a maturity score based on a child's grade and enrolment in school physical education) did not contribute to declining sit-ups performance in Swedish 16-year-old boys and girls between 1974 and 1995. Conversely, Saczuk et al.[36] 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.[51,54] 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.[19] 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 estimated to reduce to ~26–27% in children (i.e., 32% minus 6% in boys and 32% minus 1.5 multiplied by 3% in girls) and ~41–43% in adolescents (i.e., 45% minus 4% in boys and 45% minus 1.5 multiplied by 1.5% in girls). While only an estimate, this example suggests that trends in biological maturation explain only a small proportion of the trends in sit-ups performance.

Several studies have reported that temporal trends in sit-ups performance were independent of trends in body size, operationalized as height and mass,[33,55] or height, mass, and BMI.[32,39] 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.[34,35,38,56] International increases in childhood and adolescent BMI are well established,[44] reflecting both increases in fat mass and fat-free mass.[57] Mechanistically, increases in fat mass and fat-free mass will influence sit-ups performance in different ways: increased fat mass constitutes a “dead” load that will need to be overcome in order to perform repeated sit-ups, while increased fat-free mass will increase the maximal force generation capacity of the exercising muscles,[58] although its influence on sit-ups performance is less clear. While this study found that sit-ups performance improved internationally from 1964 to 2000, before stabilizing for a decade and then declining, 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 indicated a noticeable stabilizing in BMI from the mid-1990s onwards.[59] In contrast, trends in skinfold thicknesses do not appear to have stabilized, at least until 2003.[57] In the same study, Olds[57] showed there has been a shift towards central accumulation of body fat, which might hinder sit-ups performance. Nevertheless, our analysis found that national trends in BMI were a negligible, non-significant correlate of national trends in sit-ups performance, indicating that trends in other factors are probably involved.

Although no study has examined temporal trends in sit-ups while statistically controlling for trends in physical activity, several studies have reported a temporal coincidence.[33,34,60]

Sandercock and Cohen[33] 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.[34] reported that improved sit-ups performance of 13–16-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.[60] found concurrent increases in sit-ups performance, MVPA, and VPA in first grade children from Greece between 1992 and 2007. Moreover, our cross-country correlational analysis indicated that national trends in VPA were strongly and positively associated with national trends in sit-ups performance among European countries. 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 strengthening activities [including abdominal/core exercise] as recommended in national and global physical activity guidelines[14,15]) might be a suitable population approach to improving abdominal/core endurance. Indeed, a recent systematic review of studies with children and adolescents found consistent positive associations between objectively measured VPA and combined measures of local muscular endurance, which included sit-ups.[53]

While not statistically significant, trends in sit-ups performance were moderately associated with two sociodemographic indicators — HDI and urbanization (Table 2). Consider first trends in HDI. It is possible that continued improvements in national economic growth and development leads to better quality and/or quantity of opportunities for organized sport and physical activity, resulting in improved abdominal/core endurance. 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, and a moderate positive correlate of organized sport and physical activity, among children and adolescents across 49 countries.[61] However, while organized sport and physical activity positively influence muscular fitness, the association between these variables and muscular endurance is less certain.[53] Next, the moderate negative association between trends in sit-ups performance and trends in urbanization indicates the potential negative impact of rapid urbanization on habitual physical activity levels and muscular fitness. A population shift towards urbanization is described as a component of the physical activity transition,[62] which leads to a changing social and built environment that has a negative impact on daily, habitual, physical activity.

This study represents the most comprehensive analysis to date of national and international temporal trends in children's sit-ups performance. It used a detailed statistical approach previously incorporated into several other systematic analyses of trends in children's fitness.[29,30] The weighted regression and post-stratification population weighting procedures helped adjust our trends for sampling bias by incorporating the underlying population demographics. Furthermore, a post-hoc 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 on the international trends. There was also a negligible difference between trends calculated using different testing protocols (sit-ups in 30 seconds *vs*. sit-ups in 60 seconds, 180 seconds, and to volitional fatigue). These sensitivity analyses increase our confidence that large countries or testing protocols did not meaningfully bias the reported international trends.

There are several limitations to this study. First, because we estimated trends in sit-ups performance from descriptive data rather than raw data, we were unable to statistically remove the effects of potential mechanistic factors (e.g., body size, sexual maturation, physical activity levels). Second, trends in sit-ups performance are largely representative of high- and upper-middle-income countries/special administrative regions (30/31 or 97%), which limit the generalizability of our results to low-income and middle-income countries that may be experiencing a physical activity transition.[62] Third, it is also possible that methodological drift occurred over time and between studies (e.g., differences in knee position, levels 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/frames and were not always nationally representative. Nonetheless, our trends were estimated using the best available data. Fifth, while it was beyond the scope of this study to examine corresponding trends in distributional characteristics (i.e., trends in distributional variability and/or asymmetry), our trends in mean sit-ups performance may be systematically biased if concurrent trends in asymmetry (i.e., skewness) occurred. Because there is evidence of temporal trends in both positive skewness[34,35] and negative skewness[32] it is challenging to estimate the likely impact. Sixth, our finding of a strong, positive, significant relationship between national trends in VPA and national trends in sit-ups performance was limited to only European countries. Finally, because sit-ups test protocols are difficult to perform by children and adolescents and floor and ceiling effects are common, future trends studies should consider other abdominal/core endurance measures such as the plank test which have been shown to be a feasible, valid, and reliable alternative.[63]

5 Conclusion

This study found a large international improvement in abdominal/core endurance through sit-ups performance for 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. National trends were strongly and positively associated with 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/special administrative regions reporting trends in sit-ups performance were high- and upper-middle-income, there is a need for temporal data from low- and middle-income countries in order to help monitor population trends in muscular fitness and to more confidently determine true international trends. Future studies examining temporal trends in muscular fitness should: (a) report trends as absolute, percent, and standardized changes in means at the sex-age level; (b) statistically adjust for trends in underlying mechanistic factors; and (c) report corresponding trends in distributional variability and/or asymmetry.

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Data availability statement

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

Compliance with Ethical Standards

All authors declare no conflicts of interest and received no external financial support was received for this project.

Contributors

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

Disclaimer

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

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1 **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	8504	P	N/S/O	0.939 (very high)	SUP to volitional fatigue (up to 60 reps)
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	6923	NP	N	0.759 (high)	SUP in 60s
Bulgaria[w4–w7]	F (49.7%) M (50.3%)	9–17	1980–1999	7008	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	6207	P/NP	S/O	0.871 (very high)	SUP in 30s
Finalnd[w18]	F (49.3%) M (50.7%)	13–17	1976–2001	1222	P	N	0.920 (very high)	SUP in 30s
France[w2]	F (48.0%) M (52.0%)	9,11–12	1984–2000	2706	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	6849	NP	N/O	0.935 (very high)	SUP in 30s
Israel[w29]	F (54.1%) M (45.9%)	16–17	1970–1984	1816	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%) M (50.1%)	9–17	1999–2017	444,277	P	N	0.909 (very high)	SUP in 30s
Lithuania[w81]	F (50.2%)	11–17	1992–2012	16,158	P	N	0.858	SUP in 30s

Country	Sex	Age (years)	Span of years	Sample size	Sampling strategy	Sample base	HDI	Test protocol
	M (49.8%)						(very high)	
Mozambique[w82]	F (56.9%) M (43.1%)	9–15	1992–1999	1944	P	O	0.437 (low)	SUP in 60s
New Zealand[w83]	F (42.9%) M (57.1%)	10–13	1991–2003	4499	NP	O	0.917 (very high)	SUP to volitional fatigue (up to 50 reps)
Norway[w84]	F (49.5%) M (50.5%)	15	1968–1997	2224	P	S	0.953 (very high)	SUP to volitional fatigue (up to 10 reps per level, across four levels of increasing difficulty)
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–w114]	F (49.2%) M (50.8%)	9–17	1979–2010	1,535,955	P	N	0.903 (very high)	SUP in 60s
Singapore[w115]	F (59.3%) M (40.7%)	12–17	1980–1992	3398	P	N	0.932 (very high)	SUP in 60s
Slovakia[w2]	F (46.4%) M (53.6%)	9–11	1993–2015	1183	P/NP	N/S/O	0.855 (very high)	SUP in 60s
Slovenia[w116]	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[w117]	F (49.0%) M (51.0%)	16	1974–1995	980	P	S	0.933 (very high)	SUP to volitional fatigue
Switzerland[w2]	F (51.8%) M (48.2%)	11	1996–2005	535	P	S/O	0.944 (very high)	SUP in 30s
Taiwan[w118]	F (48.2%) M (51.8%)	10–17	1997–2013	5,857,636	P	N	0.907 (very high)	SUP in 60s
Thailand[w119]	F (50.8%) M (49.2%)	9–12	1990–2003	17,635	P	N	0.755 (high)	SUP in 30s
Turkey[w120]	F (42.4%) M (57.6%)	11–12	1983–2003	403	NP	O	0.791 (high)	SUP in 30s

Country	**Sex**	**Age (years)**	**Span of years**	**Sample size**	**Sampling strategy**	**Sample base**	**HDI**	**Test protocol**
UK[w121]	F (48.6%) M (51.4%)	10	1998–2014	916	NP	S	0.922 (very high)	SUP in 30s

Note: UK=United Kingdom; M=male; F=female; P=probability sampling (i.e., random selection); NP=non-probability sampling (i.e., non-random selection); N=national sampling; S=state/provincial sampling; O=other sampling (i.e., city, local area, or school-level sampling); 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;[47] Because the United Nations does not recognize Taiwan as a sovereign state, its HDI was calculated by the Taiwanese Government.[50] Web references are shown in Supplement 2. Hong Kong is a special administrative region of the People's Republic of China, and because it maintains a separate governing and economic system, national temporal trends in handgrip strength were estimated separately from China.

Table 2. Potential health-related and sociodemographic correlates of trends in sit-ups performance for children and adolescents.

Variable	Data source	Description	Correlation (95% CI)
Health			
Body mass index (BMI)	NCD-RisC[44] Trend data available for 30/31 (97%) countries/special administrative regions between 1975 and 2016.	Calculated as the change (per decade) in mean country-level BMI of boys and girls aged 5–19 years (age standardized). A positive correlation (next column) indicated country-level increases in mean BMI corresponded with increases in sit-ups performance, while a negative correlation indicated opposing trends.	0.06 (−0.31 to 0.41)
Moderate-to-vigorous physical activity (MVPA) and vigorous physical activity (VPA)	Inchley et al.[45] Data originally obtained from Health Behaviour in School-aged Children (HBSC) World Health Organization (WHO) collaborative cross-national study. Trend data available for 19 European countries (19/31 or 61% of all countries/special administrative regions) between 2002 and 2014.	Calculated as the change (per decade) in mean country-level percentage of boys and girls aged 11-, 13-, and 15-years old that achieved at least 60 minutes of MVPA everyday or VPA at least four times per week. A positive correlation indicated country-level increases in mean percentage of MVPA/VPA corresponded with increases in sit-ups performance, while a negative correlation indicated opposing trends.	MVPA 0.20 (−0.28 to 0.60) VPA 0.51 (0.07 to 0.78)
Sociodemographic			
Gini index	World Bank[46] Trend data available for 26/31 (84%) countries/special administrative regions between 1990 and 2017.	Summarizes the change (per decade) in the distribution of income among individuals in a country where 0 represents perfect equality and 100 implies perfect inequality. A positive correlation indicated country-level trends towards perfect inequality corresponded with increases in sit-ups performance, while a negative correlation indicated opposing trends.	0.12 (−0.28 to 0.48)

Human Development Index (HDI)	United Nations[47] Trend data available for 30/31 (97%) countries/special administrative regions between 1990 and 2017.	Calculated as the change (per decade) in mean country-level human development (i.e., achievements in health, education and income). A positive correlation indicated country-level increases in mean human development corresponded with increases in sit-ups performance, while a negative correlation indicated opposing trends.	0.35 (−0.01 to 0.63)
Urbanization	World Bank[48] Trend data available for 30/31 (97%) countries/special administrative regions between 1967 and 2017.	Calculated as the change (per decade) in the percentage of people living in urban areas. A positive correlation indicated country-level increases in urbanization corresponded with increases in sit-ups performance, while a negative correlation indicated opposing trends.	−0.32 (−0.61 to 0.05)

9

Figure legends

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

Figure 2. International temporal trends in mean sit-ups performance for children and adolescents between 1967 and 2017.

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

Figure 3. National temporal trends in mean sit-ups performance for children and adolescents between 1967 and 2017.

Note: data were standardized to the year 2000=100%, with higher values (>100%) indicating better sit-ups performance and lower 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; for this study, national temporal trends in mean handgrip strength for China and Hong Kong (a special administrative region of the People's Republic of China) were estimated separately.