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SYSTEMATIC REVIEW

# Temporal Trends in the Standing Broad Jump Performance of 10,940,801 Children and Adolescents Between 1960 and 2017

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## Abstract

**Background** The standing broad jump (SBJ) is an excellent functional measure of explosive lower-body strength that is significantly related to health among children and adolescents.

**Objectives** The aim of this study was to estimate national (country-level) and international (pooled global data) temporal trends in SBJ performance for children and adolescents, and to examine the relationships between national trends in SBJ performance and national trends in health-related and socioeconomic/demographic indicators.

**Methods** Data were obtained from a systematic search of studies reporting temporal trends in SBJ performance for 9- to 17-year-olds, and by examining national fitness datasets. Sample-weighted regression models estimated trends at the study/dataset-country-sex-age level, with national and international trends estimated by a post-stratified population-weighting procedure. Pearson's correlations quantified relationships between national trends in SBJ performance and national trends in health-related and socioeconomic/demographic indicators.

**Results** Data from 34 studies/datasets were extracted to estimate trends for 10,940,801 children and adolescents from 24 high-, 4 upper-middle-, and 1 low-income countries between 1960 and 2017. Collectively, there was a negligible (per decade) improvement in SBJ performance of 1.73 cm (95% CI 1.71–1.75), 0.99% (95% CI 0.97–1.01) or a standardized effect size of 0.07 (0.07–0.07) over the entire period, with the rate of improvement steady from the 1960s to the 1980s, slowing in the 1990s, before declining. Sex- and age-related temporal differences were negligible. Trends differed between countries, with most countries experiencing declines. National trends in SBJ performance were not significantly related to national trends in health-related and socioeconomic/demographic indicators.

**Conclusions** SBJ performance of children and adolescents has declined since 2000 (at least among most of the countries in this analysis) and is suggestive of a modern decline in functional explosive lower-body strength. Growing recognition of the importance of muscular fitness as a marker of population health highlights the need for continued tracking of temporal trends in SBJ, especially among low- and lower-middle-income countries for which temporal data are lacking.

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## 1 Introduction

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, also called "explosive strength"), or continuously without fatigue (endurance) [1]. In childhood and adolescence, reduced muscular fitness is significantly related to cardiometabolic disease risk [2, 3] (independent of age, sex, biological maturation, fat-free mass, cardiorespiratory fitness and physical activity levels) [4–6], adiposity [2, 3], reduced bone mineral density [2, 3] and reduced self-esteem [3]. Longitudinal evidence indicates that reduced muscular fitness in adolescence is significantly associated with cardiovascular disease [7], disability [8],

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**Key Points**

There has been a negligible (per decade) improvement in SBJ performance for all age and sex groups since 1960, with the rate of improvement steady from the 1960s to the 1980s, slowing in the 1990s, before declining thereafter.

Nationally, temporal trends in SBJ performance differed in magnitude and direction, with most (62% or 18/29) experiencing declines, especially recently.

Relationships between national (country-level) trends in SBJ performance and national trends in health-related and socioeconomic/demographic indicators were not statistically significant.

adverse glucose homeostasis [9], and premature death due to all causes, cardiovascular diseases and suicide later in life [10]. Muscular fitness cut-points for the detection of increased cardiometabolic risk [5, 11, 12] and reduced bone health [13] have also been used to identify at-risk children and adolescents in need of intervention. This health-related evidence underpins the recent addition of muscle- and bone-strengthening activities (in addition to aerobic activities) in national [14–16] and global [17] physical activity guidelines for children and adolescents.

The standing broad jump (SBJ)—a double-leg jump for the greatest horizontal distance—is a practical, feasible, widely used, ecologically valid and scalable measure of functional explosive strength for clinical and population screening and surveillance [18, 19]. In children and adolescents, the SBJ is significantly related to health (e.g., cardiometabolic disease risk, adiposity, bone mass) [2, 3], consistently related to objectively measured physical activity levels [20], with cardiometabolic risk-related cut-points available [5]. Temporal trends in SBJ performance therefore, should provide important insights into corresponding trends in population health. SBJ has moderate to high construct validity with established measures of both lower- [21] and upper-body strength [19, 22], and is strongly related to other field-based tests of explosive strength [19, 21, 22] independent of age, sex, and body size [19]. The SBJ has very high test–retest reliability [21], negligible test–retest learning and fatigue effects [21, 23] and is generally safe [24]. It has also been endorsed by both North American [24] and European [25] experts for its predictive utility and recommended for school-based fitness testing. Moreover, jumping is a fundamental movement skill used in sports and activities involving high-velocity contractions, such as athletics, gymnastics, dance, and various field, court and combat sports.

Much of the evidence examining temporal trends in physical fitness for children and adolescents has focused on cardiorespiratory fitness [26, 27], with less known about trends in explosive strength. Our previous study [28], which currently provides the most comprehensive synthesis of temporal trends in explosive strength, indicated an improvement in mean jumping (i.e., standing broad jump, running broad jump and vertical jump) performance of 0.3% per decade for 20.8 million 6- to 19-year-olds from 23 countries between 1958 and 2003. Interestingly, the trend was curvilinear across the 45-year period, with jumping performance improving internationally from the late 1950s to the mid-1980s before declining through to 2003 [28]. Subsequent reports on temporal trends in SBJ performance for children and adolescents have generally indicated declines [29–37] or no meaningful change [38–41] in recent decades.

The aim of this study was to update our previous comprehensive synthesis [28] of national (country-specific) and international (pooled global data) temporal trends in SBJ performance for children and adolescents aged 9–17 years, by extending the temporal picture from 2003 to 2017 and updating the data pooling methods. In addition, we examined relationships between national trends in SBJ performance and national trends in health-related and socioeconomic/demographic indicators, as such relationships may provide insight into the importance of these indicators to trends in population health and fitness.

## 2 Methods

### 2.1 Protocol and Registration

The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number CRD42013003657). This review followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [42].

### 2.2 Eligibility Criteria

We included studies if they reported on temporal trends in explosive strength (operationalized as SBJ 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 SBJ performance (using matched testing 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 [26]. Temporal trends must have been reported as absolute, percent or standardized (effect size) 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 [SD]) at the country-sex-age-year level (e.g., 9-year-old Australian boys tested in 1985) to calculate temporal trends. To calculate national trends, a minimum of four country-sex-age groups was required for inclusion (e.g., 9- and 10-year-old Australian boys and girls).

### 2.3 Information Sources

Studies were identified by searching electronic databases, reference lists, topical systematic analyses/reviews and personal libraries [42]. The electronic database search strategy was developed in consultation with an academic librarian experienced in systematic literature searching. The electronic database search was performed on the 30th of October 2018, and updated on the 15th of January 2020, using the Elton B. Stephens Co. (EBSCO) interface and included the Cumulative Nursing and Allied Health Literature (CINAHL), MEDLINE and SPORTDiscus. No date or language restrictions were imposed. Additional studies were located by searching reference lists, topical systematic reviews and the personal library of the lead author. Large nationally representative fitness survey data suitable to temporal trends analysis were also considered.

### 2.4 Search

The electronic database search included a keyword search for the keyword in the full text as well as the citation record. Search terms within a group were combined with a Boolean OR and were searched concurrently with other search groups using the Boolean AND. Proximity operators ("*") 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 power 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 for which trends in SBJ performance were not the primary outcome). The second group identified the population (child* OR youth OR young OR adolescen*). The third group identified the trend over time (temporal OR secular OR trend*). The search strategy for databases is shown in Electronic Supplementary Material Appendix S1.

### 2.5 Study Selection

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

### 2.6 Data Collection Process

Descriptive data were extracted into a spreadsheet by one researcher using a standardized study-specific template [26] 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 descriptive data were extracted: title, country, years of testing, sex, age (or age range), test protocol and sample size. We extracted SBJ performance results if temporal trends were reported as any of the following: rates of change in mean SBJ performance as absolute [in cm], percent and/or standardized units, including corresponding standard errors and/or 95% confidence intervals (95% CI). Note, sample sizes, means and standard deviations at each time point were extracted if rates of change in mean SBJ performance and/or corresponding standard errors/95% CIs were not reported. Missing SDs were estimated from a sample-weighted mean coefficient of variation of 13.2%, which was calculated from a large international database ($n$ = 464,900) of SBJ performances on 9- to 17-year-olds representing 29 countries [43].

### 2.8 Summary Measures and Methods of Analysis

Overall approach: Using summary statistics from each study or dataset, we calculated the overall linear rate of change in SBJ performance for each country-sex-age group, as well as the corresponding standard error. For each country, we then pooled the linear rates of change across all sex-age groups, weighting by the population size of each sex-age group for the year 2000. We also pooled the rates of change across all country-sex-age groups using population weights for the year 2000, with results pooled for each decade and overall. Finally, we visualized the best-fitting linear/non-linear trends by separately pooling the yearly rates of change across all relevant country-sex-age groups and plotting them.

In some cases, studies published temporal trends as linear rates of change in mean SBJ performance at the country-sex-age level. However, for most studies and all datasets, we estimated the temporal trends in mean SBJ performance from summary statistics for each country-sex-age group using sample-weighted linear regression (Electronic Supplementary Material Appendix S2). All regression models were computed in SPSS Statistics (v26, IBM, Chicago, IL, USA), with sample size used as the sample weight because SDs (and hence standard errors [SEs]) were not always available. Overall temporal trends were expressed as absolute rates of change (i.e., the regression coefficient), percent rates of change (i.e., the regression coefficient expressed as a percentage of the sample-weighted mean value for all means in the regression) and as standardized (Cohen's) effect sizes (ES) (i.e., the regression coefficient divided by the pooled SD for all SDs in the regression). To interpret the magnitude of rates 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 [44]. Positive rates of change indicated increases in mean SBJ performance and negative rates of change indicated declines in mean SBJ performance.

We calculated population-weighted mean rates of change (Eq. 1) at the national and international levels by pooling the overall rates of change across all relevant country-sex-age groups using a post-stratification procedure [45]. We used this post-stratification population-weighting procedure to correct for sampling bias and to standardize the rates of change to underlying population demographics. The population weights were obtained from country-sex-age-specific population estimates for the year 2000—a common testing year to most country-sex-age groups—using United Nations data [46]. (Note, because our population weights were country-sex-age-specific, some country-sex-age-specific rates of change [a required input for Eq. 1] were calculated as sample-weighted mean rates of change from corresponding study/dataset-country-sex-age-specific rates of change). The corresponding SE was calculated using Eq. 2, with the 95% CI calculated as ± 2• SE. A spreadsheet providing a worked example is provided in Electronic Supplementary Material Appendix S3.

$$\bar{\Delta}= \frac{\sum_{i=1}^{k} \Delta_i \bullet w_i}{\sum_{i=1}^{k} w_i}, \quad (1)$$

where $\bar{\Delta}$ = population-weighted mean rate of change, $\Delta$ = country-sex-age-specific linear rate of change, $w$ = country-sex-age-specific post-stratification population weight and $k$ = the number of country-sex-age groups.

$$\bar{\Delta}_{\mathrm{SE}} = \frac{\sqrt{\sum_{i=1}^{k} \left(\Delta_{\mathrm{SE}}\right)_i^2 \bullet w_i^2}}{\sum_{i=1}^{k} w}, \quad (2)$$

where $\bar{\Delta}_{\mathrm{SE}}$ = the standard error of the population-weighted mean rate of change, $\Delta_{\mathrm{SE}}$ = country-sex-age-specific standard error of the linear rate of change, $w$ = country-sex-age-specific sample weight and $k$ = the number of country-sex-age groups.

The national and international temporal patterns of change were visualized using a procedure described elsewhere [28]. Briefly, using the best fitting and most parsimonious linear or polynomial (quadratic) sample-weighted regression models, we first estimated yearly ES rates of change for every year in each country-sex-age group. We then pooled these yearly rates of change across all relevant country-sex-age groups using population weights for the year 2000 [46] to generate a series of mean yearly rates of change, which we subsequently standardized to the year 2000 = 0 before plotting.

Relationships between national trends in SBJ performance and national trends in pre-specified health-related and socioeconomic/demographic indicators were quantified using Pearson's correlation coefficients, with 95% CIs estimated using Fisher's $z$-transformation. National trends for three health-related (childhood and adolescent body mass index [BMI] [47], moderate to vigorous physical activity [MVPA] [48] and vigorous physical activity [VPA] levels [48]) and three socioeconomic/demographic (Gini index [49], Human Development Index [HDI] [50] and urbanization [51]) indicators were analyzed using linear regression models as described above. To interpret the magnitude of correlation, ES of 0.1, 0.3, 0.5, 0.7 and 0.9 were used as thresholds for weak, moderate, strong, very strong and nearly perfect, respectively, with ES < 0.1 considered to be negligible [44].

### 2.9 Additional Analyses

A post-hoc sensitivity analysis was conducted to examine the impact of countries with very large samples on the international trend.

## 3 Results

### 3.1 Study Selection

A total of 1557 unique references were identified through electronic database and additional searching, with 53 retained after the first level of screening and 29 retained after the second level. We also identified five large country-level datasets comprising nationally representative SBJ data suitable for temporal trends analysis, for a total of 34 included studies/datasets. Figure 1 illustrates the PRISMA flowchart for included studies.

### 3.2 Study Characteristics

Temporal trends in SBJ performance were estimated for 10,978,042 children and adolescents aged 9–17 years from 29 countries (3,098 country-sex-age-year groups) between 1911 and 2017 (Table 1). Data prior to 1960 were removed because they were only available for 7% (2/29) of countries representing 0.3% of all data points (e.g., Czech Republic [1923–2002] and the United States of America [1911–1985]). As a result, trends between 1960 and 2017, representing 10,940,801 children and adolescents, were calculated. Trends were available for 24 high-income, 4 upper-middle-income and 1 low-income countries [52] (or 25 very high, 3 high and 1 low human development countries) [50], which were from five continents and comprised 30% of the world's population [46]. Trend data were available for 396 country-sex-age groups, with a median sample size of 1,608 (range 75–379,294) across a median span of 24 testing years (range 7–54) (Table 1).

### 3.3 Synthesis of Results

There was a negligible (per decade) international improvement in mean SBJ performance between 1960 and 2017 (change in means per decade [95% CI]: 1.73 cm [1.71–1.75]; 0.99% [0.97–1.01]; 0.07 ES [0.07–0.07]) (Fig. 2), with negligible (per decade) temporal differences between sex and age (i.e., children [9-to 12 year-olds] vs. adolescents [13- to 17-year-olds]) groups. Collectively, the trend in SBJ performance was not uniform over time, with the rate of improvement (per decade) steady from the 1960s through to the 1980s at 0.17 ES (95% CI 0.17–0.17), slowing somewhat to 0.13 ES (95% CI 0.13–0.13) in the 1990s, before declining at − 0.29 ES (95% CI − 0.29 to − 0.29) from 2000 onwards (Fig. 2). This trend was

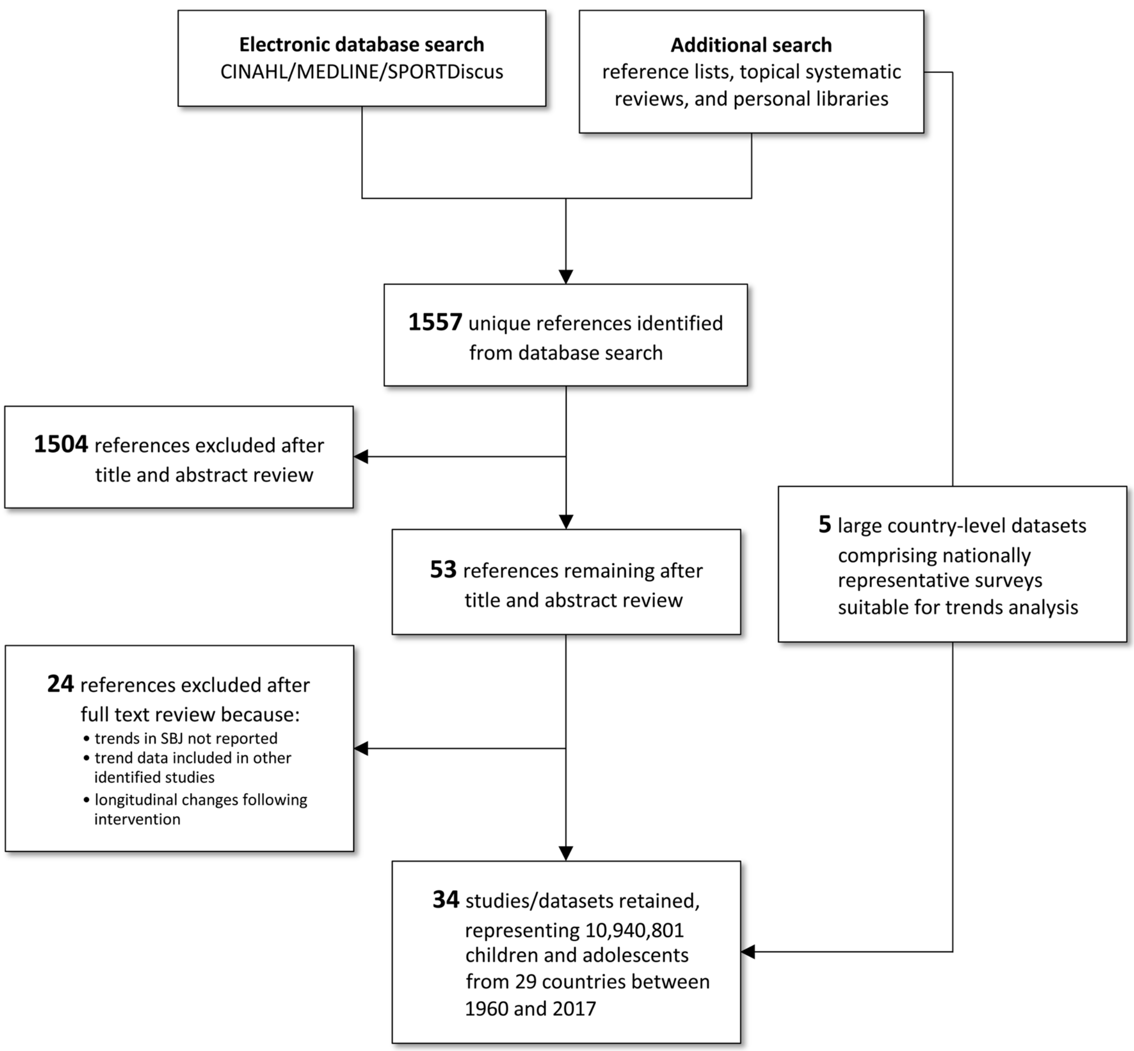


**Fig. 1** PRISMA flow chart outlining the flow of studies through the review. *SBJ* standing broad jump

**Table 1** Summary of the included studies by country

| Country | Sex | Age (years) | Span of years | Sample size | Sampling strategy | Sample base | HDI |
|---|---|---|---|---|---|---|---|
| Australia [29, 30, 53, 54] | F (41.7%)<br>M (58.3%) | 9–17 | 1961–2015 | 45,333 | P/NP | N/S/O | 0.939 (very high) |
| Belgium [43] | F (49.1%)<br>M (50.9%) | 9–17 | 1990–2010 | 20,552 | P/NP | S/O | 0.916 (very high) |
| Bulgaria [55–58] | F (50.8%)<br>M (49.2%) | 9–17 | 1960–1999 | 27,840 | P | N/O | 0.813 (very high) |
| Canada [59] | F (48.1%)<br>M (51.9%) | 9–17 | 1964–1979 | 14,209 | P | N | 0.926 (very high) |
| China [60–66] | F (49.8%)<br>M (50.2%) | 9–17 | 1985–2014 | 1,228,004 | P | N | 0.752 (high) |
| Czech Republic [38, 39, 67–69] | F (48.9%)<br>M (51.1%) | 9–17 | 1923–2002 | 59,767 | P/NP | N/O | 0.888 (very high) |
| Estonia [43] | F (53.8%)<br>M (46.2%) | 11–17 | 1992–2002 | 7711 | P/NP | S/O | 0.871 (very high) |
| Finland [70] | F (49.3%)<br>M (50.7%) | 13–16 | 1976–2001 | 1222 | P | N | 0.920 (very high) |
| France [43] | F (63.2%)<br>M (36.8%) | 9,11–14 | 1984–2008 | 2416 | P/NP | N/O | 0.901 (very high) |
| Germany [40, 43] | F (48.8%)<br>M (51.2%) | 10,13,15,16 | 1975–2009 | 82,478 | P/NP | S/O | 0.936 (very high) |
| Greece [43] | F (48.3%)<br>M (51.7%) | 9–17 | 1990–2014 | 220,331 | P/NP | N/S/O | 0.870 (very high) |
| Iceland [43] | F (48.5%)<br>M (51.5%) | 10–15 | 1985–1998 | 7312 | NP | N/O | 0.935 (very high) |
| Israel [71] | F (53.9%)<br>M (46.1%) | 16–17 | 1970–1984 | 1888 | P | S | 0.903 (very high) |
| Italy [28, 43] | F (46.0%)<br>M (54.0%) | 9–17 | 1981–2011 | 28,758 | P/NP | S/O | 0.880 (very high) |
| Japan [72–122] | F (49.9%)<br>M (50.1%) | 9–17 | 1998–2017 | 460,713 | NP | N | 0.909 (very high) |
| Lithuania [31] | F (51.4%)<br>M (48.6%) | 11–17 | 1992–2012 | 10,839 | P | N | 0.858 (very high) |
| Mozambique [123] | F (9.5%)<br>M (90.5%) | 9–17 | 1999–2012 | 1458 | P | O | 0.437 (low) |
| New Zealand [54, 124] | F (46.1%)<br>M (53.9%) | 9–13 | 1961–2003 | 6453 | P/NP | N/S/O | 0.917 (very high) |
| Poland [32–34, 43, 125] | F (49.1%)<br>M (50.9%) | 9–17 | 1979–2011 | 495,957 | P/NP | N/S/O | 0.865 (very high) |
| Republic of Korea [126–151] | F (49.6%)<br>M (50.4%) | 9–17 | 1966–2009 | 1,803,526 | P | N | 0.903 (very high) |
| Singapore [152] | F (59.3%)<br>M (40.7%) | 12–17 | 1980–1992 | 3398 | P | N | 0.932 (very high) |
| Slovakia [43] | F (46.3%)<br>M (53.7%) | 9–11 | 1993–2015 | 1187 | P/NP | N/S/O | 0.855 (very high) |
| Slovenia [153] | F (50.0%)<br>M (50.0%) | 9–17 | 1987–2012 | 467,306 | P | N | 0.896 (very high) |
| Spain [43] | F (49.7%)<br>M (50.3%) | 9–17 | 1984–2010 | 21,584 | P/NP | S/O | 0.891 (very high) |
| Taiwan [36] | F (48.2%)<br>M (51.8%) | 10–17 | 1997–2013 | 5,857,636 | P | N | 0.907 (very high) |
| Thailand [154] | F (50.8%)<br>M (49.2%) | 9–12 | 1990–2003 | 17,635 | P | N | 0.755 (high) |
| Turkey [155] | F (42.4%)<br>M (57.6%) | 11–12 | 1983–2003 | 403 | NP | O | 0.791 (high) |

**Table 1** (continued)

| Country | Sex | Age (years) | Span of years | Sample size | Sampling strategy | Sample base | HDI |
|---|---|---|---|---|---|---|---|
| UK [37, 43] | F (56.8%)<br>M (43.2%) | 9–13,15,17 | 1981–2014 | 19,708 | P/NP | N/S/O | 0.922 (very high) |
| USA [156–159] | F (48.1%)<br>M (51.9%) | 10–17 | 1911–1985 | 25,177 | P/NP | N/O | 0.924 (very high) |

*UK* United Kingdom, *USA* United States of America, *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), *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 [50]; because the United Nations does not recognize Taiwan as a sovereign state, its HDI was calculated by the Taiwanese Government [160]

broadly consistent across different sex and age groups, with slightly different trends observed for boys and adolescents for whom improvements remained steady for longer (through the 1990s) before shifting to declines after 2000.

While national trends ranged from a moderate (per decade) decline in Greece (– 13.0 cm, – 10.0% or – 0.69 ES per decade between 1990 and 2014) to a small (per decade) improvement in Singapore (4.9 cm, 2.9% or 0.32 ES per decade between 1980 and 1992), the rates of change (per decade) were typically negligible to small (26/29 or 89%) and negative (i.e., declines) (18/29 or 62%), especially from about 2000 onwards (Fig. 3). While most national trends were approximately linear, several countries experienced curvilinear trends evidenced by an increase in the rate of change (e.g., Australia, Poland and Slovenia) or a reversal of the direction of change (e.g., Bulgaria, China, New Zealand and the Republic of Korea). Sex- and age-related temporal differences at the country level were negligible, with country-level trends very strongly related between sexes (*r* [95% CI] 0.88 [0.75–0.94]) and age groups (*r* [95% CI] 0.88 [0.70–0.95]). Country-sex-specific scatterplots of mean SBJ performance are provided in Electronic Supplementary Material Appendix S4. Figure 4 shows the national temporal trends in mean SBJ performance superimposed onto the scatterplots for Chinese boys and girls separately.

Correlations between national trends in SBJ performance and national trends in health-related (i.e., BMI, MVPA and VPA) and socioeconomic/demographic (i.e., Gini index, HDI and urbanization) indicators were negligible to strong in magnitude and failed to reach statistical significance at the 95% level (Table 2).

### 3.4 Additional Analysis

The post-hoc sensitivity analysis, where countries with very large samples ($n$ > 400,000, e.g., China, Japan, Poland, Republic of Korea, Slovenia and Taiwan, which collectively comprised 94% of all data points) (Table 1) were removed, suggested that the international transition from improvements to declines occurred ~10 years earlier (i.e., in the mid-1980s vs. the mid-1990s). Despite this difference in breakpoint timing, the rates of change pre- and post-breakpoint in both the sensitivity and full analyses were similar, indicating that large countries did not meaningfully impact the observed international trend (data not shown).

## 4 Discussion

This study estimated temporal trends in SBJ performance for 10,940,801 children and adolescents from 29 countries between 1960 and 2017. The principal findings were that: (a) there was a negligible (per decade) international improvement observed across the full period for all age and sex groups; (b) the international rate of improvement was steady from the 1960s to the 1980s, slowed in the 1990s, before declining thereafter; (c) while national trends varied, most typically showed declines; and (d) national trends in SBJ performance were not significantly related to national trends in health and socioeconomic/demographic indicators. Our finding of an initial improvement and a recent decline (post-2000) indicates that the functional explosive lower-body strength of today's children and adolescents is better than that of their peers from two generations ago (i.e., in the 1960s), but worse than that of their peers from one generation ago (i.e., in the 1990s). Furthermore, because SBJ has moderate to high construct validity, trends in SBJ performance are suggestive of corresponding trends in general explosive strength [19, 21, 22]. Our trends may be meaningful to public health given the significant cross-sectional and longitudinal relationships between SBJ and health [2, 3]. We also identified a gap in the literature, with available trends in SBJ performance limited almost exclusively to high- and upper-middle-income countries. While considerable progress is needed before SBJ measurement becomes a routine part of population health surveillance globally, the ability to track trends in SBJ performance among children and adolescents highlights the importance of the SBJ as a marker of

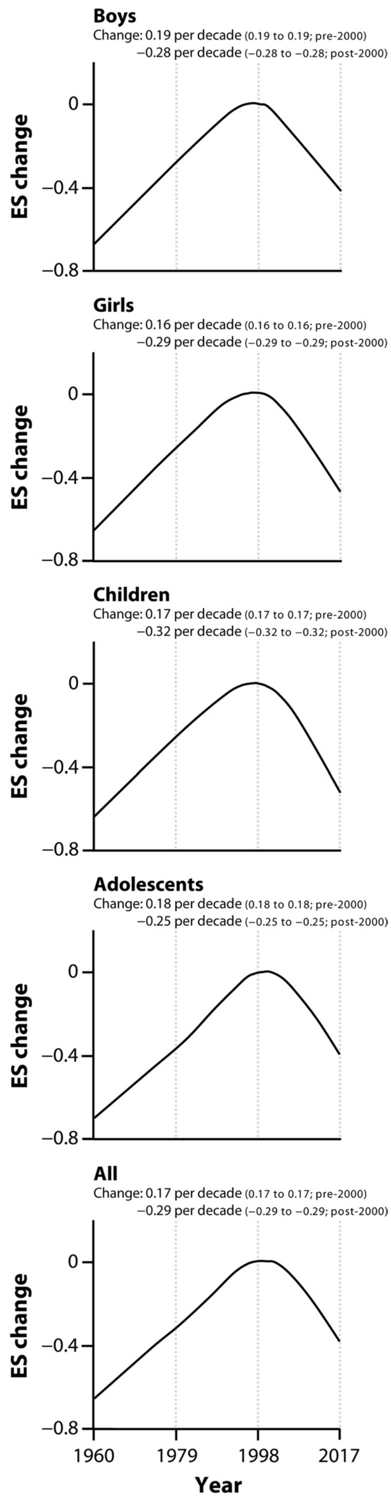


**Fig. 2** International temporal trends in mean SBJ performance for children and adolescents between 1960 and 2017. Data were standardized to the year 2000 = 0, with positive values indicating better SBJ performance and negative values indicating poorer SBJ performance; the solid lines are the LOWESS (LOcally WEighted Scatter-plot Smoother) curves, which represent the international changes in mean SBJ performance, with upward sloping lines indicating improvements in means and downward sloping lines indicating declines in means; mean ES (95% CI) rates of changes (per decade) are shown pre- and post-2000 at the top of each panel. *SBJ* standing broad jump, *ES* effect size

population health and the potential opportunity for low and lower-middle-income countries to engage in a cost effective health surveillance strategy.

### 4.1 Explanation of Main Findings

Temporal trends in SBJ performance are probably influenced by concurrent trends in biological maturation [161, 162], which along with trends in body size, are thought to be influenced by improved standards of living (e.g., improved health, education and income), healthier lifestyles (e.g., improved nutrition and physical activity levels), and more effective disease prevention and treatment [162–164] although it is difficult to estimate the effect of such factors on trends in SBJ performance. To our knowledge, only one study has directly examined temporal trends in SBJ performance while statistically controlling for trends in maturation. Moliner-Urdiales et al. [35] reported declines in SBJ performance for Spanish adolescents between 2001 and 2007 independent of trends in pubertal status, age, fat mass, fat-free mass and parental education level. Although temporal trends in biological maturation have varied over time and between countries, we can estimate the potential impact of advancing maturation on trends in SBJ performance using conservative estimates, 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 [162, 165]. Because older children typically outperform younger children, presumably because of improved physical and neuromuscular maturation, improved SBJ performance would be expected based on maturational advances alone. Cross-sectional data from Tomkinson et al. [43] indicate that SBJ performance improves with each year of age by 5.5% in boys and 2.6% in girls between the ages of 9 and 17 years. Over the 57-year period from 1960 to 2017, improvements of 6.3% for boys (i.e., 5.7 [decades] × 0.2 [years per decade] × 5.5% [age-related change]) and 4.4% for girls (i.e., 5.7 [decades] × 0.3 [years per decade] × 2.6% [age-related change]) would be expected from maturational advances alone. Between 1960 and 2000, SBJ performance improved internationally by 9.6% for boys and 9.2% for girls, which reduces to 5.2% for boys (i.e., 9.6% − [4.0 × 0.2 × 5.5%]) and 6.1% for girls (i.e., 9.2% − [4.0 × 0.3 × 2.6%]) when corrected for trends in biological maturation. These estimates suggest that advances in biological maturation explain a significant proportion of the improved SBJ performance over the period 1960–2000. However, while advances in maturation do not help explain the recent (post-2000) international decline, they do at least suggest that we have underestimated the true magnitude of decline. For example, between 2000 and 2017, improvements of 1.7% (boys) and 1.3% (girls) would be expected from maturational advances alone, yet we found declines of − 5.6% (boys) and − 5.8% (girls), suggesting that

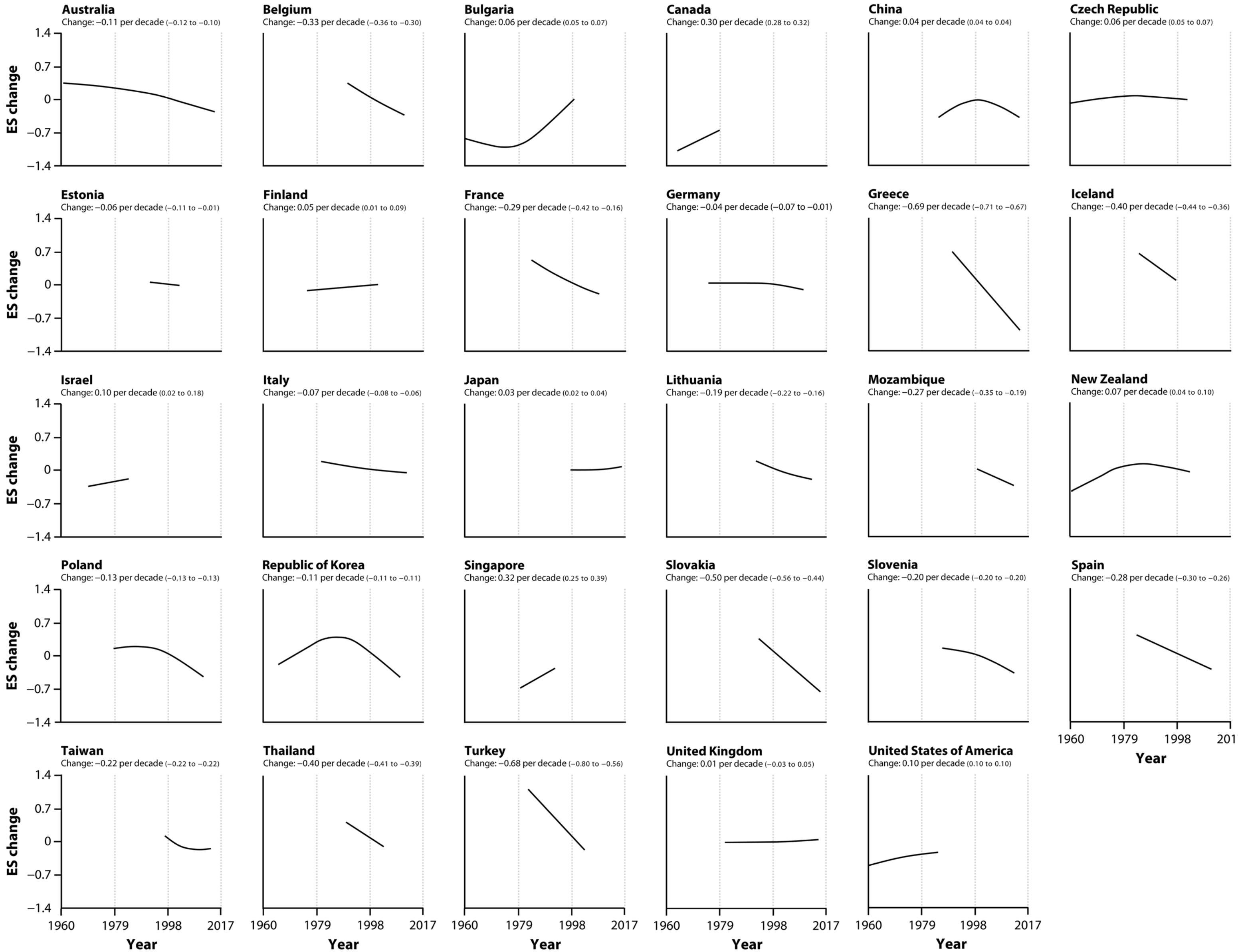


**Fig. 3** National temporal trends in mean SBJ performance for children and adolescents between 1960 and 2017. Data were standardized to the year 2000 = 0, with positive values indicating better SBJ performance and negative values indicating poorer SBJ performance; the solid lines are the LOWESS (LOcally WEighted Scatter-plot Smoother) curves, which represent the national changes in mean SBJ performance, with upward sloping lines indicating improvements in means and downward sloping lines indicating declines in means; mean ES (95% CI) rates of changes (per decade) are shown at the top of each panel. *SBJ* standing broad jump, *ES* effect size

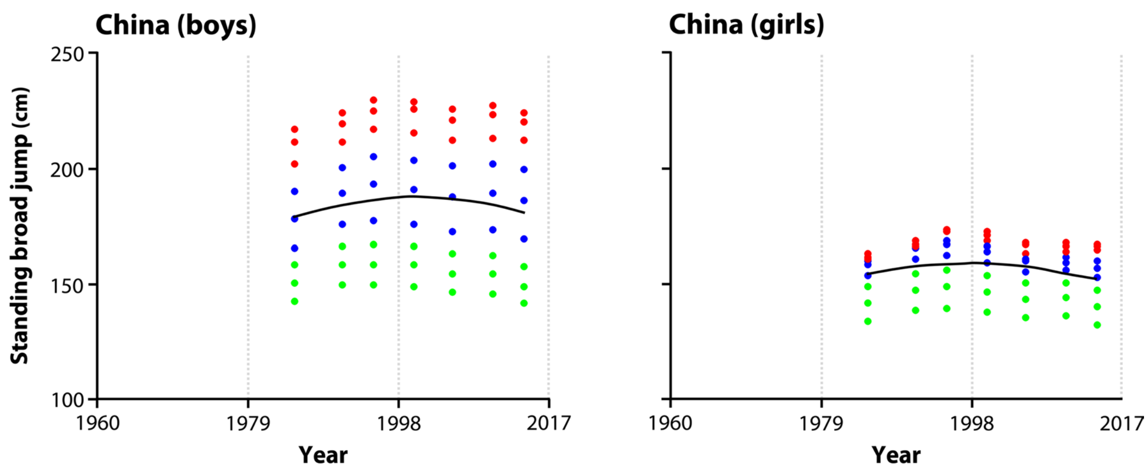


**Fig. 4** National temporal trends in mean SBJ performance for Chinese boys (left) and girls (right) between 1985 and 2014. Each dot represents a single study/dataset-age-year mean, with green dots representing 9-to 11-year-olds, blue dots representing 12-to 14-year-olds and red dots representing 15-to 17-year-olds. Higher values indicate better SBJ performance and lower values indicate poorer SBJ performance; the solid lines are the LOWESS (LOcally WEighted Scatterplot Smoother) curves, which represent the national changes in mean SBJ performance standardized to the year 2000 = the population-weighted mean SBJ performance of 188 cm for boys and 159 cm for girls; upward sloping lines indicate improvements in means and downward sloping lines indicate declines in means

the true underlying declines were potentially − 7.3% (boys) and − 7.1% (girls). Furthermore, it is possible that the relationship between trends in maturation and trends in SBJ performance is mediated by psychosocial factors such as physical self-concept [166]. It could be that earlier maturing girls perceive themselves to be weaker and less competent at sports, resulting in reduced physical activity levels (especially participation in muscle- and bone-strengthening activities) and reduced muscular fitness [167, 168].

Several studies have reported temporal trends in SBJ performance independent of trends in body size, operationalized as (a) height and mass [30, 32, 37], (b) BMI [169], (c) height, mass, and BMI [31] or (d) fat mass and fat-free muscle mass [29, 35]. Other studies, while not directly controlling for trends in body size, have reported concurrent temporal trends in SBJ performance and (a) height and mass [38, 39, 59], (b) BMI [36, 70, 124], (c) height, mass, and BMI [41, 125] and (d) fat mass [123]. International increases in child and adolescent BMI are well established [47], reflecting both increases in fat mass and fat-free muscle mass [170]. Increased fat mass will negatively impact SBJ performance by increasing the force requirement of jumping, while not contributing to it. On the other hand, increased fat-free muscle mass will positively impact SBJ performance through increased maximal force generation capacity of larger exercising muscles [171]. While we found that SBJ performance improved internationally from the 1960s to the 1980s, before slowing in the 1990s and declining thereafter, it is possible that differential trends in fat mass and fat-free muscle mass were involved. For example, the recent decline in SBJ performance might reflect that children and adolescents have become fatter, or less muscular, at the same BMI, suggesting that the detriment of increased fat mass has recently overridden the benefit of increased fat-free muscle mass. Evidence from high-income countries indicates that BMI has stabilized from the mid-1990s onwards [172], whereas skinfold thicknesses have continued to increase, at least until 2003 [170]. However, we did not find a statistically significant relationship between national trends in SBJ performance and national trends in BMI, indicating that trends in other factors are likely also involved.

A recent systematic review of studies with children and adolescents found consistent positive associations between maximal muscular strength/power and objectively measured MVPA, VPA and organized sport participation [20]. Because of the difficulty in obtaining accurate measurements and temporal differences in sampling and methodology, trends in physical activity levels for children and adolescents are lacking. Currently there is no compelling evidence for a recent international decline in physical activity levels or organized sport participation for children and adolescents [48, 173–175]. However, consistent declines in self-reported active transportation (especially cycling, which imposes a greater physiological demand on the lower-body than does walking) have been reported for children and adolescents from high-income and upper-middle-income countries, and may have contributed to the recent decline in SBJ performance [173]. While no study has statistically controlled trends in SBJ for trends in physical activity, several studies have reported a temporal coincidence [37, 70, 169]. We did not find a statistically significant relationship ($r$ [95% CI] 0.51 [− 0.06 to 0.83]) between national trends

**Table 2** Potential health-related and socioeconomic/demographic correlates of trends in SBJ performance for children and adolescents

| Variable | Data source | Description | Correlation (95% CI ) |
|---|---|---|---|
| *Health* | | | |
| Body mass index (BMI) | NCD-RisC [47]<br>Trend data available for 29/29 (100%) countries between 1975 and 2016 | Trends were calculated as the change (per decade) in mean country-level BMI of boys and girls aged 5–19 years (age standardized). With increasing SBJ performance, a positive correlation (next column) indicated an increase in mean BMI and a negative correlation indicated a decline | −0.10 (−0.45 to 0.28) |
| Moderate to vigorous physical activity (MVPA) and vigorous physical activity (VPA) | Inchley et al. [48]<br>Data originally obtained from Health Behaviour in School-aged Children (HBSC) World Health Organization (WHO) collaborative cross-national study. Trend data available for 13 European countries (13/29 or 45% of all countries) between 2002 and 2014 | Trends were 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 min of MVPA everyday or VPA at least four times per week. With increasing SBJ performance, a positive correlation indicated an increase in the mean percentage of moderately to vigorously or vigorously active children and a negative correlation indicated a decline | MVPA<br>0.51 (−0.06 to 0.83)<br>VPA<br>0.27 (−0.33 to 0.71) |
| *Socioeconomic/demographic* | | | |
| Gini index | The World Bank [49]<br>Trend data available for 24/29 (83%) countries between 1979 and 2017 | The Gini index is a measure of the distribution of income across a population. Trends were calculated as the change (per decade) in the distribution of income among individuals in a country where 0 represents perfect equality and 100 implies perfect inequality. With increasing SBJ performance, a positive correlation indicated a trend towards perfect inequality and a negative correlation a trend towards perfect equality | 0.16 (−0.26 to 0.53) |
| Human development index (HDI) | United Nations [50]<br>Trend data available for 25/29 (86%) countries between 1990 and 2017 | The HDI is a composite measure combining country-specific life expectancy, education and per-capita income. Trends were calculated as the change (per decade) in mean country-level human development (i.e., achievements in health, education, and income). With increasing SBJ performance, a positive correlation indicated an increase in the mean human development and a negative correlation indicated a decline | −0.07 (−0.45 to 0.33) |
| Urbanization | The World Bank [51]<br>Trend data available for 28/29 (97%) countries between 1967 and 2017 | Urbanization refers to the population shift from rural to urban areas. Trends were calculated as the change (per decade) in the percentage of people living in urban areas. With increasing SBJ performance, a positive correlation indicated an increase in urbanization and a negative correlation indicated a decline | 0.30 (−0.08 to 0.61) |

in MVPA and national trends in SBJ performance among European countries. Given that muscular fitness is sensitive to changes in physical activity levels [20], and that physical activity guidelines now recommend that muscle- and bone-strengthening activities be performed at least three times per week in childhood and adolescence [14–17], our finding of a recent decline in SBJ suggests that participation in muscle- and bone-strengthening activities requires further encouragement to alter current trends. It is however possible that the recent international decline in SBJ performances reflects a corresponding decline in fundamental movement skills (e.g., jumping skill competency) [176]. Children and adolescents with low levels of explosive strength and/or poor fundamental movement skills may therefore be unable or unwilling to perform activities of daily living proficiently.

### 4.2 Comparisons with Other Studies on Trends in Muscular Fitness

The international trend in SBJ performance (i.e., a steady rate of improvement from the 1960s to the 1980s, which slowed in the 1990s, and shifted to a decline thereafter) is broadly consistent with the international trend for other explosive, weight-bearing fitness measures such as sprinting ability [28]. Our previous study [28] indicated an improvement in mean sprinting ability (i.e., 30–60-m sprint and sprint-agility running) for 28.3 million 6-to 19-year-olds from 26 countries between 1958 and 2003. Internationally, sprinting ability improved from the late 1950s to the mid-1980s, and then stabilized until at least until 2003. In contrast, evidence for trends in muscular strength (e.g., maximal isometric handgrip strength measured using handgrip dynamometry) indicated a different temporal pattern [177]. In our recent systematic analysis of temporal trends in handgrip strength for 2,216,320 children and adolescents (aged 9–17 years) from 19 countries/special administrative regions between 1967 and 2017 [177], we found a negligible (per decade) improvement of 3.8%, or 0.14 ES, with the international rate of improvement progressively increasing over time.

Apart from between-study differences (e.g., in populations, sampling, span of testing years) among the included studies, temporal differences in SBJ performance and handgrip strength may be due to the differential effects of corresponding trends in biological maturation and body size. For example, earlier in the Discussion we reported that SBJ performance improves with each year of age by 5.5% in boys and 2.6% in girls between the ages of 9 and 17 years [43]. The corresponding improvements in handgrip strength for boys and girls are 14.2% and 9.3%, respectively [43]. These data indicate that corresponding advances in maturation appear to benefit handgrip strength more so than SBJ performance. Increased fat-free muscle mass will benefit both SBJ performance and handgrip strength through increased muscular force generation capacity, whereas increased fat mass will harm SBJ performance (by increasing the force requirement) but not handgrip strength (a weight independent strength task). In addition, if skill contributes more to SBJ performance than it does to handgrip strength performance, then the observed temporal differences might be influenced by corresponding trends in fundamental movement skills [176].

### 4.3 Strengths and Limitations

This study currently represents the most comprehensive synthesis of national and international temporal trends in SBJ performance for children and adolescents. We estimated trends in SBJ performance, which is a feasible, ecologically valid and scalable measure of functional explosive strength [18, 19] that is significantly related to current and future health [2, 3]. It used a novel analytical approach—a method by which data from different sources are pieced together to create an overall temporal picture using analytical techniques beyond those used in a typical meta-analysis—that has been previously used in other studies on temporal trends in fitness for children and adolescents [26, 28]. The sample-weighted regression and post-stratification population weighting procedures adjusted our trends for sampling bias by incorporating the underlying population demographics, and our stratified trends analysis enabled us to assess and control for potential confounding factors (e.g., age, sex and country).

This study is not without limitations. First, because trends in SBJ performance were estimated from summary statistics rather than raw data, and because corresponding descriptive data were (almost) never reported for potential mechanistic factors (e.g., biological maturation, body size, physical activity levels), we were unable to statistically remove the effects of trends in such factors. Second, our trends in SBJ performance are almost exclusively representative of high- and upper-middle-income countries (28/29 or 97%), which restricts generalizability to low-income and lower-middle-income countries. Third, we have low confidence in our correlations (Table 2) because: (a) of the small number of included countries (e.g., we were limited to only 13 European countries when examining relationships between trends in SBJ performance and trends in MVPA/VPA); (b) the homogeneity in the available trends between countries; (c) the mismatch in the time span over which trends in SBJ performance were calculated versus the time span over which the trends in health-related and socioeconomic/demographic indicators were calculated; and (d) the potential for ecological fallacy. Fourth, while differences in SBJ testing protocols (e.g., number of trials, practice, levels of encouragement, motivation, test instructions, diurnal variation) will affect the variability of SBJ results, such differences are unlikely to have biased our trends because all within-study/dataset trends used matched protocols. Fifth, while many studies/datasets used exclusively probability sampling, few exclusively used nationally representative data. Nonetheless, we included studies/datasets that estimated trends using state/provincial-, city-, and/or community-level data as they provided the best available estimate of national trends in those countries. Moreover, we did not formally assess the risk of bias in individual studies because the mix of study designs and publication types (e.g., studies primarily reporting trends, studies primarily reporting other outcomes but including descriptive data suitable for trends analysis, and large nationally representative datasets suitable for trends analysis) prevented the use a single assessment tool. Finally, our trends in mean SBJ performance could be systematically biased if concurrent trends in skewness occurred, although this is unlikely given evidence of uniform trends across the distribution [29, 70].

## 5 Conclusion

This study found a negligible (per decade) international improvement in SBJ performance for all age and sex groups since 1960, with the rate of improvement steady from the 1960s to the 1980s, slowing in the 1990s, before declining thereafter. Trends in SBJ performance varied between countries, with most countries experiencing declines, with national trends not significantly related to national trends in health and socioeconomic/demographic indicators. This study also identified a gap in the literature for low-income and lower-middle-income countries. The growing recognition of the importance of muscular fitness as a marker of population health highlights the need for continued tracking of temporal trends in muscular fitness to help evaluate the effectiveness of healthy public policies and interventions, and to potentially predict future trends. Future research on temporal trends in SBJ performance should aim to: (a) report trends as absolute, percent and standardized changes in means at the sex-age level; (b) statistically adjust for trends in mechanistic factors (e.g., body size, sexual maturation, physical activity levels, fundamental movement skill competency); and (c) report complementary trends in measures of variability (e.g., SDs, coefficients of variation) and/or asymmetry (e.g., skewness).

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## Declarations

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**Ethics approval** Not applicable.

**Consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Availability of data and materials** The datasets analyzed in this review are available from the corresponding author upon reasonable request.

**Code availability** Not applicable.

**Author contributions** GRT developed the research question and designed the study. GRT, TK and FLD designed the systematic review strategy, had full access to the data, and take responsibility for the integrity of the data. GRT led the statistical analysis, synthesis of results and drafted the initial manuscript. All authors contributed to the interpretation of results, editing and critical reviewing of the final manuscript, approved the final manuscript as submitted, and agreed to be accountable for all aspects of the work.

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