Title	Temporal changes in long-distance running performance of Asian children between 1964 and 2009
Author(s)	Tomkinson, GR; Macfarlane, D; Noi, S; Kim, DY; Wang, Z; Hong, R
Citation	Sports Medicine, 2012, v. 42 n. 4, p. 267-279
Issued Date	2012
URL	http://hdl.handle.net/10722/176078
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Title

Temporal changes in long-distance running performance of Asian children between 1964 and 2009.

Authors' name

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Running title

Temporal changes in Asian children's long-distance running performance.

Word count

3889.

Acknowledgements

None. There are no funding provided for the preparation of the paper; there are no relevant conflicts of interest for all authors; and there are no other persons who made substantial contributions to the work, but who do not meet the criteria for authorship.

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Figure 2. Temporal patterns of change in long-distance running performance of 23,897,571 Asian children aged 9–17 years between 1964 and 2009. Temporal patterns of change are shown at the regional (Asia) and national level [China (Mainland and Hong Kong), Japan, Republic of Korea, and Singapore] for all children and for children separated by sex (boys and girls) and age (9–12 and 13–17 years). Mean percent changes (per decade) and the corresponding 95% confidence intervals are also shown. Data are standardised to the year 2000 =100%, with higher values (>100%) indicating better running performance.

Figure 3. Temporal patterns of change in Asian children for: (a) percent body fat; (b) prevalence of overweight and obese; and (c, d and e) body mass index (BMI) and long-distance running performance. Percent body fat data (median values estimated using the Slaughter[40] equations which use the triceps and subscapular skinfolds as regression inputs) are from Olds[35] and represent 5,491 children aged 9–15 years from China (Hong Kong) and Japan between 1958 and 1996. The prevalence of overweight and obesity data [estimated using >120% of the median (Hong Kong) or mean (Japan) of BMI values] are from Student Health Service (Department of Health, Government of the Hong Kong Special Administrative Region, data on file, 1995–2009) and National Network of Physical and Mental Health in Japanese Children[41] and represent >3.5 million children aged 9–17 years from China (Hong Kong) and Japan between 1977 and 2009. The BMI data are from all but one of the studies included in this review[15,20–25] and represent 27,124,047 children aged 9–17 years from China (Mainland and Hong Kong), Japan and the Republic of Korea between 1964 and 2009. BMI

and long-distance running performance data are standardised to the year 2000 =100%, with higher values (>100%) indicating higher BMI or better running performance.

Figure 4. Temporal patterns of change in: (1) long-duration exercise performance for (a) Asian children and (b) children from other parts of the world; and (2) short-duration exercise performance [as indicated by (c) jumping performance and (d) sprint/agility running performance] for Asian children. The 'rest of world' data, which indicate changes in long-distance and endurance shuttle running performance, are from Armstrong et al.[34] and represent 1,156,091 children aged 9–17 years from 24 countries (including Africa, Australasia, Europe, the Middle East and North America) between 1964 and 2008. The short-duration exercise performance data are from Tomkinson[16] and represent 43,679,018 children aged 9–17 years from five Asian countries [China (Mainland), Japan, Republic of Korea, Singapore, and Thailand] between 1964 and 2002. Data are standardised to the year 2000 =100%, with higher values (>100%) indicating better exercise performance.

Abstract

Aerobic fitness is considered to be an important marker of current health and even a predictor of future health. The aim of this study was to systematically analyse the available scientific information on temporal changes in maximal long-distance running performance (a widely and long used marker of aerobic fitness) of Asian children. A systematic review of the scientific literature was undertaken to locate studies explicitly reporting on temporal changes (spanning a minimum of 5 years) in maximal long-distance running of apparently healthy (free from known disease or injury) Asian children aged 9–17 years. Studies were located up to October 2010 via computerised searching of bibliographic databases, reference list searching, and personal communication with international experts. Temporal changes were analysed at the country by sex by age by test level using best-fitting linear or polynomial regression models relating the year of testing to long-distance running performances expressed as average running speeds. Changes in means were expressed as percent changes and as standardised effect sizes. Eight studies reporting temporal changes in long-distance running performance of 23,897,571 children aged 9–17 years from four Asian countries over the period 1964–2009 were included. Overall, there was a large decline in long-distance running performance equivalent to –16.6 ±1.3% (mean change ±95% confidence interval) or –1.2 ±0.1 standard deviations. Temporal changes were generally consistent for different sex and age groups, but not for different countries, with large declines observed for children from China and the Republic of Korea, small declines for children from Japan, and very small declines for children from Singapore. There is overwhelming evidence of meaningful declines in maximal long-distance running performance of Asian children in recent decades, which are probably caused by a network of social, behavioural, physical, psychosocial and physiological factors. These declines highlight the need for regular surveillance of Asian children's health-related fitness and proactive public health strategies.

Background

Aerobic fitness is strongly and independently associated with cardiovascular and all-cause disease mortality and morbidity in adults, as well as a range of cardiovascular disease risk factors and co-morbidities.[1,2] A recent meta-analysis by Kodama et al.[3] reported that for every one metabolic equivalent (3.5 $ml.kg^{-1}.min^{-1}$) decrease in aerobic fitness there was a increase in all-cause and cardiovascular disease mortality of 13% and 15%, respectively. There are also meaningful associations between aerobic fitness and cardiovascular disease risk factors, total and abdominal adiposity, cancer and mental health (e.g. depression, anxiety, self-esteem and academic performance) in children.[4] Furthermore, both aerobic fitness and cardiovascular disease risk factors track moderately well from childhood into adulthood.[5–8] This evidence provides strong support for why aerobic fitness is now considered to be a powerful marker of current health and even a predictor of future health.

Peak oxygen uptake (peak VO_2) is currently the best single measure of children's aerobic fitness.[9] While few data are available to allow examination of temporal changes in peak VO_2 of Asian children, the two studies that have directly examined such changes show conflicting results. Using mass-specific peak VO_2 data ($ml.kg^{-1}.min^{-1}$) from direct gas analysis of Japanese 10–12 year olds tested in 1969 and 1979, Miyashita and Sadamoto[10] reported declines of −11.8 ±3.4% per decade (mean change ±95% confidence interval). In contrast, Lin et al.[7], also using gas analysis, reported improvements in mass-specific peak VO_2 of 7.6 ±0.6% per decade in 11–17 year old Chinese boys between 1962 and 1994. Unfortunately, our understanding of these reported changes in peak VO_2 is confounded by data acquired using different ergometers (e.g. cycle, treadmill), and on relatively small, volunteer samples of Asian children who might have been athletically inclined.

Compared to criterion laboratory-based peak VO_2 testing, properly conducted maximal field-based long-distance running tests offer a simple, feasible, and practical alternative, and have been shown to demonstrate high test-retest reliability and moderate-to-high validity in children.[12–14] Fortunately, validated field-based long-distance running tests have long been administered to Asian children, with a number of Asian countries collecting and publishing representative data that are well-suited to temporal analysis, with the most extensive databases being those of the Japanese and Korean Ministries of Education, which include annual data dating back several decades.[15] The aim of this study therefore, was to systematically analyse the published literature in order to quantify temporal changes in maximal long-distance running performance (a widely and long used marker of aerobic fitness) of Asian children. These temporal changes should provide (a) worthwhile insight into temporal changes in health and well-being; (b) a better understanding of the possible underlying causal mechanisms; and (c) a regional context from which temporal changes at the national and local level can be compared.

Methods

Search strategy

A systematic review of the scientific literature was undertaken to locate studies explicitly reporting on temporal changes in maximal long-distance running performance of Asian children. Candidate studies were searched for in October 2010 using a computerised bibliographic database search [Cumulative Index to Nursing and Allied Health Literature (CINAHL; 1981–), Education Resources Information Center (ERIC; 1966–), Medline (1948–), PubMed (1948–) and SPORTDiscus (1975–)]. The search string used for the computer search was: ((children) OR adolescen*) AND ((((fitness*) OR aerobic*) OR cardiovascular*) OR cardiorespiratory) AND (((trend*) OR secular) OR temporal). All titles and abstracts (when available) were assessed to identify eligible articles. If there was doubt as to an article's eligibility, or the abstract was not available, the full text paper was retrieved. Email contact was also made with numerous international pediatric exercise scientists to ask whether they knew of any appropriate studies.

Inclusion criteria

Studies were included if they explicitly reported on temporal changes (spanning a minimum of 5 years) in maximal long-distance running performance of apparently healthy (free from known disease or injury) 9–17 year olds from Asia, or if they published data from which changes could be calculated. Only studies reporting changes in means (or those publishing data allowing changes in means to be calculated) for Asian children, from population-representative surveys of children, were included. Studies were excluded if they reported changes that were published in another identified study. The reference lists of all included studies were examined and cross-referenced to try to identify additional studies. If further clarification of study details or additional data were required prior to study inclusion, then an email request was sent to the corresponding author.

Initial data analysis

Prior to calculating temporal changes, all data were initially analysed using a modification of the procedures described by Tomkinson[16]. The following descriptive data were extracted from each included study: country, sex, age, sample size, mean, standard deviation, years of testing, and ergometer/test used. All distance running performances were expressed as average running speeds in $m.s^{-1}$ because mass-related VO_2 varies linearly with running speed, and therefore running speed should appropriately reflect VO_2 (i.e. the underlying oxygen cost required to complete the distance run).[14,17,18] When standard deviations were unavailable, they were estimated by multiplying the reported mean value by the sex by age by test-specific pooled coefficient of variation, which was calculated by pooling coefficients of variation generated from means and standard deviations reported in all other studies within the same sex by age by test group. Age was expressed in whole years as the age at last birthday.

Statistical analysis

All temporal changes were analysed at the country by sex by age by test level (e.g. changes for Korean boys aged 12 years tested on the 1,200 m run) using best-fitting unweighted linear or polynomial regression models relating the year of testing to running speed. Linear models were used when data were available for only two time points, with best-fitting (and most parsimonious) linear or polynomial (quadratic or cubic) models used when data were available for three or more time points. Changes in means were expressed as percent changes and as standardised effect sizes. Percent changes (% per year) were calculated as the slope of the regression line expressed as a percentage of the overall mean value (taken as the mean of all of the mean running speed values used in the regression). (Note, a series of slopes on the polynomial curves were calculated by differentiation for every included year of testing). Standardised effect sizes (SDs per year) were calculated as the slope of the regression line divided by the pooled standard deviation. The pooled standard deviation was calculated by first determining the pooled coefficient of variation, which was calculated from coefficients of variation generated from all of the mean running speed values (plus their corresponding standard deviations) used in the regression; and second, by converting the pooled coefficient of variation to a standard deviation by multiplying it by the overall mean value. Effect sizes of 0.2, 0.5 and 0.8 were used as thresholds for small, moderate and large.[19] Positive changes indicated increases (or improvements) in mean running speed and negative changes indicated declines in mean running speed.

A modification of the procedure described by Tomkinson[16] was then used to describe the temporal patterns of change. By starting with the earliest year (Y_1) covered by any study by country by sex by age by test group, every group including Y_1 in its span of testing years was located, with every change (% per year and SDs per year) recorded. This process was applied to all years for which change data were available (Y_1 ... Y_n), yielding a series of yearly changes. Mean changes were calculated for all children, and for children split by sex, age, and country, and were expressed as a rate of change per decade by averaging all yearly changes and multiplying the average by 10. The ninety five percent confidence interval (95%CI) for a mean change was calculated as the mean change ±1.96 multiplied by the standard error of change multiplied by 10. The standard error of change was calculated as the standard deviation of the yearly changes divided by the square root of the number of changes. Best-fitting unweighted linear or polynomial regression models relating the year of testing to the yearly changes were then calculated for all children, and for children split by sex, age, and country, in order to estimate the temporal patterns of change for different groups. These temporal patterns of change were graphically illustrated using the iterative procedure described by Tomkinson.[16]

Results

Table 1 summarises the eight included studies or datatsets. Of these, two were identified through bibliographic database searching and personal communication with international colleagues, and six were identified through reference list searching. Email contact was made with the corresponding authors of four studies in order to clarify study details or to request additional data, with all contacted authors satisfactorily responding to the email requests (Figure 1).

<<< Insert Table 1 and Figure 1 about here >>>

Long-distance running performances were available for 23,897,571 children aged 9–17 years from four Asian countries [China (Mainland and Hong Kong), Japan, Republic of Korea, and Singapore] between 1964 and 2009. A total of 108 country by sex by age by test groups (57 for boys and for 51 girls; 33 for 9–12 year olds and 75 for 13–17 year olds) were derived, with a median sample size of 25,109 (range: 132 to 2,757,289) and a median span of testing years of 17 (range: 6 to 45). Data were collected using distance running (600–2,400 m) and timed running (9 min) tests.

Temporal patterns of change in long-distance running performance of Asian children are shown in Figure 2 with mean percent changes shown. Examination of the bottom-right panel in Figure 2 shows that long-distance running performance improved at the regional level from the mid-1960s to the mid-1970s and declined thereafter, although it is important to note that change data at the regional level prior to 1980 represent only changes in children from Japan and the Republic of Korea. Overall, there was a large decline in long-distance running performance of Asian children between 1964 and 2009 (mean change ±95%CI: –16.56 ±1.33% or –1.21 ±0.10SDs); with small improvements in the 1960s (5.48 ±4.03% or 0.44 ±0.31SDs); very small improvements in the 1970s (0.73 ±2.20% or 0.07 ±0.16SDs); small declines in the 1980s (–4.03 ±1.58% or –0.28 ±0.13SDs) and 1990s (–6.69 ±2.35% or –0.43 ±0.16SDs); and moderate declines in the 2000s (–7.07 ±2.94% or –0.56 ±0.22SDs).

<<< Insert Figure 2 >>>

Temporal patterns of change were generally consistent for different sex and age groups, both at the regional and national level. Examination of the bottom row in Figure 2 shows that at the regional level, long-distance running performance consistently declined from about 1975 for all sex and age groups. Overall, there were large declines for boys (–19.32 ±1.87% or –1.42 ±0.14SDs), girls (–13.78 ±1.89% or –0.99 ±0.14SDs), younger children (9–12 years: –24.99

±3.36% or –1.74 ±0.24SDs), and older children (13–17 years: –14.36 ±1.35% or –1.05 ±0.10SDs). Temporal patterns of change for different sex and age groups were also broadly similar at the national level, with small differences in rates of change between boys and girls (median difference: 2.17% or 0.20SDs) and younger and older children (4.79% or 0.40SDs). However, despite large differences in data coverage, the most striking feature of Figure 2 is the substantial differences in temporal patterns of change at the national level. Examination of the first four rows in Figure 2 shows that there were large declines in long-distance running performance for children from the Republic of Korea (–32.87 ±1.92% or –2.22 ±0.14SDs between 1971 and 2009) and China (–11.30 ±1.12% or –0.97 ±0.08SDs between 1985 and 2006), small declines for children from Japan (–5.46 ±1.26% or –0.45 ±0.11SDs between 1964 and 2009), and very small declines for children from Singapore (–0.86 ±0.80% or –0.10 ±0.08Ds between 1980 and 1992).

Discussion

This study provides overwhelming evidence of meaningful declines in maximal long-distance running performance of Asian children over recent decades. It is probable that declines in long-distance running performance have been caused by a network of social, behavioural, physical, psychosocial and physiological factors.[27] Proximate causes of declines in long-distance running performance are a function of declines in physiological factors or various aspects of aerobic fitness such as peak VO_2, mechanical efficiency and fractional utilisation.[28–30] For example, a decline in mass-specific peak VO_2 will impair long-distance running performance because peak VO_2 limits the rate at which oxygen can be provided; a decline in mechanical efficiency will change the running speed-VO_2 relationship, and increase the oxygen cost for any given running speed; and a decline in fractional utilisation will mean that only a reduced exercise intensity can be maintained for any given length of running time.

Furthermore, a decline in affective (e.g. degree of motivation) and/or cognitive (e.g. ability to judge pace) aspects of long-distance running performance may also be important.[31] Unfortunately, there is no compelling evidence to suggest that there have been temporal declines in these physiological or psychosocial factors. There have been two small studies that have directly examined temporal changes in mass-specific peak VO_2 of Asian children, which collectively indicate very small changes over the period 1962–1994, equivalent to 0.12 ±0.11% or 0.01 ±0.01SDs per decade.[10,11] On the other hand, declines in long-distance running performance are suggestive of declines in underlying aspects of aerobic fitness because a moderate-to-large (35–60%) proportion of the variability in long-distance running performances over 600–2400 m can be explained by mass-specific peak VO_2.[13,14] In addition, different long-distance running tests impose different physiological and psychosocial demands. For example, factors such as VO_2 kinetics and anaerobic capacity will be relatively more important for tests requiring children to run over shorter distances—although the effect will be very small over distances of more than several hundred metres[32]—and peak VO_2 will be relatively more important for tests requiring children to run over longer distances.[14]

Physiological changes are in turn affected by physical changes such as increases in fat mass, declines in muscle mass, as well as declines in levels of regular moderate-to-vigorous physical activity (MVPA), which may ultimately lead to declines in cardiovascular function.[27,33,34] Despite the fact that there are insufficient data available to examine temporal changes in cardiovascular function, there is convincing evidence of worldwide increases in the fat mass of children in recent decades.[35–37] Using data from indirect measures of fat mass [percent body fat, prevalence of overweight and obesity, and body mass index (BMI)] collected since the late 1950s, Figure 3 shows that fat mass has also increased over time in

Asian children. The rates of increase in these indirect measures of fat mass in Asian children are greater than or equal to those observed in children from other parts of the world. For example, percent body fat has increased in Chinese (Hong Kong) and Japanese children at about 1.5% points per decade between 1958 and 1996, which is somewhat greater that the increase of 0.7% points per decade for the same time-period in children from 27 different African, Australasian, European, Middle Eastern, and Central, North and South American countries.[35] Interestingly, these temporal increases in fat mass (crudely operationalised as BMI) have coincided with declines in long-distance running performance (Figure 3, panels c-e). While the temporal coincidence of these patterns is potentially circumstantial, it does at least suggest that there is a strong association, because as fat mass starts to increase, long-distance running performance starts to decline. Increases in fat mass could lead to declines in long-distance running performance either directly through the increased energy demand associated with moving a heavier body mass through space or indirectly through the likely affect of reducing regular MVPA.[33,34,38] The causal connection between increases in fat mass and declines in long-distance running performance has been examined directly in Australian and New Zealand children, with increases in fat mass explaining 35–70% of the declines in long-distance running performance.[31,39] (Note, see Tomkinson and Olds[27] and Tomkinson et al.[33] for a discussion of the broad social and behavioural changes that probably underlie increases in fat mass). Therefore, while changes in fat mass account for a moderate to large proportion of the changes in long-distance running performance, other factors such as lower levels of physical activity or reduced experience with MVPA must also play a role.[27]

<<< Insert Figure 3 about here >>>

A recent review of international studies examining temporal changes in self-report and objective measures of physical activity in children suggest that physical activity levels have not changed substantially in recent decades.[42] Self-report data from Hong Kong suggest that the prevalence of extracurricular sports participation declined between 1995 and 2000 in boys and girls by 1.7% and 0.6% per year, respectively.[43] It is however possible that children's physical activity levels have declined in domains not accurately assessed by self-reported measures or by objective measures that do not fully quantify the intensity of movement (e.g. pedometers).[42] In addition, there is some Japanese evidence that suggests that children have been less exposed to maximal sustained efforts in school physical education over recent decades. In Japan, school physical education has changed almost every decade since the Second World War, with 'systematic exercise' emphasised in the 1960s, 'physical fitness' in the 1970s, 'play' in the 1980s and 'fun' in the 1990s.[44] These curriculum changes have coincided with changes in Japanese children's long-distance running performance which improved in the 1960s, plateaued in the 1970s, and declined in the 1980s and 1990s (Figure 2). Irrespective of the mechanistic factors, it is the decline in Asian children's ability to perform prolonged and exhaustive aerobic activities—the ability to run faster, play harder and keep moving longer—that has the greatest implications for health, well-being, physical activity levels and successful sports participation.

Temporal comparisons: long-duration vs. short-duration exercise and Asia vs. the rest of the world

Figure 4 shows temporal comparisons in long-duration exercise performance between Asian children and children from other parts of the world, and between long- and short-duration exercise performance of Asian children. Comparative data were taken from Armstrong et al.[34] (representing 1,156,091 long-distance and endurance shuttle running performance results of 9–17 year olds from 24 non-Asian countries between 1964 and 2008) and Tomkinson[16] [representing 43,679,018 jumping and short-distance sprint/agility running results of 9–17 year olds from China (Mainland), Japan, Republic of Korea, Singapore, and

Thailand between 1964 and 2002]. Examination of Figure 4 (panels a and b) suggests that there has been a similar pattern of change in long-duration exercise performance for Asian children and children from other parts of the world, at least from the mid-1960s to about 2000, where long-duration exercise performance initially improved across the world, followed by a decline from about 1975. However, while long-duration exercise performance has continued to decline in Asian children since 2000, it appears to have stabilised or improved slightly in children from other parts of the world. This could be in part due to recent changes in fat mass (as evidenced by changes in the prevalence of overweight and obesity), which appear to have plateaued since 2000 in several countries, including Australia,[45] France,[46,47] New Zealand,[48] Sweden,[49] and the United States[50], yet still continue to increase in most Asian countries (Figure 3).

<<< Insert Figure 4 about here >>>

Figure 4 also suggests that there has been a different pattern of change in Asian children's ability to perform long-duration (panel a) and short-duration exercise (panels c and d). Jumping and short-distance sprint/agility running performance of Asian children improved from the mid-1960s to the mid-1980s and declined slightly thereafter, with average improvements of 2.4% and 0.4% per decade across the 1964–2002 period respectively. This is in contrast to the large decline of –3.7% per decade in long-distance running performance across the 1964–2009 period. While the underlying reasons for these temporal differences are not clear, it may be that changes in body composition, which effect the balance between energy demand and energy supply, have differential effects on changes in long- and short-duration exercise performance (see Tomkinson[16] for a more detailed discussion).

Strengths and limitations

This study brings together long-distance running performances on over 23 million 9–17 year old Asians who were tested over the period 1964–2009. Although it is not the first comprehensive study of temporal changes in Asian children's long-distance running performances, it does update the comprehensive study of Macfarlane and Tomkinson[15] by (a) extending the end of the temporal picture from 2002 to 2009, (b) reporting changes as percent changes and standardised effect sizes, and (c) reporting temporal changes as changes in running speed, which should better reflect changes in underlying oxygen cost.[14,17,18] It also reports changes in population-representative children from four Asian countries, and uses a statistical approach that allows the temporal patterns of change to be described for all children, and for different sex and age groups, at both the regional and national level.

Although this study is limited to studies that reported on temporal changes in Asian children's long-distance running performance, it would have been more complete if it included every report on Asian children's long-distance running performance, even those reporting data collected at a single point in time. Unfortunately, the long-distance running data may not have always been collected under precisely the same conditions, and temporal changes in sampling methods, testing conditions (e.g. environmental conditions, practice and running surfaces) and measurement errors (e.g. calibration and type of equipment, methodological drift and diurnal variation) might have occurred, although the inclusion of only large, randomised national survey data would have minimised sampling- and methodology-related issues. Nonetheless, without evidence of systematic temporal changes in these factors, the results of this study should not be biased, although our confidence in them will be reduced. This study was also limited to temporal changes in mean values, which will be systematically biased if there were concomitant changes in skew. Changes in medians were not examined because median values were rarely reported. While there is no evidence of temporal changes in skew in long-distance running performance of Asian children, international studies typically report temporal shifts in skew towards the poorer performing end of the distribution.[51,52] However, it appears that changes in skew are attenuated when changes are expressed in running speed as opposed to running time or distance,[53] probably because running speed is typically more normally distributed and therefore more amenable to parametric statistical analysis. Furthermore, temporal changes in long-distance running performance will be affected by concurrent changes in biological maturation, which would generally favour children of the same chronological age in the more recent surveys and thus somewhat underestimate the true temporal declines.[33] Finally, the broad data coverage of the large Japanese and Korean datasets meant that temporal changes at the regional level were largely driven by (especially in the early decades) data from these two countries, and not by data from China and Singapore for which the temporal picture was less complete. In addition, the reported changes reflect only changes in four Asian countries, representing high- and middle-income economies,[54] and it is unknown whether similar patterns of change are found in other Asian countries whose lower-income economies are still developing.

Conclusion

This study provides strong evidence for meaningful declines in maximal long-distance running performance of Asian children in recent decades. It is probable that a network of social, behavioural, physical, psychosocial and physiological factors has been responsible. Irrespective of the underlying mechanistic factors, it is the decline in Asian children's ability to perform prolonged and exhaustive aerobic activities that has the greatest implications for health, well-being, physical activity levels and successful sports participation. The results of this study highlight the need for regular surveillance of Asian children's health-related fitness and proactive public health strategies.

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Table 1. Summary of the included studies that have used stratified and random representative samples of the host countries' school population.

	Country	Years	Sex	Ages (y)	*n*	Test(s): running distance or duration	Sample information	Sampling method
Macfarlane and Tomkinson[15] + Research Team of Students' Physical Fitness and Health in China[20]	China (Mainland)	1985–2005	M, F	13–17	501,591	800 m, 1000 m	National surveys (*n* = 5)	School-based; stratified, random.
Macfarlane and Tomkinson[15] + Education Bureau, Government of the Hong Kong Special Administrative Region [21]	China (Hong Kong)	1999–2006	M, F	9–17	21,704	9 min	National surveys (*n* = 6)	School-based; stratified, random.
Ministry of Education, Culture, Sports, Science and Technology[22]	Japan	1964–2009	M, F	12–17	545,670	1000 m, 1500 m	National surveys (*n* = 45)	School-based; stratified, random.
Tomkinson et al. [23] + Ministry of Culture and Tourism[24] + Ministry of Education, Health, Recreation and Dance[25]	Republic of Korea	1971–2009	M, F	9–17	22,824,180	600 m, 800 m, 1000 m, 1200 m, 1600 m	National surveys (*n* = 37)	School-based; stratified, random.
Quek et al.[26]	Singapore	1980–1992	M, F	12–17	3,398	2400 m	National surveys (*n* = 2)	School-based; random.

Shown is the country, reported span of testing years, sex (F = female, M = male), ages, total sample size, running test used, sample information and sampling method. Note, the ages and sample sizes shown in this table may differ to those reported in the study itself, as the data here have been restricted to the 9–17 year olds.

Table 2. Mean changes (per decade) in aerobic performance-fitness of 9–17 year olds (n = 24,090,119) from Asia between 1964 and 2009.

	Percent change per decade ±95%CI						**Effect size per decade ±95%CI**					
	1960s	**1970s**	**1980s**	**1990s**	**2000s**	**1964–2009**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**1964–2009**
Sex												
Boys	3.12 ±0.24	–0.30 ±0.42	–4.74 ±0.32	–6.72 ±0.03	–3.78 ±0.51	–3.93 ±0.43	0.30 ±0.03	–0.01 ±0.03	–0.35 ±0.02	–0.51 ±0.01	–0.28 ±0.04	–0.29 ±0.03
Girls	7.97 ±0.65	1.61 ±0.60	–3.49 ±0.30	–5.47 ±0.06	–5.22 ±0.10	–2.64 ±0.57	0.61 ±0.05	0.13 ±0.04	–0.23 ±0.02	–0.40 ±0.01	–0.41 ±0.01	–0.19 ±0.04
Ages (y)												
9–12	6.36 ±0.30	1.48 ±0.65	–5.79 ±0.55	–9.35 ±0.06	–5.07 ±0.77	–4.67 ±0.73	0.49 ±0.04	0.06 ±0.05	–0.39 ±0.03	–0.61 ±0.01	–0.41 ±0.04	–0.32 ±0.05
13–17	5.46 ±0.53	0.30 ±0.48	–3.74 ±0.23	–5.10 ±0.02	–4.29 ±0.15	–2.92 ±0.43	0.45 ±0.04	0.06 ±0.04	–0.27 ±0.02	–0.40 ±0.01	–0.32 ±0.02	–0.21 ±0.04
All	**5.62 ±0.46**	**0.66 ±0.51**	**–4.13 ±0.31**	**–6.11 ±0.04**	**–4.50 ±0.30**	**–3.29 ±0.50**	**0.45 ±0.04**	**0.06 ±0.04**	**–0.29 ±0.02**	**–0.45 ±0.01**	**–0.35 ±0.02**	**–0.24 ±0.04**

Note, positive values for percent changes and effect sizes indicate increases in mean values and negative values indicate declines. 95%CI = 95 percent confidence interval. Changes shown for the 1964–2009 period are also represented as mean changes per decade, although they are presented in text as the mean change for the entire testing period.

Figure captions

Figure 1. Flow chart outlining the identification of the included studies.

Figure 2. Historical patterns of change in aerobic performance-fitness (*n* = 24,090,119) of 9–17 year old Asians between 1964 and 2009. Data are shown for all children, and for children separated by sex (boys and girls), age (9–12 and 13–17 years), and country [China (Mainland), China (Hong Kong), Japan, Republic of Korea, and Singapore]. Data are standardised to the year 2000 =100%, with higher values (>100%) indicating better performance-fitness.

Figure 3. Historical patterns of change in Asian children for: (a) percent body fat (top left panel); (b) prevalence of overweight and obese (bottom left panel); and (c) body mass index (BMI) and aerobic performance-fitness (right panels). Percent body fat data (median values estimated using the Slaughter[32] equations which use the triceps and subscapular skinfolds as regression inputs) are from Olds[29] and represent 5,491 children aged 9–15 years from China (Hong Kong) and Japan between 1958 and 1996. The prevalence of overweight and obesity data (estimated using >120% of the median BMI values) are from HK*** and National Network of Physical and Mental Health in Japanese Children[33] and represent 3,359,867*** 9–17 year olds from China (Hong Kong) and Japan between 1977 and 2009. The dots shown in the left panels represent individual country by sex by age groups. The BMI data are from all but one of the studies included in this review[8,15–21] and represent 27,124,047 children aged 9–17 years from China (Mainland and Hong Kong), Japan and the Republic of Korea between 1964 and 2009. Mean BMI values at the country by sex by age level for children from China (Mainland), Japan and the Republic of Korea were estimated from reported mean height and

mass values. (Note, there is a nearly perfect correlation of *r* =0.999 between reported group mean BMI values and group mean BMI values calculated from reported mean heights and masses, with a difference of only 0.3%[19]). BMI (right panels, dotted lines) and aerobic performance-fitness (right panels, solid lines) data are standardised to the year 2000 =100%, with higher values (>100%) indicating higher BMI and better performance-fitness.

Figure 4. Comparison of historical changes in: (a) aerobic performance-fitness between Asian children and children from other parts of the world (top two panels), and (b) aerobic and anaerobic performance-fitness of Asian children (bottom two panels). The 'rest of world' aerobic performance-fitness data (second panel) are from Tomkinson[39] and represent 1,156,091 children aged 9–17 years from 24 countries (including children from Africa, Australasia, Europe, the Middle East and North America) between 1964 and 2008. The anaerobic performance-fitness data (power and speed/speed-agility) are from Tomkinson[9] and represent 43,679,018 children aged 9–17 years from five Asian countries [China (Mainland), Japan, Republic of Korea, Singapore, and Thailand] between 1964 and 2002. Data are standardised to the year 2000 =100%, with higher values (>100%) indicating better performance-fitness.

Figure 1

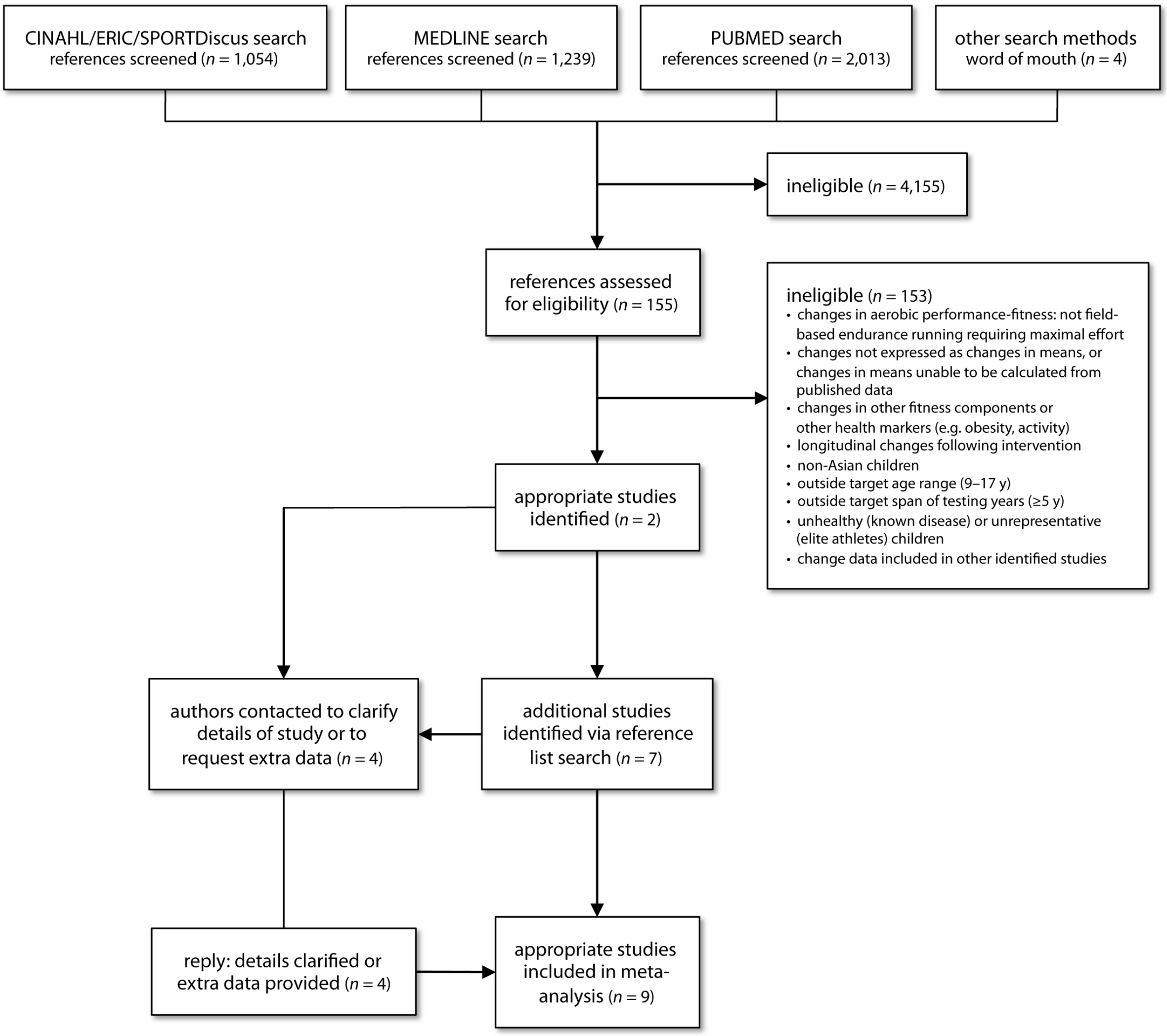

CINAHL/ERIC/SPORTDiscus search
references screened (n = 1,054)
MEDLINE search
references screened (n = 1,239)
PUBMED search
references screened (n = 2,013)
other search methods
word of mouth (n = 4)
ineligible (n = 4,155)
references assessed for eligibility (n = 155)
ineligible (n = 153)
• changes in aerobic performance-fitness: not field-based endurance running requiring maximal effort
• changes not expressed as changes in means, or changes in means unable to be calculated from published data
• changes in other fitness components or other health markers (e.g. obesity, activity)
• longitudinal changes following intervention
• non-Asian children
• outside target age range (9–17 y)
• outside target span of testing years (≥5 y)
• unhealthy (known disease) or unrepresentative (elite athletes) children
• change data included in other identified studies
appropriate studies identified (n = 2)
authors contacted to clarify details of study or to request extra data (n = 4)
additional studies identified via reference list search (n = 7)
reply: details clarified or extra data provided (n = 4)
appropriate studies included in meta-analysis (n = 9)

Figure 2

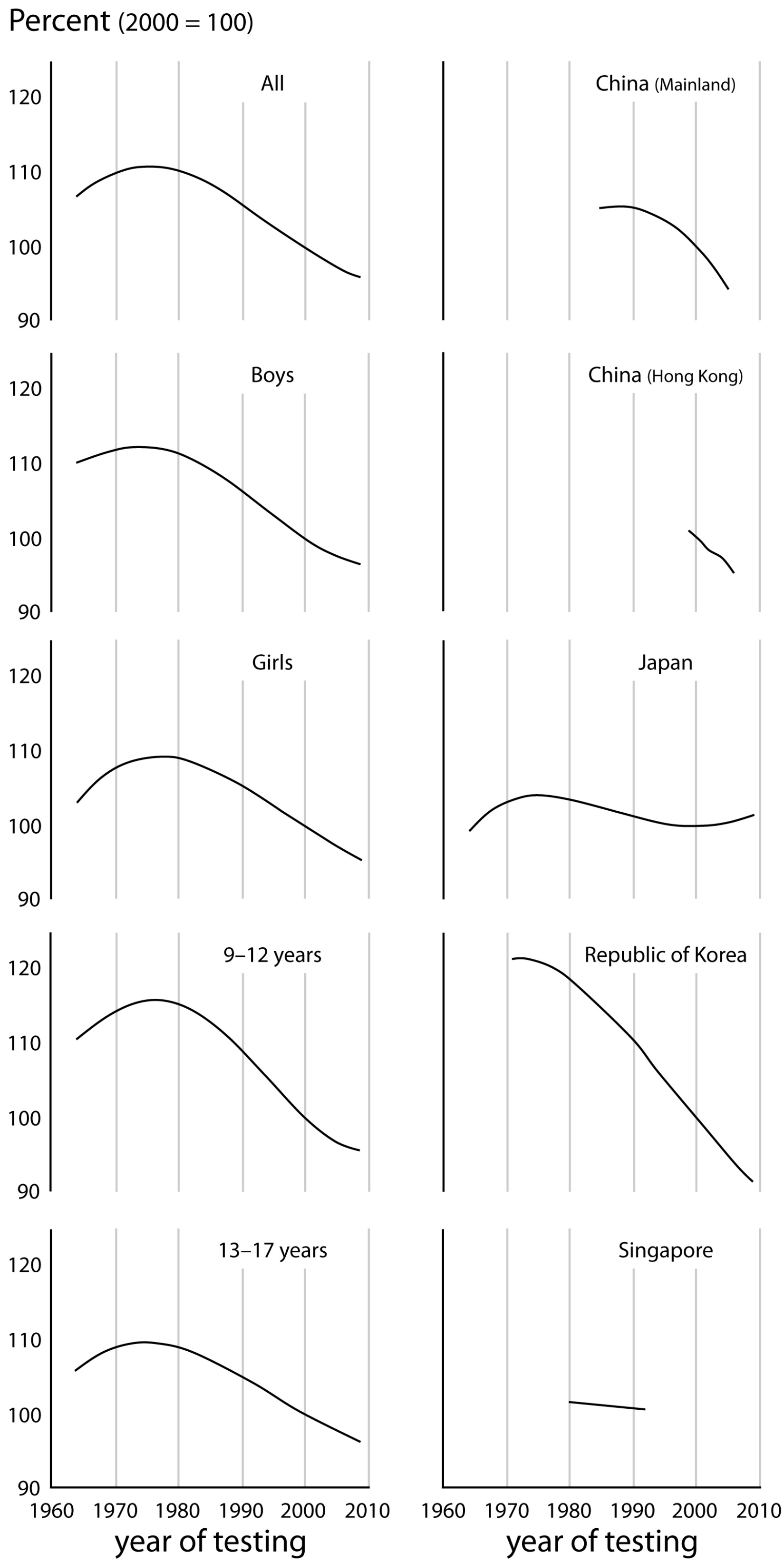

Percent (2000 = 100)
All
China (Mainland)
Boys
China (Hong Kong)
Girls
Japan
9–12 years
Republic of Korea
13–17 years
Singapore
120
110
100
90
1960
1970
1980
1990
2000
2010
year of testing
year of testing

Figure 3

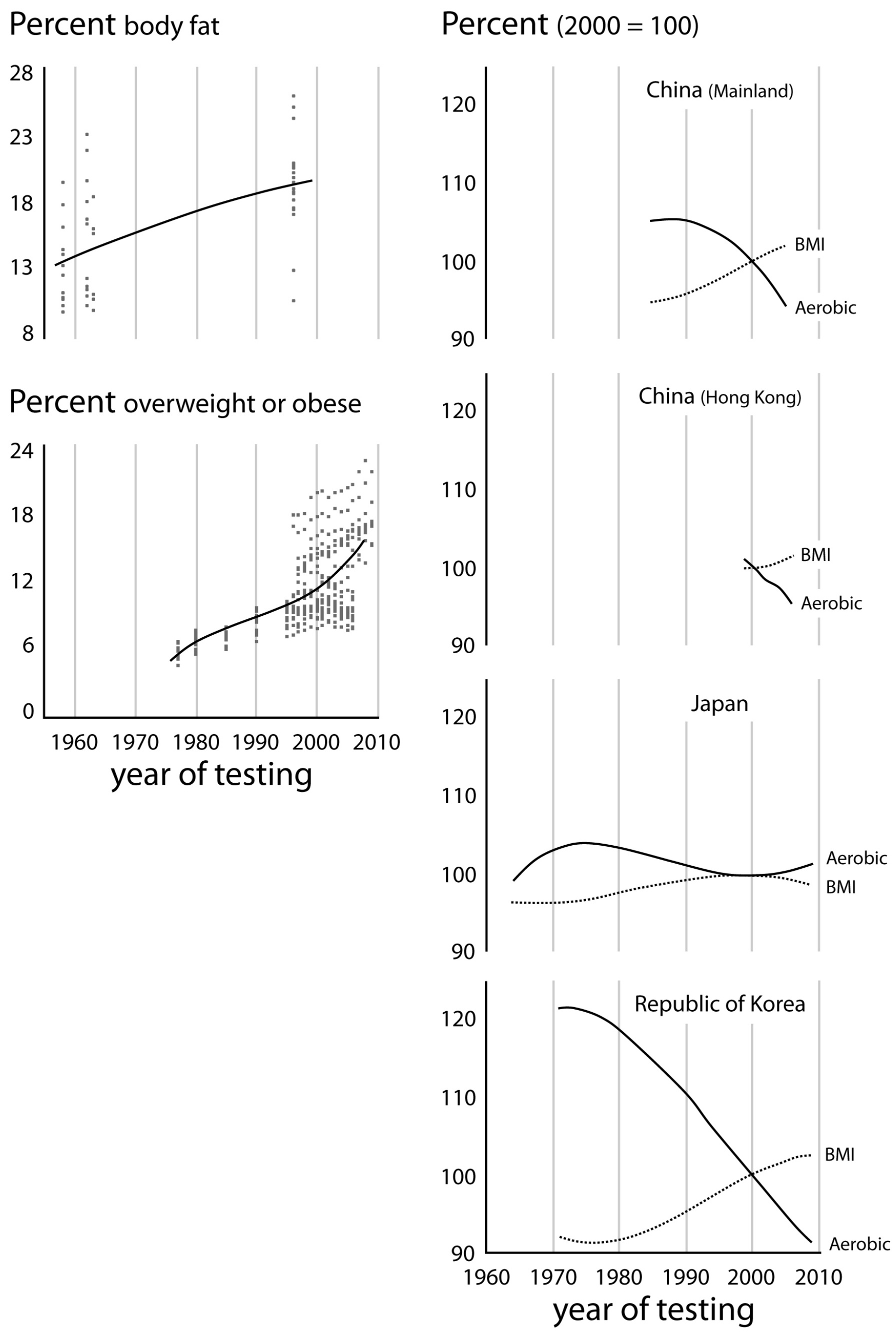
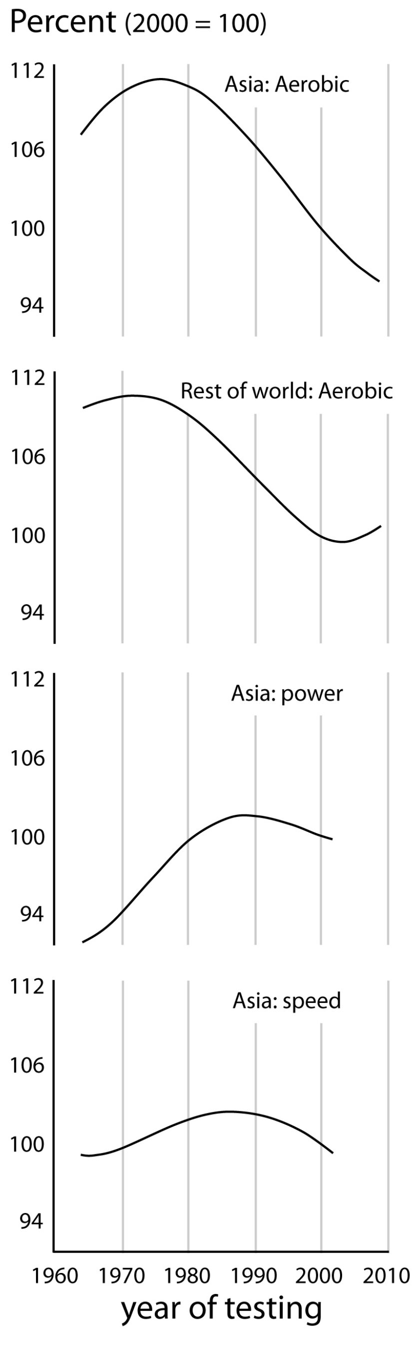

Percent body fat
28
23
18
13
8
Percent overweight or obese
24
18
12
6
0
1960 1970 1980 1990 2000 2010
year of testing
Percent (2000 = 100)
China (Mainland)
120
110
100
90
BMI
Aerobic
China (Hong Kong)
BMI
Aerobic
Japan
Aerobic
BMI
Republic of Korea
BMI
Aerobic
1960 1970 1980 1990 2000 2010
year of testing

Figure 4


Percent (2000 = 100)
112
106
100
94
Asia: Aerobic
Rest of world: Aerobic
Asia: power
Asia: speed
1960
1970
1980
1990
2000
2010
year of testing