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Trends in means and distributional characteristics of cardiorespiratory endurance performance for Italian children (1984–2010)

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ABSTRACT

Cardiorespiratory endurance (CRE) is an important health marker. The aim of this study was to examine temporal trends of CRE performance for Italian children between 1984 and 2010. Using a repeated cross-sectional study design, 5303 CRE test results were available for 2520 children aged 11–13 years from a single Northern Italian middle-high school between 1984 and 2010. CRE was measured as 1000-m and 12-min run test performance. With adjustments for BMI, temporal trends in means were estimated using linear regression, with trends in distributional characteristics described visually and estimated as the ratio of coefficients of variation (CVs). There was a significant small increase in BMI (effect size (ES) [95%CI]: 0.40 [0.32, 0.48]) over the entire period. When adjusted for BMI, there were significant small to moderate declines in mean running speed (ES [95%CI]: 1000-m, – 0.34 [−0.39, – 0.29]); 12-min, – 0.65 [−0.70, – 0.60]). Declines were larger for boys compared to girls. Variability substantially increased over time (ratio of CVs: range, 1.7–2.9), with larger declines in children with low running speed compared to children with average or high running speed. Our findings may be important to public health because low CRE is significantly related to current and future health.

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Cardiorespiratory fitness; secular trend; child; body mass index; running; public health

1. Introduction

Cardiorespiratory endurance (CRE) is the ability to perform continuous, rhythmic, large-muscle, whole-body physical activity (Raghuveer et al., 2020), and is considered an important marker of current health and a predictor of future health (Saltin, 1973). In adults, low CRE is associated with early cardiovascular, metabolic, and all-cause mortality (Jensen et al., 2017; Kodama et al., 2009; Lee & Blair, 2002). In children and adolescents, low CRE is associated with increased cardiovascular disease risk, increased adiposity, poor bone health, low self-esteem (García-Hermoso et al., 2019; Smith et al., 2014), and early all-cause mortality in later life (Högström et al., 2016). This health-related evidence supports the promotion of aerobic physical activities in global guidelines (Bull et al., 2020), which recommend an average of 60 minutes of moderate-to-vigorous intensity physical activity every day for children and adolescents aged 5–17 years. In addition to health implications, CRE is an important determinant of success for many popular youth endurance sports and athletic events (e.g., basketball, football (soccer), distance running, swimming; Armstrong et al., 2011).

CRE can be measured using maximal or submaximal field- or laboratory-based run/walk, cycling, or step tests. While indirect calorimetry using expired gas analysis is the criterion measure of peak oxygen uptake ($\dot{V}O_{2peak}$), such testing is time-consuming, expensive, and requires a high level of tester expertise. Alternatively, long-distance run/walk tests are acceptable, feasible, and scalable field-based measures of CRE. Among children and adolescents, long-distance run/walk tests such as the 1000-m and 12-min run tests demonstrate moderate criterion validity for estimating gas-analysed $\dot{V}O_{2peak}$ (in ml/kg/min; (Mayorga-Vega et al., 2016)), high test-retest reliability (O'Keeffe et al., 2020; Tomkinson & Olds, 2008), and are regarded as safe.

Current knowledge of temporal trends in children's CRE is primarily limited to long-distance run/walk and shuttle run test performance. Our previous meta-analyses indicated international declines in mean long-distance run/walk and shuttle run test performance for children and adolescents from the mid-1970s to the turn of the century, with little change thereafter, at least among upper-middle- and high-income countries (Tomkinson et al., 2019; Tomkinson & Olds, 2007). Trends in mean CRE for Italian children were summarized in these two meta-analyses and indicated declines between 1981 and 2007 for 11- to 18-year-olds, but were limited to data from published studies that used different sampling strategies and sampling bases. Temporal trends in the distributional characteristics (i.e., variability, asymmetry) of CRE performance have not been

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reported for Italian children. Information about such trends would help identify whether trends in mean CRE were uniform (i.e., similar for those with low, medium, or high CRE) or non-uniform (i.e., dissimilar for those with low, medium, or high CRE) across the distribution, and therefore, would improve our understanding of how the trends came about and how best to address them (e.g., if declining). Furthermore, adjustment of trends in CRE for body size (i.e., body mass index [BMI]), which has rarely been reported in the peer-reviewed literature, may provide additional insight into possible underlying factors.

Since CRE is an important health-related measure, temporal trends in CRE should reflect corresponding trends in population health and assist with the promotion and evaluation of public health policies. The aim of this study, therefore, was to examine temporal trends in BMI-adjusted means and distributional characteristics of CRE performance for Italian children between 1984 and 2010.

2. Materials and methods

2.1 Sample and study design

Using a repeated cross-sectional study design, 5303 CRE test results were available for 2520 children (n = 1386 [55%] males; n = 1134 [45%] females) aged 11–13 years from a single middle-high school in Northern Italy (near Milan) between 1984 and 2010. All children freely participated and were included if they (a) had no known neurological/orthopaedic or cardiovascular diseases, (b) no known illness considered to affect growth, and (c) actively participated in school PE classes. Parents (or legal guardians) provided written consent after having reviewed a detailed explanation of the study procedures, including the potential risks and benefits. Children provided verbal assent and were informed that their participation was voluntary and that they could withdraw at any time without prejudice. This study was approved by the Institutional ethical boards (Prot. 1523; Cod 123.1/6) and was conducted in accordance with the Declaration of Helsinki (JAMA, 2013).

2.2 Testing procedures

Over the 26-year period, at the same time of day (8:00 am to 1:00 pm) and in the first month of every school year (mid-September to mid-October), participants were tested by the same teacher during two consecutive physical education (PE) classes. Participants were tested up to three times during their schooling from age 11 to 13. Body mass and height were measured without shoes and in light clothes using procedures described by the International Society for the Advancement of Kinanthropometry (Clarys et al., 2006). Body mass was measured using a balance scale (Seca 864, Seca GmbH & Co., Hamburg, Germany) to the nearest 0.1 kg. Height was measured with a stadiometer (Seca 213, Seca GmbH & Co., Hamburg, Germany) to the nearest 1 cm, with participants standing upright and their head in the Frankfort plane. BMI was calculated as body mass (kg) divided by height-squared (m^2).

CRE was measured as performance on the 1000-m and 12-min run tests. Groups of 9–14 children performed the 12-min run on the first day of PE class and the 1000-m run on the second day of PE class. The 12-min run required participants to run (or walk) as far as possible on a flat 350-m marked outdoor course (a grassed playground), with the distance run in 12 minutes recorded to the nearest 5 metres. The 1000-m run

Table 1. Descriptive statistics for BMI and 1000-m and 12-min running speed among Northern Italian children aged 11–13 years between 1984 and 2010.

		Boys				Girls			
	Year	n	Mean	SD	Median	n	Mean	SD	Median
BMI (kg/m^2)	1984–1986	454	18.8	3.4	18.1	224	19.0	3.5	18.7
	1987–1989	455	19.0	3.5	18.3	223	19.8	3.7	19.3
	1990–1992	247	19.3	3.4	19.0	263	19.8	3.3	19.5
	1993–1995	242	19.6	3.6	19.0	283	20.2	3.7	19.7
	1996–1998	285	20.1	3.7	19.6	211	20.2	4.4	19.7
	1999–2001	261	20.0	3.8	19.6	276	20.5	4.2	19.8
	2002–2004	285	19.9	3.5	19.2	309	19.9	3.9	19.2
	2005–2007	318	20.0	3.7	19.2	261	20.0	3.7	19.0
	2008–2010	351	20.7	4.3	19.6	355	21.3	4.0	20.5
1000-m running speed (m/s)	1984–1986	439	3.8	0.5	3.8	224	3.0	0.3	3.0
	1987–1989	454	3.8	0.5	3.7	223	3.2	0.4	3.2
	1990–1992	247	3.5	0.5	3.4	263	3.1	0.4	3.1
	1993–1995	242	3.5	0.5	3.5	283	3.1	0.4	3.1
	1996–1998	285	3.5	0.5	3.5	211	3.1	0.4	3.1
	1999–2001	261	3.6	0.5	3.6	276	3.2	0.5	3.2
	2002–2004	285	3.6	0.6	3.6	309	3.1	0.5	3.1
	2005–2007	318	3.6	0.6	3.6	261	3.2	0.5	3.1
	2008–2010	349	3.5	0.7	3.5	355	3.0	0.4	3.0
12-min running speed (m/s)	1984–1986	251	3.0	0.4	3.1	224	2.6	0.2	2.6
	1987–1989	453	3.1	0.4	3.2	223	2.6	0.3	2.6
	1990–1992	246	3.0	0.4	3.0	263	2.7	0.3	2.8
	1993–1995	241	3.0	0.4	3.0	283	2.7	0.3	2.7
	1996–1998	284	3.0	0.5	3.0	211	2.7	0.4	2.8
	1999–2001	261	2.9	0.4	3.0	276	2.7	0.4	2.7
	2002–2004	285	3.0	0.4	3.1	309	2.6	0.4	2.6
	2005–2007	318	2.9	0.5	2.9	261	2.6	0.3	2.6
	2008–2010	350	2.8	0.5	2.8	355	2.4	0.3	2.4

Abbreviations: n = sample size; SD = standard deviation; 1000-m = 1000-metre; 12-min = 12-minute.

required participants to run (or walk) as fast as possible on the same outdoor course, with time taken to run 1000-m recorded to the nearest second. Table 1 presents the descriptive statistics for BMI and 1000-m and 12-min run test performance stratified by gender and wave of study.

2.3 Statistical analysis

All data were manually entered into a spreadsheet and checked for transcription errors, with corrections made where appropriate. CRE performances were expressed in the common metric of mean running speed (metres per second [m/s]). Since mass-specific $\dot{V}O_2$ and $\dot{V}O_{2max}$ vary linearly with speed and maximal speed, running speed should, therefore, be proportional to O_2 (i.e., the oxygen cost of running).

We pooled data into 3-year study waves (e.g., 1984–86, 1987–89 … 2008–10) and stratified our analysis into separate test-gender-age groups (e.g., 11-year-old boys tested on the 1000-m run). For each wave, a mean of 581 children (range: 475–706) completed the anthropometric and CRE performance testing. We calculated overall temporal trends in BMI-adjusted 1000-m and 12-min running speed using linear regression for each test-gender-age group as well as the corresponding 95% confidence intervals (CI; calculated as 1.96 multiplied by the standard error of the regression coefficient; Tomkinson et al., 2020). For each test-gender-age group, we used regression models to estimate CRE performance for each year while controlling for BMI and the interaction of BMI by year. This provided CRE performance estimates adjusted for BMI for each year. We expressed the overall linear trends as absolute trends (i.e., the regression coefficient), percent trends (i.e., the regression coefficient expressed as a percentage of the mean for all values in the regression), and as standardized (Cohen's) effect sizes (ES) (i.e., the regression coefficient divided by the standard deviation (SD) for all values in the regression). To interpret the magnitude of the trends, 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 (Cohen, 1988). Positive trends indicated temporal increases and negative trends indicated temporal declines. We also calculated weighted mean trends for boys, girls, and all children by pooling the test-gender-age-specific trends using a post-stratification population weighting procedure (Tomkinson et al., 2020). This helped adjust for sampling bias by incorporating the underlying population demographics. Population weights were obtained from United Nations gender-age-specific population estimates for Italy in 2000 (United Nations, 2019).

Temporal trends in distributional characteristics were examined visually and as trends in the coefficient of variation (CV; the ratio of the SD to the mean). Trends in CVs were analysed as the ratio of CVs between the first wave (1984–86) and last wave (2008–10) using the procedure described elsewhere (Tomkinson et al., 2021). Ratios >1.1 indicated substantial increases in variability (i.e., the magnitude of variability in relation to the mean increased over time), ratios <0.9 indicated substantial declines in variability (i.e., the magnitude of variability in relation to the mean decreased over time), and ratios between 0.9 and 1.1 indicated negligible trends in variability (i.e., the magnitude of variability in relation to the mean did not change substantially over time; Tomkinson et al., 2021). Distributional trends were examined visually using LOWESS (LOcally WEighted Scatter-plot Smoother) curves (tension = 55; Cleveland & Devlin, 1988), by plotting the trends in BMI-adjusted 1000-m and 12-min running speed across a range of percentiles (range: 10^{th} to 90^{th}; Liu et al., 2021).

3. Results

Collectively, we found a significant small increase in BMI (trend [95%CI]: 1.5 kg/m^2 [1.2, 1.8]; 7.6% [6.2, 9.1]; 0.40 ES [0.32, 0.48]) over the 1984–2010 period, with negligible gender- and age-related temporal differences (Supplement 1). Distributional variability increased substantially for 12- and 13-year-old girls, with negligible trends found for the remaining gender-age groups.

When adjusted for BMI, we found significant small to moderate declines in mean 1000-m running speed (trend [95%CI]: − 0.13 m/s [−0.15, − 0.11]; − 3.7% [−4.2, − 3.2]; − 0.34 ES [−0.39, − 0.29]) and mean 12-min running speed (trend [95%CI]: − 0.19 m/s [−0.20, − 0.18]; − 6.5% [−7.0, − 6.0]; − 0.65 ES [−0.70, − 0.60]) between 1984 and 2010 (Table 2). There were small to moderate temporal differences between boys and girls, with moderate to large declines for boys (temporal trend [95%CI]: 1000-m, − 0.59 ES [−0.66, − 0.52]; 12-min, − 0.89 ES [−0.96, − 0.82]) and negligible to small declines for girls (trend [95%CI]: 1000-m, − 0.08 ES [−0.14, − 0.02]; 12-min, − 0.40 ES [−0.46, − 0.34]; Figure 1). Temporal trends also improved with age, with rates of decline slowing with age for boys and slowing before improving (1000-m) or stabilizing (12-min) for girls.

Trends in BMI-adjusted mean 1000-m and 12-min running speed were not uniform across the distribution. We found substantial temporal increases in variability across all test-gender-age groups, with the ratio of CVs ranging from 1.7 (95%CI: 1.3, 2.1) for 11-year-old girls' 1000-m running speed to 2.9 (95%CI: 2.4, 3.4) for 11-year-old boys' 12-min running speed (Table 1). Trends in distributional asymmetry indicated that both tails of the distribution had moved away from the middle over time (Figure 2). For boys, we found substantially larger declines (ES > 0.2) in those with low running speed (below the 25^{th} percentile) compared to those with average (at the 50^{th} percentile) or high (above the 75^{th} percentile) running speed. There were similar trends for girls, with the largest declines found in those with low running speed compared to those with average or high running speed who experienced smaller declines or improvements.

4. Discussion

This study estimated temporal trends in BMI-adjusted CRE performance for Italian children aged 11–13 years between 1984 and 2010. We found (a) a significant small increase in BMI across all gender-age groups, (b) significant small to moderate declines in BMI-adjusted mean CRE performance, with declines larger for boys compared to girls, and rates of decline slowing with age for boys and stabilizing or improving with age for girls, and (c) a substantial temporal increase in the variability of BMI-adjusted CRE performance because both ends of the

Table 2. Temporal trends in means and variability for BMI-adjusted 1000-m and 12-min running speed among Northern Italian children aged 11–13 years between 1984 and 2010.

	Gender	Age (years)	n	Trends in means (95%CI) Absolute	Percent	Standardized ES	Ratio of CVs (95%CI)
BMI-adjusted 1000-m running speed	*Boys*	11	971	−0.34 (−0.39, − 0.29)	−9.9 (−11.3, − 8.5)	−0.92 (−1.05, − 0.79)	2.6 (2.1, 3.1)
		12	954	−0.24 (−0.29, − 0.19)	−6.7 (−8.0, − 5.4)	−0.65 (−0.78, − 0.52)	2.1 (1.7, 2.5)
		13	955	−0.07 (−0.11, − 0.03)	−1.9 (−3.1, − 0.7)	−0.20 (−0.32, − 0.08)	2.0 (1.6, 2.4)
	Girls	11	792	−0.14 (−0.18, − 0.10)	−4.7 (−5.9, − 3.5)	−0.39 (−0.49, − 0.29)	1.7 (1.3, 2.1)
		12	809	−0.12 (−0.16, − 0.08)	−3.7 (−5.0, − 2.4)	−0.32 (−0.43, − 0.21)	2.5 (2.0, 3.0)
		13	804	0.17 (0.13, 0.21)	5.2 (3.9, 6.5)	0.45 (0.34, 0.56)	2.1 (1.7, 2.5)
BMI-adjusted 12-min running speed	*Boys*	11	948	−0.32 (−0.36, − 0.28)	−11.3 (−12.5, − 10.1)	−1.13 (−1.25, − 1.01)	2.9 (2.4, 3.4)
		12	888	−0.24 (−0.27, − 0.21)	−8.2 (−9.3, − 7.1)	−0.86 (−0.98, − 0.74)	2.4 (1.9, 2.9)
		13	853	−0.19 (−0.23, − 0.15)	−6.2 (−7.4, − 5.0)	−0.68 (−0.81, − 0.55)	2.3 (1.8, 2.8)
	Girls	11	792	−0.20 (−0.23, − 0.17	−7.8 (−8.9, − 6.7)	−0.69 (−0.78, − 0.60)	1.9 (1.5, 2.3)
		12	809	−0.13 (−0.16, − 0.10)	−4.9 (−6.2, − 3.6)	−0.45 (−0.57, − 0.33)	2.7 (2.2, 3.2)
		13	804	−0.01 (−0.04, 0.02)	−0.5 (−1.7, 0.7)	−0.05 (−0.16, 0.06)	2.4 (1.9, 2.9)

Notes: Absolute trends are expressed in metres per second (m/s). Positive trends indicated temporal increases and negative trends indicated temporal declines. Standardized (Cohen's) effect sizes (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. Ratio of CVs >1.1 indicated substantial temporal increases in variability, ratios <0.9 indicated substantial temporal declines in variability, and ratios between 0.9 and 1.1 indicated negligible trends in variability.

Abbreviations: BMI = body mass index; 95%CI = ninety-five per cent confidence interval; n = sample size; ES = effect size; CV = coefficient of variation; 1000-m = 1000-metre; 12-min = 12-minute.

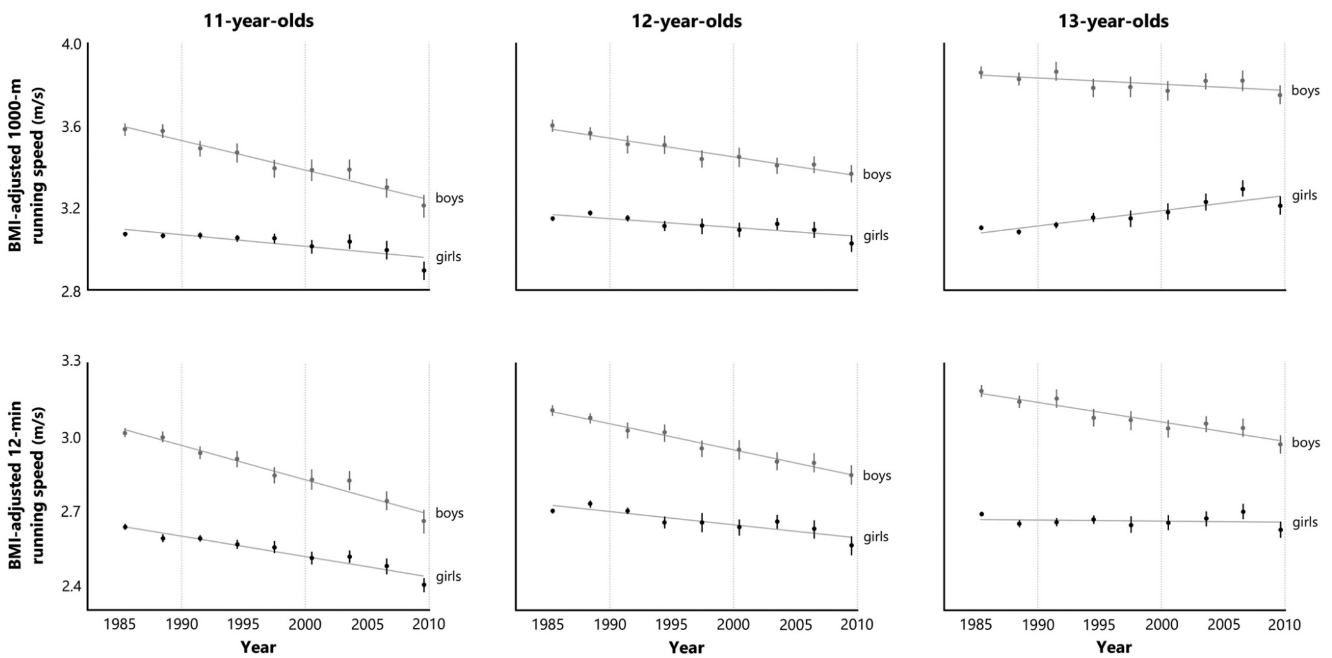

Figure 1. Temporal trends in BMI-adjusted mean 1000-m and 12-min running speed (m/s) for Northern Italian children aged 11–13 years between 1984 and 2010.

distribution had moved away from the middle. Our findings may be important to public health and sport because CRE is significantly associated with current and future health as well as sporting success (Armstrong et al., 2011; García-Hermoso et al., 2019; Högström et al., 2016; Raghuveer et al., 2020; Smith et al., 2014).

We have previously argued that temporal trends in CRE are probably influenced by trends in a network of physiological, physical, behavioural, social, and environmental factors (Gan et al., 2019; Manferdelli et al., 2019; Masanovic et al., 2020; Tomkinson et al., 2019; Tomkinson & Olds, 2007). While our finding of declines in BMI-adjusted mean CRE performance has been previously reported [e.g., (Albon et al., 2010; Arboix-Alió et al., 2020; Giuriato et al., 2020; Olds et al., 2007; Sandercock et al., 2015; Tomkinson et al., 2012)], it indicates that declines in CRE are probably caused by other factors than increases in body size. For example, because 1000-m and 12-min run test performance has moderate criterion validity (Mayorga-Vega et al., 2016), declines in running speed likely reflect corresponding declines in underlying $\dot{V}O_{2peak}$ (and/or relative oxygen transport capability) and other aerobic factors (i.e., mechanical efficiency and fractional utilization of oxygen). Trends in psychosocial factors (e.g., motivation, pacing, discomfort tolerance) may also be involved (Tomkinson et al., 2019; Tomkinson & Olds, 2007).

Declines in BMI-adjusted CRE performance are probably influenced by reduced vigorous physical activity levels and increased sedentary behaviours. Though reliable trend data on children's physical activity levels and sedentary behaviours are few, data on 11-, 13-, and 15-year-old Italian children from

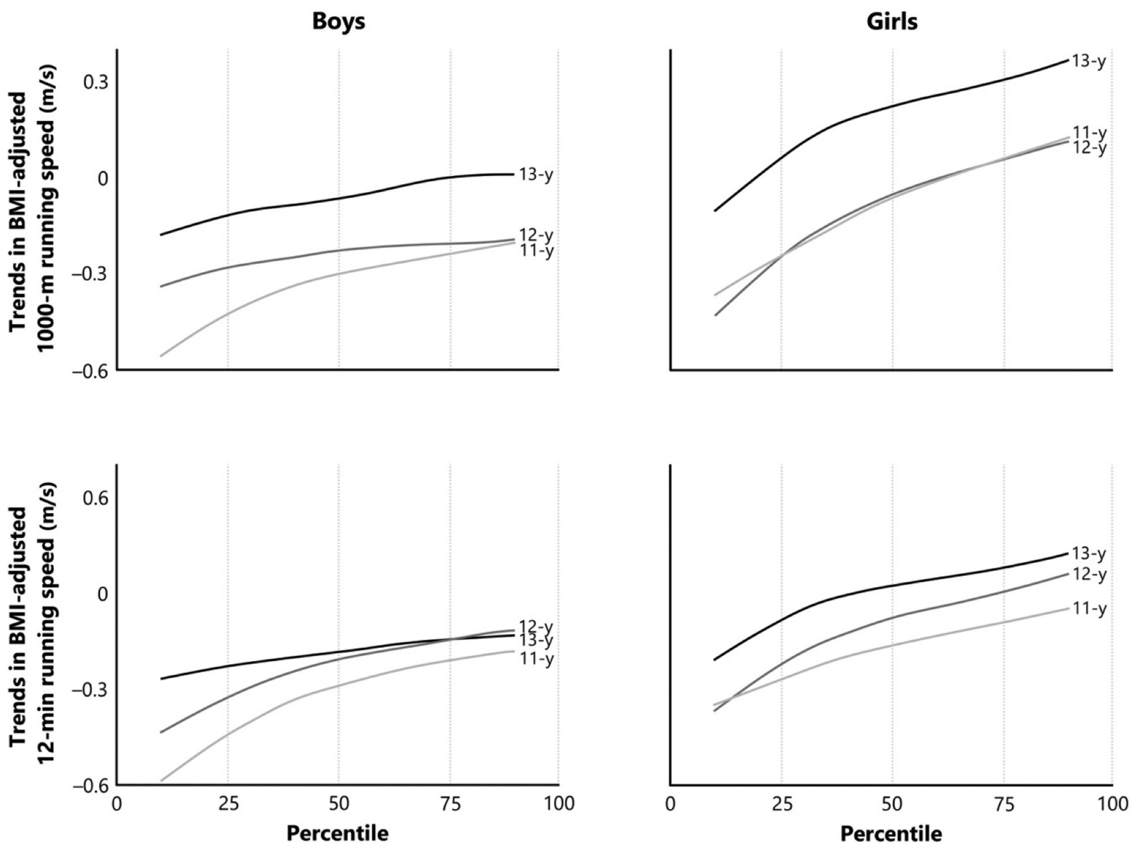

Figure 2. Distributional trends in BMI-adjusted 1000-m and 12-min running speed (m/s) for Northern Italian children aged 11–13 years between 1984 and 2010.

the Health Behaviour in School-aged Children (HBSC) World Health Organization (WHO) collaborative cross-national study (2002–2014; World Health Organization, 2017) indicate (a) a decline in the country-level prevalence of children who achieved at least 60 minutes of moderate-to-vigorous physical activity every day or vigorous physical activity at least four times per week, and (b) an increase in the country-level prevalence of children who used computers recreationally for at least 2 hours every weekday. Such trends are supported by Guthold et al. (2020) who reported that the country-level prevalence of insufficient physical activity (i.e., doing less than 60 minutes of moderate-to-vigorous physical activity every day) increased among Italian children aged 11–17 years between 2001 and 2016.

National efforts that promote physical fitness/activity may help improve population-level CRE. While we do not know whether our declines in CRE performance have continued beyond 2010, we are certainly encouraged by the release of Italy's first national guidelines for physical activity in 2019 (Ministero della Salute, 2020). These guidelines support the *National Prevention Plans* (2014–2019 and new 2020–2025; Ministero della Salute, 2020), which promote health-enhancing physical activity for children through school policy, structured life skills interventions, safe active travel to/from school programmes (e.g., the *Pedibus*), sports participation, and active lesson breaks. Other national initiatives such as the *Sport di Classe* (Sports Class Notebooks) programme, established by the Ministry of Sports and Health and the Ministry of Education, aims to increase physical activity and sports education in primary schools by encouraging young children to be more active and ensuring they receive a minimum of 2 hours of PE every week (Ministero dell'Istruzione). Future studies should evaluate the effectiveness and monitor the progress of implemented physical activity promotion efforts by examining recent temporal trends (post-2010) in CRE levels for Italian children (Lang et al., 2018).

Our finding of a substantial temporal increase in the variability of BMI-adjusted CRE performance was the result of both ends (especially the low end) of the distribution moving away from the middle. While evidence of trends in the distributional characteristics of CRE performance are rare, our findings are consistent with Albon et al. (2010) and Dollman et al. (1999) who found larger declines in children with low CRE compared to children with high CRE. Collectively, these findings suggest that some factor is differentially affecting certain subsets of children, and that a more targeted approach or early intervention should be considered for children with low CRE. In the absence of universal criterion-referenced health-related cut-points for CRE in youth (Rollo et al., 2022), future research should determine the population health consequences of these trends.

This study is the first formal analysis of temporal trends in means and distributional characteristics of CRE performance for Italian children. While environmental factors (e.g., weather, temperature, humidity, ground conditions) can affect long-distance run/walk performance, such factors were unlikely to have systematically biased our trends because we used data on children from a single Northern Italian school collected by a single teacher at the same time of year using standardized testing protocols. Our statistical adjustment for BMI and stratified analysis helped control for the confounding effects of body size, gender, and age.

Unfortunately, we were unable to control the effects of underlying mechanistic factors such as physical activity levels and biological maturation. For example, trends in biological maturation (Malina, 2004), which generally favour children of the same chronological age in more recent surveys, suggest that improved CRE performance would be expected based on maturational advances alone; meaning, that our declines probably underestimated true declines. We were unable to estimate whether our trends were systematically biased by trends in less fit/healthy children either opting out or being excluded (e.g., in the early surveys). Caution should also be taken when interpreting our trends because they were estimated using children from a single Northern Italian middle school and may not be generalizable to all Italian children or to the most recent decade. Nonetheless, our study provides the most up-to-date analysis of trends in CRE performance for Italian children, with previous trends calculated as part of large meta-analyses (Tomkinson et al., 2019; Tomkinson & Olds, 2007), which pooled data from studies that used different sampling strategies and sampling bases. For example, in our most recent meta-analysis (Tomkinson et al., 2019), we estimated trends in CRE performance for 5218 children aged 12–17 years between 1986 and 2007, with data pooled from both probability and non-probability samples of Italian children tested at the local, school, and city levels. Our study, therefore, extends the temporal coverage for trends in mean CRE performance for Italian children from 2007 to 2010 (Tomkinson et al., 2019), and adds new information on trends in distributional characteristics and trends in BMI-adjusted CRE performance, neither of which have previously been reported.

We recognize that our analysis was limited to the 1984–2010 period, but it was challenging to measure physical fitness among Italian children in PE classes without a national guideline for physical fitness assessment. Moreover, our 25-year data collection in the same school by the same PE teacher (up until the teacher's retirement from work) was further challenged by changes in the school's administration and protocols. However, our mean CRE performance values from 2010 are like those recently published for Italian children (Manferdelli et al., 2019), suggesting that our data are broadly representative. Over the same period, there has been an international decline in children's CRE performance (measured as 20-m shuttle run test performance) since the mid-1980s, which has slowed and stabilized after 2000 (Tomkinson et al., 2019). In contrast, our trends indicate that the decline in CRE performance has continued among 11- to 13-year-old Italian children, at least up until 2010. We also found relatively larger declines in Italian children with low CRE performance. Collectively, these trends represent a call to action for Italy to implement national fitness surveillance to complement existing health surveillance and to inform decision making, and for targeted fitness-enhancing programmes aimed at those with low CRE as they are in the greatest need. Our study also significantly contributes to the scientific literature because body-size adjusted analyses of temporal trends in means and distributional characteristics of CRE performance are scarce.

In conclusion, we found significant small to moderate declines in BMI-adjusted mean CRE performance for 11-to 13-year-old Italian children between 1984 and 2010, which are suggestive of corresponding declines in construct CRE and population health. Such trends were probably influenced by declines in vigorous physical activity levels and increases in sedentary behaviours. We also found that these declines were asymmetric across the distribution because both ends of the distribution (especially the low end) had moved away from the middle over time. We applaud recent national efforts and strongly encourage additional health-enhancing fitness/activity promotion strategies to improve population-level CRE. We also recommend that CRE measures be included in national health surveillance systems (Ministero della Salute, 2020) to help monitor the progress of implemented public health policy.

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